An analysis of the extent and severity of soil degradation in Wales

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July 2016

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1 Executive summary

The processes of soil degradation can impact adversely on soil functions and the ability of soils to deliver vital ecosystem goods and services. These processes include: climate change effects on soils; loss of soil organic carbon/matter; loss of soil biodiversity; soil erosion; soil compaction; and loss of soil to development (soil sealing). The objective of this review was to source and analyse the evidence on the severity (magnitude) of each of these degradation processes and their spatial extent in Wales. The vulnerability and resilience of Welsh soils to each degradation process is also discussed. The review is set against Walesôspecific landscapes, soils, climate, land use/cover and habitats. The review builds on a previous report (CEH, 2002) on the state of and pressures on Welsh soils, by updating the evidence base where possible.

To meet the objective, a rapid evidence assessment (using the principles of a systematic review) was carried out primarily using three sources: Defra/Welsh Government funded research reports; peer reviewed papers; and grey literature articles. Whilst focus was put on Welsh data, it is recognised that much of the current evidence originates from UK-wide studies, which may not represent the soils, land uses and landscapes specific to Wales.

1.1 Climate change

Predictions of future climate change scenarios inevitably involve some uncertainty. However, the evidence reviewed suggests predicted climate change in Wales will not significantly change the duration of soil wetness (field capacity days) or potential soil moisture deficits until 2080. However, there will be a shift in the seasonal distribution of the field capacity period, which will mean drier autumn and wetter spring periods. Consideration of drought criteria in the Agricultural Land Classification (ALC) under future climate change scenarios indicates Welsh soils may become more droughty. As a result, many sites will be downgraded, although the extent in Wales is not reported specifically. Additionally, some sites may have improved ALC grades. Increased grassland productivity would lead to higher stocking densities that could be associated with more extensive soil compaction. Modelling (unvalidated) indicates the severity and extent of soil erosion by water will increase in upland areas, particularly in autumn. Changes in soil microbial community structure are expected as a response to drying of water-saturated soils (e.g. wet upland organic and organo-mineral soils). Only soil carbon in organo- mineral and peat soils shows a response to climate change. There is little evidence on the vulnerability and resilience of different soil types to climate change in Wales.

1.2 Loss of soil organic matter

There is conflicting evidence from two national monitoring programmes (Countryside Survey CS + Glastir Monitoring and Evaluation Programme - GMEP and the National Soil Inventory - NSI) for the extent of soil carbon change in topsoils in Wales. CS and GMEP report no significant change overall in soil carbon from 1978-2007 for topsoils in Wales. The NSI reports losses in topsoil carbon for England and Wales over the same period, but does not discriminate for Wales specifically. The CS and GMEP data also indicates no change in soil carbon in improved grassland systems in Wales between 1978-2013. Differences in intensive and extensive systems are anticipated and reporting on this is pending. Both monitoring programmes report a loss of organic carbon in arable topsoils in England and Wales but evidence is not reported for Welsh soils specifically. An increase in topsoil carbon in woodland sites was observed between 2007 and 2013 (GMEP). NSI data reported the largest rate of decline in organic matter in topsoils in England and Wales was on peat soils, bog and upland heath, although this conclusion was not supported by the CS data. The lack of change in soil carbon for Welsh topsoils may be related to the limited land use change in Wales over the monitoring period. The resilience of Welsh soils to loss of organic carbon/ matter is not reported in the evidence explicitly.

1.3 Loss of soil biodiversity

There is no evidence on the loss of soil biodiversity in Wales. A recent study aimed to ascertain baseline conditions of soil microbial community structure in broad habitat types in Wales. European-wide evidence suggests that intensely managed systems are at greater risk of loss in soil biodiversity than semi-natural habitats. Changes in soil biodiversity are likely to be related to i) land use change (both intensification / extensification), ii) loss of soil organic matter and/or iii) climate change. Reported low rates of change in land use and/or organic matter levels in Wales could infer little change in soil biodiversity.

1.4 Soil erosion

There are no studies that directly quantify the severity or spatial extent of soil erosion (by water, wind, co-extraction and/or tillage) in Wales. Existing modelled estimates of soil erosion by water in Wales have not been validated with observed erosion rates. Peat / organic soils are particularly vulnerable to erosion by wind and water, especially the latter process in upland areas due to high rainfall. As soil erosion represents an absolute reduction in soil volume / depth, shallow soils will be less resilient to the impacts of soil loss compared to deeper soils.

1.5 Soil compaction

Although the relative risk of soil compaction can be estimated from soil wetness classes and land use / management, little is known of the actual severity or extent of soil compaction in Wales. Studies on compaction in grassland soils reported for England and Wales combined show 10-15 % of sites were in poor condition and 50-60% in moderate condition. The study did not report conditions for Welsh sites specifically. Severe structural degradation in arable sites (with late harvested crops) and moderate degradation in permanent grasslands was reported in SW England, which could be used as a reasonable soil and climate analogue for parts of Wales. No data exists on compaction in arable land in Wales specifically. No Welsh specific data exists for the vulnerability and resilience of different soil types (or land uses) to compaction.

1.6 Loss to development

There are no statistics on the increase in artificial surfaces post 2007 from land cover data. This data is required to produce a national estimate of the current severity or spatial extent of soil loss to development. There is no evidence that has collated land use change statistics at sufficient resolution to identify the extent of soil sealing in Wales on different soil types or land uses.

1.7 Interactions between threats

Many of the threats are interconnected by two primary drivers: climate change and land use change. Shifts in the seasonality and duration of the field capacity period under climate change will impact on the timing of field operations and livestock grazing periods, and associated increased risk of soil compaction, particularly for slowly permeable soils. Soil biology is responsive to changes in soil water regimes, with specific shifts in microbial community structure in water saturated soils that will experience more frequent drying episodes. In catchments dominated by slowly permeable soils, the increased frequency of extreme rainfall events will lead to greater incidences of lateral and overland flow especially when soils are at or beyond field capacity, so increasing surface water flood risk. Likewise, these extreme rainfall events will also increase the risk of soil erosion by water in susceptible areas. The small areas of high grade agricultural land (Grade 1 and 2) are likely to be downgraded in response to increased summer drought. However, drier conditions may be beneficial for other marginal areas that could see an improvement in ALC grade (i.e. shift from Grade 4 to 3b). This could initiate a land use change in response to drier summer conditions but it is uncertain how this will manifest in the future.

Conversion of non-arable to arable land has the most significant impact on soil threats. It is plausible that areas of improved grassland, that are currently marginal for arable agriculture, may be converted to arable and horticultural uses in the future. This change will mean a loss of soil organic matter, change in the microbial community structure and function, and increased risk of compaction and erosion, particularly if late-harvested crops are adopted. Expansion of improved grassland and increased grass productivity (potential responses to a changing climate) could have implications for soil carbon loss, change the soil microbiology and also subject land to increased compaction risk. Expansion of woodland would potentially increase topsoil carbon but it is uncertain whether this would mean overall carbon sequestration as this trend might not be reflected in soil below the topsoil.

1.8 Key knowledge gaps and recommendations

Climate change

The seasonal shift in the water balance and specific saturation period warrants further investigation, particularly where this will impact on areas with slowly permeable soils.

The hydrological response of slowly permeable soils requires specific assessment in response to extreme events. This could provide indications of the likely surface water flood risk in catchments where these soils are common.

A shift in ALC grade due to increased limitations of summer drought criteria under climate change needs to be extracted specifically for Welsh NSI sites. A clearer picture of areas affected by downgrading or upgrading of ALC will emerge.

Loss of soil organic matter

An analysis of topsoil monitoring data from CS +GMEP and NSI programmes should be extracted for sites in Wales specifically. Further analysis of topsoil carbon changes stratified by soil type and land use should be determined for this sub-set.

A significant carbon store exists in soil below the topsoil and the change in carbon stock of the whole soil profile should be taken into account in monitoring programmes.

Changes in soil carbon between improved and unimproved grassland in Welsh soils requires further investigation This information could offer insight into changes in land management that could occur in response to a changing climate.

Critical thresholds of soil organic matter loss should be defined regionally and for specific soil types given the environmental constraints on soil systems in Wales.

Loss of soil biodiversity

Building on the baseline survey, characterisation of microbial community structure should also be extended to key soil types within the broad habitats in Wales.

Continued monitoring is required to ascertain any changes in soil biodiversity over time (GMEP programme). This should also be extended to areas where land use change has occurred.

There is incomplete understanding of the change in the functional response of soil biological communities and impacts on soil functions, although there is emerging evidence for a shift in microbial community structure under different land use types at a European level.

Soil erosion

An understanding is needed of the severity and spatial extent of soil erosion by water, wind, co-extraction and/or tillage across Wales, as currently no UK data exists.

Modelled estimates of the severity and extent of different processes of soil erosion in Wales need field validation through surveys and monitoring. This also requires better resolution of erosion prediction models to enable local scale predictions.

Soil compaction

Current knowledge has been generalised from England and Wales data. A focus on systematic assessment of structural degradation in arable and grassland soils in Wales is required.

Review of forestry compaction mitigation measures is required to ascertain the true extent and vulnerability of compaction from forestry operations.

A greater understanding of soil resilience to compaction is required in key soil and land use combinations in Wales.

Loss to development

The extent of soil loss to development needs to be collected systematically at the national level and an understanding of potential resilience of soils subject to development is required.

The loss of good grade agricultural land (Best and Most Versatile) and other soil types that support nationally significant habitats should be assessed.

1 Crynodeb weithredol

Gall prosesau diraddiad pridd effeithio'n andwyol ar swyddogaethau a gallu pridd i gyflawni nwyddau a gwasanaethau ecosystem hollbwysig. Mae'r prosesau hyn yn cynnwys: effeithiau newid hinsawdd ar briddoedd; colli carbon organig pridd/sylwedd; colli bioamrywiaeth pridd; erydiad pridd; cywasgiad pridd; a cholli pridd i ddatblygiad (selio pridd). Nod yr adolygiad hwn oedd i adnabod tarddiad a dadansoddi'r dystiolaeth ar ddifrifoldeb (maint) pob un o'r prosesau diraddiad hyn a'u hyd a'u lled gofodol yng Nghymru. Trafodir hefyd fregusrwydd a gwytnwch priddoedd Cymreig i bob proses ddiraddiad. Gosodir yr adolygiad yn erbyn tirweddau penodol Cymru, priddoedd, hinsawdd, defnydd/gorchudd tir a chynefinoedd. Mae'r adolygiad yn adeiladu ar adroddiad blaenorol (CEH, 2002) ar gyflwr a'r pwysau ar briddoedd Cymreig, gan ddiweddaru'r sail dystiolaeth lle'n bosibl.

I gyfarfod â'r nod, cafwyd asesiad tystiolaeth cyflym (gan ddefnyddio egwyddorion adolygiad systematig) yn defnyddio'n gyntaf tair ffynhonnell: Defra/prosiectau ymchwil wedi'u cyllido gan Lywodraeth Cymru; papurau a adolygwyd yn gyfradd; ac erthyglau llenyddiaeth llwyd. Er i'r canolbwyntio fod ar ddata Cymreig, cydnabyddir bod llawer o'r dystiolaeth gyfredol yn tarddu o astudiaethau ledled y DU, sydd o bosibl ddim yn cynrychioli'r priddoedd, defnyddiau tir a thirweddau penodol i Gymru.

1.1 Newid hinsawdd

Mae darogan brasluniau newid hinsawdd yn y dyfodol yn anorfod ansicr. Fodd bynnag, mae'r dystiolaeth a adolygwyd yn awgrymu na fydd y newid hinsawdd a ragwelir yng Nghymru yn effeithio'n arwyddocaol ar hyd gwlypter pridd (dyddiau cynhwyster cae) neu ddiffygion posibl gwlybaniaeth pridd hyd at 2080. Fodd bynnag, bydd newid yn nosbarthiad tymhorol y cyfnod cynhwyster cae, fydd yn golygu cyfnodau sychach yn yr hydref a gwlypach yn y gwanwyn. Mae ystyriaeth o feini prawf sychder yn y Dosbarthiad Tir Amaethyddol (DTA) dan frasluniau newid hinsawdd yn y dyfodol yn dangos y gallai priddoedd Cymreig ddod yn sychach. O ganlyniad, caiff nifer o safleoedd eu hisraddio, er nad adroddir yn benodol ar hyd a lled hynny yng Nghymru. Yn ychwanegol, gall rhai safleoedd gael graddau DTA gwell. Byddai cynnyrch glastir uwch yn arwain at ddwysedd stocio uwch a fyddai'n gysylltiedig â chywasgiad pridd helaethach. Mae modelu (heb ei ddilysu) yn dangos bydd difrifoldeb a hyd a lled erydiad pridd gan ddŵr yn cynyddu mewn ardaloedd uwchdir, yn enwedig yn yr hydref. Disgwylir newidiadau yn strwythur gymunedol microbig pridd fel ymateb i sychu priddoedd llawn dŵr (e.e. priddoedd uwchdir gwlyb organig ac organo-fwynaidd). Dim ond carbon pridd mewn priddoedd organo-fwynaidd a phriddoedd mawn sy'n dangos ymateb i newid hinsawdd. Ychydig o dystiolaeth sydd ar fregusrwydd a gwytnwch gwahanol fathau o bridd i newid hinsawdd yng Nghymru.

1.2 Colli sylwedd pridd organig

Mae tystiolaeth wrthdrawiadol o ddwy raglen fonitro genedlaethol (Arolwg Cefn Gwlad ACG + Rhaglen Fonitro a Gwerthuso Glastir - GMEP a'r Rhestr Bridd Genedlaethol - RhBG) ar gyfer hyd a lled newid carbon pridd mewn uwchbriddoedd yng Nghymru. Nid yw ACG na GMEP yn adrodd am unrhyw newid arwyddocaol cyffredinol mewn carbon pridd o 1978-2007 ar gyfer uwchbriddoedd yng Nghymru. Mae'r RhBG yn adrodd colledion mewn carbon uwchbridd ar gyfer Lloegr a Chymru dros yr un cyfnod, ond nid yw'n manylu am Gymru yn benodol. Mae data'r ACG a GMEP hefyd yn dangos dim newid mewn carbon pridd mewn systemau glastir gwell yng Nghymru rhwng 1978-2013. Disgwylir gwahaniaethau mewn systemau dwys ac eang a disgwylir adrodd ar hyn. Mae'r ddwy raglen fonitro yn adrodd am golled carbon organig mewn uwchbriddoedd âr yn Lloegr a Chymru ond nid oes manylu ar dystiolaeth am briddoedd Cymreig yn benodol. Sylwyd ar gynnydd mewn carbon uwchbridd mewn safloedd coetir rhwng 2007 a 2013 (GMEP). Adroddodd data RhBG bod y gyfradd fwyaf o ostyngiad mewn sylwedd organig mewn uwchbriddoedd yn Lloegr a Chymru ar briddoedd mawn, cors a gwaun uwchdir, er na chefnogwyd y casgliad hwn gan ddata ACG. Gallai'r diffyg newid mewn carbon pridd ar gyfer uwchbriddoedd Cymreig fod yn perthyn i'r newid defnydd tir cyfyngedig yng Nghymru dros gyfnod y monitro. Nid adroddir ar wytnwch priddoedd Cymreig i golli carbon organig/sylwedd yn y dystiolaeth yn benodol.

1.3 Colli bioamrywiaeth pridd

Nid oes tystiolaeth ar golled bioamrywiaeth pridd yng Nghymru. Anelodd astudiaeth ddiweddar at ganfod amodau gwaelodlin strwythur cymunedol microbig pridd mewn mathau cynefin eang yng Nghymru. Mae tystiolaeth ledled Ewrop yn awgyrymu bod systemau a reolir yn ddwys mewn perygl mwy o golli bioamrywiaeth pridd na chynefinoedd lled naturiol. Mae newidiadau mewn bioamrywiaeth pridd yn debygol o fod yn berthynol i i) newid defnydd tir) dwyshau / ehangu), ii) colled sylwedd pridd organig a/neu iii) newid hinsawdd. Gallai cyfraddau isel o newid defnydd tir a adroddir a/neu lefelau sylwedd organig yng Nghymru awgrymu newid bach mewn bioamrywiaeth pridd.

1.4 Erydiad pridd

Nid oes astudiaethau sy'n cyfrif dwyster neu hyd a lled gofodol erydiad pridd yn uniongyrchol (gan ddȐr, gwynt, cyd-dyniad a/neu amaethu yng Nghymru . Ni chafodd amcangyfrifon cyfredol a fodelwyd o erydiad pridd gan ddȐr yng Nghymru eu dilysu gyda graddfeydd erydu a arsylwyd. Mae priddoedd mawn / organig yn neilltuol o fregus i erydiad gan wynt a dȐr, yr ail broses yn enwedig mewn ardaloedd uwchdir oherwydd y glawiad uchel. Gan fod erydiad pridd yn cynrychioli gostyngiad absoliwt mewn cyfaint / dyfnder pridd, bydd priddoedd bas yn llai gwydn i effeithiau colled pridd o gymharu â phriddoedd dyfnach.

1.5 Cywasgiad pridd

Er bod modd amcangyfrif risg gymharol cywasgiad pridd o ddosbarthiadau gwlypter pridd a defnydd tir / rheolaeth, ychydig a wyddom am ddifrifoldeb gwirioneddol neu hyd a lled cywasgiad pridd yng Nghymru. Adroddodd astudiaethau ar gywasgiad mewn priddoedd glastiroedd ar gyfer Lloegr a Chymru ar y cyd yn dangos bod 10-15 % o safleoedd mewn cyflwr gwael a 50-60% mewn cyflwr cymhedrol. Ni wnaeth yr astudiaeth adrodd ar amodau ar gyfer safleoedd Cymreig yn benodol. Adroddwyd ar ddiraddiad strwythurol dwys mewn safleoedd âr (gyda chnydau cynhaeaf hwyr) a diraddiad cymhedrol mewn glastiroedd parhaol yn ne orllewin Lloegr, a allai gael ei ddefnyddio'n gyfatebiaeth pridd a hinsawdd rhesymol ar gyfer rhannau o Gymru. Nid oes data yn bodoli ar gywasgiad mewn tir âr yng Nghymru yn benodol. Nid oes data Cymreig penodol ar gyfer breguster a gwytnwch mathau gwahanol o bridd (neu ddefnyddiau tir) i gywasgiad.

1.6 Colled i ddatblygiad

Nid oes ystadegau ar y cynnydd mewn arwynebeddau artiffisial ar ôl 2007 o ddata gorchuddio tir. Mae angen y data hwn i gynhyrchu amcangyfrif cenedlaethol o ddwyster cyfredol neu hyd a lled gofodol colled pridd i ddatblygiad. Nid oes tystiolaeth sydd wedi cydosod ystadegau newid defnydd tir i fanylder digonol i adnabod hyd a lled selio pridd yng Nghymru ar fathau gwahanol o bridd neu ddefnyddiau tir.

1.7 Rhyng-weithredoedd rhwng bygythiadau.

Mae llawer o'r bygythiadau yn gysylltiedig â'i gilydd gan ddau brif yrrwr: newid hinsawdd a newid defnydd tir. Bydd newidiadau yn nhymoroldeb a hyd y cyfnod capasiti maes dan newid hinsawdd yn cael effaith ar amseru gweithrediadau maes a chyfnodau pori da byw, a chynnydd cysylltiedig risg cywasgiad pridd, yn enwedig ar gyfer priddoedd araf eu treiddiad. Mae bioleg pridd yn ymatebol i newidiadau mewn trefniannau dȒr pridd, gyda symudiadau penodol mewn strwythur meicrobial cymuned mewn priddoedd gorlawn o ddȒr fydd yn profi cyfnodau sychu amlach. Mewn ardaloedd a reolir gan briddoedd araf eu treiddiad, bydd amlder cynyddol digwyddiadau glaw eithafol yn arwain at fwy o lifiad ochrol a throsdirol yn enwedig pan fo priddoedd ar neu tu hwnt i gapasiti'r cae, gan gynyddu risg gorlif dȒr ar yr wyneb. Yn yr un modd, bydd y digwyddiadau glaw eithafol hyn hefyd yn cynyddu risg erydiad pridd gan ddȒr mewn ardaloedd bregus. Mae'r ardaloedd bach o dir amaethyddol graddfa uchel (Gradd 1 a 2) yn debygol o gael eu hisraddio mewn ymateb i sychder cynyddol yr haf. Fodd bynnag, gallai amodau sychach fod o fudd i ardaloedd eraill ar y cyrion a allai weld gwelliant mewn graddfa ALC (hynny yw, symudiad o Raddfa 4 i 3b). Gallai hyn gychwyn newid defnydd tir mewn ymateb i amodau sychach yn yr haf ond mae'n ansicr sut y bydd hyn yn amlygu ei hun yn y dyfodol.

Newid tir di-âr i dir âr sy'n cael yr effaith mwyaf arwyddocaol ar fygythiadau pridd. Mae'n debygol y gallai ardaloedd o lastir wedi'i wella, sydd ar hyn o bryd ar y cyrion ar gyfer amaethyddiaeth âr, gael eu troi i ddefnyddiau âr a garddȒriaethol yn y dyfodol. Bydd y newid hwn yn golygu colled sylwedd pridd organig, newid i strwythur a swyddogaeth cymuned microbig, a risg gynyddol o gywasgiad ac erydiad, yn enwedig os yw cnydau a gynaeafir yn hwyr yn cael eu mabwysiadu. Gallai ehangu glastir wedi'i wella a chynnyrch gwair cynyddol (ymatebion posibl i hinsawdd sy'n newid) gael goblygiadu ar gyfer colled carbon pridd, newid meicrofioleg y pridd a hefyd osod mwy o risg i'r tir o gywasgiad cynyddol. Byddai ehangu coetir o bosibl yn cynyddu carbon uwchbridd ond mae'n ansicr a fyddai hyn yn golygu casglu carbon cyffredinol gan na fyddai'r duedd hon yn cael ei adlewyrchu mewn pridd o dan yr uwchbridd.

1.8 Prif fylchau gwybodaeth ac argymhellion

Newid hinsawdd

Mae'r symudiad tymhorol yn y cydbwysedd dȒr a chyfnod gorwlychu penodol yn gwarantu ymchwil pellach, yn enwedig ble bydd hyn yn effeithio ar ardaloedd gyda phriddoedd araf eu treiddiad.

Mae ymateb hydrolegol priddoedd araf eu treiddiad yn gofyn am asesiad penodol mewn ymateb i ddigwyddidau eithafol. Gallai hyn ddarparu dangosyddion o'r risg gorlifo dȒr arwyneb mewn ardaloedd lle mae'r priddoedd hyn yn gyffredin.

Mae angen symudiad mewn graddfa ALC oherwydd cyfyngiadau cynyddol ar feini prawf sychder haf dan anghenion newid hinsawdd i gael eu tynnu allan yn benodol ar gyfer safleoedd RhBG Cymreig. Daw darlun cliriach o ardaloedd a effeithir gan israddio neu uwchraddio ALC i'r golwg.

Colli sylwedd pridd organig

Dylid tynnu dadansoddiad o ddata monitro uwchbridd gan raglenni ACG +GMEP a RhBG allan ar gyfer safleoedd yng Nghymru yn benodol. Dylai dadansoddiad pellach o newidiadau carbon uwchbridd s haenedig fesul math o bridd gael ei bennu ar gyfer yr is-set hon.

Mae storfa garbon arwyddocaol yn bodoli mewn pridd o dan yr uwchbridd a dylid cymryd y newid hwn mewn stoc carbon o'r proffil pridd cyfan i ystyriaeth mewn rhaglenni monitro

Mae newidiadau mewn carbon pridd rhwng glastir wedi'i wella a heb ei wella mewn priddoedd Cymreig yn hawlio ymchwil pellach. Gallai'r wybodaeth hon gynnig golwg ar newidiadau mewn rheolaeth tir a allai ddigwydd mewn ymateb i hinsawdd yn newid.

Dylid diffinio trothwyau hollbwysig o golled sylwedd organig pridd yn rhanbarthol ac ar gyfer mathau penodol o bridd yn ngoleuni'r cyfyngiadau amgylcheddol ar systemau pridd yng Nghymru.

Colli bioamrywiaeth pridd

Adeiladu ar yr arolwg gwaelodlin, dylai nodweddiad strwythur cymuned microbig gael ei estyn i fathau allweddol o briddoedd o fewn cynefinoedd eang yng Nghymru.

Mae angen monitro parhaus i adnabod unrhyw newidiadau mewn bioamrywiaeth pridd dros amser (rhaglen GMEP). Dylai hyn hefyd gael ei estyn i ardaloedd lle mae newid defnydd tir wedi digwydd.

Mae dealltwriaeth anghyflawn o'r newid yn ymateb gweithredol cymunedau biolegol pridd ac effeithiau ar swyddogaethau pridd, er bod tystiolaeth yn dod i'r amlwg dros symudiad mewn strwythur cymuned microbig dan wahanol fathau defnydd tir ar lefel Ewropeaidd.

Erydiad pridd

Mae angen dealltwriaeth o ddwyster a hyd a lled gofodol erydiad pridd gan ddȐr, gwynt, cyd-dyniad a/neu amaeth ar draws Cymru, gan nad oes ar hyn o bryd unrhyw ddata yn bodoli yn y DU.

Mae angen dilysu amcangyfrifon wedi'u modelu o ddwyster a hyd a lled gwahanol brosesau erydiad pridd yng Nghymru yn y maes trwy arolygon a monitro. Mae hyn hefyd yn gofyn am well dadansoddiad o fodelau rhagweld erydu i alluogi rhagweliadau ar raddfa leol.

Cywasgiad pridd

Mae gwybodaeth gyfredol wedi cael ei gyffredinoli o ddata Lloegr a Chymru. Mae angen ffocws ar asesiad systematig o ddiraddiad strwythurol mewn priddoedd âr a glastir yng Nghymru.

Mae angen adolygiad o fesurau lliniaru cywasgiad coedwigaeth i ddadansoddi gwir hyd a lled a bod yn agored i gywasgiad o weithrediadau coedwigaeth.

Mae angen dealltwriaeth helaethach o wytnwch pridd rhag cywasgiad mewn cyfuniadau allweddol defnydd pridd a thir yng Nghymru.

Colled i ddatblygiad

Mae angen casglu hyd a lled colled pridd i ddatblygiad yn systematig ar y lefel genedlaethol ac mae angen dealltwriaeth o wytnwch posibl priddoedd sy'n rhwym wrth ddatblygiad.

Dylid asesu colled tir amaethyddol graddfa uchel (y Gorau a'r Mwyaf Amlochrog) a mathau eraill o bridd sy'n cefnogi cynefinoedd o arwyddocad cenedlaethol.

2 Background

The Welsh Government has recently committed to the sustainable and holistic management of natural resources by passing the Environment (Wales) Bill on 2 February 2016. This includes planning and managing natural resources sustainably at a national and local level. Soil is a cornerstone natural resource that offers many benefits to society through the delivery of provisioning, regulating, supporting and cultural ecosystem goods and services. These core economic, environmental and societal services include:

<u>Provisioning</u> of material goods and services

- Agricultural production of food, fodder and biofuel.
- Forest products
- Water supply to surface and groundwater for subsequent extraction
- Land to support infrastructure
- Raw materials for building and fuel (e.g. aggregates; peat)

<u>Regulation</u> of ecosystem and environmental processes

- Water storage for flood control and catchment flow regulation
- Carbon storage in soils to regulate the climate and potentially mitigate future climate change by sequestering CO_2 from the atmosphere
- Cycling of nutrients for plant availability
- Filtering pollutants to provide clean water

<u>Supporting</u> environmental services

- Land-based habitats, including priority habitats
- Supporting above and below ground biodiversity
- Development of new soil material through soil formation

<u>Cultural</u>, non-material services
- Key component of landscape aesthetic
- Spaces for recreation and amenity especially in urban environments
- Protection of buried archaeological heritage

This review provides a high level summary of the evidence base of the severity and extent of soil degradation processes in Wales. ‘Severity’ is defined as magnitude of the soil degradation process, for example tonnes per hectare per year for soil loss by erosion. ‘Extent’ is defined as the spatial area (ha^{-1} or km^2) affected by the soil degradation process. These definitions follow the methodology used in Defra SP08007. Six key soil degradation processes (or threats to soil resources) are detailed in the EU Thematic Strategy for Soil Protection as having significant impact on the provision of ecosystem goods and services through the degradation of soil resources and functions. The six threats considered most relevant to Wales are:

1. Climate change
2. Loss of soil organic matter
3. Loss of soil biodiversity
4. Erosion
5. Compaction
6. Loss of soil to development

The purpose of this review is to contribute to an evidence base that can be used to inform and support development of natural resource management policy in Wales. The review covers the following objectives:

- Provide a narrative on the six threats and identify the severity and extent of each threat in Wales. This includes consideration of the vulnerability and resilience of the soil (and or region/s) to each threat. Here, óvulnerabilityô is defined as sensitivity or susceptibility of soils to each degradation process. óResilienceô is defined as resistance (degree of change) coupled with recovery (rate and extent of subsequent recovery) from a disturbance (Corstanje et al., 2015)
- Identify gaps and uncertainties in the evidence base and evaluate the potential impact on policy development.
- Recommend topics for priority research.

The review consists of a short, rapid evidence assessment of a number of key evidence sources, listed in order of priority. The first extracted Welsh-specific evidence from the Defra and Welsh Government funded research and development evidence base. The second was a search of academic literature for research articles on each threat published since 2002, related to the U.K. and Wales. The third was grey literature consisting of reports, briefing notes and guidelines that can be obtained through initial rapid internet searches. This review builds upon a previous report that detailed the state, pressures and controls on the state of soils in Wales (Centre for Ecology and Hydrology 2002) and will provide an update of the evidence base, where present, since this report was published in 2002. The findings of the CEH 2002 report are summarised in Table 1 focusing on the soil threats relevant to this review. It reported that there was little or no indication for the national extent of the following threats to soil in Wales; loss to development; climate change and soil compaction. Loss of soil biodiversity was not considered as part of the CEH review. This previous review indicated that several significant knowledge gaps existed that prevented the national scale assessment of the extent and impact of key soil threat in Wales.

Table 1. Summary of finding of previous review on the state and pressures of soils in Wales (CEH, 2002).

Threat	**Extent in Wales**	**Impact on soil function**	**Knowledge gaps**
Loss to development	• Extents of soil loss to development is not systematically collated at a national level.	• Loss of most functions except providing a platform for infrastructure and some amenity use.	• High grade agricultural land protected under Best and Most Versatile land ï (BMV) in planning policy. However, soils of lower quality agricultural land appear not to be as adequately protected (although may have significant ecological value).
Erosion	• Sources of large scale national data are limited. • Site specific data available but limited rate (i.e. severity) of erosion available. • Focus on upland erosion with most extensive erosion found on peat soils. • The principal areas of arable cultivation in Wales, including Dyfed and Pembrokeshire, are likely to be subject to similar erosion pressures and patterns such as those in England - channel erosion and rilling. • Anecdotal evidence of wind blow in small areas of sandy soils (e.g. Wrexham). • In lowland grassland erosion features are typified by poaching. However, results indicated that soil erosion was not a significant process on established, enclosed grassland.	• Effects on crop production are less pronounced in Wales than other regions of the UK. • In upland areas eroded soils have reduced capacity to buffer water for regulating river flows. • Significant off-site impacts e.g. eutrophication of water bodies.	• Comprehensive survey and monitoring scheme stratified by soil and land use type in Wales is required. • Inadequate or non-existent information on rates (severity) of erosion. • No evaluation of the efficacy of current erosion control measures.
Soil structure	• Virtually no data exists for the extent	• Reduces agricultural	• Systematic survey of structural

Threat	Extent in Wales	Impact on soil function	Knowledge gaps
	of structural degradation in Welsh soils. • Therefore it is impossible to determine if this is a significant threat to soil in Wales.	productivity, impacts on soil biodiversity and changes soil hydrology.	condition of Welsh soils is required.
Soil organic matter	• Mean topsoil organic carbon decreased by 0.5 % under arable and permanent grassland between 1980 and 1996. • Mean organic carbon content of the top 15 cm of soil is 10.8 % (data from NSI). • Absolute total organic matter content of soils in Wales is unknown as most studies have only focused on top 15 cm of soil.	• The adequate stocks of soil C in Wales is not limiting to agricultural productivity. • Climate change and / or intensification of land use and /or change of land use could lead to substantial losses of carbon. • Reduction of buffering capacity of soils and structural stability. • Impact on water quality by DOC.	• More recent data on soil carbon stocks is needed. • Difficulty in linking change in organic matter to soil function at a practical level. • Systematic data collection required through a national monitoring programme.
Climate change	• No information explicitly on extent.	• Change in soil C attributed to climate change, although uncertainties on actual stock change due to complex feedback mechanisms. • Influence on productivity of soils (arable and grassland). • Increase in erosion and nutrient transfer to waters. • Increase in DOC in waters attributed to warming. • Interaction with GHG emissions.	• Issues with uncertainties of the soil carbon stock impact on how CC can affect C dynamics in soils.

A recent review of soil evidence focused on research questions related to sustainable soil management and delivery of ecosystem services in England and Wales (SP1620). Whilst there are some synergies between SP1620 and this review, the former reviewed the evidence base for very specific research questions (e.g. ñAt what point do degradation processes significantly affect soil quality and function?ò). Whilst some questions may map indirectly onto the objectives of this project (e.g. soil degradation theme), the focus of what was asked of the evidence base was different and thus the resulting evidence extracted from both reviews will be different. This current review focuses on; extracting Welsh specific evidence for a number of key threats; ascertaining the evidence for the extent and severity of these threats in Wales and; reporting on the vulnerability and resilience where evidence exists.

2.1 Soil, climate and land use in Wales

2.1.1 Landscape, climate and habitat

The Welsh landscape is diverse ranging from spectacular coastlines to upland areas of Snowdonia in the north, Brecon Beacons and the Black Mountains in the south and the Cambrian mountains in central Wales. These areas support key habitats such as upland peat bogs and heather moorland, including several priority habitats (Blanket bog and upland heath), although they are small in extent. There are three national parks (Pembrokeshire coast, Snowdonia and Brecon Beacons) accounting for about 20 % of the land area. These nationally important areas support diverse range of habitats. The most extensive landscapes are the hilly grassland areas that support livestock grazing and forestry. Coastal areas have a diversity of habitats from sand dunes, saltmarshes and coastal cliffs. Most land is >200m with upland areas exceeding 500 m with peaks of >1000 m and >800m in Snowdonia and Brecon, respectively (Figure 1).

The climate of Wales is strongly influenced by the prevailing weather systems from the Atlantic and the mountainous nature of the country. Average annual rainfall varies from <1000 mm in the border and coastal areas to >3000 mm in the central uplands and Snowdonia (Figure 2). The pattern of rainfall varies over the year. October to January are the wettest months and late spring and early summer are the driest months. Average annual temperature in low altitudes varies from 9.5 °C to 11 °C and between 3.5 °C and 7.5 °C in the uplands (Figure 3).

Figure 1. Elevation.

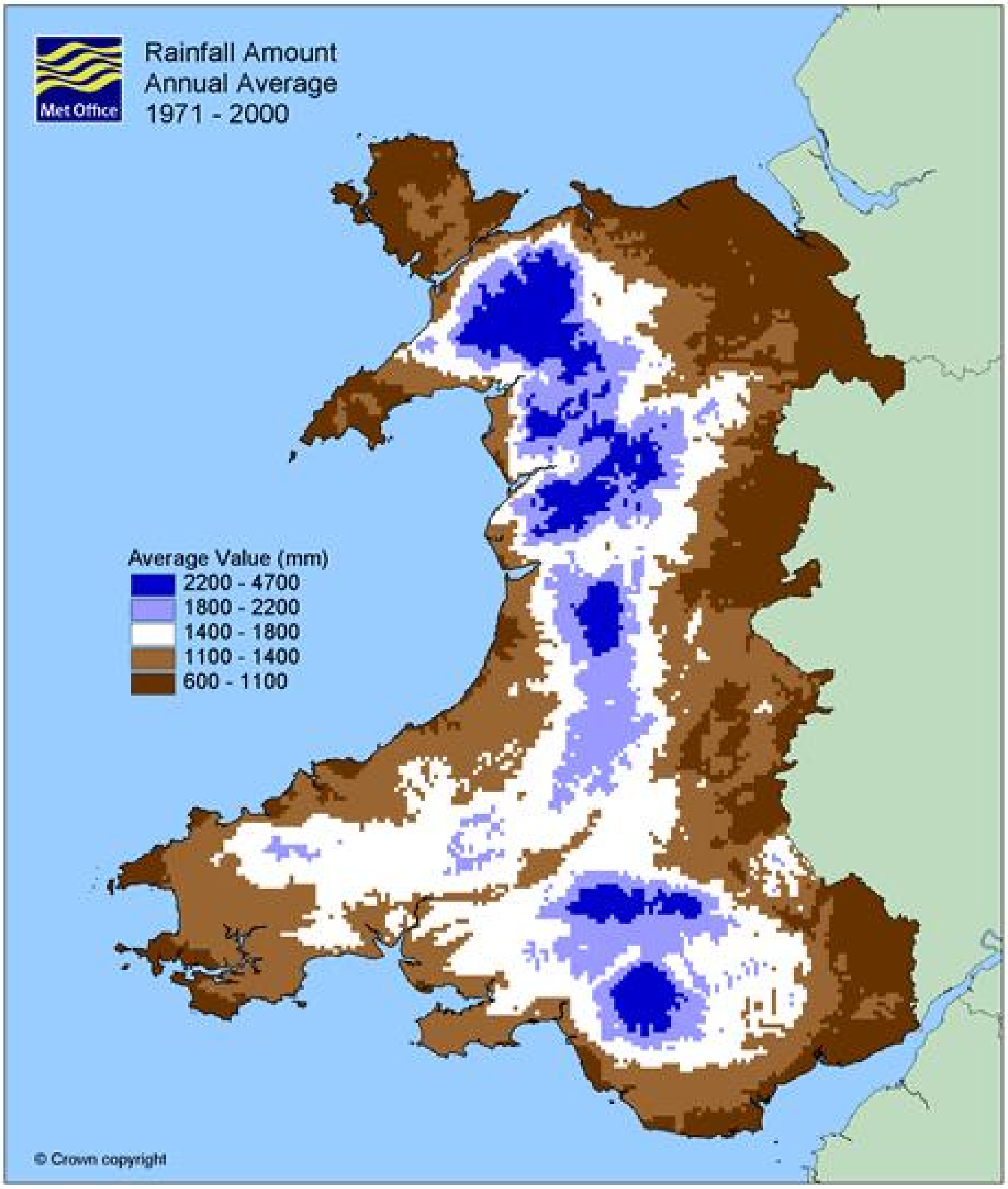


Figure 2. Average annual rainfall (Source: Meteorological Office)

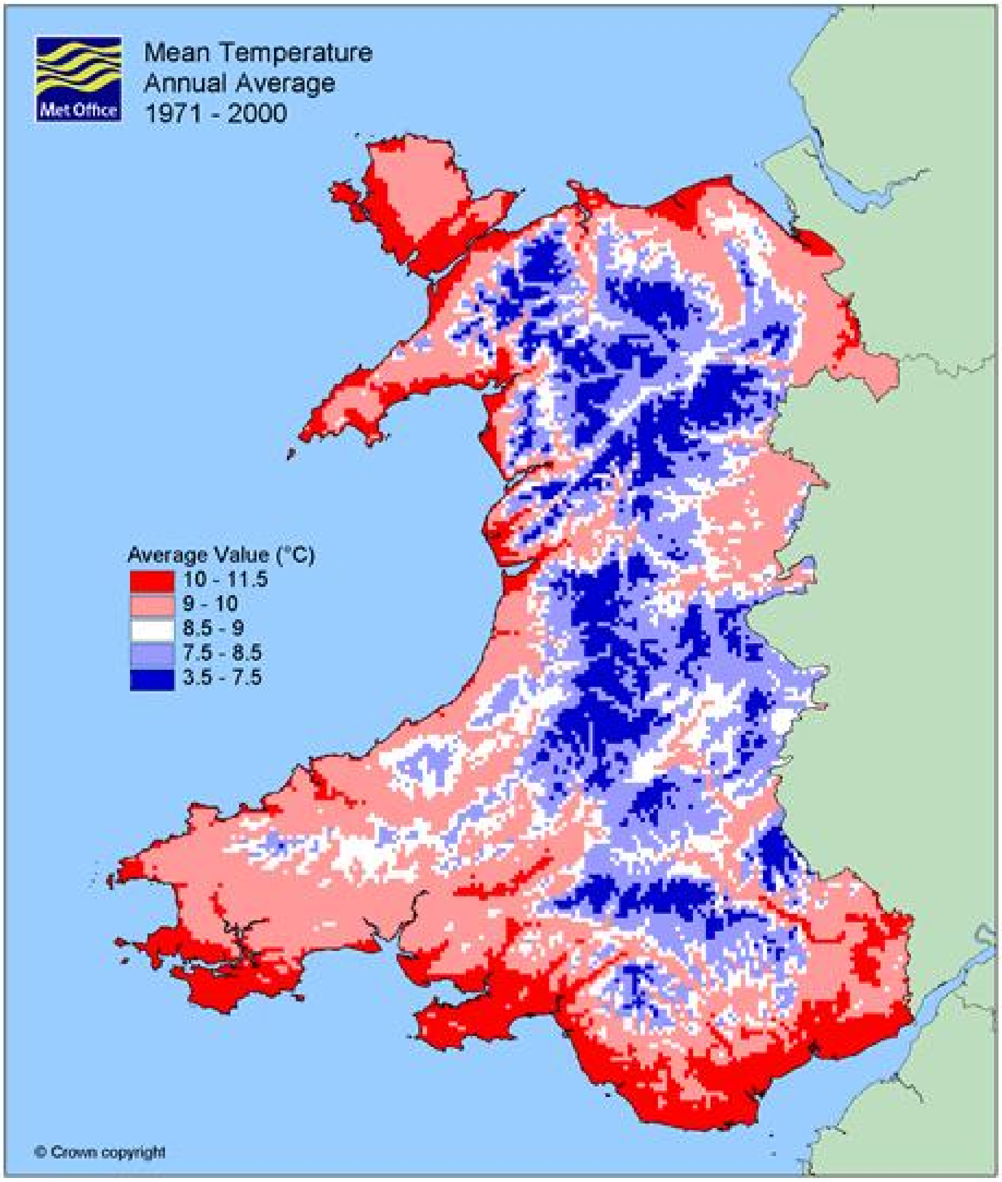


Figure 3. Average annual temperature (Source: Meteorological Office)

2.1.2 Soil

Soil in Wales is strongly influenced by climate (and altitude) and the underlying sediments or rocks (Figure 4). In the widespread hilly and lowland areas the soils are a mixture of acidic (e.g. Manod), well drained soils (e.g. Denbigh), and slowly permeable soils that have impeded drainage (e.g. Cegin). The well drained soils are formed over slowly weathered hard rocks such as shales, mudstones and siltstones and because of the high rainfall leaching is the dominant process which leads to acidification. The slowly permeable soils have a layer at depth that impedes drainage making them seasonally waterlogged in the winter. In upland areas the soils are characterised by very limited extents of blanket peat and leached wet soils with peaty surfaces (e.g. Hafren). In steep areas the soils are shallow with a thin organic-rich layer of peat lying directly over rock. In the coastal fringes in south and north-west Wales, soils are formed on coastal flats and have groundwater near the surface. Table 2 indicates the proportion of land area occupied by each broad soil type and Table 2b summarises the dominant soil association found within each dominant soilscape in Wales.

Table a2. Summary of Soilscapes area in Wales.

Soilscapes	**Area (km^2)**	**Area (%)**
Peat soils	699	3.3
Very acid loamy upland soils with a wet peaty surface	1879	8.9
Freely draining acid loamy soils over rock	4801	22.6
Freely draining very acid sandy and loamy soils	149	0.7
Naturally wet very acid sandy and loamy soils	36	0.2
Freely draining slightly acid soils	5795	27.3
Freely draining floodplain soils	380	1.8
Loamy and clayey floodplain soils with naturally high groundwater	348	1.6
Loamy and clayey soils of coastal flats with naturally high groundwater	279	1.3
Loamy soils with naturally high groundwater	30	0.1
Slightly acid loamy and clayey soils with impeded drainage	389	1.8
Slowly permeable soils	5291	24.9
Shallow soils	303	1.4
Saltmarsh and Sand dune soils	176	0.8
Restored soils mostly from quarry and opencast spoil	139	0.7

Table 3b. Summary of dominant Soilscapes and corresponding dominant soil series in Wales

Dominant soilscape	**Dominant soil association**
Peat soils	Crowdy
Very acid loamy upland soils with a wet peaty surface	Hafren
	Lydcott
	Gelligaer
Freely draining acid loamy soils over rock	Manod
	Withnell
	Parc
	Moor Gate

Freely draining very acid sandy loamy soils over rock	Anglezarke
Freely draining slightly acid soils	Oglethorpe
	Milford
	Eardiston
	Neath
	Denbigh
	Wick
	East Keswick
	Ston Easton
Slowly permeable soils	Cegin
	Brickfield
	Salop
	Wilcocks
Loamy and clayey floodplain soils with high groundwater	Conway

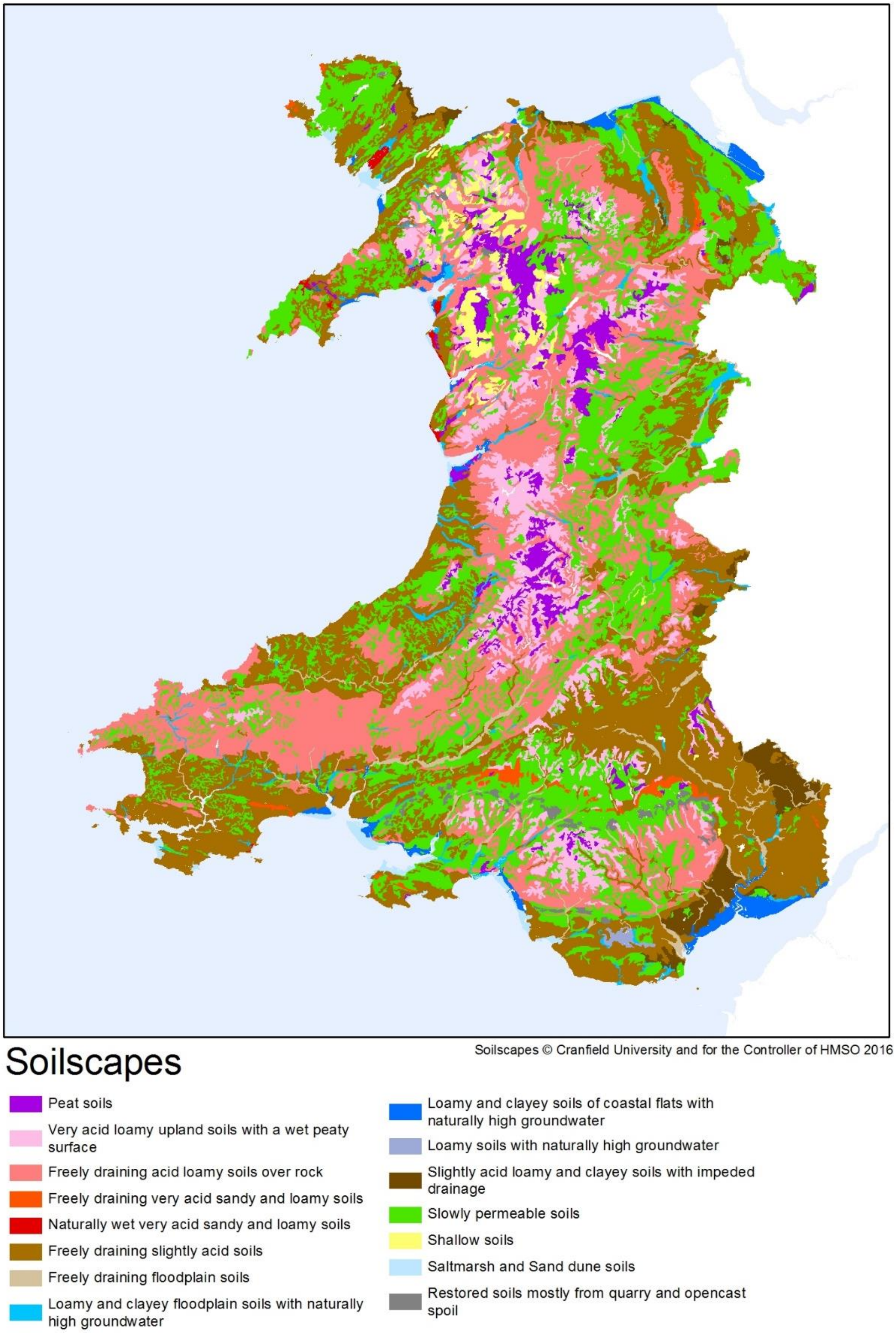


Figure 4. Soilscapes Source: Cranfield University

2.1.3 Land cover and land use

Land used for agricultural purposes accounts for over 88% of the total land area of Wales (Welsh Government, 2015), which includes improved grassland, rough grazing, arable and land registered to qualify for farm woodland schemes (Welsh Government, 2015). The total area of arable crops and bare fallow was 87,400 hectares in June 2015 (Welsh Government, 2015), this amounted to 8.5% of land area in the LCM 2007 (Table 4). Due in part to environmental constraints the dominant agricultural activity is restricted to grazing for cattle and sheep. Woodland accounts for 13% of the area at 306,000 ha (Forestry Commission, 2015). This is a mixture of large, conifer plantations, and smaller privately owned mixed woodlands (Forestry Commission, 2015). Urban areas including built up areas and gardens account for 4% of the land cover. Other land cover types restricted to upland areas include bog and heath (7%).

Table 4. Summary of land cover classes from Land Cover Map 2007 (Morton et al.,, 2011)

Land cover class	**Area (%)**
Permanent grassland[1]	65
Woodland & Forestry[2]	13
Arable & Horticulture	8.5
Heath	5.0
Urban	4.0
Bog	2.0
Other[3]	2.5

[1]improved and semi-natural grassland; [2]broadleaf and conifer; [3]rock, inland water, coastal sediment/environments

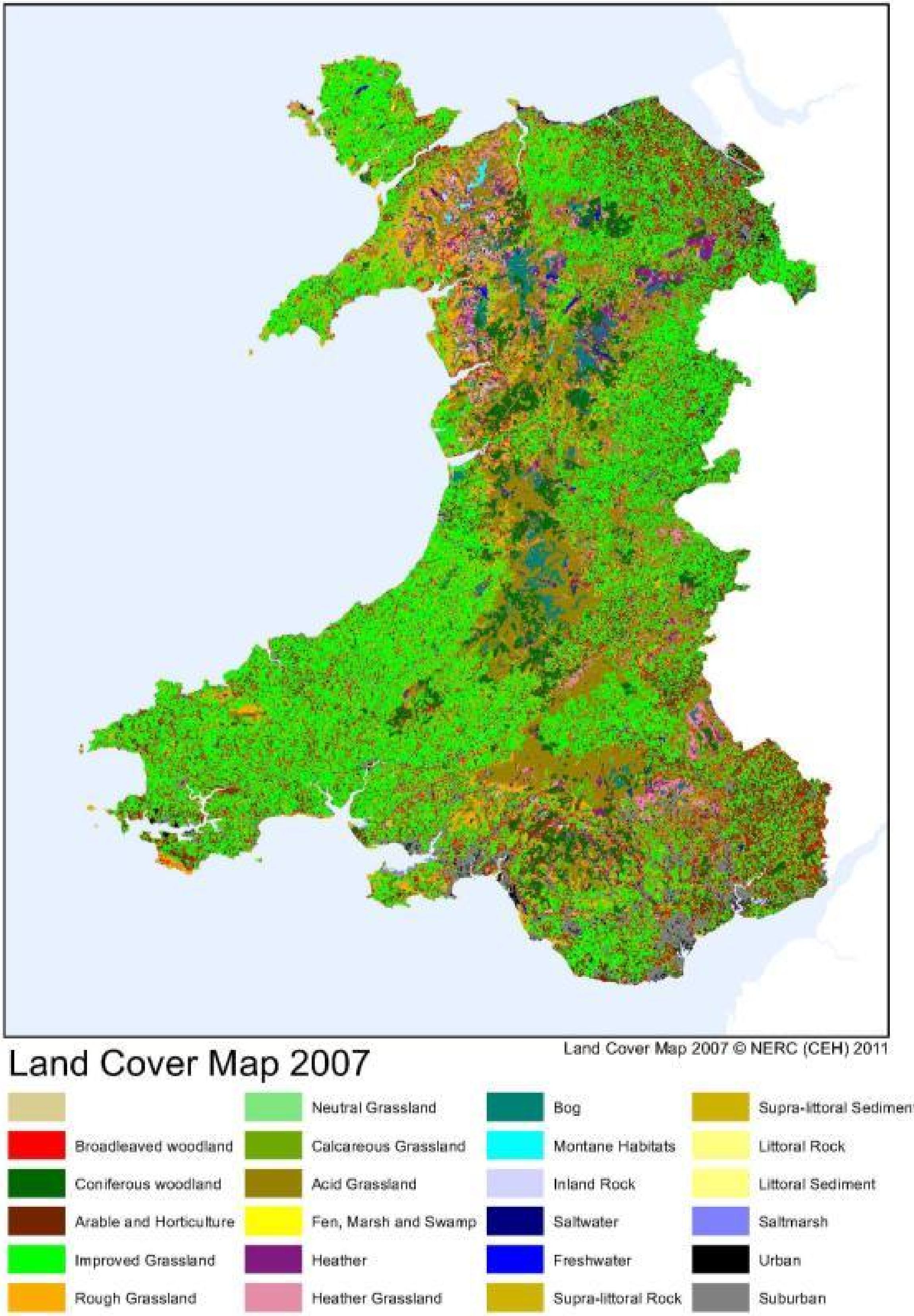


Figure 5. Land cover for 2007.

3 Methodology

Data extraction was undertaken on three document types; Defra reports, scientific literature and grey literature. The methods applied in this extraction are outlined below.

3.1 Defra reports data extraction

a. Defra personnel extracted completed and ongoing project reports excluding those with publication restrictions. This gave approximately 12,500 reports. These were screened by Defra business unit, and irrelevant areas were removed outright (e.g. Veterinary medicine, marine). The remaining report details (7390 reports) were sent to Cranfield staff in an Excel spreadsheet.
b. These reports were initially scrutinised by an automated search for key search terms (Table 5) within the individual project objectives, approaches and description.

Table 5. Key terms used in scrutinising the received Defra projects list.

Threat	Search term
General	Soil
Climate change	Climate change
Loss of organic matter	Carbon
Loss of biodiversity	Biodiversity
Erosion	Erosion
Compaction	Compaction
Loss to development	Sealing

c. Using these results the project list was divided into three separate workable lists based on 1) reports that contained ‘soil’ 2) reports that did not contain ‘soil’ but did contain specific threat search terms and 3) reports that did not contain ‘soil’ or other key search terms.
d. These reports were all screened for relevance and identified as being ‘in’, ‘out’ or for ‘review’. Reports identified for review were looked at by other team members for a second and third opinion. A proportion of the results were cross checked between the team members for consistency.
e. The reports included in this sift were checked against the 385 reports referenced in the ADAS (2015) Soils Research – Evidence Review.
f. Of the reports listed, only 26 had not already been considered (present in the ‘in’ or ‘out’ lists). These reports were screened for relevance. Post screening, none of the reports were added to the existing list.
g. Reports considered to be ‘in’ (212) were then more closely scrutinised for inclusion in the final review.

Table 6 summarises the number of reports from the start to the end Defra report filtering process.

Table 6. Summary of Defra reports numbers through the screening process.

Threat	Reports available	Screened as relevant*	Referenced
Climate change		79	5
Loss of organic matter		83	6
Loss of biodiversity	7390	107	1
Erosion		43	12
Compaction		15	6
Loss to development		17	3

*The number of reports does not equal 212 as reported above, as many reports were identified as being relevant to multiple soil threats.

3.2 Scientific literature data extraction

Another search was undertaken using Scopus; a large database of peer-reviewed scientific journal articles. Threat-based search terms (Table 7) were applied to the title, abstract and key words in combination with ñUKò and a restriction on publications from 2002 onwards. The search results were then further limited using a ókey wordô search for the United Kingdom. This further filtered the results despite already including UK in the main search string.

Table 7. Search strings applied in Scopus.

Soil threat	Search term strings
Climate change	óSoilô AND óClimate changeô
Loss of organic matter	óSoilô AND óorganic carbonô OR óorganic matterô
Loss of biodiversity	óSoilô AND óbiodiversityô
Erosion	óSoilô AND óerosionô
Compaction	óSoilô AND ócompactionô
Loss to development	óSoilô AND ósealingô OR óurbanisationô OR ópavementô ósoil degradationô AND óurbanô OR óconstructionô

One example of a search string used in Scopus is given below.

TITLE-ABS-KEY (**"climate change"** AND **"soil"** AND **"UK"**) AND PUBYEAR > **2001** AND (LIMIT-TO (EXACTKEYWORD , **"United Kingdom"**))

Results were screened for applicability to Wales and/or the UK (for areas with similar soil and land uses such as SW and NW England) (Table 8). Resulting reports were stored in Mendeley, a reference/document management system.

Table 8. Summary of scientific literature identified at each sifting stage.

Threat	Scopus hits	Screened as relevant	Referenced
Climate change	151	94	40
Loss of organic matter	75	34	16
Loss of biodiversity	82	44	10
Erosion	114	13	7
Compaction	21	6	14
Loss to development	266	9	8

3.3 Grey literature data extraction

Due to time constraints a very rapid internet search was applied to identify grey literature. Google search engine was used to identify any relevant publications in the grey literature. Climate change was omitted from this search owing to the large volume of data from Defra reports and scientific literature that had already been collated.

Table 9. Grey literature search terms and results for each soil threat, excluding climate change.

Soil threat	Search term string	No. hits
Loss to development	wales threat OR degradation "soil sealing"	5,110
Loss of organic matter	wales threat OR degradation "organic"	712,000
Loss of biodiversity	wales threat OR degradation "biodiversity"	425,000
	wales threat OR degradation "loss of biodiversity"	141,000
Compaction	wales threat OR degradation "compaction"	202,000
Erosion	wales threat OR degradation "erosion"	404,000

The first 5-10 pages of results were then scanned for relevant documents and links to relevant documents were saved to a spreadsheet identifying which of the soil threats was covered. A total of 33 additional documents and websites were identified in this way.

3.4 Review of extracted data

Each soil degradation threat was investigated in turn by considering the reports and literature captured in the extraction process. This required further scrutiny of the literature beyond scanning abstracts and executive summaries to ascertain the relevance of the evidence for inclusion in the review. Where information was not contained within the extracted data, but was known to exist elsewhere this was also drawn upon.

4 Climate change

The evidence reviewed (>173 reports) suggests predicted climate change in Wales:

- has little or no change in the duration of soil wetness (field capacity days) or potential soil moisture deficits until 2080.
- shifts the seasonal distribution of the field capacity period, which will mean drier autumn and wetter spring periods.
- reduces the waterlogging duration of slowly permeable soils by 2080
- indicates drought criteria become the most limiting factor to agricultural land classification, resulting in many sites becoming downgraded.
- has little significant influence on soil carbon losses with the *exception* of peat and organo-mineral soils.
- Increase grassland productivity, leading to higher stocking densities that could be associated with more severe and extensive incidence of soil compaction and soil erosion.
- has uncertain temperature effects on soil biological activity but drying of water saturated soils (e.g. wet upland organic and organo-mineral soils) may stimulate biological activity that was suppressed by waterlogged conditions.
- will increase the severity and extent of soil erosion in upland areas in autumn seasons by 2090, but with less erosion in winter (despite higher rainfall amounts), due to increased vegetation cover.

There is little evidence on the vulnerability and resilience of different soil types to climate change in Wales.

4.1 Overview

Changing climate is defined by the UKCP09 scenarios and summaries from the IPCCs reports and for the purpose of this review are summarised by the following high level scenarios:

- **Increased land temperatures** *"Surface temperature is projected to rise over the 21st century under all assessed emission scenarios." (IPCC, 2014)*
- **Increased frequency of extreme events** (e.g. heatwaves and extreme rainfall). *"It is very likely that heat waves will occur more often and last longer, and that extreme precipitation events will become more intense and frequent in many regions (IPCC, 2014)*

- **Changing seasonal pattern of rainfall distribution** *drier summers and wetter winters (UKCP09).*

UKCP09 have produced regional climate projections based on assemblage models for three emission scenarios (low, medium, high) and summary data for climate baselines. These are detailed in Table 10 for Wales.

Observed mean daily temperature values indicate annual and seasonal temperatures have increased for the period 1961-2006 (Table 10). For the climate projection scenarios this pattern continues with an increase in mean temperature (Figure 6) and in both winter and summer temperature from 2020s through to 2080s (Table 10). The distribution of temperature change is uniform across Wales with all areas experiencing similar % increases in annual, summer and winter temperatures (Figure 6).

Observed rainfall in Wales increased by 36% during the period 1960-2006. For future climate scenarios the total annual precipitation is not predicted to change from baseline values. The baseline values differ in the UKCP09 scenario (1961-1990) compared with the observed time series reported in Table 10. Differences exist in the seasonal distribution of rainfall over the time periods, with a decrease in summer precipitation and increase in winter precipitation. This difference becomes spatially explicit by the 2080s. Greatest reductions in summer precipitation are apparent in the Gower, South Wales and the border regions and greater increases in winter precipitation in South Wales and the Llyn peninsula (Figure 8).

The review is focused on the impact of climate change to the soil system directly. It will not consider impacts related to feedback mechanisms that would contribute to changes in the greenhouse gas (GHG) inventory or emissions from agriculture.

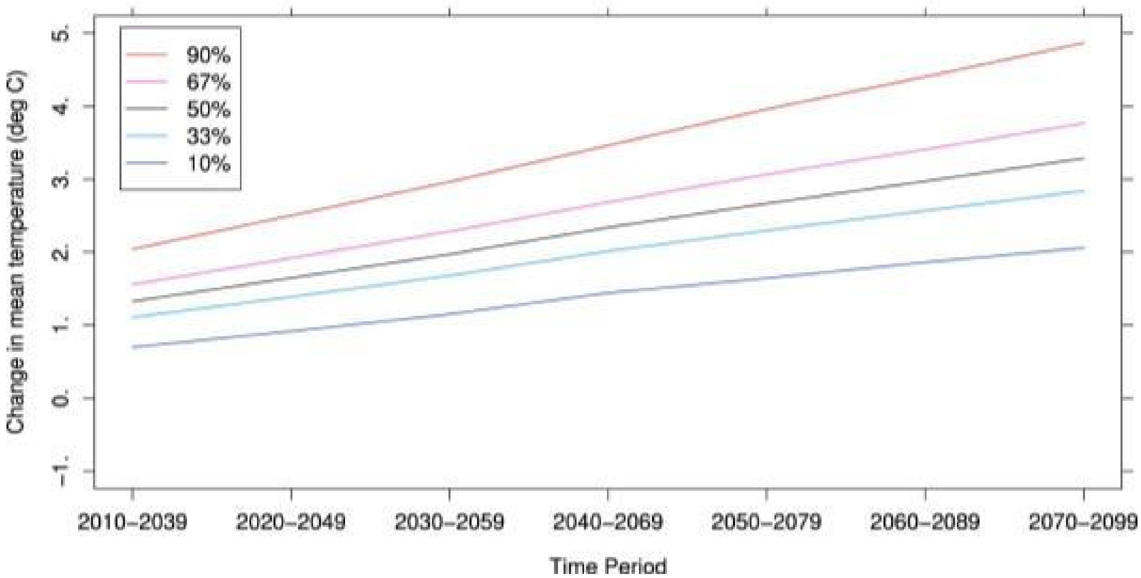


Figure 6. Mean annual change in temperature (medium emissions scenario) in Wales for a range of probabilities. © UK Climate Projections 2009

Table 10: Summary of observed and predicted climate change in Wales. Observed changes use data from 1961-2006. 1961-1990 observed changes; projected changes from the 1961-1990 baseline for 2020s, 2050s and 2080s are based on the UKCP09 medium emission scenario central (50%) estimate. Observed changes include data from 1961-2006. Blank cells indicate summaries were not calculated. Source: UK Climate Projections http://ukclimateprojections.metoffice.gov.uk/.

	Spring	Summer	Autumn	Winter	Annual average
1961-2006					
Daily mean temperature °C	1.44	1.36	1	1.7	1.33
rain days (> 1mm)	0.5	ï 0.7	2.9	4.6	5.7
% total precipitation	8.4	ï 5.6	22.3	27	13.6
2020s					
Daily mean temperature		1.4		1.3	
% change total precipitation		-7		7	0
2050s					
Daily mean temperature		2.5		2	
% change in total precipitation		-17		14	0
2080s					
Daily mean temperature		3.5		2.8	
% change total precipitation		-20		19	0

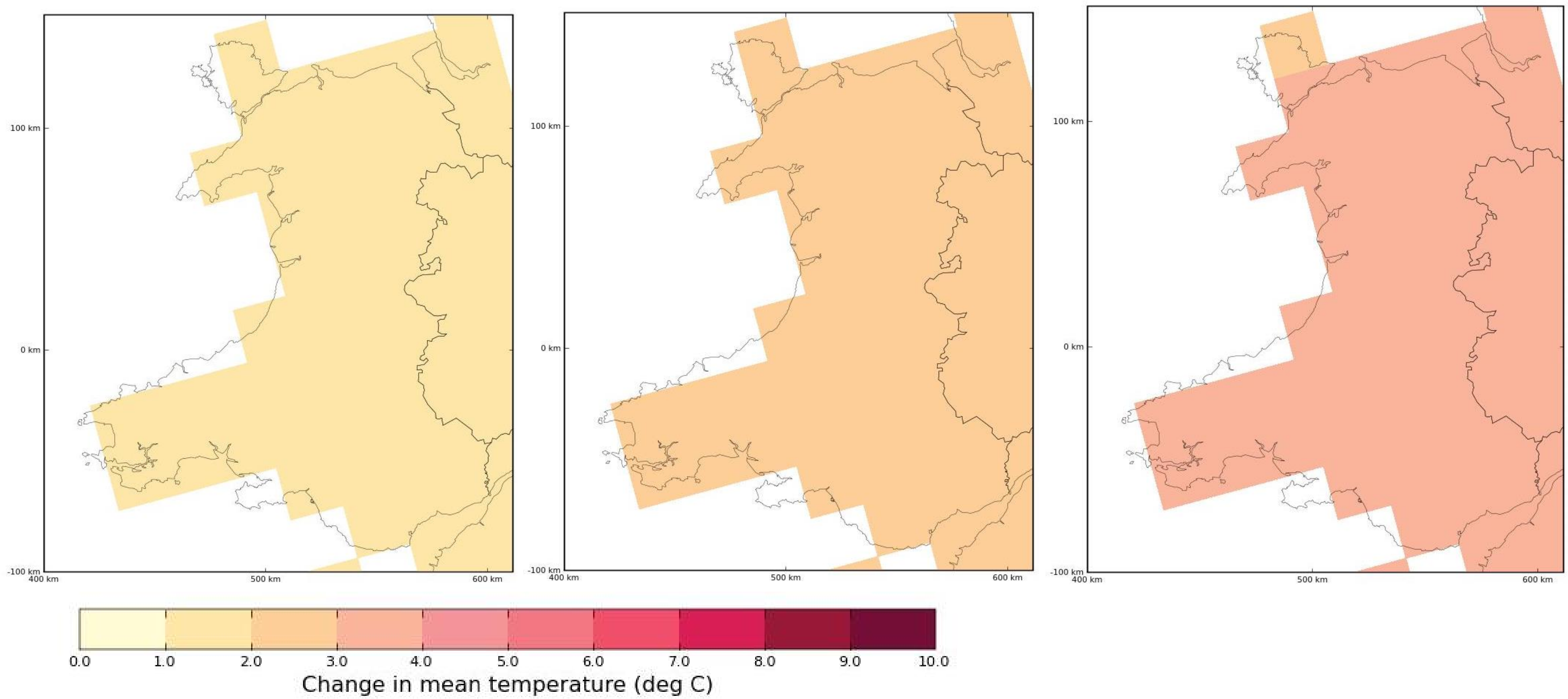


Figure 7. Climate predictions for average annual temperature, medium scenario, 50% probability (L-R: 2020, 2050, 2080). © UK Climate Projections 2009.

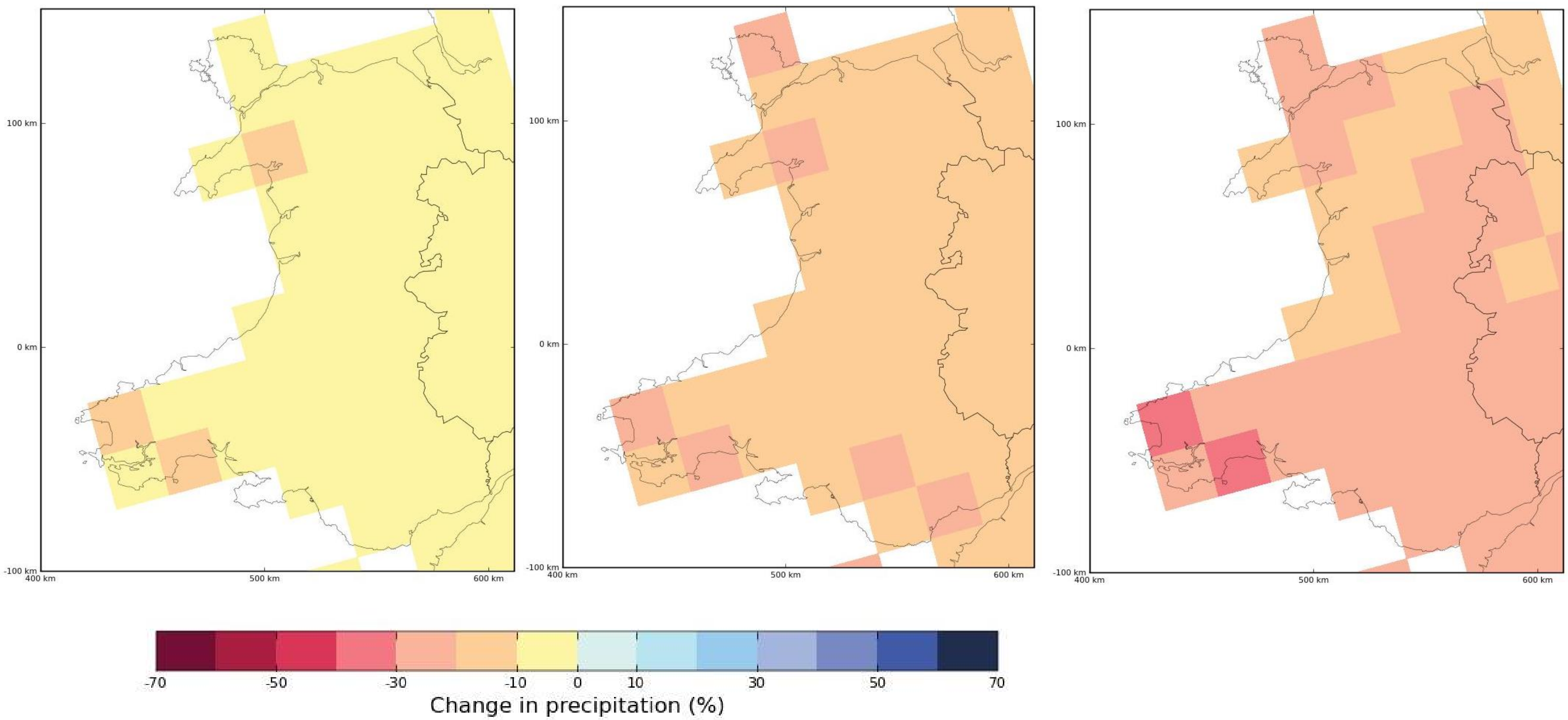


Figure 8. Climate predictions for precipitation – % changes in summer precipitation, medium scenario, 50% probability (L-R: 2020, 2050, 2080). © UK Climate Projections 2009.

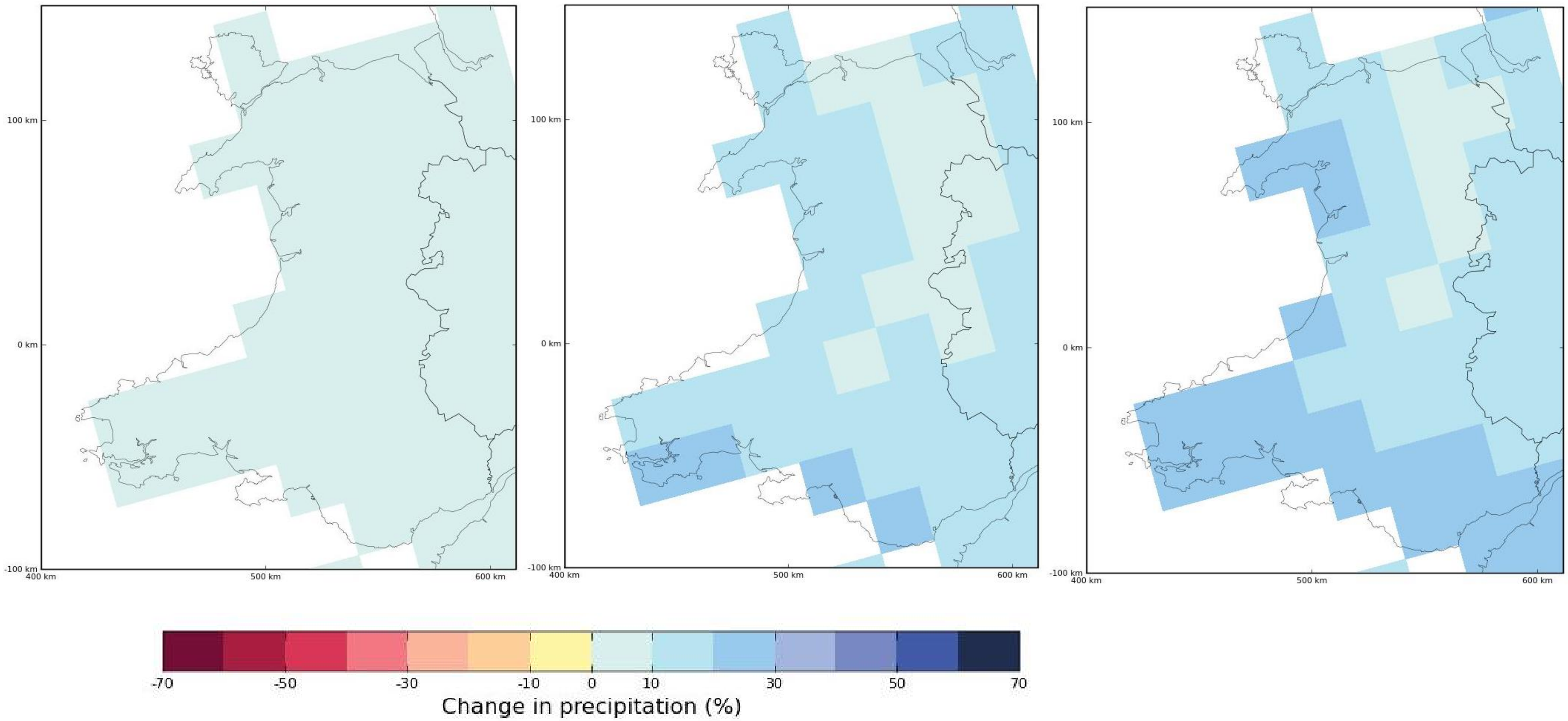


Figure 9 cont'd. Climate predictions for precipitation – % changes in winter precipitation, medium scenario, 50% probability (L-R: 2020, 2050, 2080). © UK Climate Projections

4.2 Climate change impacts to soils in Wales

Broad changes in soil function as a response to climate change have been reviewed by Bradley et al., 2005 (SP0538) and Bardgett et al., 2010 (SP1601), and although many of these are applicable to Wales they tend to focus on impacts in lowland arable areas. The following key impacts of climate change are selected from the Bardgett et al., 2010 (SP1601) and Bradley et al., 2005 (SP0538) reviews and also include evidence on land classification impacts from Keay et al., 2014 (SP1104) (Table 11). The key type of response in Wales is also indicated (Table 11) and the following sections provide more detail on the evidence for these impacts.

Table 11. Changes in soil function in response to climate change.

Soil response to climate change	Key soil/landscape areas impacted	Type of response in Wales
Change in duration of seasonal waterlogging and hydrological response of soils	Slowly permeable soils. Change in water regime of wet organic (peat) or organo-mineral soils. Other soils that may have restricted storage capacity. Change in water holding capacity in organic soils.	Duration of Field capacity period not significantly changed across Wales in 2020 and 2050 but start and end date shifted (later onset of return to field capacity in Autumn). Potential soil moisture deficits (PSMD) are similar in 2020 to the baseline but increase by 2080. Some evidence for a small reduction in the period of waterlogging in slowly permeable soils by 2080. As saturation period has not changed this could imply that there is limited hydrological buffering to events, increasing the susceptibility to runoff and flooding. Change in grade of agricultural land due to shift in climatic drought criteria.
Change in soil carbon dynamics	Wet organic (peat) or organo-mineral soils.	Declines in soil carbon related to climate change alone are small, although upland areas will experience greater amount of C loss.

Soil response to climate change	Key soil/landscape areas impacted	Type of response in Wales
Change in soil erosion risk by water	Fine sandy and silty soils. Peat soils.	Grassland systems less vulnerable to erosion.
Soil biota responses	Potentially all soils but focus on soils with maximum change e.g. organic (peat) or organo-mineral soils.	Change in biological response as a result of drying previously saturated soils.
Change in grazing pressure as a result of grassland productivity ï impacts of livestock on soils e.g. compaction*	Improved and permanent grassland systems.	Increase in grazing window means greater pressure on soils from livestock (compaction and associated erosion).
Primarily change in shrink swell soils	Soils in urban areas and infrastructure routes.	Few soils susceptible to shrink-swell in Wales combined with low PSMD.
Increase risk of wildfires ï peat loss and hydrophobicity	Peat and organo-mineral soils.	Extreme events (drought)

*indirect effect

4.2.1 Changes in soil wetness due to climate change

A number of studies have modelled climatically driven changes to soil wetness using UKCP09 scenarios. Soil wetness or moisture deficit can be characterised by a number of parameters derived from climate data. These include:

1. Field capacity days (FCD): FCD are the number of days a soil is at near saturation (the maximum amount of water it can retain against gravity) during a year. Principally it is calculated by accumulating the number of days that rainfall exceeds evapotranspiration. This occurs between autumn, when the soil returns to field capacity and spring, when evapotranspiration exceeds rainfall. It is difficult to derive and consequently a number of methods are used in difference schemes to estimate FCD. For example, in the Agricultural Land Classification (ALC) it is derived from regression equations using summer and winter rainfall and adjusted by location and altitude (Keay et al. 2014) (SP1104)
2. Potential soil moisture deficit (PSMD): PSMD is the calculated balance of rainfall (water input to the soil system) and evapotranspiration (water loss). It is accumulated on a monthly basis and the maximum monthly amount (mm) is recorded as the PSMD. The maximum climatic deficit

occurs during the summer months when evapotranspiration exceeds rainfall.

3. Drought/aridity indices. In ALC drought criteria are calculated as the difference between the moisture deficit for two reference crops (wheat and potatoes) and the amount of water available in the soil during the growing season. The moisture deficit is estimated from regression equations with average summer rainfall and accumulated summer temperature.

In SP1104 soil wetness (indicated by the duration of FCD and soil drainage characteristics) and was shown to be largely unaffected by climate change (Figure 9). This is because the predicted duration of field capacity is relatively constant over the predicted periods 2020, 2050 and 2080. The majority of Wales exceeds 225 days at field capacity until 2080, when coastal and border regions show a decrease in the field capacity duration. These calculations only estimate the climatic influence on soil wetness and do not take into account the specific hydrological characteristics that will govern the duration of waterlogging. Although the duration of the field capacity period is relatively stable over the predicted time periods this does not account for the change in the seasonal distribution of rainfall (Figure 8). Drier and warmer summers would lead to a later return to field capacity in the autumn. Wetter winters are likely to extend end of the field capacity period to later in the spring (Keay et al., 2014, SP1104). Other studies have applied a óworkable daysô model that use FCD derived by JULES (Joint UK Land Environment Simulator) to calculate soil water content to assess the relative changes in the vulnerability of soil to compaction (Cooper et al., 2010, SP0571) (Figure 11). It defines a day as óworkableô if the soil is drier than field capacity (FC; -10 kPa water potential was used in this study) but does not take into account the specific hydrological characteristics of different soils. The study identifies increases in the number of average annual work days (ie greater number of days with soils < field capacity) in Wales for 2030-2090 compared to a 2000-2009 baseline. This uses a different baseline and field capacity definition to the study of Keay et al. (2014) (SP1104), which may account for the differences in duration of field capacity between the two studies.

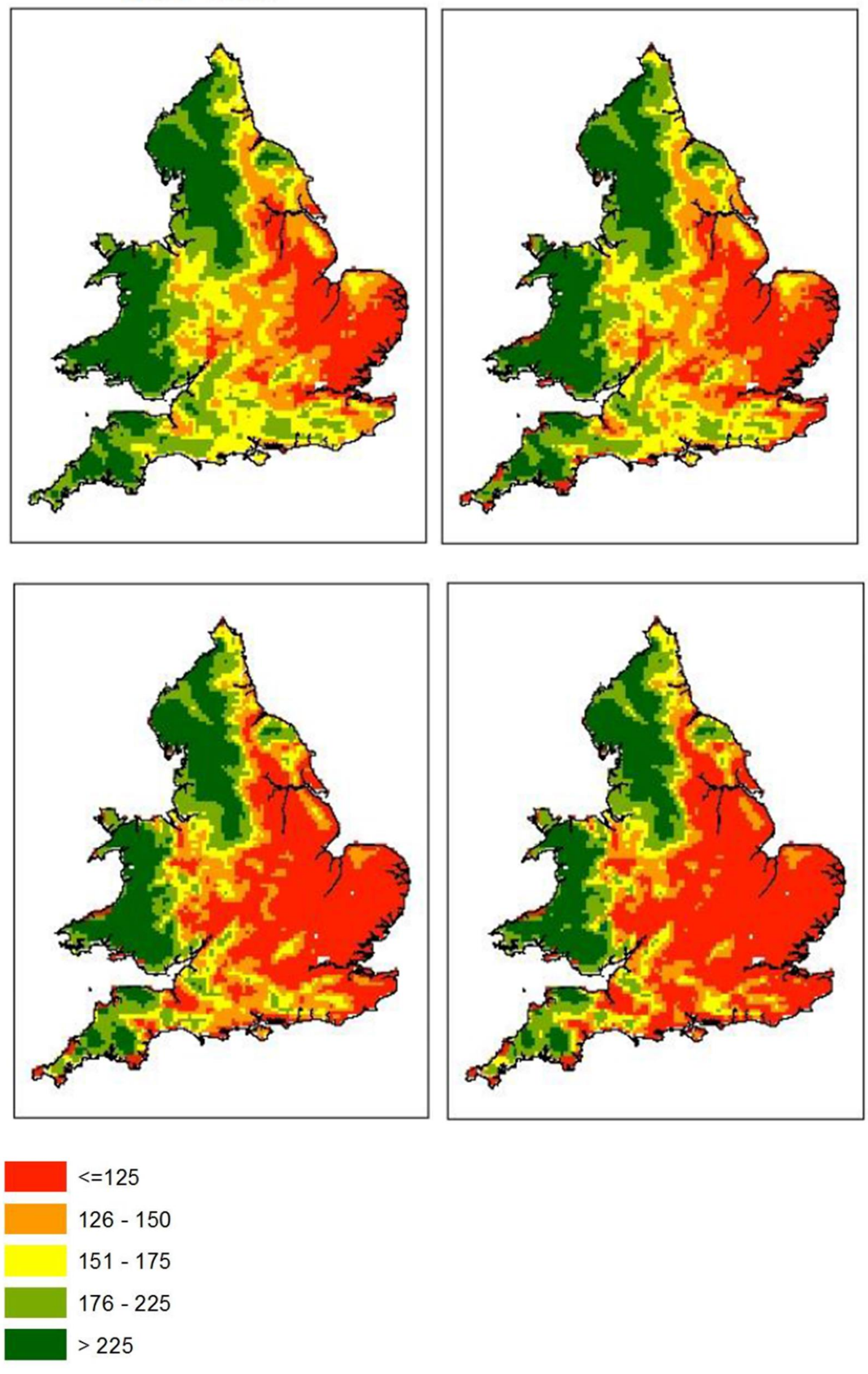


Figure 10. Field capacity days from top L-R 1961-1990; 2020 medium emission scenario; bottom L-R 2050; 2080 medium emission scenario. Source: Keay et al., 2014 (SP1104).

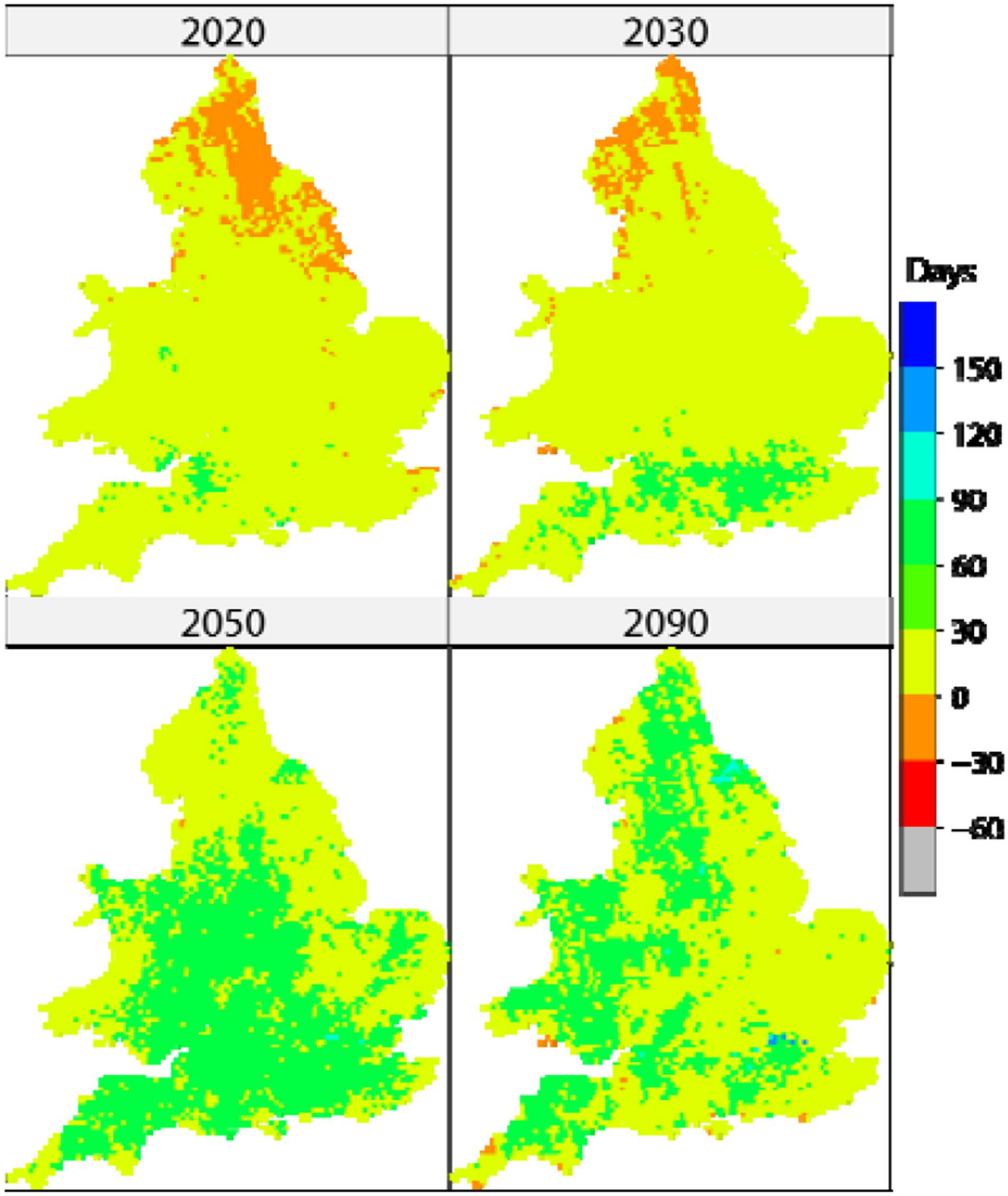
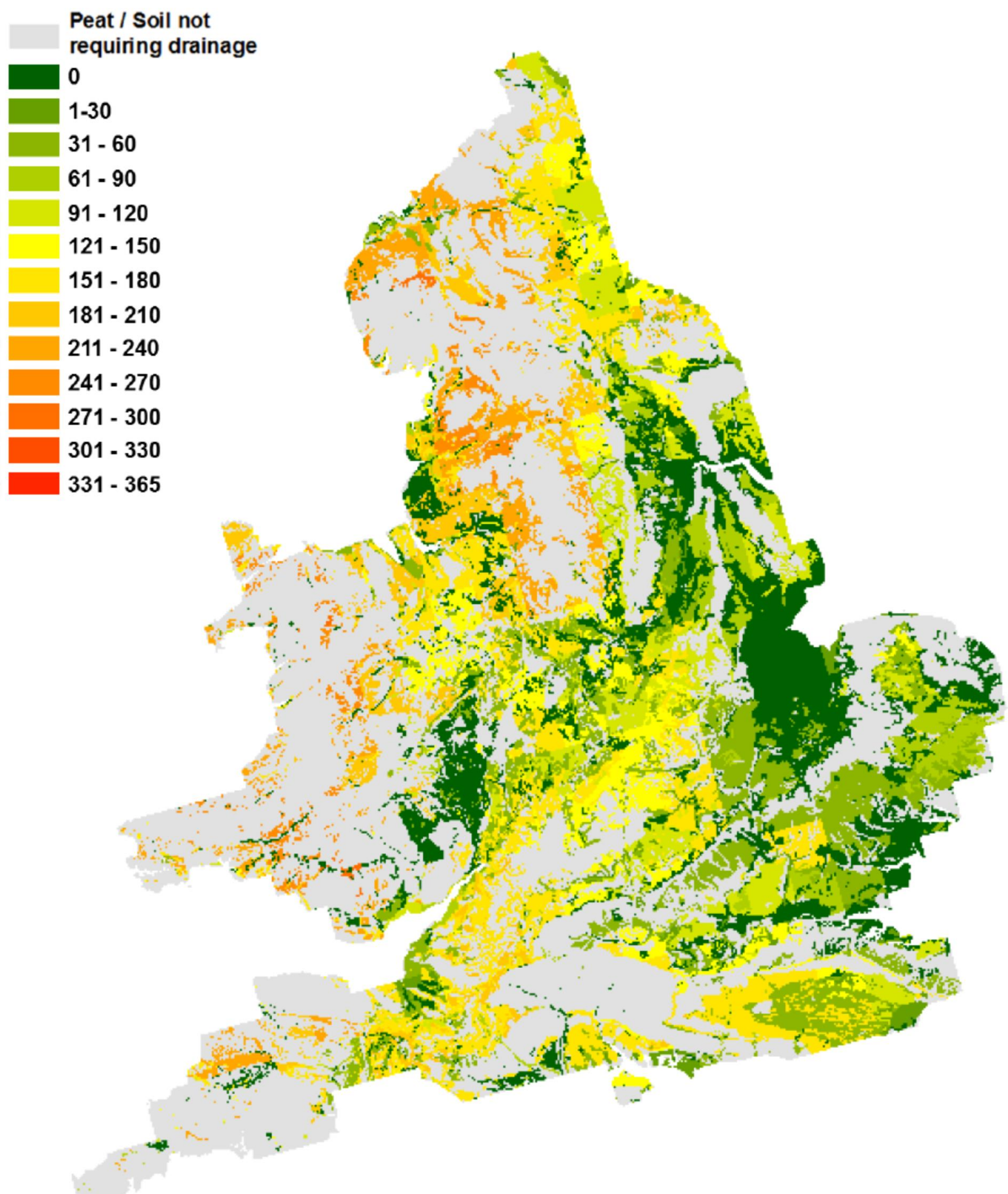


Figure 11. Change in average annual workable days from 2000-2009 baseline (for water content in the topsoil 0-10cm) Source: Cooper et al., 2010 (SP0571).

Other projects have attempted to estimate the potential duration of waterlogging by integrating the FCD with the spatial distribution of soil wetness class, which provides an indication of the number of days of waterlogging (Balshaw et al, 2015, SP1316). This study indicated a decrease in the duration of waterlogging by 2080 (

Figure 12) in some small areas. The area area of soils in Wales under consideration was limited due to omission of peat or peaty soils or those not requiring drainage. Where the baseline waterlogging was severe (> 200 days) these soils were still predicted to experience in excess of 150 days of waterlogging by 2080.



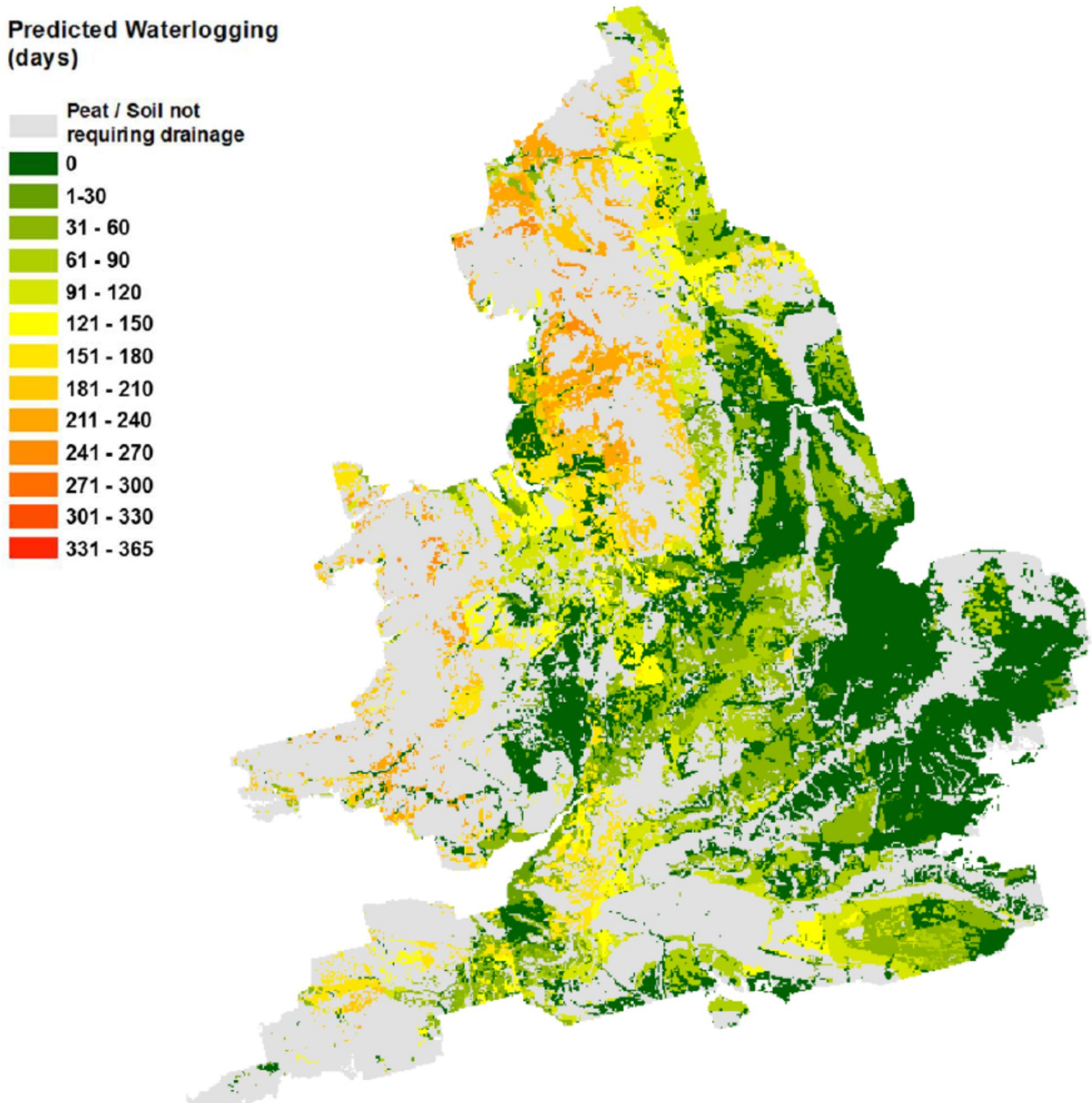


Figure 12. Predicted median days of waterlogging Top: baseline. Bottom: 2080 medium emission scenario Source: Balshaw et al., 2015 (SP1316).

Predictions of the potential soil moisture deficit (PSMD), which is the balance of rainfall and evapotranspiration have been calculated for the UK or England and Wales in several studies. These have used different techniques to estimate PSMD, specifically the calculation of evapotranspiration from climatic variables. In SP1104 PSMD was calculated using different emission scenarios for two predicted periods, which indicate little change in PSMD in 2020 but an increase in PSMD from 2020 to 2080 (Figure 13). Focus on one 25 x 25 km grid square in Wales showed the predicted moisture deficit increased from <50 mm in the baseline to 150 mm by 2080. This suggests that sites in Wales will become more droughty, with moisture deficits similar to present day London by 2080. However, this is likely to represent an extreme case as the analysis used a óworst caseôhigh emission scenario for 2080. Other studies have also shown similar trends (Pritchard et al., 2015), with little change from the baseline in PSMD by 2030 and PSMD increasing in some areas of Wales by 2050 (Figure 14). A change in PSMD is unlikely to exceed 20-40 mm by 2050. Although for extreme events that would lead to prolonged drying, areas outside the core uplands may be affected by increased moisture deficits (Pritchard et al. 2015).

Figure 13. Average annual maximum potential soil moisture deficit for 1961-1990 baseline, 2020 low emissions scenario and 2080 high emission scenario Source: Keay et al., 2014 (SP1104)

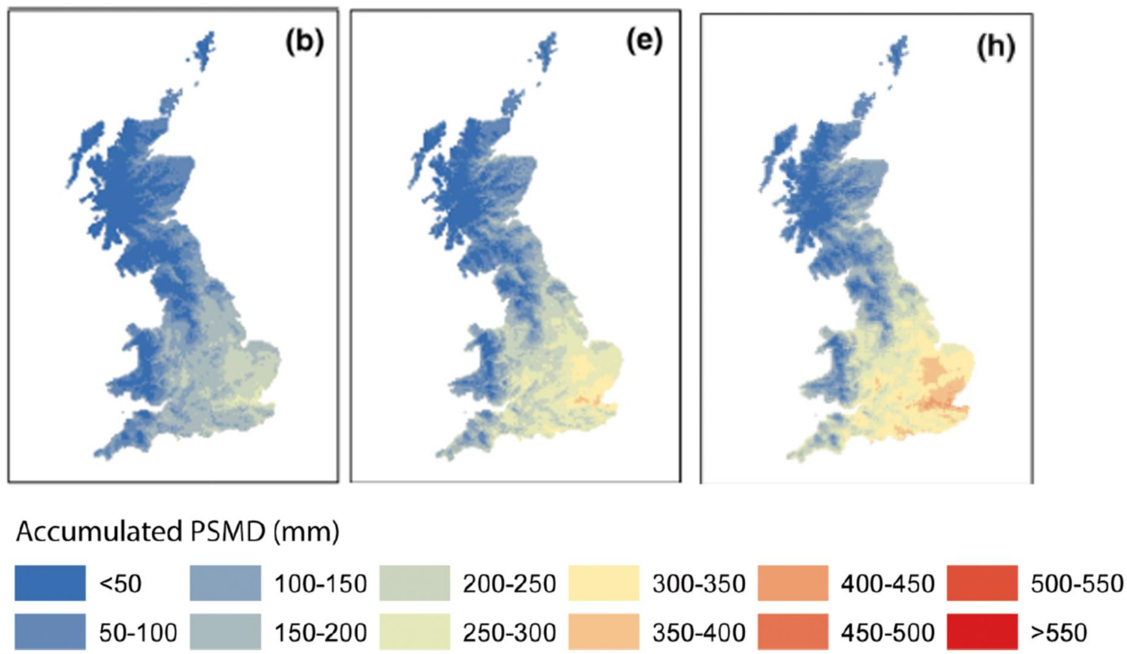


Figure 14. Average annual maximum potential soil moisture deficit for b) 1961-1990 baseline central estimate (50th percentile) and e) 2030 (2020-2049) medium emission scenario central estimate (50th percentile) h) 2050 (2040-2069) medium emission scenario 90% percentile (representing extreme events) Source: Pritchard et al., 2015.

The seasonality of rainfall distribution may be important during the field capacity period particularly in the winter where there will be increased precipitation and thus excess water exceeding soil storage capacity. This may be particularly enhanced in slowly permeable soils with limited storage capacity and could result in excess surface and sub-surface runoff during these periods, particularly if the precipitation events are extreme. Using one HADRM3H climate projection (Bell et al., 2009) identified climate change would increase peak surface water flows in Wales. This study used a gridded model that took into account the hydrological characteristics of soils (HOST classification). The peak flows are due in some respect to saturation excess runoff (i.e. excess water when the soil is already at saturation, such as during the field capacity period) but also infiltration excess where the intensity of the rainfall event exceeds the infiltration capacity of the soil. It was highlighted that more work was needed to identify the effects of extreme, intense rainfall on different types of soil and terrain.

SP1104 used UKCP09 climate data to calculate predicted change in the ALC grade at National Soil Inventory (NSI) points (topsoil sampling point every 5 km across England and Wales) for various emission scenarios in 2020 to 2080. The effect of climate on ALC grade only becomes significant when drought criteria are considered and this becomes the most limiting criteria. This resulted in the ALC grade being downgraded at many sites by 2080. The change in grade is not reported specifically for Wales. For England and Wales the proportion of sites classified as Grade 4 (poor) rose from 7% in 1961-1990 to 70% in 2080 under a high emission scenario. Application of aridity indices (SP1104) indicate that Wales will remain in a humid climate zone by 2080 and not experience the significant shift in climatic zone that is predicted for parts of south east England (e.g. a shift towards present day conditions in southern France).

The evidence suggests that modelling soil wetness represented by the number of days the soil is at near saturation (FCD) shows no significant change. This does not account for the change in the seasonal distribution of FCD duration. This could impact on field operations and crop performance during spring and autumn, where the timing of the field capacity period will shift later. Conversely, the application of drought criteria in ALC indicates a significant downgrading of agricultural land class due to drought limitations. The drought criteria is based on a crop specific moisture deficit for two reference arable crops (potatoes and wheat) and the amount of water available to the plants in the soil. These parameters are estimated from regression equations using average summer temperature and rainfall, both of which will significantly change over the predicted time periods (Table 8). This does not take in to account any seasonal shift in the crop growth stages (and thus requirements for water) that may also occur due to climate change.

4.2.2 Soil carbon status due to climate change

Although increased temperatures are expected to accelerate the decomposition of soil organic matter, our knowledge of the exact mechanisms and factors regulating temperature sensitivity of carbon processes in soil is still very limited. This impacts on the confidence in projected changes in carbon cycling as a response to climate change (and associated land cover/land use change). Several mechanisms have been used to determine the effects of climate change on soil carbon dynamics which include modelling, long term field observation, field and laboratory manipulation. We will focus on evidence related to modelling soils that include Wales and field sites or soil samples originating from locations in Wales or similar environments. Many studies have focused on high carbon soils and thus there is bias to reporting of dynamics in peat soils or organo-mineral soils, however these represent a small proportion of the soil in Wales. Isolating the effects of climate from other factors that influence soil carbon (such as land use change) is difficult. A more detailed analysis of the loss of soil carbon is covered in section 5.

Analysis of the influence of climate on the organic carbon content for NSI sites sampled at two intervals between 1970's and 1990's was achieved by fitting multiple linear regressions to climate data and soil carbon data over the sampling time period (Barraclough et al. 2015). This study revealed for organo-mineral and mineral soils, only 0–5% of the observed decline in carbon concentration can be predicted from changes in climate. For arable soils, the regression models using NSI data, suggest that none of the changes in soil carbon can be predicted from changes in temperature and rainfall between two surveys. For grassland (rotational and permanent) the regressions predict very small or no climate-related change in soil carbon between the first and second NSI surveys. The carbon declines between the surveys in grasslands is attributed primarily to changes in livestock densities (Barraclough et al. 2015; Kirk & Bellamy 2010). In contrast, 9ï 22% of the changes reported for organic soils in semi-natural habitats are consistent with changes in temperature and rainfall between the two NSI surveys.

Simulations of future climate using the ECOSSE model (Cooper et al., 2010, SP0571) indicate that relatively small changes in soil carbon content (-5% by 2080 in Wales) are related to climate change. The model used a HADRM3Q0 ensemble run for a medium emissions scenario. This is likely to be due to increased decomposition from elevated temperatures being offset by increased primary productivity returning carbon to the soil. The rate of change per year is much less than that reported by the observed changes in the CEH and NSI data (for more detail refer to section 5), presumably because the latter also includes effects of land use and management as discussed above.

Modelling soil C in simple climate scenarios for blanket peats in the UK indicate that the greatest effect was observed for a +4°C MAT (mean annual temperature) and ï 25% MAP (mean annual precipitation) scenario, in which the mean SOC continually declined over 200 years (Heinemeyer et al. 2010). This was mainly attributed to a shift in the water table depth. However, more recent IPCC climate change scenarios indicate stable MAP rather than a reduction and a shift in the seasonal distribution of rainfall.

Laboratory experiments using a grassland soil from Wales and labelled carbon (Farrar et al. 2012) demonstrated that there is no simple effect of temperature on soil C turnover. Rather, discrete pools of C respond in distinct ways to temperature and to priming (i.e. adding additional substrate such as glucose). Monitoring soils at the ECN site in Snowdon revealed no change in soil C over a period of 40 years with a temperature change of +1.5°C over the same period (McGovern et al., 2013).

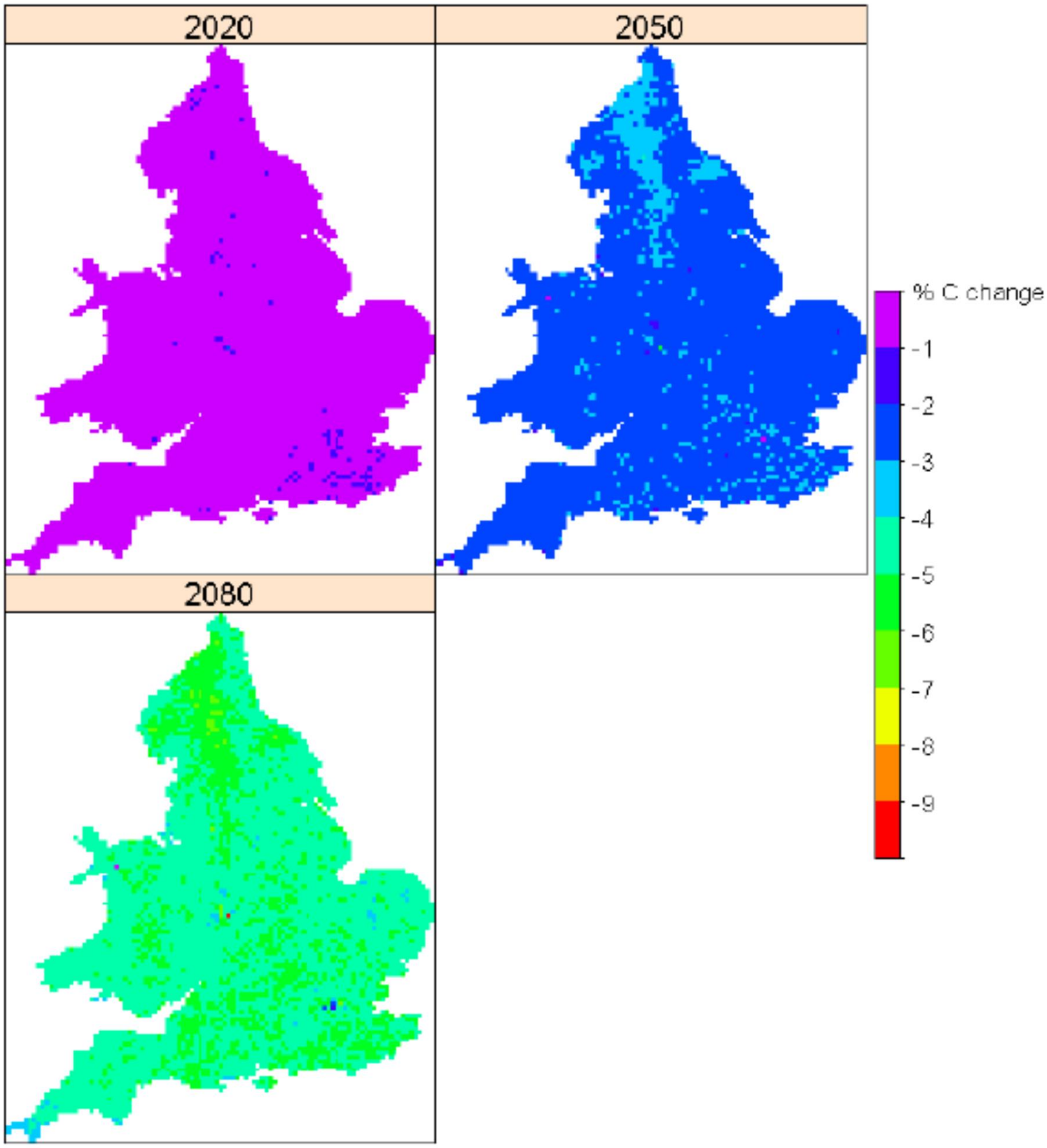


Figure 15. Changes in soil carbon stocks from initial 2010 values due to climate change. Source Cooper et al., 2010, SP0571.

4.2.3 Soil erosion due to climate change

Most indications of climate change impacts on soil erosion (Bradley et al., 2005, SP0538) relate to effects on soils cultivated for arable agriculture including the increased risk of soil erosion through extreme events (Boardman 2015) in susceptible soil landscapes when the soil has limited vegetation cover. Even in these situations erosion events may be significant but are usually localised. Risk in Wales is reduced because of the dominant grassland land use. The severity and extent of soil erosion in Wales is discussed in section 7. Modelling studies have assessed the risk of climate change to water erosion in England and Wales using the PESERA model under fixed land use (Cooper et al, 2010, SP0571). There was a projected small increase in the average erosion rate on pasture from 0.38 to 0.4 t ha yr^{-1}, although this value is reported for grassland areas in both England and Wales combined. Changes in erosion risk show seasonal variation in response to the change in rainfall distribution in the climate change scenarios (Figure 16). Upland areas of Wales show an increased risk in autumn by 2090 but a decrease in the winter despite an increase in rainfall. The factor influencing this is the vegetation cover, which PESERA predicts will increase, providing greater protection from erosion (Cooper et al., 2010, SP0571).

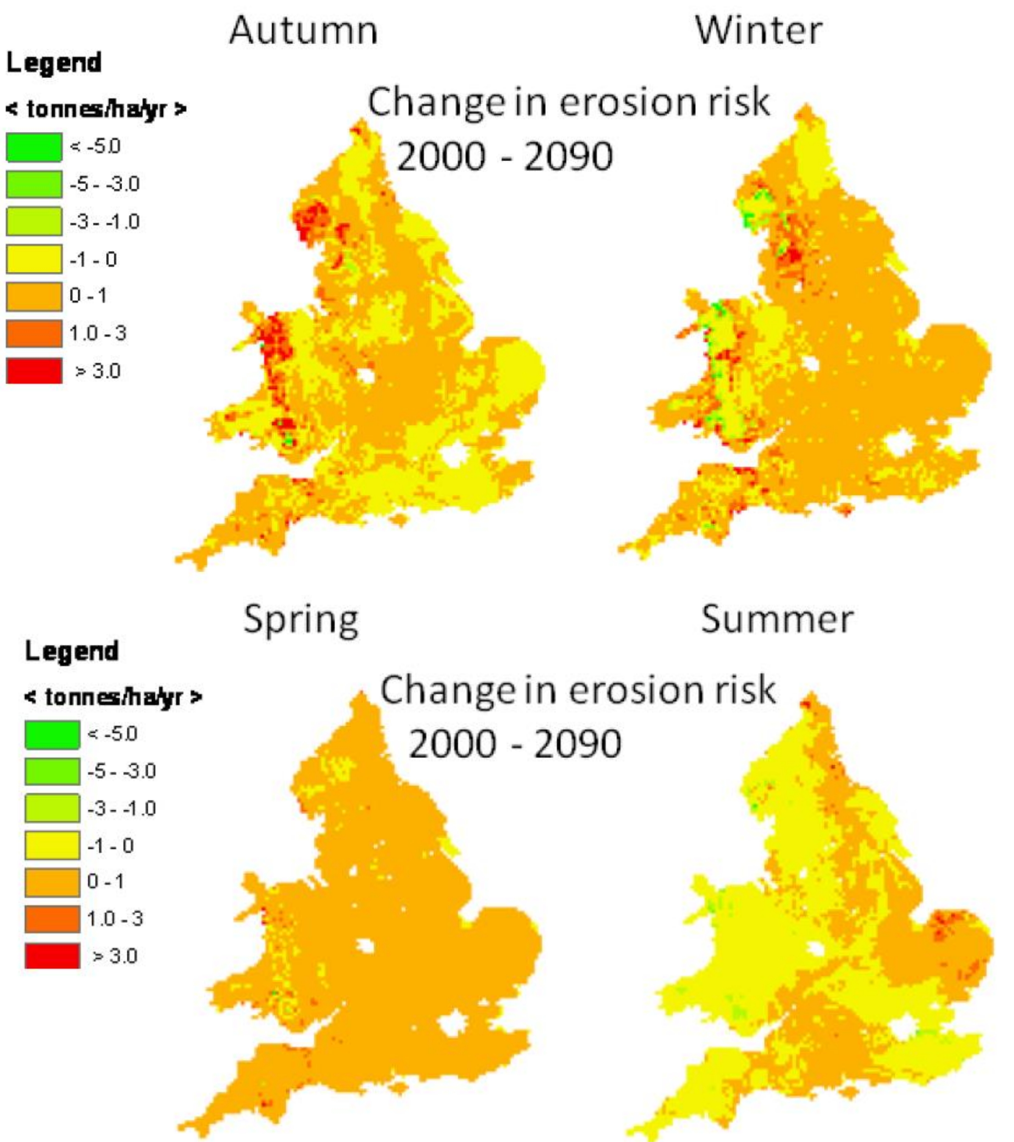


Figure 16. Seasonal changes in Erosion risk 2000-2090 (t ha^{-1} yr^{-1}) using PESERA model Source: Cooper et al., 2010 Defra project SP0571.

4.2.4 Soil biodiversity linked to climate change

A summary of the effects on climate change on soil biota are indicated in Table 12 (Bardgett et al., 2010, SP1601). Soil biota responses to temperature change are uncertain; several studies show that soil microbial and animal communities are insensitive to small increases in temperature (e.g. Kandeler et al., 1998; Bardgett et al., 1999; Wardle, 2002), and others show that soil organisms are responsive to temperature change (Emmett et al., 2004). Studies have indicated soil moisture changes (usually by imposed drought conditions) rather than temperature cause the greatest response in the soil biological system (Sowerby et al. 2008). However, many of these studies are manipulations on systems commonly saturated with water where microbial activity is stimulated by the reduced water saturation. Ritz et al. (2011) Defra project SP0570 investigated the biological response of grassland soils (representing a climate gradient in Europe) to wetting and drying laboratory manipulation to mimic climate change events. The soil respiration rate was resilient to a single perturbation of a wetting and drying event, indicating overall microbial activity was resistant to the perturbation However, changes in the microbial community structure were apparent after the wetting and drying event indicating that there was low resilience in the composition of the microbial profile. Temperature was not included in this study and neither was the response to repeated perturbations that might represent sequential flooding events that could manifest by the increased frequency of extreme events.

Effects on soil respiration and water holding capacity with climate change simulations in the Clocaenog field site in North Wales reveal organo-mineral soils are more sensitive to repeated modest drought than to subtle warming, and that the drought impact does not attenuate at a decadal time scale (i.e. respiration does not return to pre-warming rates within the decadal timescale of the study). These sites show high vulnerability to the projected increases in the frequency of severe droughts (Domínguez et al., 2014). In addition there is a change in the water holding capacity of the soils after repeated drought cycles due to the destabilisation of soil aggregates and resulting changes in soil structure. At the same site repeated summer drought, equivalent to a 20% reduction in summer rainfall (i.e. similar to 2080s climate predictions for Wales), stimulated biological activity that was previously limited by water excess, resulting in CO_2 flux.

4.2.5 Changes to grassland productivity and livestock

The effects of climate change on pastoral systems and regions are likely to increase grass production. Moran et al. (2009) Defra project AC0307 used a grassland model (Molle et al., 2006) with UKCP09 scenarios to predict the changes in the increased forage availability and thus the annual grazing period. Average start days for the beginning of the dairy grazing season advance by 10, 16 and 24 days, in 2020, 2050 and 2080, respectively. In addition grass productivity increases. This means herds are likely to increase and animals can be kept outdoors for longer impacting on soil issues associated with livestock such as increased compaction and erosion.

Climate change is likely to have an impact on arable production in the UK positively increasing yield as a response to warmer temperatures and increased CO_2 concentrations but also negatively impacting yield by increasing water stress (Keay et al., 2014, SP1104). It is currently unclear what the combined effect of environmental change will have on crops and this has not been reported for specifically for Wales. The impact of climate change on agriculture will also be dependent on the extent to which the industry responds and adapts.

4.2.6 Effect of climate change on soils in the built environment

Urban areas in Wales constitute 4 % of the land area and soils in urban environments are highly variable as a result of the history of the site (the previous use of the area type of construction and materials) and the resulting urban use. A review of the climate change impacts on urban soils (Rawlins et al., 2010, SP1605) identified the following effects on urban soils: 1) change in shrink swell soils leading to infrastructure failure. Since the Rawlins et al. (2010) SP1605 review shrink-swell has been modelled for the UK and indicates a significant increase in the risk of infrastructure failure in susceptible soils as a result of changing PSMD (Pritchard et al. 2015). However, these soils are not common in Wales nor do they intersect with infrastructure. As a result the analysis showed a low risk of infrastructure failure or subsidence in Wales as a result of climate change effects on shrink-swell soils; 2) changes in soil carbon- there was insufficient evidence to ascertain effects; 3) capacity for electrical earthing ï this is sensitive to drought situations and is unlikely to be manifested in urban environments in Wales; and 4) water quality and availability and impacts on mobility of pollutants- the effects are likely to be very localised and difficult to predict.

Table 12. Climate change effects on soil biota (after Bardgett et al., 2010, SP1601).

Future climate scenario	Response of soil biota	Effect on key soil function/service
Warmer and drier summers	• Drier soils may affect the mobility of soil fauna such as nematodes and earthworms (Bardgett 2005; Eggleton et al., 2009). • Changes to habitat may favour drought tolerant soil biota; soil may experience a shift in species, which may impact on the overall function of the soil depending on redundancy in the system (Castro et al., 2010). • Summer droughts may cause stress in some soil microbial communities and result in changes in fungal diversity impacting on functional diversity (Toberman et al., 2008). • Drier conditions and higher temperatures may accelerate decomposition of organic material through increased oxygen availability and increased microbial activity. However, additional input of leaf litter from increased production may offset net loss of carbon from the soil profile (Dawson and Smith, 2007)	• Nutrient cycling ï specifically its role in soil organic matter decomposition (although link between microbial respiration and temperature is not clear) • Soil biodiversity ï changes in functional diversity of the system
Warmer and wetter winters	• Increase the likely survival of soil pests and diseases. • Inward migration of soil biota from warmer areas. • Water logging will reduce the availability of oxygen in the soil profile affecting both soil fauna and soil flora (Sowerby et al., 2008).	
Extreme events	• Drying of the top soil followed by sudden rewetting encourages flushes of microbial activity and nutrient loss from soil (Sowerby et al., 2008; Gordon et al., 2008).	

4.2.7 Increase in fire risk

Changes in drier and hotter summers increase fire risk ï especially in semi-natural areas e.g. peat moorland and afforested areas. Lower summer rainfall and higher temperatures contributed to a significant burn event in 2006 in the Scottish highlands (Davies et al., 2013), where peat soil itself was burnt during the event. This releases a significant amount of carbon to the atmosphere and the resulting charred surface peat was hydrophobic (water repellent), thus increasing runoff from these burn sites. A probabilistic fire incidence model using climate predictions (UKCP02 data) predicted increased summer wildfires after 2070 in the Peak District, although these are likely to be episodic corresponding with dry and hot spells (Albertson et al., 2010).

4.3 Extent and severity

4.3.1 Changes in soil wetness

Most studies indicate that the duration of field capacity is unlikely to change across Wales in 2020 and 2050. Predictions for 2080 indicate areas on the border and in coastal regions may experience reduced field capacity days. The duration of waterlogging in soils requiring drainage (e.g. Slowly permeable soils) indicate that there is a reduction in the waterlogging duration by 2080. However, these soils are still predicted to experience >150 days of waterlogging. There is no indication of the likely change in other soil types as these are not reported directly in the evidence (e.g. loamy, freely drained soils that cover many parts of the country).

The change in ALC presented in SP1104 indicated a downgrading in ALC grade in England and Wales due to changes in the drought criteria, which are based on crop requirements for water during the growing season. The results from this study were intended to show general trends and not specific details; the uncertainty of the input parameters and climate scenarios means that results should not be interpreted at a local scale. The policy brief that accompanied the report indicated that they should not be used for the purpose of projected national maps of ALC grade as they are only representing ALC at a specific point on a 5 km grid. The results were not originally reported on a Welsh specific basis and with this in mind in we can only make some generalisations about the extent and severity of changes in ALC in Wales. For the points studied, most grade 1 and 2 sites have been downgraded by 2080, representing a significant impact on good quality agricultural land, of which there are only small areas in Wales. There is an increase overall in the proportion of sites classified as grade 4 land, particularly in the central border region of Wales, although not all these sites are a result of being downgraded. It is also worth noting that some land has improved (i.e. a shift from grade 4 to 3b). Without specific analysis of these relationships it is difficult to ascertain the trends for specific areas and soil types based on the NSI sites. In addition, the drought criteria are only calculated for two arable crops and the impacts of drought under grassland systems was not considered. There are likely to be significant drought impacts on shallow rooting grass systems. This could affect yield and herbage quality in the areas that are showing most significant change by 2080 in soil wetness such as the border regions and coastal areas.

Assessment of climatic indices and aridity indices in SP1104 indicated that Wales in general would still be classified in a humid climate zone by 2080. Climate change will affect all areas of Wales but will have significant impact on sensitive environments that are already characterised by strong climatological controls. These areas include the upland regions of Wales and their associated Peat and organo-mineral soils, and as a result this is where most research on the impacts of climate change has focused. These environments represent small extents in Wales. Use of Bioclimatic Envelope Models (BECMs) in upland areas of Britain has identified the sensitivity of these areas to climate change. BECMs derive statistical relationships between the observed current distribution of the uplands and their corresponding climatic variables that define the ‘environmental space’ of upland habitats (House et al. 2010). The upland bioclimatic envelopes include areas of Peat soils and soils with peaty surface horizons such as podzols and humic gleys that have developed as a result of the climatic controls of soil formation favouring organic matter accumulation. The BECMs indicate that under UKCIP02 climate scenarios the area of upland in Wales, defined by its climatic envelope, will reduce by 2080 (Clark et al., 2010) (Figure 17). Whilst these models show the environments are likely to be under climatic stress they do not model the associated response of the system to the shift in climate.

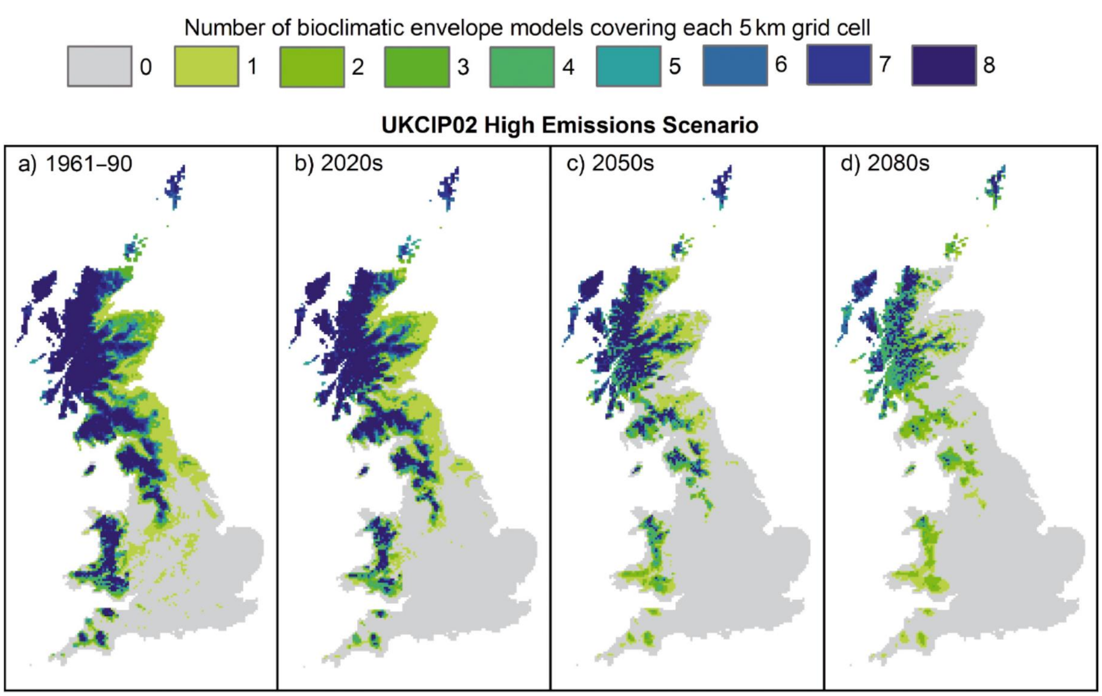


Figure 17. Reduction in climatic characterisation of upland environments as a response to climate change. Source (Clark et al. 2010).

4.3.2 Soil carbon and soil erosion responses to climate change

Historical data and future climate predictions indicate that there is little change in soil carbon for soils in Wales that can be attributed directly to climate change. The only exception is the semi-natural organic soils (peat) in upland areas, which show sensitivity to temperature and rainfall. However, these environments have small extents in Wales. From current evidence the historical change in soil carbon in more extensive land use types (such as grassland and arable) has been driven primarily through changes in land management.

Modelling studies using climate predictions indicate a seasonal shift in the erosion risk in England and Wales. In autumn there is an increases risk in upland areas based on current land use. Climate change is likely to change land use and management practices that could increase the area of land at risk from erosion (e.g. expansion of arable land). Erosion events are commonly localised and will respond to a combination of land management practices and extreme events. In future climates extreme rainfall events are predicted to increase but there is no direct evidence how this will impact on the extent or severity of erosion events in Wales.

4.3.3 Soil biodiversity as a response to climate change

Studies have focused on environments that are currently limited by water saturation and thus waterlogged soils and upland organic soils that may be subject to drying could show responses in soil biodiversity. These environments have small extents in Wales. Although many soils will show changes in the seasonal distribution of soil wetness there is no evidence to indicate specifically how this will impact on soil biodiversity. There is no evidence to indicate the severity of climate change impacts on soil biodiversity in Wales.

4.4 Vulnerability and resilience

In many cases the evidence has not separated or reported impacts on a soil type or land use specific basis in Wales. Peat and organo-mineral soils have indicated a response in soil carbon and biodiversity as a result of climate change, although the resilience of these systems has not been reported. Slowly permeable soils indicate a decrease in the waterlogging period by 2080 but this change in soil wetness or water availability was not reported for other soil types. Table 13 summarised the vulnerability and resilience of different soil types in Wales to climate change based on the reported evidence.

Table 13. Vulnerability and resilience of soil types in Wales to climate change based on evidence reported

Soil type/landscape	**Proportion of land cover (%)**	**Vulnerability**	**Resilience**
Organic soils (Peat)	3	+++ (carbon change) +++ (biological change)	?
Organic soils (organo-mineral soils)	9	+++ (carbon change) ++ (biological change)	?
Slowly permeable soils (SPS)	25	++ (reduction of waterlogging period)	?
Freely drained loamy soils	26	? no direct evidence	?
Sandy (‘light soils’)	1	? no direct evidence	?
Clay (‘heavy soils’)	*	? no evidence ++ (shrink swell soils only)	?
Grassland systems	65	? no direct evidence	?
Arable systems	9	++ (drought impacts reported for wheat and potatoes)	?

*these are not separated specifically in the soilscapes (Table X) + low; ++ medium; +++ high; ? unclear or no direct evidence.

5 Loss of organic matter

The evidence reviewed (>117 reports) on the loss of soil organic matter in Wales suggests:

- there is conflicting evidence from two monitoring programmes (Countryside survey CS + GMEP and National Soil Inventory - NSI) for the extent of soil carbon change in topsoils in Wales
- one monitoring programme reports no significant change in soil carbon from 1978-2007 (CS and GMEP) in topsoils in Wales, another reports losses in topsoil carbon reported for England and Wales over the same period (NSI)
- a loss of organic carbon in arable topsoils in England and Wales was reported in both programmes (NSI and CS) but evidence was not reported specifically for Welsh soils
- no change in soil carbon in improved grassland systems in Wales 1978-2013 (CS and GMEP), although differences in intensive and extensive systems is anticipated
- increase in topsoil carbon in woodland sites between 2007 and 2013 (GMEP)
- the largest rate of decline in organic matter was reported on peat soils, bog and upland heath for the NSI data, although this conclusion was not supported by the CS data
- no change in soil carbon for Welsh topsoils may be related to the limited land use change in Wales over the monitoring period
- The resilience of Welsh soils to loss of organic matter is not reported in the evidence explicitly.

5.1 Overview

Loss of organic carbon or organic matter from soils is related to the balance of inputs and decomposition dynamics of C in soil systems. Primarily this is due to a shift in the above ground inputs to soil through land use change. In environments that accumulate large amounts of carbon such as peat and organo-mineral soils this has a primary climatic control where the degradation process of organic matter are slowed by water saturation and lower temperature. Thus changes to the wetness status of these systems has the capacity to release carbon from the system through mineralisation processes once oxygen is introduced into the system through drainage or a change in the water balance. It is in these high carbon soil environments where most evidence is focused as processes leading to soil carbon loss have significant impact on soil carbon stock. Key losses of soil carbon include CO_2 to the atmosphere, dissolved carbon to surface and grounds waters and soil lost by erosion (Figure 18). Soil organic matter is a ‘keystone’ soil property affecting many other soil properties and soil functions (soil structure, water holding capacity, soil biota).

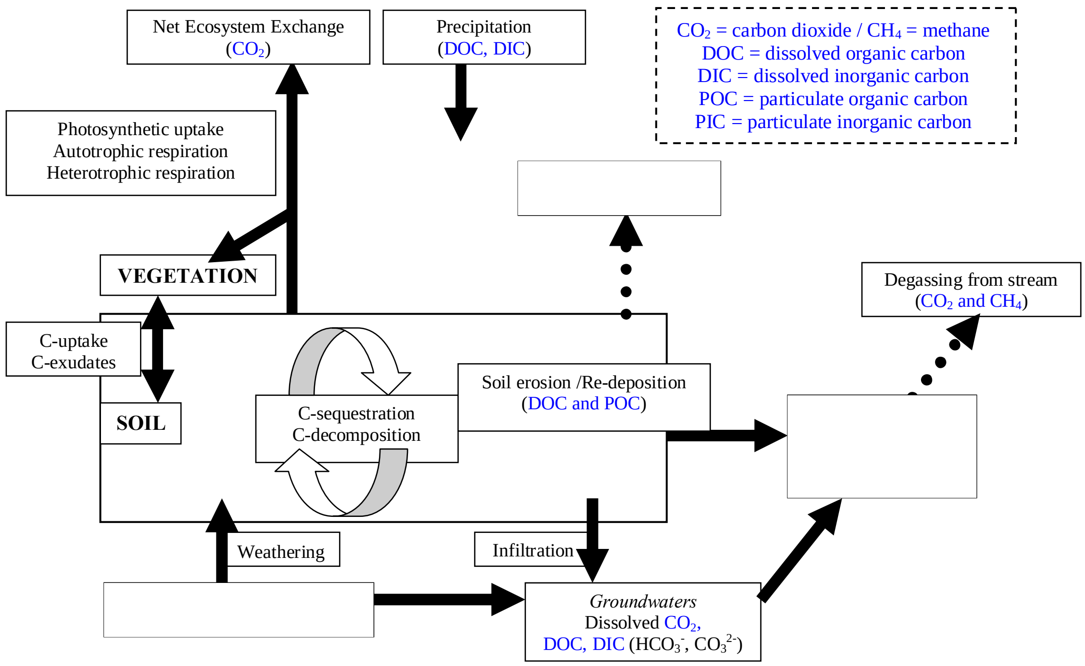


Figure 18. Terrestrial carbon ecosystem processes and pathways. Source Defra SP08010.

5.2 Loss of soil organic matter in Welsh soils

Several approaches are available to assess the loss or potential loss of organic matter or soil carbon from soils in Wales. These include national scale monitoring schemes, field scale monitoring and modelling.

5.2.1 Monitoring (national scale)

Several studies have measured topsoil carbon (ca. 0-15 cm) through monitoring programmes but there is conflicting evidence on the rate of change of carbon between these studies and in most cases it is reported on a country wide basis or for broad land use/soil types for combined nations. The two studies the National Soil inventory for England and Wales NSI) and the Countryside Survey (CS). NSI reported topsoil carbon losses between 1978 and 2003 (Bellamy et al. 2005). A review of organic matter loss in soils (Defra, SP0545) linked to the Bellamy et al. (2005) study indicated peat soils followed by lithomorphic (shallow) soils are the most vulnerable in terms of rate of loss of soil carbon in topsoil over time. The most vulnerable land use to loss of topsoil SOC is bog (upland peat) followed by upland heath/grass/moor. Arable and permanent and rotational grass sites are losing SOC at only half the relative rate of bogs. Soilscapes with sites in extensive management with a higher than average loss rate of SOC are: Very acid loamy upland soils with a wet peaty surface (e.g. Podzols); slowly permeable wet very acid upland soils with a peaty surface; and upland peat soils.

Conversely, the Countryside Survey topsoil samples indicate no significant change in topsoil carbon in Wales between 1978 and 2007 (Reynolds et al. 2013). When split by broad habitat (but reported for England and Wales collectively) the topsoil carbon showed significant decreases in arable sites and increases in broadleaf woodland between 1978 and 2007. Other land uses show no significant differences over the same survey period. Further samples taken in 2013/2014 for the Glastir Monitoring and Evaluation Programme (GMEP) extended the time series and also indicated no change in topsoil carbon for Wales overall (Emmett, 2015). However, when summarised by Whole Farm Code habitats, the data shows an increase in topsoil carbon in woodland sites, a decrease in ôhabitatô (all land excluding improved land, woodland and arable) and no change on improved land (improved grassland) in Wales from 2007-2013 (Figure 19).

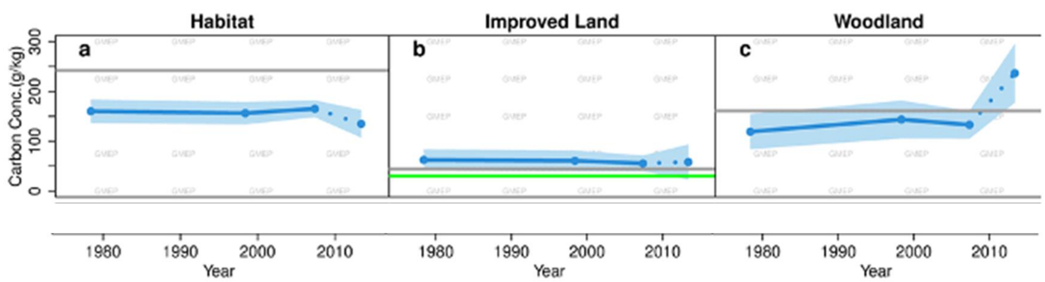


Figure 19. Topsoil carbon content for CS sites in Wales. Solid line CEH countryside survey data; dotted line GMEP data (Source: GMEP).

In the NSI and CEH studies the impact of land use change was not considered. The differences between the two studies have not been reconciled despite further analysis of potential issues related to differences in sampling design and analysis (Kirk et al., 2010; Defra, SP1101). There are also differences in the approaches to sampling and reporting between the two studies. The NSI focused on soil samples taken from 5km fixed grid intersections and results were stratified by soil type and land use. The CS soil samples were collected in addition to habitat surveys from 1km grid squares in stratified land classes, representing key habitats of the UK.

An analysis of carbon stock changes using the National Soils Inventory of Scotland indicated that there was no significant change in carbon stock for equivalent surface horizons (0-15 cm) between 1978 and 2009 (Chapman et al. 2013). Although when partitioning by land use there were significant gains in soil C in the surface soils on moorland and woodland sites, contrary to the (Bellamy et al. 2005) study for England and Wales.

5.2.2 Monitoring (field scale)

Sites that have monitored soil carbon change in Wales directly at the field scale have focused on upland areas, although these represent a small proportion of the land area in Wales. Environmental Change Network (ECN) sites on Snowdon on a variety of soil types found no change in topsoil C between 1968 and 2008 (McGovern et al. 2013), although there were increases in Brown Podzolic soils but it was not reported if this was significant (Figure 20).

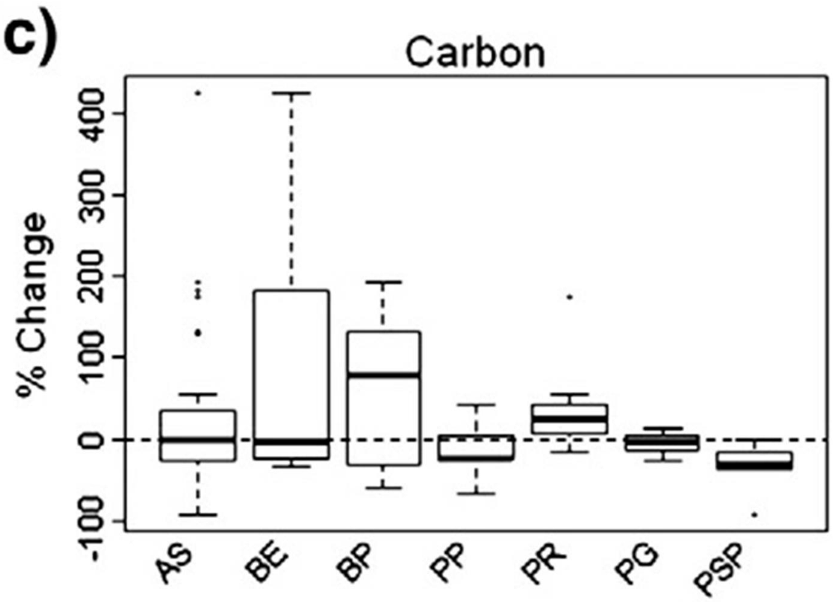


Figure 20. Percentage change in topsoil carbon from 1968 to 2008 at Snowdon ECN sites. AS=all soils n=31, BE=brown earth n=5, BP=brown podzolic n=6, PP=peaty podzol n=5, PR=peat ranker n=7, PG=peaty gley n=3 and PSP=peaty soil and peat n=5. Circles represent outliers. Dashed line indicates no change. Source: (McGovern et al. 2013).

The topsoil monitoring schemes indicate two conflicting trends; no significant change in topsoil carbon in upland or lowland peat in the CS (Reynolds et al. 2013); a decrease in topsoil carbon in NSI peat sites over a similar period (Bellamy et al. 2005). Monitoring losses of carbon from peat soils has focused on the measurement of dissolved organic carbon (DOC) draining peat areas or by assessing the flux of CO_2. Actual changes in soil carbon values are not reported but measurements of these outputs (e.g. Figure 18) indicate accelerated losses of soil C via these pathways. Assessment of peat soil condition from a new unified peat map indicated that many upland and lowland peat soils in Wales are in ‘poor’ ecological condition with drained sites emitting approx. 330 kt CO_2 eq yr^{-1}. Studies of 194 catchments across the UK indicate the dominant source of DOC was organic soils, there was also significant DOC export from grazed land on mineral and organo-mineral soils. There has been a trend of increasing DOC in surface waters indicating a significant carbon loss from these areas attributed to drainage and drought periods in peat soils. However, other evidence in the literature attributes this loss of DOC (Evans et al. 2007; Evans et al. 2012) to the recovery from acidification from atmospheric pollution rather than climate change or peat management over the period.

5.2.3 Modelling

Soil carbon losses occur when grasslands, managed forest lands or native ecosystems are converted to croplands, and soil carbon gains are made when croplands are converted to grasslands, forest lands or native ecosystems (Ostle et al. 2009). Conversion of forest lands into grasslands does not affect soil carbon in all cases, but does reduce total ecosystem carbon due to the removal of above-ground biomass. Modelling and inventory results show that between 1990 and 2000 UK land use change resulted in the land becoming a net source of carbon dioxide, losing 6.5ï 9.4 million tonnes of carbon as CO_2 (with an uncertainty range of 50ï 100 percent) (Falloon et al., 2006; Smith et al., 2007). These inventory and carbon-modelling exercises also identified the conversion of grassland to arable cropland as the largest single contributor to soil carbon losses from land use change in the UK between 1990 and 2000.

A modelling study (Bell et al. 2011) reviewed land use change from 1925-2007 to identify UK wide carbon flux and stocks over this time period. Modelling suggests that SOC loss as a result of climate change has been offset by land use change. However, modelling was for UK wide data and did not make any regional assessments so impacts in Wales specifically cannot be determined.

UK-wide land use change in minerals soils was modelled using RothC (Falloon et al. 2006) and indicated that land use change accounts for loss of C in these soils, with the largest contributor being grassland to arable conversion. Uncertainties in the predictions can be large as a result of the uncertainty in the original carbon stock inputs.

Few data exist for crop returns under long-term managed grass which makes it difficult to estimate the potential soil carbon gain or loss with modelling. However, modelling with few of these data indicated that SOC contents of permanent grassland soils will increase in all soils in the long-term (Defra, SP0306). The values used are not necessarily representative (Park Grass experiment in Rothamsted) of permanent grassland in other parts of the UK, in particular the acid loamy soils in Wales.

Assessing carbon stock changes as a result of land use change indicate that the mean time for changes causing carbon loss to reach equilibrium is 100 years throughout the UK (Moxley et al, 2014; Defra, SP1113). For changes which increase soil organic carbon (SOC) stocks, the mean time to equilibrium is 200 years in England and Wales .Conversion rates of land use changes in Wales were assessed for two time periods (2007/8 and 2008/9) and indicates stability of grassland land use systems. In 2007/8 where 96.5% of the area underwent no change, rising to 97.1% in 2008/9; both change analyses were dominated by permanent grassland remaining as permanent grassland (Moxley et al., 2014; Defra, SP1113). The potential for carbon stock changes by major land use change is potentially minimal in Wales given the current low rates of land use conversion, although this could change as a result of adaptions in agriculture to climate change.

Soil carbon stock change may be altered by changes in grassland management such as intensification/improved pasture by measures such as drainage, liming or fertilisation that could increase SOC stocks. However, there is a gap in the published research on the effect of intensification on rough grazing land on high carbon soils. Expert opinion indicates intensification on rough grazing land is not equivalent to intensification of lowland pasture on mineral soils, and could lead to release of SOC due to chemical oxidation and increasing soil respiration. Similarly, allowing marginal improved pasture to revert to rough grazing might increase SOC stocks in practice (Moxley et al., 2014; Defra, SP1113).

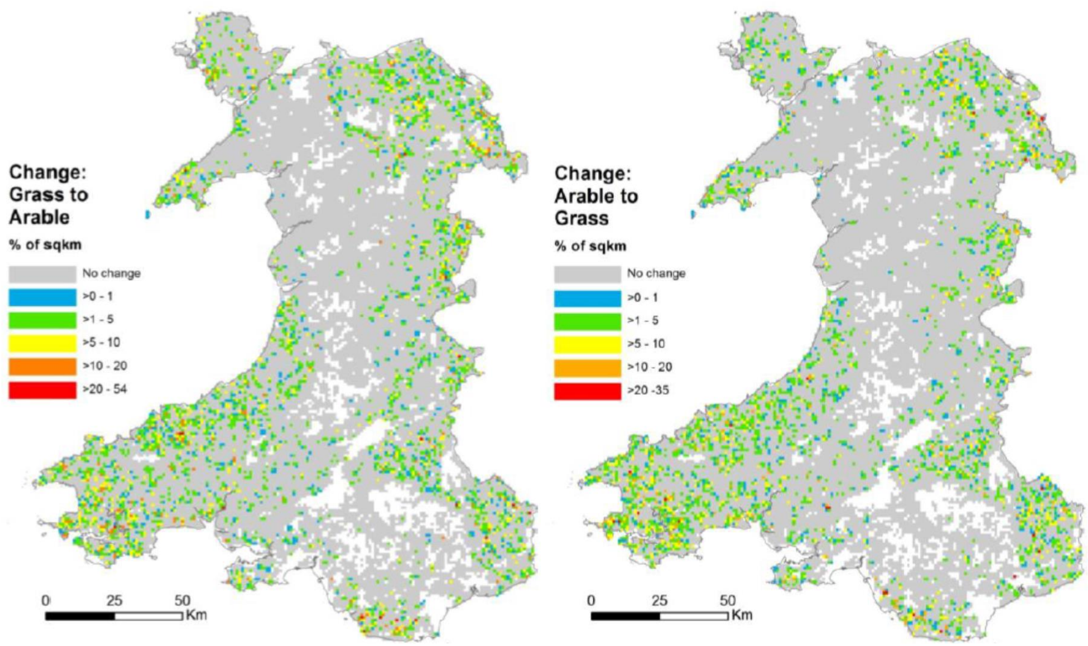


Figure 21. Proportion of 1 km square undergoing annual change in land use in Wales between 2007/8 and 2008/9. Source: Moxley et al., 2014; Defra, SP1113

5.3 Extent and severity

There is evidence for no change in the last 30-40 years in topsoil carbon overall in Wales. One study reported topsoil carbon losses for England and Wales over a similar period but data was not reported for Welsh soils specifically. Differences are evident when reported on a land use basis from these monitoring studies (Table 14). Widespread land uses such as grassland (65% land cover) show no change in topsoil carbon, although there may be differences between improved and unimproved grassland (indicated by modelling and pending reporting from GMEP). Defra BD5003 has yet to report but is investigating differences in soil carbon with depth in a range of intensively and extensively managed grasslands in England. Initial findings (Ward et al. 2016) have indicated that long-term changes in the intensity of grassland management have strongly influenced soil carbon, and that this effect is observed to considerable depths down the soil profile. The vulnerability of soil carbon in these different land use systems will be influenced significantly by a major land use change (e.g. change from grassland to arable systems). This has been shown by modelling studies. The current land conversion rates in Wales are low but external pressures such as climate change adaptation or a shift in agricultural markets may cause future change.

Data on arable soils was not reported specifically for Wales but a decline in organic carbon in topsoils was identified for England and Wales collectively. Woodland topsoils in Wales indicate an increase in soil carbon over the period 2007-2013. For upland and lowland peat soils there is conflicting evidence; one study shows a significant decline in topsoil carbon and another no change. However, measurements of carbon flux from soil by DOC and CO_2 indicate there are significant losses of soil carbon from these systems, so it is likely that the rate of loss is more than inputs, particularly if the peat is drained.

Table 14. Summary of soil carbon change for land uses or soil types in Wales reported in the evidence.

Land use/soil type	**% land cover**	**Topsoil carbon change (country reported and study)**	**Evidence**
Arable (+horticulture)	9	Decrease (England and Wales)	(Bellamy et al. 2005) (Reynolds et al. 2013)
Grassland	65	No change (England and Wales CS) No change (Wales CS + GMEP Improved grassland)	(Reynolds et al. 2013) (Emmett 2015; Reynolds et al. 2013)
Woodland	13	Increase (Wales CS+GMEP) Decrease (England and Wales)	(Emmett 2015; Reynolds et al. 2013) (Bellamy et al. 2005)
'Habitat'	?	Decrease (Wales CS+GMEP)	(Emmett 2015)
Peat soils (upland and lowland)	3	Decrease (England and Wales NSI) Inferred decrease (Wales) No change (England and Wales CS)	(Bellamy et al. 2005) (Emmett 2015) (Reynolds et al. 2013)

5.4 Vulnerability and resilience

Vulnerability of soil to a change in soil carbon in Wales is driven by a number of broad and interacting factors such as land use change, land management practices and climate that can initiate a shift in the carbon dynamics in soil systems. These are not fully understood but evidence suggests that 1) land management in arable farming has contributed to carbon loss in topsoils through mineralisation and reduction in inputs 2) differences in carbon exist between intensively and extensively managed grassland systems 3) changes to peat hydrology and thus organic matter have resulted in carbon loss.

Resilience is defined in this context as no significant change or the ability to recover from change over time. There is evidence potentially for the first scenario as one monitoring programme indicated the carbon content of topsoils overall in Wales have been relatively stable over the last 30-40 years. This result could alternatively indicate that the system is in slow recovery from historical (i.e. pre-1970s) perturbations. However, another study indicates that significant carbon losses have occurred in topsoils over the same period, particularly between different land uses. This conflicting evidence suggests we do not yet know enough about the resilience of the soils to carbon change under different land use and management systems.

Most data on carbon change is reported for topsoil samples (typically 0-15cm) and although most change is expected in surface soils it does not account for any change in carbon with depth. Studies have indicated 50% of carbon stock in soils in England and Wales exists below 30 cm (Gregory et al. 2014). Other reports have ascertained differences in carbon stocks with depth due to land use or management (Ward et al. 2016) but there are very few examples of assessing the change in soil carbon change at depth over time.

Table 15. Vulnerability and resilience of soil in Wales to organic matter loss.

Soil type/landscape	**Proportion of land cover (%)**	**Vulnerability**	**Resilience**
Organic soils (Peat)	3	?++ (conflicting evidence from monitoring programmes)	?
Organic soils (organo-mineral soils)	9	?++ (conflicting evidence from monitoring programmes)	?
Slowly permeable soils (SPS)	25	? no direct evidence	?
Freely drained loamy soils	26	? no direct evidence	?
Sandy (‘light soils’)	1	? no direct evidence	?
Clay (‘heavy soils’)	*	? no direct evidence	?
Grassland systems	65	++ (no change in ‘improved land’)	? no direct evidence

Soil type/landscape	Proportion of land cover (%)	Vulnerability	Resilience
Arable systems	9	?+++ (no direct evidence for Wales)	? no direct evidence
Woodland	13	+ (increases in soil C over in monitoring programme)	+++ (shows increase in C over 30 year time period)

*these are not separated specifically in the soilscapes (Table X) + low; ++ medium; +++ high; ? unclear or no direct evidence.

6 Loss of biodiversity

The evidence reviewed (>151 reports) on the loss of soil biodiversity in Wales suggests:

- A recent baseline survey for soil biodiversity in broad habitats in Wales (GMEP) indicates differences in community composition related to land use and management.
- No direct evidence exists for soil biodiversity loss in Welsh soils
- Changes in soil biodiversity are likely to be related to i) land use change (intensification / extensification), ii) loss of organic matter and/or iii) climate change. Reported low rates of change in land use and/or organic matter levels in Wales infer little change in soil biodiversity.
- There is no data on the vulnerability and resilience of Welsh soils to losses in soil biodiversity.

6.1 Overview

Soil organisms constitute the belowground diversity in biota that control the cycling of several key nutrients, notably carbon, nitrogen and phosphorus, improving/controlling soil structure through biopores and stabilising soil aggregates and supporting above ground vegetation by increasing plant available nutrients. The diversity in soil functional groups is found to influence soil processes (such as organic matter decomposition) rather than the species number per se (Heemsbergen et al. 2004). These functional aspects are also manifest in interactions between species so assessing the potential change of a loss of a particular species can be difficult. However, many studies indicate that functional redundancy is prevalent in soil microbial communities as different species can have the same function in ecosystems, so that the loss of species does not necessarily alter ecosystem functioning as the function is replaced by other species that can maintain the processes (Loreau, 2004).

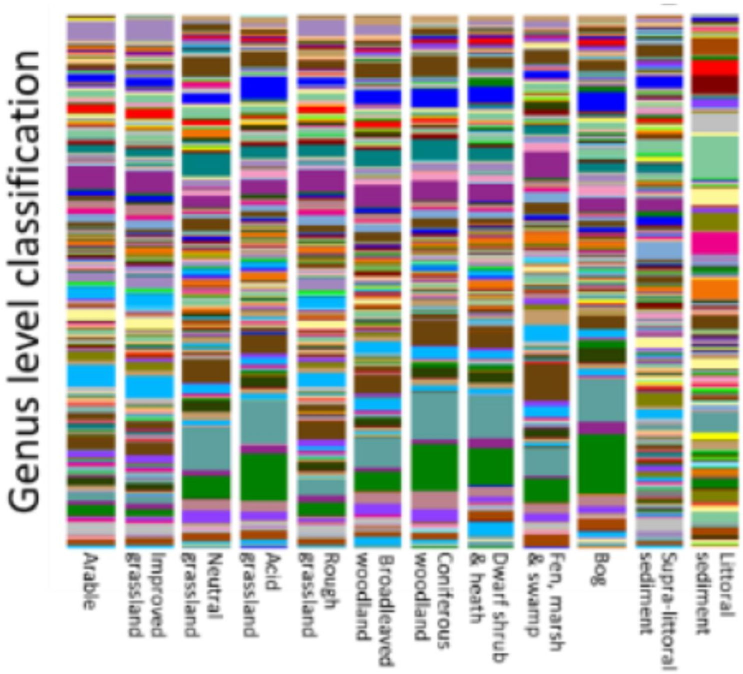
Diversity and function of soil biology also manifests at different spatial and temporal scales, across different land uses and soil types. There is a de-coupling of above ground biodiversity and below ground biodiversity, the latter often driven by the diversity of microhabitats available within a three dimensional soil profile (Bardgett & Van Der Putten, 2014). The spatial distribution and potential diversity of soil biota is determined by different processes acting at different scales. At the microscale soil heterogeneity determines pore space and substrate availability. At the local scale (meters to tens m) the distributions are often related to soil properties or conditions such as the availability of water, nutrients and carbon, and the soil pH. At the ecosystems scale (meters to 1000 km) climate and topography are important in addition to the associated soil conditions (Bardgett & Van Der Putten, 2014).

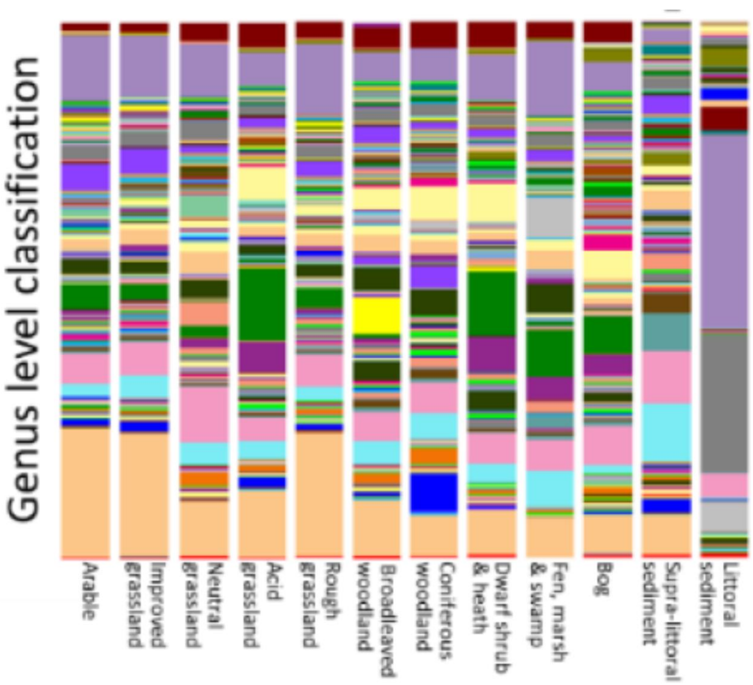
While these studies have increased recognition of the functional importance of soil organisms for biogeochemical processes, our understanding of the impact of species loss below ground still has many gaps. Relationships between soil species richness and ecosystem functioning, for example in nutrient cycling, the diversity effects are of most importance at the low end of the diversity spectrum, and they are dependent on species traits rather than species richness per se (Bardgett & Van Der Putten 2014). The common view is that there is high functional redundancy in soil communities for nutrient mineralization, and that changes in belowground community composition, rather than species diversity, are of most importance for ecosystem functioning (Bardgett & Van Der Putten, 2014).

6.2 Soil biodiversity and potential loss in Welsh soils

6.2.1 Baseline measurements of soil biodiversity

Monitoring programmes for soil biodiversity loss are rare and there is a paucity of data for even determining the current baseline levels of soil biodiversity from field to regional scale in most areas (Gardi et al., 2013). However a recent sampling programme (GMEP) has identified a baseline of soil microbial communities for Welsh soils across broad habitats (Emmett, 2015). Broad habitat types in Wales have unique microbial communities and thus land use has a major impact on the structure of soil microbial communities (Figure 22). Improved grasslands and arable sites have similar community compositions. Unimproved grasslands show different community structures suggesting that land use change and/or a reduction in inputs could initiate a shift in community composition. Littoral soils have very different community compositions compared to all other broad habitat types. This data provides a baseline survey of soil biodiversity in Wales by broad habitat type. There is no evaluation of how the microbial communities are changing over time.


Genus level classification
Arable
Improved grassland
Neutral grassland
Acid grassland
Rough grassland
Broadleaved woodland
Coniferous woodland
Dwarf shrub & heath
Fen, marsh & swamp
Bog
Supra-littoral sediment
Littoral sediment


Genus level classification
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Broadleaved woodland
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Fen, marsh & swamp
Bog
Supra-littoral sediment
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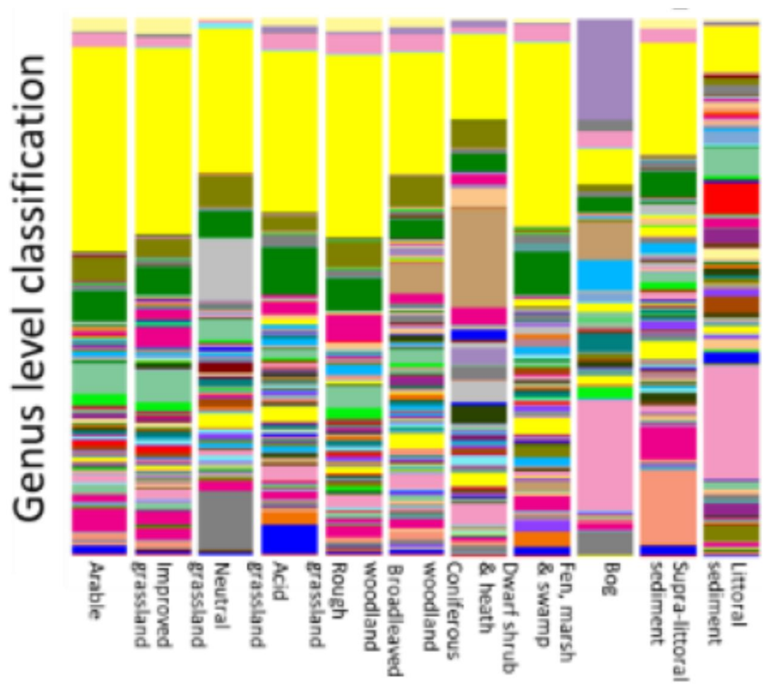

Figure 22. Bacterial (top), non-fungal eukaryotes (middle) and fungal communities (bottom) at genus level for Broad Habitat types in Wales in 2013. The coloured bars represent different bacterial and fungal types at each taxonomic level. Note: there is uncertain labelling of some habitat types in the bottom figure that is present in the original source document. Source (Emmett, 2015).

6.2.2 Potential threats to loss of soil biodiversity

A list of potential threats to soil biodiversity has been determined though expert judgement (Orgiazzi et al. 2016) and is summarised in Figure 23 below. The identified threats to soil organisms (fauna, microorganisms and functions) were also mapped onto land use typologies in Figure 24 indicating the high risk to organisms for intensely managed systems compared with semi-natural habitats. The study also produced composite ‘threat’ maps for the European Union that were based on a simple scoring system using existing EU-wide datasets as potential surrogates for each individual threat detailed in Figure 25.

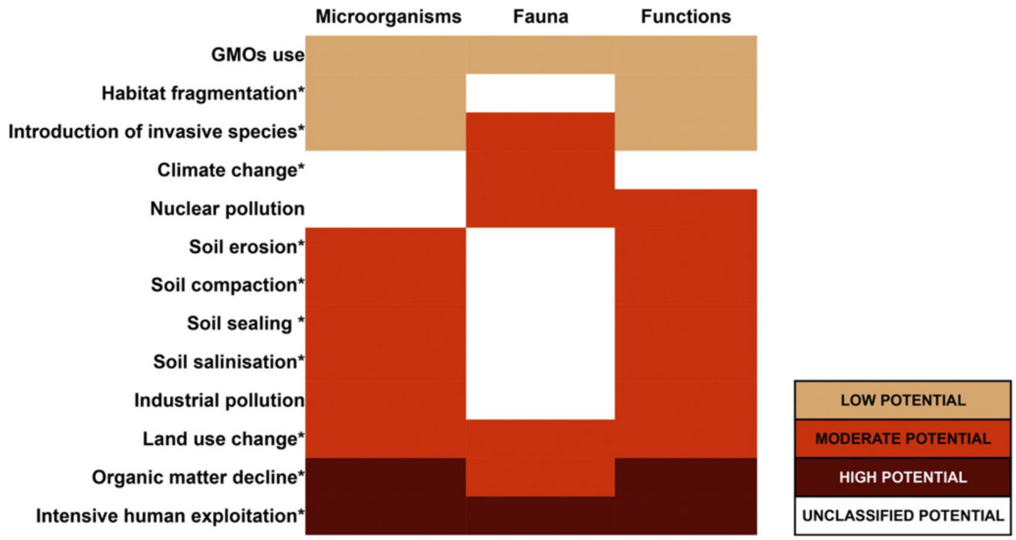

Figure 23. Threats to soil biodiversity Source: Orgiazzi et al., 2016.

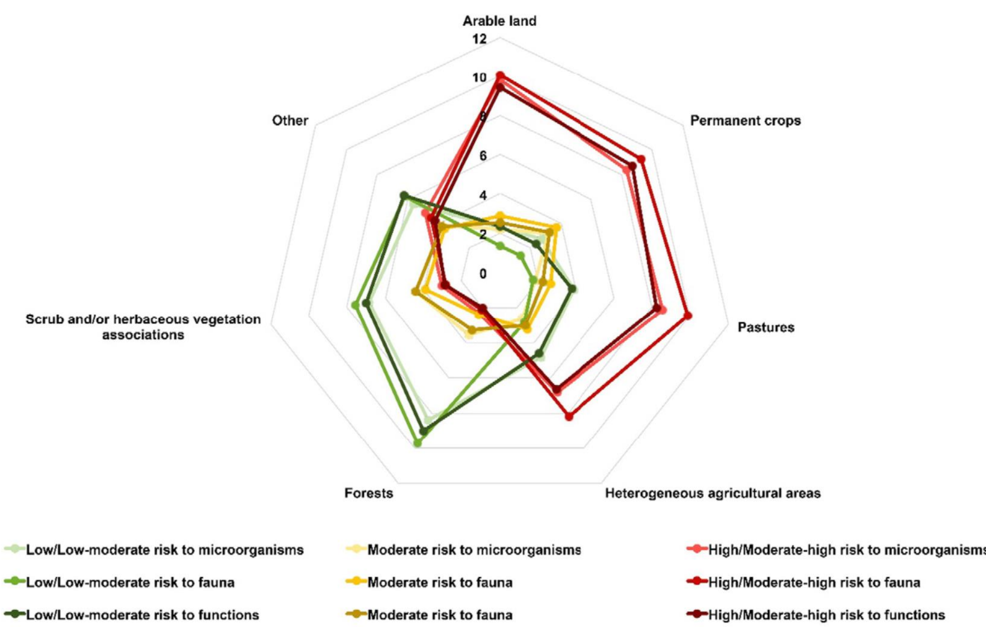

Figure 24. Threats related to land use types. Source: Orgiazzi et al., 2016

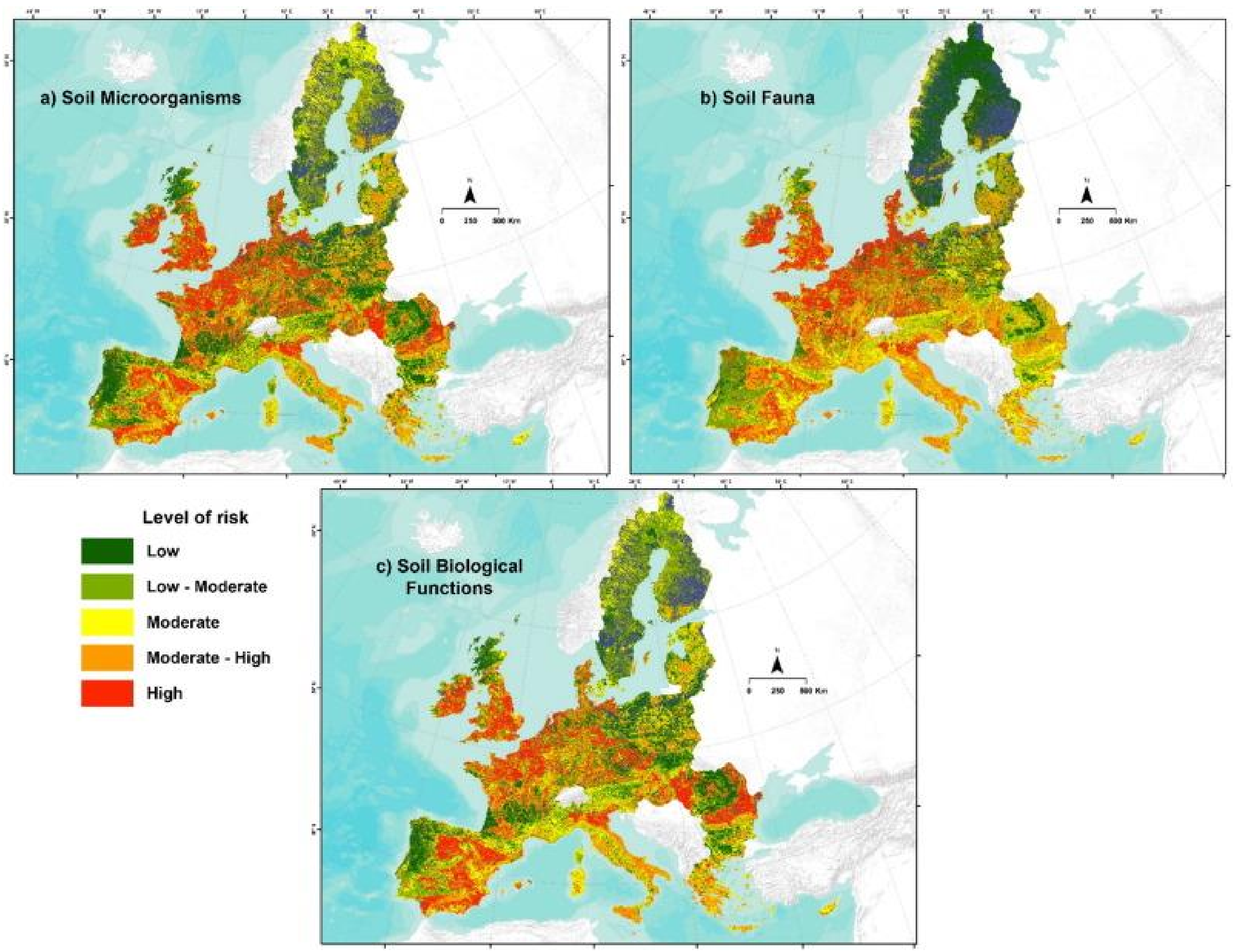

Figure 25. Threat to soil biodiversity in EU. Source: Orgiazzi et al., 2016

For the purpose of this review we will concentrate on evidence related to the primary threats indicated in Figure 23 that show moderate or high potential for change across all three groups. These include land use change or intensification, loss of organic matter and climate change. We will set these threats in context of relevant soil, land use and climate characteristics of Wales.

6.2.3 Loss of soil biodiversity as a consequence of land use intensification and land use change

Land use intensification has shown to affect soil biodiversity consistently across several European countries with contrasting soil and climate (Tsiafouli et al. 2015). Increasing land-use intensity from grassland to extensive and intensive rotation decreased diversity within soil faunal taxonomic groups, diversity among functional groups, and the average trophic level in the soil food web.

In selected arable, grassland and forest sites across Europe land use intensification also clearly showed changes in the interactions between soil biota types (Creamer et al. 2015). Increasing intensification resulted in lower density networks (connections between different taxonomic groups), a reduction in the strength of the connections between bacteria and most other taxonomic units and a reduction in the average number of neighbours (the number of connections each taxonomic units has). Forest soils displayed the greatest density of network connections suggesting a more stable system with a strongly developed food web in place. In contrast, the arable sites revealed relatively poor density, with a dominance of a few taxonomic groups, suggesting a partial food web driven by few taxonomic groups.

Bacterial communities were significantly different between different land use categories (agricultural vs early successional) of the same soils type in close proximity and thus similar climatic controls (Lauber et al. 2013). The study also showed short-term (8 month) changes in the dynamics of these communities was also influenced by the land use with the greatest change in soil bacterial communities in the agricultural soil related to fluctuating above ground inputs. Other studies also indicate that shifts in below ground microbial communities, resulting from agricultural intensification, could be of equal importance for ecosystem function as those that happen above ground (de Vries et al. 2012).

6.2.4 Loss of organic matter

Organic matter loss is primarily linked to land use change so similar patterns are expected as discussed in the previous section for land use changes linked to declines in organic carbon (e.g. reversion of grassland to arable). However, there are complex interactions between the above ground vegetation and below ground soil biology that will affect C storage and cycling. There are still improvements required in the understanding of the functional context of the role of soil biodiversity in the cycling and carbon balance in soils.

6.2.5 Climate change

Climate change effects on soil biota have been discussed in Section 4.2.4. However, there are still large gaps in the understanding of the feedback mechanisms related to climate change effects on above ground vegetation, changes to soil biogeochemical cycles and the potential impact on the diversity of soil biota. There are no current frameworks to model the effect of climate change on soil communities (Defra, SP0571). Defra Project SP0570) experimental work on grassland soils indicates that the effect of drying (i.e. drought) in areas currently with high water saturation will show changes to the soil biological community and structure.

Studies on earthworm populations in upland peat (Moor House, ECN site in Cumbria) show earthworm responses to soil warming and their potential contribution to DOC release from the peat soils. In peat soils there is an initial positive response of increased earthworm abundance with warming but these effects may be non-linear, particularly if the peat subsequently dries out during drought events (Cole et al. 2002).

6.3 Extent and severity

There is no direct evidence on the loss of soil biodiversity in soils in Wales as currently only a baseline survey exists. An indication of the potential loss of soil biodiversity is shown in the EU maps (Figure 25) based on the primary drivers for soil biodiversity loss and available data proxies for Europe (Orgiazzi et al. 2016). This therefore represents the potential for soil biodiversity loss rather than areas experiencing known loss in soil biodiversity. Following from the indicated threats and their consequences the following areas are most likely to be vulnerable to potential soil biodiversity loss:

- Areas where there is an occurrence of significant land use change. Previous parts of the review indicate that the land use system in Wales is relatively stable due to the current and projected environmental constraints on the expansion of arable agriculture.
- Shrinking of upland areas in response to climate change may have an impact on changing land use from rough grazing to improved grazing on peripheral land that may impact on the diversity of soil biota.
- Environments where a significant loss of organic matter is occurring or may be expected includes high-carbon environments such as peatland and organo-mineral soils, although for these soils in Wales there is not conclusive evidence that this has occurred.

6.4 Vulnerability and resilience

It is difficult to ascertain a direct link between soil type or habitat and the potential vulnerability or resilience to soil biodiversity loss due to a lack of evidence. Studies show that soils under different land uses have different species composition and interactions and in some habitats e.g. peat soils there are very specific species traits and compositions that are suited to the particular environment. Thus any change or perturbation, even with the concept of functional redundancy, may result in greater change. In these environments this may not result in a biodiversity loss because the soil biota moves towards a different state in response to the changing land use or vegetation and soil biodiversity may actually increase.

7 Erosion

The evidence reviewed (>56 reports) on the loss of soil by erosion in Wales suggests:

- There are no studies that directly quantify the severity or spatial extent of soil erosion (by water, wind, co-extraction and/or tillage)
- Modelled national estimates of soil erosion by water (SP1609) have not been validated with observed erosion rates. These provide coarse scale indications of potential rates
- A study of upland erosion indicated that rates had increased over the monitoring period, although this represents a response to a specific extreme event
- Peat / organic soils are particularly vulnerable to wind and water erosion, especially the latter process in upland areas due to high rainfall
- Based on land use statistics, of the total land area of Wales the areas vulnerable to tillage erosion and to co-extraction with crops / farm machinery are estimated to be 8.5% and 0.5% respectively
- As soil erosion represents an absolute reduction in soil volume / depth, shallow soils will be less resilient to the impacts of soil loss compared to deeper soils.

7.1 Overview

Soil erosion in the context of a degradation threat is ñthe accelerated loss of soil as a result of anthropogenic activity in excess of accepted rates of soil formationò (Gregory et al., 2015). Tolerable rates of soil erosion across Europe have been estimated at between 0.3 and 1.4 t ha^{-1} yr^{-1} (Verheijen et al., 2009). Evidence suggests that these rates are often exceeded (Verheijen et al., 2009).

Erosion can occur as a result of water, wind, tillage, co-extraction with root vegetables and farm machinery and human and animal impact (from recreation and grazing).

7.1.1 Water erosion

Water erosion is the most common form of erosion. It relies on three process; detachment of soil particles by raindrops, entrainment of detached particles, and transport of detached particles (Morgan, 2005). It can result in either sheet loss, rill or gully formation on even slightly sloping land. Mean rates for Europe have been estimated at 0.1-88 t ha^{-1} yr^{-1} (rill and sheet erosion only) (Verheijen et al., 2009). The occurrence and rate of water erosion processes are influenced by regional climate, local soil properties, and past and present land use. (Verheijen et al., 2009).

7.1.2 Wind erosion

Wind erosion is caused by the simultaneous occurrence of three conditions: high wind velocity; susceptible surface of loose particles; and insufficient surface protection (Verheijen et al., 2009). Estimated annual erosion rates are much lower than water erosion at between 0.1-2.0 t ha^{-1} yr^{-1} (Verheijen et al., 2009). Wind erosion also affects fewer fields than water erosion and probably occurs less frequently (Boardman and Evans, 2006).However, when wind erosion does occur it can be more severe than water erosion, (Boardman and Evans, 2006). This is a result of it impacting the whole field area and not just specific areas whilst water erosion is focussed where water channels in the field (SP1606).

7.1.3 Tillage erosion

Tillage erosion occurs on cultivated (tilled) arable and horticultural land (Defra, SP08007). Contour ploughing and ploughing up or down hill produces a net movement of soils. The greatest impact stems from contour ploughing in which soil is turned downhill (Defra, SP08007). This is approximated to move 1000 times as much soil as soil creep (Defra, SP08007). Verheijen et al. (2009) estimates this to result in a total erosion of 3.0 to 9.0 t ha^{-1} yr^{-1}. The intensity of tillage erosion depends upon slope variation, with fields with rolling topography most at risk; tillage implement type; tillage depth; tillage speed; plough direction (Defra, SP08007).

7.1.4 Co-extraction

Soil can be eroded from a field through co-extraction on harvested root crops and/or on the wheels and implements of farm machinery (Defra, SP08007). Whilst the UK has the lowest losses in the EU, they are still considered to be substantial with an estimated 2 t ha^{-1} yr^{-1} eroded during the harvest of sugar beet and potatoes alone (Defra, SP08007). Considering the land used in Wales for potato production in 2015 (2,846 hectares, Welsh Government, 2015a) this could equate to as much as 5,692 t of eroded soil. Whilst this soil is often recycled elsewhere, it is lost from the field system. It has also been estimated that between 1 ï 2 t ha^{-1} yr^{-1} of soil is eroded from the field by adhering to agricultural machinery used in sugar beet harvest (Defra, SP1606).

7.1.5 Animal and human/upland erosion

The combined effect of water, wind, frost and animals acting on bare soil in the uplands is often referred to as óupland erosionô (Evans, 1997). Areas of land, typically in the uplands are often subject to recreational and agricultural pressures (Defra, SP0402). This results in accelerated erosion through soil disruption as well as an increased erosion risk through vegetation removal (Defra, SP0402). Overgrazing is one example of this whereby soil is exposed to the elements and in upland areas can increase the likelihood of wind and water erosion (Defra, SP1606).

Figure 26. Areas of soil erosion risk in England, Wales and Scotland, based on land use, soil type and landform (i.e. slope). N.B. Upland includes both water and wind erosion. Source Defra SP08007 originally from Boardman and Evans, 2006.

7.2 Impacts of soil erosion

7.2.1 Diffuse pollution

Erosion by water can result in ‘dirty’ runoff that has the potential to result in the diffuse pollution of receiving water bodies. This can have several ecological and economic impacts depending on the runoff content. In English watercourses, agricultural runoff is believed to make up 70 % of sediment pollution, 60 % nitrate pollution, 25 % phosphate pollution (National Audit Office, 2010), and 90 % of pesticide pollution. Increased phosphorous and nitrate levels can result in eutrophication. Elevated nitrate levels can also impact the water industry with increased costs for water treatment. Increased sediment can silt up fish breeding grounds, and reduce the capacity of rivers and reservoirs increasing the risk of flooding. Pesticide pollution could affect ecosystem diversity. All of these impacts affect the success of a water course meeting the ‘good ecological status’ classification as required by the European Water Framework Directive.

7.2.2 Loss of soil fertility

Once detached, lighter particles such as nutrient rich clay and more organic fractions can be easily transported by wind or water. This results in enriched runoff leaving behind a lower nutrient and coarser soil. This could result in lower/poorer quality yields unless increased fertiliser inputs can be made. However, such inputs do not replace the organic matter lost, this requires a longer term approach. The impact of this degradation threat is discussed in greater detail in Section 5.

7.2.3 Loss of soil depth

As soil is eroded the soil volume is reduced (Defra, SP1606). This can reduce the rooting depth available to plants negatively impacting resulting yields in cropping systems. It can also impact soil biodiversity as habitat is reduced as well as the soil organic matter content as there is less of a store available. This could also negatively affect infiltration as the most permeable layer is reduced.

7.2.4 Reduced infiltration

Soil infiltration can be reduced by raindrops. Firstly, the rain drop impact can compact the soil sealing the pores and generating an impermeable barrier (structural seal/crust) that reduces infiltration into the soil (Morgan, 2005). Secondly, soil that is detached by raindrops is dispersed and re-deposited and if not transported away can also result in clogging soil pores, reducing infiltration (Morgan, 2005). This reduced infiltration increases surface runoff than can in turn increase peak discharge and the risk of localised flooding.

7.3 Extent and severity

Wales is predominantly susceptible to water and upland erosion (Boardman and Evans, 2006) (Figure 26), although no quantified rates have been recorded to estimate the severity or extent of this degradation process (Defra, SP1609). Modelled estimates (e.g. SP1609; Figure 28) using the PESERA model provide a broad level indication for soil erosion by water. This study used coarse scale data that does not capture local scale factors that are commonly responsible for most erosion events. The modelled rates have not been validated by field data / observations due to lack of data. Large areas (65%) of Wales are assumed to have low erosion rates due to grassland land use, although this has not been quantified by measurements or observations.

With a lack of measured data, only inferences of risk can be made. In the case of tillage erosion, 8.5 % of Wales is at risk based on the total arable and horticultural land, all of which is presumed to be under tillage. The land area at risk of erosion by co-extraction could be approximated at 0.5% of the total arable land area. This is based on the area of sugar beet and potato production in 2014 (Welsh Government, 2015a).

Defra project SP0407 assessed the extent (changes in area and volume of erosion feature) of soil erosion on both arable and upland NSI field sites in England and Wales following one extreme weather event (wet autumn and early winter of 2000/1). These data were compared with similar measurements of soil erosion made on previous visits to the same field sites (Defra NT1004, SP0402). Data indicted an increase in erosion in specific upland sites in Wales (Figure 27). The causes (reported for England and Wales sites combined) attributed recent erosion primarily to the following causes: livestock (sheep and cattle); water; and human influence (drainage, vehicles, walkers). There have been no further surveys since this report on the extent of erosion features in uplands in Wales. This study represents a snapshot of the response of sites already experiencing erosion to an extreme event (very wet winter) and thus does not take into account any long term trends or any new erosion episodes in other areas.

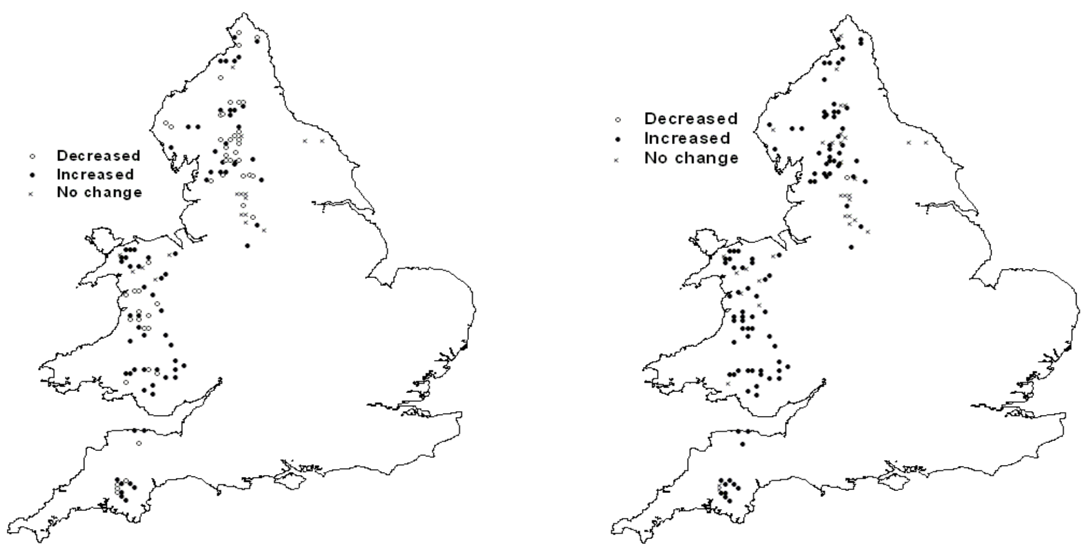

Figure 27. Distribution of upland NSI field sites on which an increase, decrease or no change in soil erosion area (left) or volume (right) extent was measured. Source Defra SP0407

Wind erosion is most likely to occur on upland peat areas when summers have been sufficiently dry to make the peat friable (Defra, SP1606).

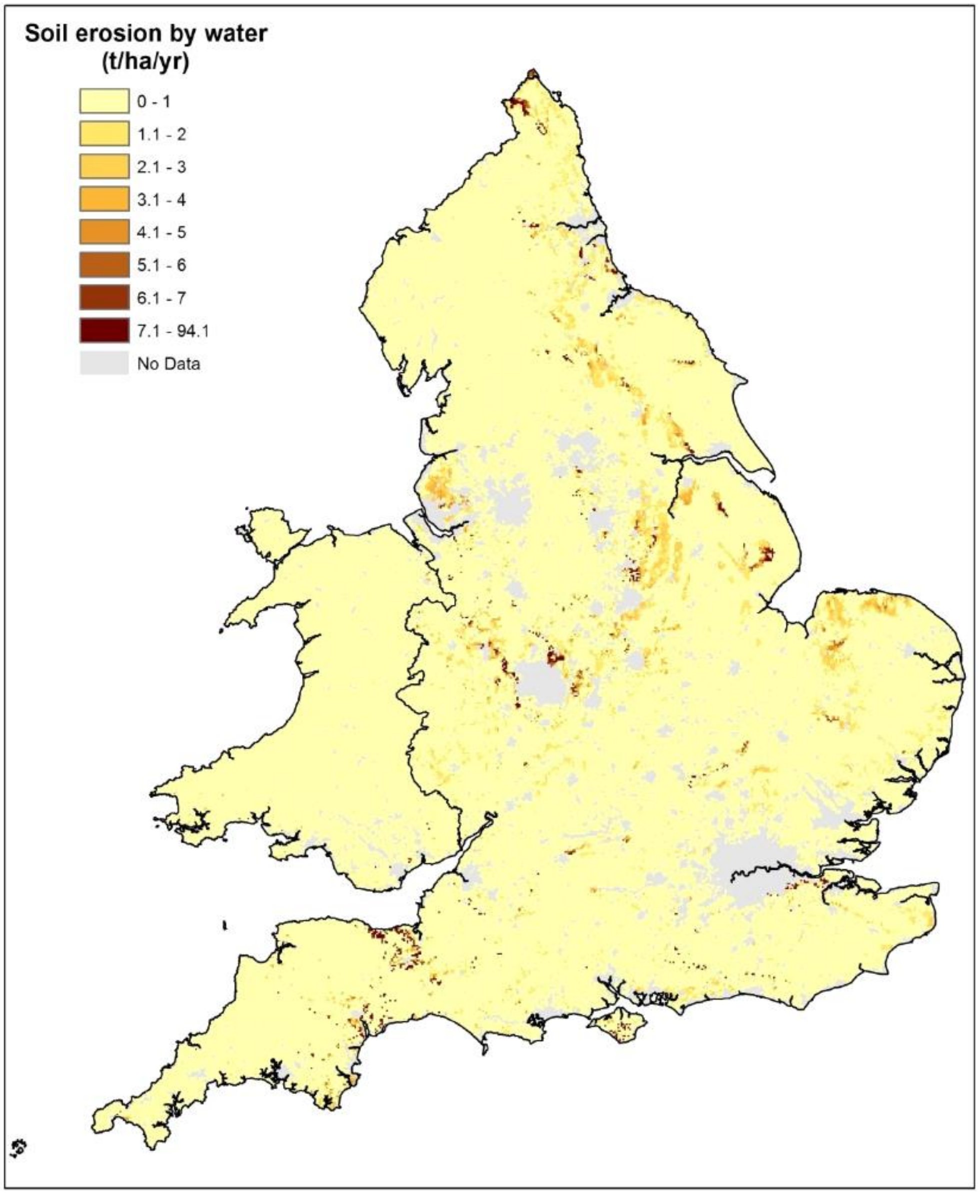

Figure 28. PESERA map of mean annual rates of soil erosion by water (t ha^{-1} yr^{-1}) Source: SP1609.

7.4 Vulnerability and resilience

Vulnerability and resilience is reported in Table 16. Vulnerability in this context is the susceptibility of soil to erosion events and resilience is the recovery of the soil to an erosion event. Peat soils are particularly vulnerable to wind and water erosion (Defra, SP0532). This is because they have low aggregate stability due to a high organic matter content (>20-30%) and resulting small soil particle size (Defra, 2005). Soils with increasing organic matter between 0 and 10% are less vulnerable to erosion due to increased aggregate stability (Defra, SP0532). Peat/organic soils are particularly vulnerable to soil erosion by water (Defra, SP0532) due to their small capacity to accept winter rainfall (EA, 2007). This increases runoff and therefore the risk of erosion. The location of peat/organic soils also affects vulnerability to soil degradation by erosion with upland areas receiving higher annual rainfalls thus increasing upland peat vulnerability.

In arable systems, the vulnerability to erosion is influenced by topsoil texture. Soils topsoil textures dominated by sand and silt are more vulnerable to soil loss than those with a higher clay content (Morgan, 2005; Evans, 1990). There is no direct evidence of erosion rates or frequency on arable sites in Wales specifically, and sandy and silty soils have small spatial extents in Wales.

In Defra SP1606, a relative risk matrix was devised to ascertain the susceptibility of broad land use and soil types to erosion risk and has been incorporated into Table 13. Evidence is scarce to derive actual vulnerabilities that would require regular monitoring of erosion events in Wales. The vulnerabilities are based on mechanisms identified to exacerbate soil erosion and are linked to soil and land use types in Wales. There is no evidence of the resilience of systems to erosion events although ongoing work in SP1317 is identifying the potential impacts on ecosystem services due to changes in soil depth (primarily associated with erosion loss). SP1317 highlights that shallow soils will be less resilient than deeper soils to erosion events. Soil lost from erosion cannot be replaced through natural processes (soil formation and aerial deposition) because these can take many decades to millennia to form a few cm of new soil material. Some evidence of resilience in upland soils is indicated by the re-vegetation of areas previously experiencing erosion (SP0407) was reported, although this represents very small spatial extents.

Table 16. Soil/landscape vulnerability and resilience to erosion.

Soil type/landscape	**Proportion of land cover (%)**	**Vulnerability**	**Resilience**
Organic soils (Peat)	3	+++	?
Organic soils (organo-mineral soils)	9	++	?
Slowly permeable soils (SPS)	25	+ (low due to predominant grassland land use on this soil type)	?
Freely drained loamy soils	26	? no direct evidence	?
Sandy ('light soils')	1	+++	
Clay ('heavy soils')	*	+	
Grassland systems	65	+/++ (inferred no direct evidence)	?
Arable systems	9	++ (dependent on soil type and land	?

Soil type/landscape	Proportion of land cover (%)	Vulnerability	Resilience
		management)	
Woodland	13	+	

+ low; ++ medium; +++ high; ? unclear or no direct evidence.

8 Compaction

The evidence reviewed (>21 reports) on soil compaction in Wales suggests:

- Studies on compaction in grassland soils reported for England and Wales combined show 10-15 % of sites were in poor condition and 50-60% in moderate condition. The study did not report conditions for Welsh sites specifically.
- Soil and land use conditions in South west England, that are broadly similar to Welsh arable and improved grassland areas, reported high structural degradation in arable sites with late harvested crops and moderate degradation in permanent grasslands.
- No data exits on compaction in arable land in Wales specifically.
- No Welsh specific data exists on the vulnerability and resilience of different soil types and land uses to compaction.

8.1 Overview

Soil compaction is the physical reduction in volume of soil due to a compressive force (Defra, SP1606). This reduces the pore space between soil particles (Figure 29) and results in an increase in bulk density (Graves et al., 2015,). Larger (macro) pores are preferentially reduced, and the alignment of pores changed, affecting pore connectivity (Gregory et al., 2015; Newell-Price et al., 2013). Compaction is affected by soil particle size (sand, silt and clay) and different soil types; these affects are discussed in Section 8.1.2.

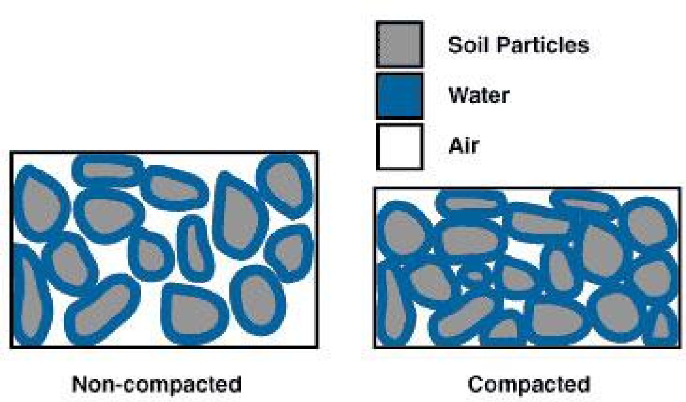

Figure 29. The effects of soil compaction on pore space between soil particles. Source: http://www.extension.umn.edu/agriculture/tillage/soil-compaction/

Increased pressure on the soil surface can come from heavy machinery, livestock and human trampling, and can result in different belowground effects (Table 17).

Table 17. Reported compaction depths for different soil surface pressures.

	Machinery			**Livestock**	**Human**
	Arable/ horticulture	**Grassland**	**Forestry**		
Compaction depth (mm)	0 - >400[a]	0 - >300[b]	0 ï >1000[c]	0-150[b]	0-50[d]

[a]Defra, BD2304. [b]Newell-Price et al., 2013. [c]Batey, 2009. [d]Kuss, 1983.

Vehicles can result in both surface (<0.40mm) and subsurface compaction (Defra, BD2304). This is influenced by machinery load, type and dimension of tyres, inflation pressure, vehicle speed, wheel slip and the number of passes are all influential on the extent of compaction (Table 18, Defra, BD2304). Heavy machinery is used across a range of land uses pertinent to Wales; grassland, forestry, arable and horticulture at different intensities. Grassland vehicle trafficking can be double the intensity of vehicle traffic in an arable system (Defra BD2304). Machinery used to extract timber is so heavy that it causes degradation of rural roads, a much stronger surface than soil.

Table 18. Vehicular causes of surface and subsurface soil compaction. Source: Defra, BD2304.

Surface compaction (<0.40 m depth)	**Subsurface compaction (>0.40 m depth)**
• Ground contact pressure • Increased number of wheelings/vehicle passes	• High axle loads • Number of vehicle passes • Weight independent of the pressure on the soil surface. • Tyre inflation pressure • Tyre width

Livestock compaction, also known as poaching, can occur from the hooves of grazing animals. The pressure exerted by animal hooves is at least doubled with movement and can be comparable to that exerted by an unloaded tractor (Scholefield and Hall, 1986; Blunden et al., 1994). Compaction effects are limited to the topsoil between approximately 0-150 mm deep (Newell-Price et al, 2013). When a soil with a moisture content near saturation is subject to poaching, soil structure can become homogenised as the hooves generate soil plastic flow around them (Defra, BD2304).

Compaction to a depth of 0.40 m can be rapidly remediated using agricultural machinery. However, machinery selection is very important as in some circumstances this can result in the creation of compaction to a greater depth.

8.1.1 Susceptible land use

Table 19 identifies urban, horticulture, arable (intensive and extensive) improved grassland and forestry as land uses most susceptible (at high risk) to compaction. This table was compiled as part of the Defra SP1606 report using available data to aid the evaluation of soil degradation consequences (impacts and costs).

Table 19. The relative risk of compaction in each land use and soil type category Source: Defra, SP1606.

Land use	**Soil types**			
	Clay	**Silt**	**Sand**	**Peat**
Urban	H	H	H	H
Horticulture	H	H	L	H
Arable intensive	H	H	L	H
Arable extensive	H	M	L	M
Grassland improved	H	H	?	H
Grassland unimproved	M	M	L	M
Rough grassland	M	M	L	M
Forestry	H	M	?	H
Woodland	L	L	L	L
Wildscape	L	L	L	L

- Note: H = high probability of soil degradation; M= moderate probability of soil degradation; L = low probability of soil degradation; ? = Uncertain probability. Forestry ï High during planting, harvesting and extraction, low at all other times (SP1606)

Based on the percentage land cover of Wales reported in Section 2.1 approximately:

- 86 % of the total land area of Wales (grassland, woodland and forestry, arable and horticulture) is at risk of compaction from heavy machinery
- 65 % of Wales (grassland) is at risk of compaction from livestock
- An unknown area of land is at risk from human trampling as a result of recreational activities.

However, only a percentage of the area under each land use will actually be affected by compaction (Table 20).

Table 20. Estimates of areas liable to agricultural compaction by soilscape in England and Wales. Source: modified from Graves et al., 2015.

Land use	**Area of land use affected by compaction (% of land use)**	**Equivalent area of Wales affected by compaction (% of land use)**
Horticulture	41	3.6
Arable	42	3.6
Grassland[a]	39	25
Forestry[b]/woodland/wildscape	0	0

[a]Excludes rough grassland. [b]Varies according to development phase.

8.1.1.1 Grassland

In grassland, 25% of the total area in Wales is liable to agricultural compaction (Table 20). This area will be attributed to field trafficking by machinery for fertiliser and slurry spreading, rolling, harvesting and transport of grass (Defra, BD2304) and livestock poaching particularly around gateways and feeders (Newell-Price et al., 2013). Figure 30 shows the spatial distribution of the risk levels of soil compaction in grasslands in England and Wales. High levels of risk are associated with areas of high compaction stress and soil/climate-based vulnerability. This shows that in England and Wales between 250,000 and 650,000 hectares (10%) of grassland could be in poor physical condition, and that 2ï 3 million hectares (60%) could be moderately compacted (Defra, BD2304).

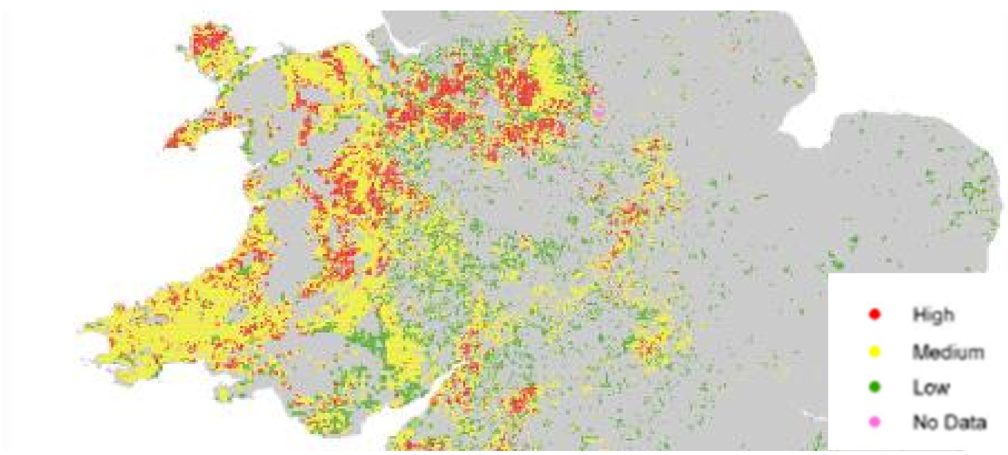

Figure 30: Risk of soil compaction in grasslands in England and Wales. Source: Defra BD2304.

8.1.1.2 Arable and horticultural land

Of the 8.5% of Wales under arable and horticultural production only 3.6 % is liable to agricultural compaction. This would correlate with areas of machinery compaction.

8.1.1.3 Woodland

It is difficult to calculate the percentage of woodland affected, as it depends on the woodland development phase ï i.e. planting, harvest and extraction although (Table 20).

Table 20 Using the 5 year average woodland cover average from 2010 to 2014 (Welsh Government, 2015b) it is possible to calculate the percentage of newly planted (0.2%) and restocked (0.7%) woodland over 2014. Harvest area data was not available. Therefore (excluding harvesting area) a minimum 1% of the total woodland and forestry area may be affected by compaction. This area is likely to correspond with that trafficked by heavy machinery during planting, harvest and extraction (transport of cut timber). The harvest of timber causes deep ruts which may persist for many years, and have been recorded up to 30 (Batey, 2009).

8.1.1.4 Urban areas

Although unquantified, where construction occurs such as in urban development over-compaction of soils is an inevitable by-product as areas are repeatedly trafficked irrespective of soil moisture conditions (Defra, SP1607).

8.1.2 Susceptible soil types

The general risk of compaction across land use and soil type is reported in Table 19. Soil properties that affect the ability to withstand compression include soil texture, moisture content and organic matter content (Jones et al., 2003; Davies et al., 2001).

Considering soil types, sandy soils are particularly vulnerable to compaction. Sandy soils only cover 1.2% of Wales. Soils with low organic matter contents are also vulnerable. Clay soils are better able to recover from compaction. This is due to their greater shear strength and in some clay soils their ability to shrink and swell (Gregory et al., 2009). However, this is only relevant to <2% of soils found in Wales.

A high soil moisture content can increase soil vulnerability to compaction (Gregory et al., 2009; Davies et al., 2001; Jones et al., 2003). The UK soil field capacity days and annual workability days are presented in Section 4.2.1. This could particularly affect 39% of Wales where soils are considered wet, slowly permeable or have high groundwater. However 17% of this area also comprises upland soils with a peaty surface. This organic matter component could ensure good recovery as they are more resilient to compression (Defra, SP1605).Soil moisture content is affected by climate, with wetter climates increasing the risk of increased soil moisture content and thus degradation from compaction. For example occurrence of soil degradation from livestock compaction is most likely in spring and autumn or during wet summers on susceptible soils (Defra, BD2304).

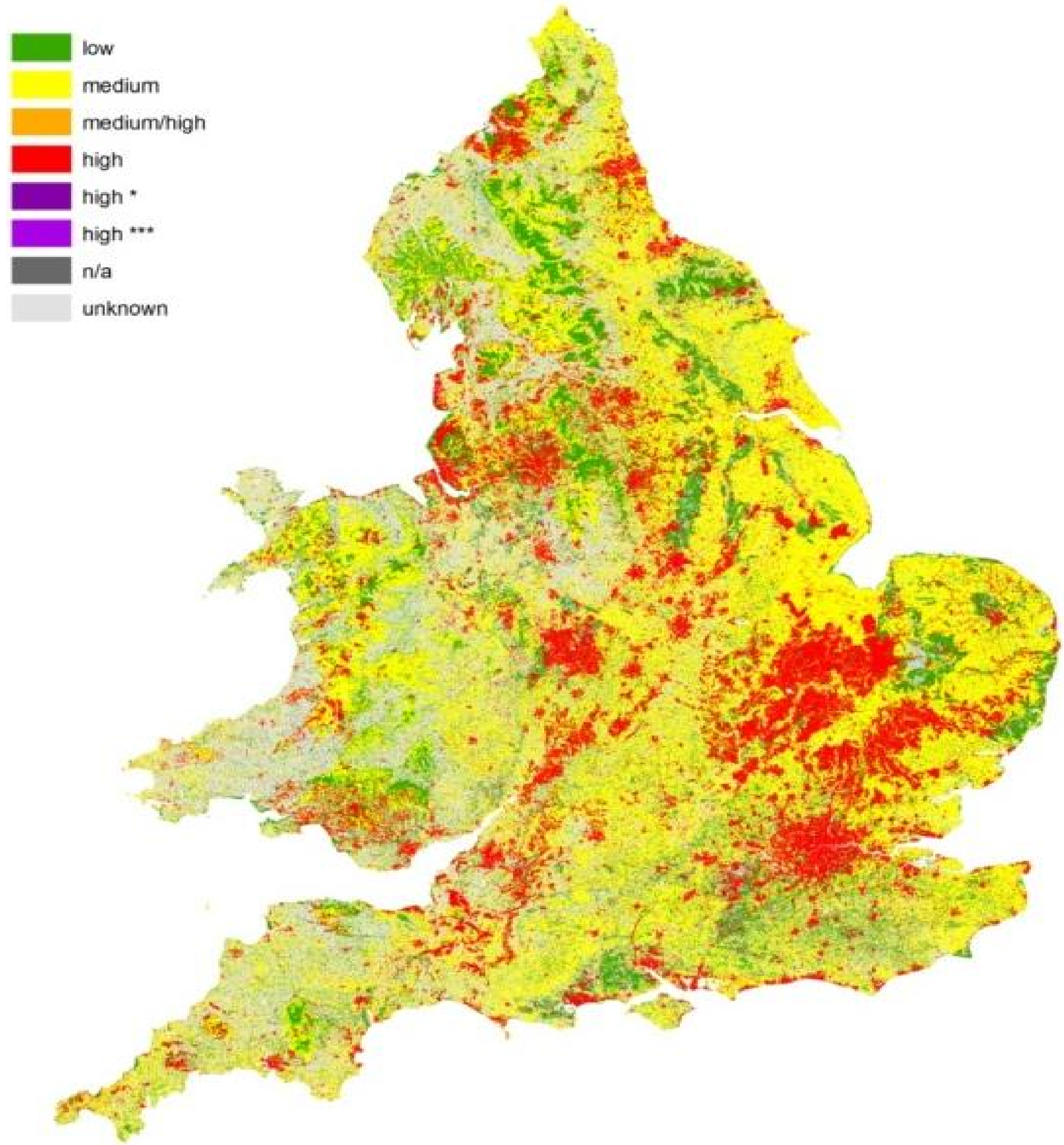

Figure *31* shows the spatial probability of soil degradation resulting from compaction based upon the land use and soil type as presented in Table 19. This suggests that in Wales there are large areas for which the probability of compaction induced soil degradation is unknown. Of the areas for which the probability has been identified, low, medium and high probabilities exist, with medium being the most frequently assigned.

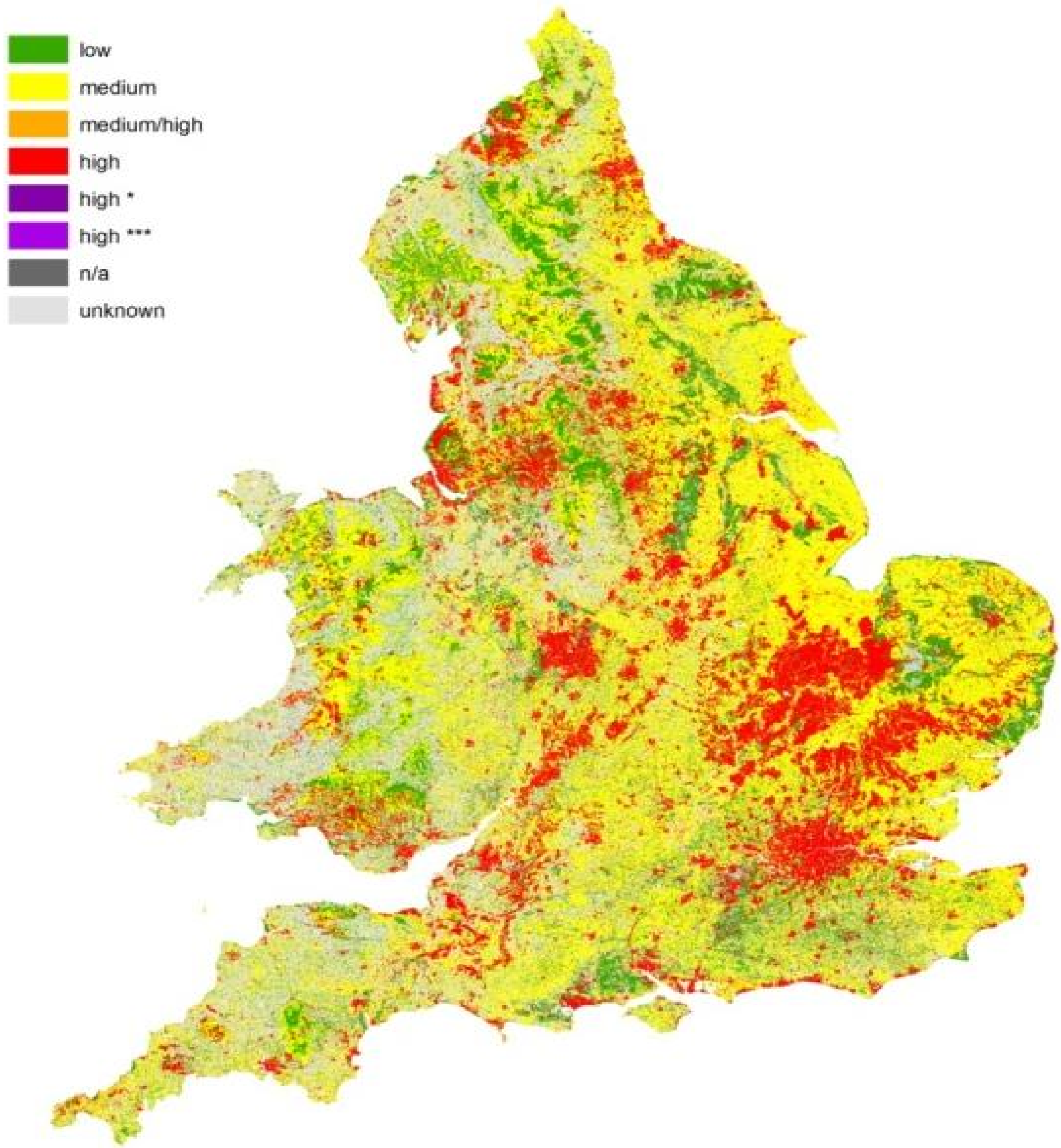

Figure 31. The spatial distribution of degradation probability from compaction. Source: Defra, SP1606.

8.2 Impacts of soil compaction

Compaction can have many environmental consequences (Figure 32) with significant implications on the ability of soils to perform a range of ecosystem services. Almost all supporting (e.g. nutrient cycling, primary production and biodiversity), provisioning (e.g. food, fibre, fodder and fuel) and regulating (e.g. climate, flood, disease, water purification) services become impaired as the soil is compressed and virtually sealed off from the surrounding environment. The effect on cultural services depends upon the land use of the compacted areas with the potential for aesthetic and recreational services to become impaired. This could be a result of unsightly waterlogged ground and potential closure/restricted access of the area if it forms part of a recreational footpath.

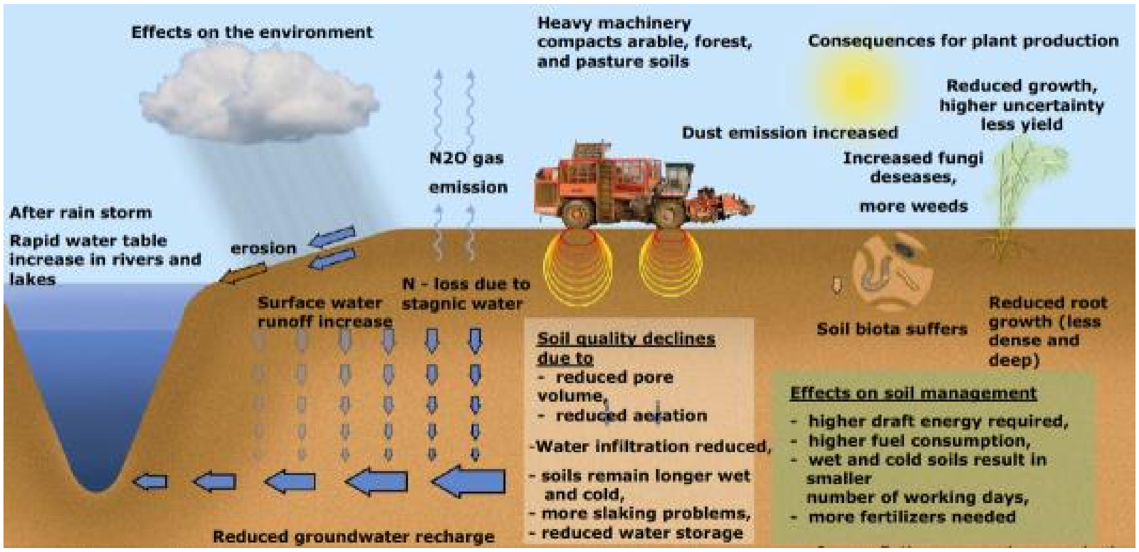

Figure 32: Soil and environmental consequences of soil compaction. Source: Montanarella, 2006

8.2.1 Increased risk of flooding

A reduction in pore space and connectivity will reduce the infiltration capacity and rate thus increasing runoff (SP1606). This will increase the pressure put on the local water catchments and increase the risk of flood events. Reduced infiltration will also slow ground water recharge, reducing base flow (SP1606).

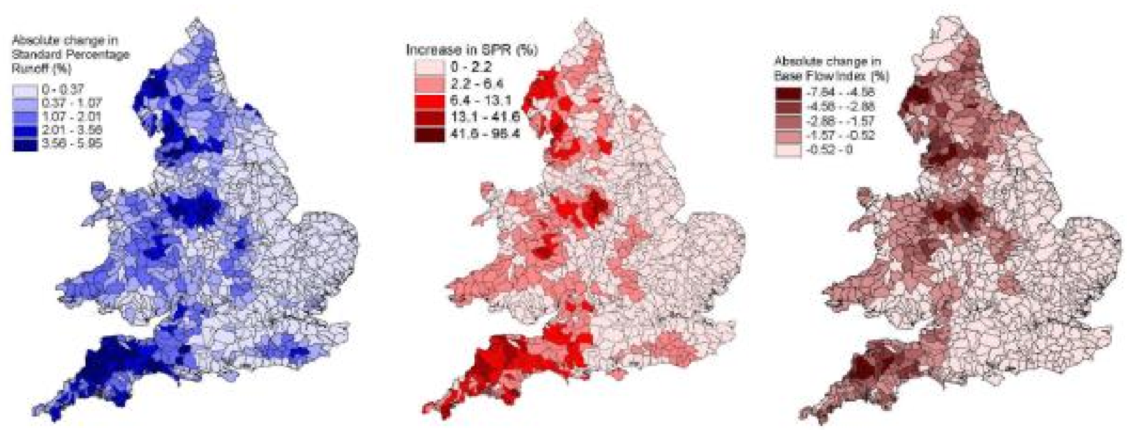

Figure 33: Effects of grassland soil compaction on runoff and water resources – (left) indicative absolute increase in Standard Percentage Runoff (SPR); (centre) relative increase in SPR and (right) absolute decrease in Base Flow Index. Source: Defra, BD2304.

8.2.2 Increased risk of erosion

An increase in surface runoff will increase the risk of erosion. The runoff can detach soil particles and move them to another location. The movement of livestock can also break up soil aggregation and structure and damage vegetation increasing the volume of loose soil available for detachment.

8.2.3 Water quality

Nutrients and pathogen transport into the soil profile is limited by reduced pore size and connectivity thus increasing their presence on the soil surface (Defra, BD2304). These along with detached soil can be mobilised and transported by surface runoff, resulting in a reduction in water quality of any receiving bodies of water (SP1606). In sufficient volumes this could impact the success of a water course meeting the ógood ecological statusô classification required by the Water Framework Directive.

8.2.4 Climate regulation

The ability of the soil to regulate climate will be impaired as respiration is reduced. This reduces carbon dioxide emissions, whilst nitrous oxide and ammonia emissions will increase. Methane emission uptake will also reduce.

8.2.5 Loss of yield

Compaction has been linked with yield reductions. This reduction results from inhibited root growth (Defra, SP1606). Compaction alters root dimensions and distribution (Defra, SP1606). Root tips become thicker in order to penetrate through compacted soil, however the pore sizes are too small to provide sufficient space around the root tip for effective growth (Defra, SP1606). Consequently root growth ceases and above ground productivity is affected (SP08005). Confined pore spaces also restricts the air and water available to roots (SP08005). Surface water logging further reduces the pore space resulting in plant death (SP08005). In grassland, the impact on yield varies with cultivar with losses ranging between 4 and 12 % (Figure 34).

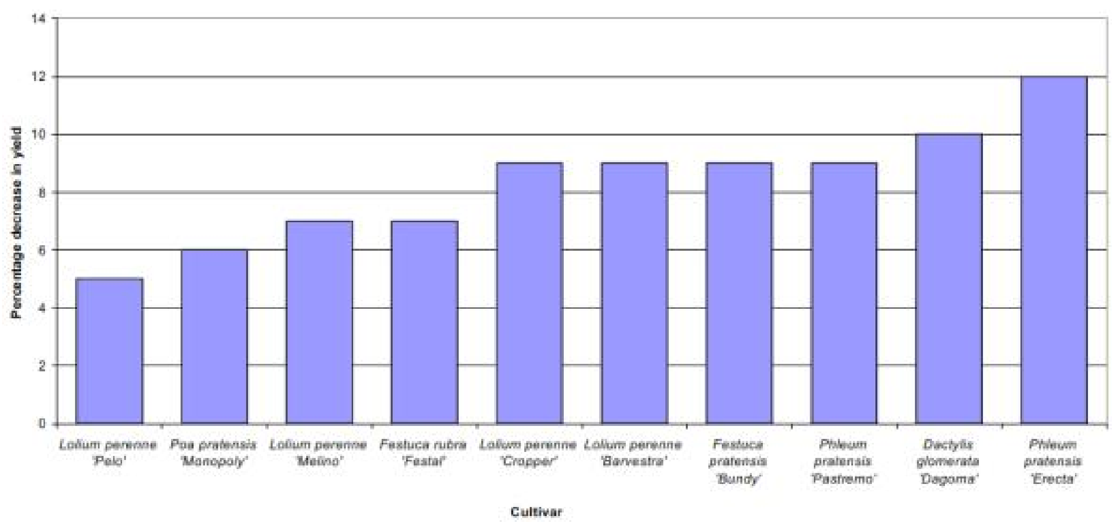

Figure 34. The loss of yield in 10 grass cultivars in response to increased soil compaction caused by experimentally-controlled trafficking. Source: Defra, BD2304.

8.2.6 Loss of biodiversity

A reduction in porosity will reduce the habitat available for soil organisms (Defra, SP1606), with larger organisms such as earthworms and moles most affected. Reduced pore connectivity may also indirectly reduce the metabolic processes of soil organisms as the dynamics of water, solute, gas and volatile transport are changed (Defra, SP1606).

8.2.7 Animal welfare/health

A compacted field and the resulting water logged conditions can impact animal welfare through a decline in livestock health. In all livestock lameness can become a problem (Tripney, 2016). In dairy cattle, mastitis and somatic cell counts can rise as a result of udder contact with wet soil (Tripney, 2016). This has financial implications for dairy farmers through loss of milk production and additional costs of treatment.

8.3 Extent and severity

Compaction in Wales most likely extends across areas under grassland, arable, forestry, urban and recreational land uses. Compaction assessments for Welsh soils specifically have not been reported. However, compaction assessments in grasslands have been reported for England and Wales collectively and in other parts of England that show similar soil and climate characteristics (e.g. southwest England).

Defra BD5001 reported soil structural condition on 300 grassland sites across England and Wales, the majority of sites in Wales were located on loamy soils (Figure 35). This report concluded that for England and Wales collectively the majority of fields were in poor (10-15%) or moderate (50-60%) condition. In the ‘poor’ sites a higher proportion were located on ‘unimproved’ grassland compared with ‘improved’ grassland. The principal predictors of bulk density were the number of machinery passes and organic matter content. The stocking rate was not a significant predictor although the timing of grazing rather than total number of livestock may be important. Soils with higher organic matter contents (e.g. organo-mineral soils) and older grass swards also showed greater resilience to compaction compared with mineral soils with younger grass swards. This study gives an indication of the nature of the extent of structural degradation on grassland soils but does not report on specific extents for Wales.

Other studies have indicated compaction assessment in soils in south west England which are broadly similar in terms of soil type and climate to many parts of Wales currently under improved grassland. Results indicated structural damage under cultivated sites (including ley grass) was far more severe and widespread than under permanent grass (Palmer & Smith 2013). In arable sites where late-harvested crops had been grown (e.g. maize and potatoes), about 75% of sites showed high or severe levels of soil structural degradation. For permanent grassland the majority of sites (> 65%) were in moderate condition.

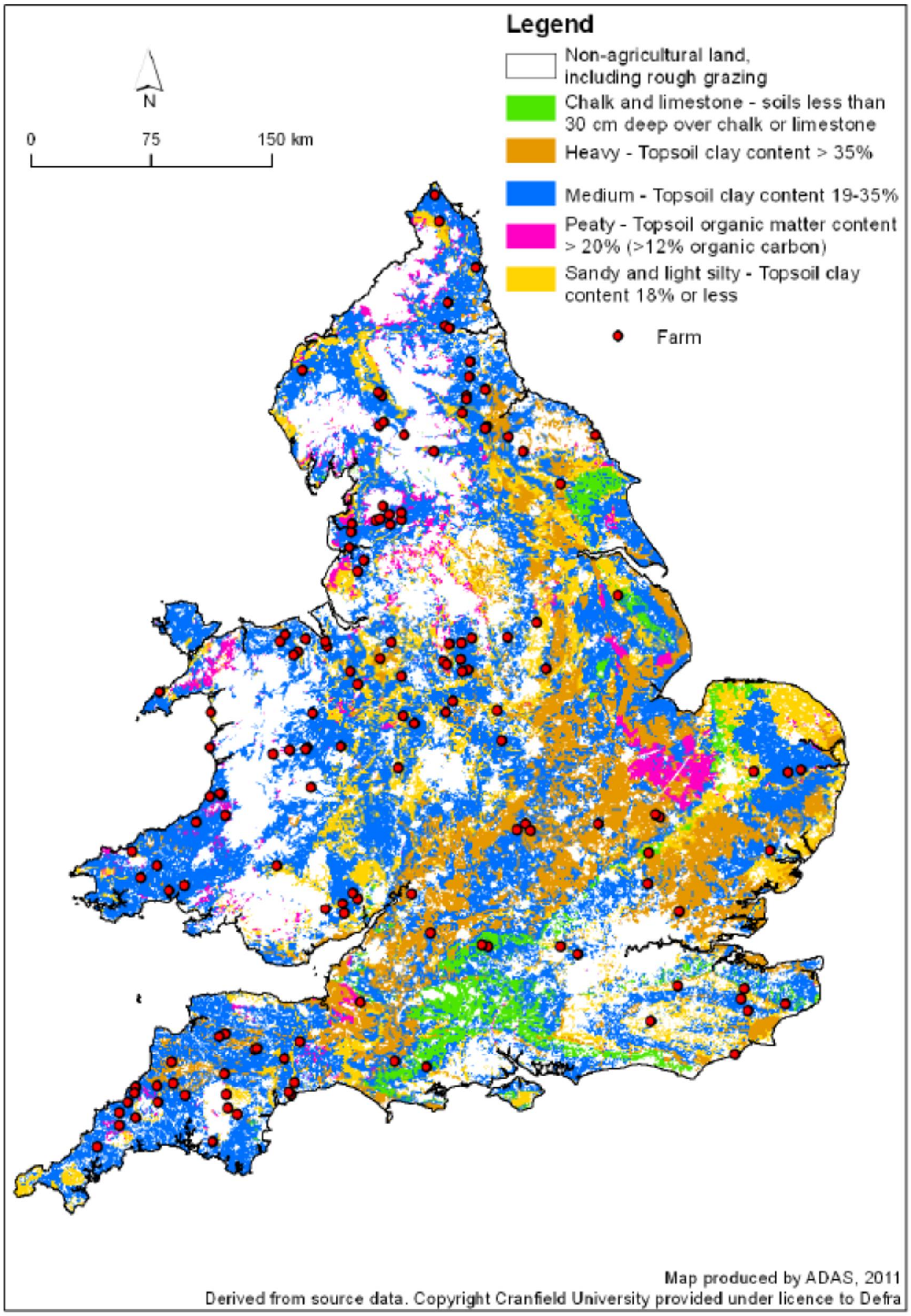

Figure 35. Location of farms studied for soil structural assessment of grasslands Source BD5001.

8.4 Vulnerability and resilience

Vulnerability to compaction is the combination of the susceptible soil and land uses described previously that predisposes soils to structural degradation. Direct observations have not reported for individual soil and land use types in Wales, except on grasslands. Thus the assessment of vulnerability in Table 21 is based on inferred relationships described between soil type and land use and land management that may make soils or land use type vulnerable to compaction in Wales. There is almost no indication of the resilience of these systems with the exception of few studies related to the recovery of soils with high organic matter contents. óResilienceô could be augmented by interventions to reverse compaction but these operations are not considered in this context.

Table 21. Soil/landscape vulnerability and resilience to compaction.

Soil type/landscape	Proportion of land cover (%)	Vulnerability	Resilience
Organic soils (Peat)	3	++	+++
Organic soils (organo-mineral soils)	9	+	++ (under grassland)
Slowly permeable soils (SPS)	25	++ (not reported directly but wet conditions would increase vulnerability)	?
Freely drained loamy soils	26	? no direct evidence	?
Sandy (ólight soilsô)	1	+	
Clay (óheavy soilsô)	*	+++ (inferred no direct evidence)	
Grassland systems	65	++ (inferred no direct Welsh evidence)	?
Arable systems	9	+++ (inferred - dependent on soil type and land management. No specific Welsh evidence)	?
Woodland	13	+	

9 Loss to development

The evidence reviewed (>26 reports) on the loss of soil to development (soil sealing) in Wales suggests:

- There are no statistics on the increase in artificial surfaces post 2007 that are needed to estimate the current severity or spatial extent of soil loss to development
- There is no evidence that has collated land use change statistics at sufficient resolution to identify the extent of soil sealing in Wales on different soil types or land uses
- No new data have been published since the CEH report (2002)
- Soils of lower quality agricultural land appear not to be as adequately protected, although may have significant ecological value (as reported in the CEH report, 2002)

9.1 Overview

Loss to development for the purpose of this report refers to the loss of land to urban development. Therefore housing, businesses and all related infrastructure are considered and other development such as mineral and peat extraction excluded.

Developing land for new housing and associated amenities, new businesses and transport infrastructure can result in soil loss. The European Commission (2013) identifies two threats to soil loss from development:

- **Land-take** ñbuilding on land that was formerly open soilò(EC, 2013)
- **Soil sealing** ñthe covering of the ground with impermeable material such as concreteò(EC, 2015)

Coming out of the recent economic downturn, the drive for development is increasing. One such example is the development of new housing across the UK with a target of constructing 1 million new homes by 2020. The total urban area of Wales is increasing (Figure 36). Between 1990 and 2000 the urban area increased by 0.5 % and has increased by an additional 0.4% up to 2007. The latest available data shows that the physical extent of the total urban area is approximately 696 km^2 (Morton et al., 2007). Based on a recent population estimate of 3,092,036 (Welsh Government, 2015c) this equates to just over 200 m^2 per citizen, the EU average sealed surface area (EC, 2013).

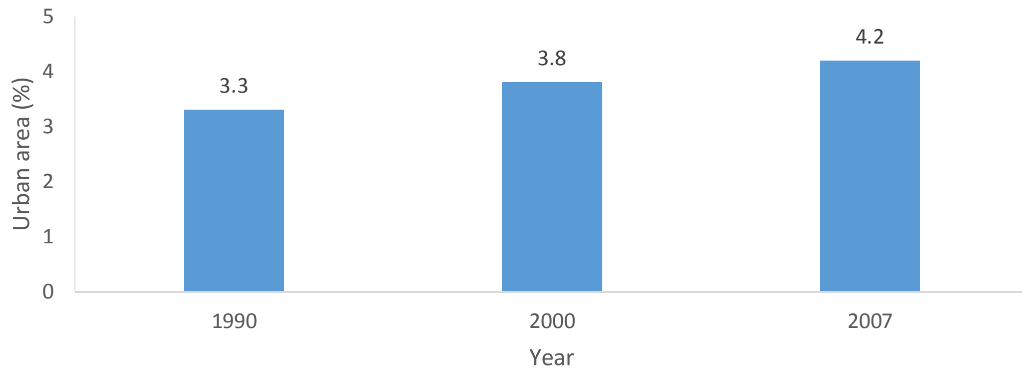

Figure 36. Urban area land cover in Wales from the CEH Land Cover Map 1990, 2000 and 2007. The urban area includes suburban, rural and urban development. Data source: CEH, 1990, 2002, 2007.

Good planning such as the prioritisation of derelict and developed land reuse in favour of expanding on undeveloped land could minimise the risk of development on soil. In addition investment in brownfield sites would also minimise the threat of soil loss. This effect is summarised in Table 22 where the risk of soil sealing for each land use was estimated to evaluate consequences (impacts and costs) of soil degradation (Defra, SP 1606).

Table 22. The relative risk of surface sealing in each land use and soil type category. Source: Defra, SP1606.

Land use	**Soilscapes**			
	Clay	**Silt**	**Sand**	**Peat**
Urban	H	H	H	H
Horticulture	M	M	M	M
Arable intensive	M	M	M	M
Arable extensive	H	H	H	H
Grassland improved	H	H	H	H
Grassland unimproved	H	H	H	H
Rough grassland	H	H	H	H
Forestry	M	M	M	M
Woodland	L	L	L	L
Wildscape	L	L	L	L

Note: H = high probability of soil degradation; M= moderate probability of soil degradation; L = low probability of soil degradation; ? = Uncertain probability

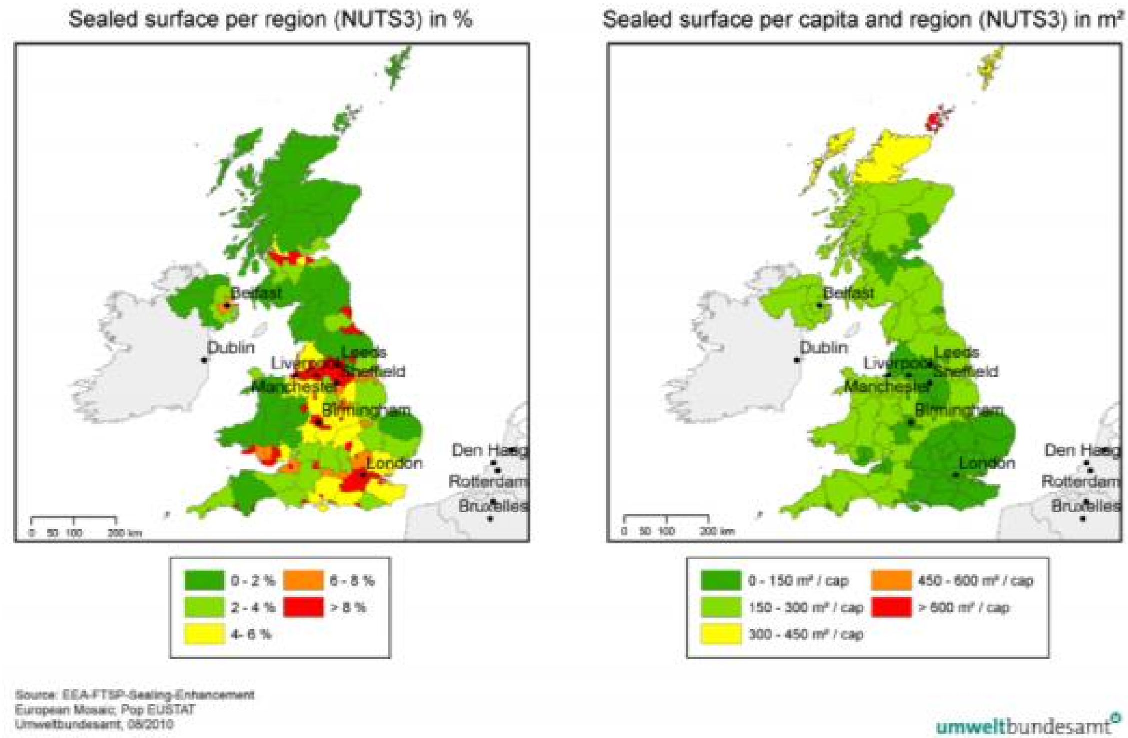

Figure 37 Soil sealing in the UK in 2006 per region. Source: Prokop et al., 2011.

9.2 Impact of soil sealing

Land-take for development directly impacts the soil ecosystem services as a result of land use change. Principally this impacts provisioning and cultural soil services. Where grassland, woodland, forestry, arable or horticultural land is taken then the provision of food, fodder, fibre and fuel production will be reduced. Given that grassland makes up the majority of land cover in Wales land take is most likely to affect food, fodder and fibre production. Cultural services would be affected when the land holds cultural value such as for archaeological importance, recreation or aesthetic appeal. This service would be threatened with a change of land use. The Best and Most Versatile (BMV) land is protected under current Planning Policy in Wales. This ensures development on good grade agricultural land (ALC grades 1, 2 and 3a) is a key consideration in the planning process. This is particularly relevant in Wales because BMV land is very scarce and thus development in these areas should be carefully controlled.

The physical covering or sealing of the soil surface generates a largely impermeable layer that disconnects the soil from the surrounding environment; the biosphere, atmosphere and hydrosphere (Gregory et al., 2015). This severely limits soil function and ecosystem service delivery to merely operating as a platform/supporting material to the impermeable layer above. The most notable effect of the loss of soil function and ecosystem services delivery relates to flood and climate regulation. An increase in impermeable areas results in increased peak discharge rates and surface water runoff volumes (EC, 2012). This puts pressure on drainage and fluvial systems at both local and watershed scales resulting in an increased risk of flood events (EC, 2012). This effect could worsen with the increased extreme rainfall events predicted with climate change. Increased flooding also increases the risk of erosion of soil surfaces and river banks.

Soils can moderate climate through evaporative cooling; without this temperatures can increase. This can affect the local environment by amplifying the climate change threat to soils. This threat is discussed in detail in Section 4.2.6.

Both land-take and soil sealing require soil movement and handling. This amplifies other soil threats; loss of soil biodiversity, loss of organic matter and compaction. Soil biodiversity is reduced as invertebrates, particularly earthworms, suffer large scale declines as they are crushed by the compaction and shearing forces imparted by heavy earth-moving equipment (Tilston et al., 2010).

Storing soil in stockpiles further increases the loss of soil biodiversity as soil microbes can be reduced by as much as 95% compared to the undisturbed value. When the stockpiled soil is reused, research suggests that less than 10% of the stockpiled soil volume is recoverable to its pre-disturbance microbial population (Harris and Birch 1990). Organic matter can be lost through mineralisation during topsoil stripping (EC, 2013). This means that once put back in place it is degraded.

Soil compaction is a by-product of urban development. It can occur deliberately such as in the preparation of foundations and subgrades. It can also occur unintentionally as a result of excavation works and heavy vehicular traffic crossing the same area over a long period of time in all weather conditions (Defra, SP08005).

9.3 Extent and severity

The extent and severity of soil loss to development in Wales largely depends upon the existing land protection legislation and the nature of the proposed development. There is no evidence that has collated land use change statistics at sufficient resolution to identify the extent of soil sealing in Wales on different soil types or land uses. Project SP1501 used Land Use Change Statistics (LUCS) from data collected by the Ordnance Survey (OS) that provides information on relative land use change. This included the assessment of land use changes from agricultural to other permanent land uses across England. The project also considered the proportion of BMV land lost to development over a 10 year timescale in England. No similar study was conducted for Wales.

Severity can be linked to the consequences of soil sealing, which generally is assumed to have significant impact on multiple soil functions. This is also enhanced if the land is classified as BMV indicating a loss in good quality land for agriculture. An example of a recent large development scheme in Wales is the Vibrant and Viable Placesô£100 million regeneration investment due for completion in 2017. This is aimed at development of town centres, coastal communities and deprived areas (Welsh Government, 2015d). In this example the regeneration of existing urban areas minimises the impact of soil sealing as most developed land will be brownfield sites. As the severity of the impact will be dependent on the present land use, brownfield sites have lower impact than other non-urban land uses. However, given that 96% of Wales is not currently classed as urban a large potential area is available to develop on which the reduction of other land uses (such as Grassland, Woodland and Agriculture) and their associated ecosystem services would equate to a severe impact. There is no data available on the conversion of non-urban to urban land uses in Wales so the severity cannot be assessed at a national level.

9.4 Vulnerability and resilience

All soils can be considered equally vulnerable to soil sealing as it is not a function of their properties, but their geographical location relative to proposed development. For this reason soils in upland areas could be considered to be least vulnerable, as they are less favourable for development (and may be protected under other policies) but still could be vulnerable to some sealing such as for wind farms.

No measure of resilience of soils to sealing has been identified. Therefore the resilience of different soil types and land uses is unknown. To ascertain this in the future, measurements could be made on brownfield sites that have been reverted back to parkland. Although this would require knowledge of original base line conditions. Alternatively laboratory experiments could be undertaken that can investigate the effect of different surface seals on different soil types for varying durations.

10 Interactions between degradation threats

Six degradation processes that threaten soil resources in Wales have been considered separately in the preceding chapters, but many are interrelated or have common drivers that can exacerbate multiple threats.

10.1 Climate change and soil threats

Climate change is a key driver for environmental change including impacts on soil systems. In Wales, the dominant effects relate to the changes in soil wetness, in particular the seasonal shifts in the period of waterlogging drought impacts in summer. The duration of waterlogging and the duration of the field capacity period is not expected to change until 2080, where evidence shows a decrease. These effects will have impacts on soil carbon, soil biodiversity and compaction and erosion risks.

Changes in the seasonality and duration of the period when soils are at (or beyond) field capacity indicate a shift in the end of the field capacity period to later in the Spring than at present. This means soils are wetter for longer in the Spring periods. This increases the incidence of waterlogged soils when access to land is required during Spring operations. This will result in an increased risk in soil compaction, particularly in slowly permeable soils. Increases in grassland productivity as a result of warmer conditions could mean increased stocking densities on grassland soils. Organo-mineral soils under grassland may have a greater resilience to increased frequency of vehicle and livestock traffic due to the higher carbon contents in their topsoil.

Changes in water regimes can produce a shift in the microbial population, impacting on soil biodiversity as the community responds to new environmental conditions. Evidence suggests soil biology is more sensitive to changes in water regimes than to temperature effects. The most significant changes in microbial community structure are likely to be in soils that are currently waterlogged for most of the year and will experience increased drying episodes in response to climate change in the future. These soils are upland peat and the wet, acid soils on the periphery of the uplands supporting shrub and heath. The unique microbial community profiles that are currently observed in these habitats will change if significant drying episodes affect these soils. It is not clear how this shift in community structure will impact of the functional role of the soil microbial community.

Increases in extreme rainfall events would initiate increases overland or sub-surface run-off, especially during the field capacity period. These impacts will be greatest in Welsh catchments dominated by slowly permeable soils, where soil water storage capacity is limited and runoff will be generated. In these catchments water storage and regulation will be compromised resulting in more frequent surface water flooding. Greater frequency of high intensity rainfall events would also increase the risk of soil erosion by water in susceptible areas (i.e. on erodible soils, with steep slopes and minimal ground cover). These areas include sandy and silty soils under horticultural / arable agriculture but represent very small areas in Wales. It is likely that the dominant grassland land use in Wales will buffer this effect due to adequate ground cover and root development making most of the land area resilient to soil erosion by water under extreme events.

During the summer, increased soil moisture deficits will cause soils in Wales to become more droughty as indicated by drought criteria in ALC. Results are not presented specifically for Wales but it is likely that the small areas of high grade agricultural land (Grade 1 and 2) will be downgraded due to droughtiness, but other areas currently limited by wetness class may improve (i.e. shift from Grade 4 to 3b). This could initiate a land use change in response to drier summer conditions (discussed further below), but it is uncertain how this will manifest in the future.

Climate change will reduce the current bioclimatic envelope that defines upland areas, resulting in upland habitats shrinking to core areas. This will reduce the areal extent of upland habitat and in the longer term modify the associated soils that develop under these conditions. The soil microbial population structure will also change responding to the above ground shift in vegetation communities. In addition, soils in these habitats are the only ones in Wales where a loss in soil carbon is predicted as a response to climate change. This has consequences for the future storage of carbon in the peat and organo-mineral soils in these areas. In turn, this will have implications for many areas that are currently undergoing peatland restoration (e.g. drain blocking) as restoration interventions will need to be futureproofed for potential climate change impacts to ensure these areas remain as carbon sinks.

10.2 Land use change and soil threats

Land use change is a major factor that impacts on many soil degradation processes including the loss of soil carbon, soil biodiversity, loss to development, erosion and compaction. Although current rates of land use change in Wales are relatively stable, several factors have the potential to cause changes in land use and land management. Primary drivers for change in Wales are land management incentives under the Glastir agri-environment schemes, climate change adaption (see above) and market changes. The effect of recent schemes on some key soil properties (e.g. carbon) will not be detectable for a number of decades, and historic land management practices will continue to influence these properties.

Conversion of non-arable to arable land has the most significant impact on the severity and extent of soil degradation processes. It is plausible that areas of improved grassland, that are currently marginal for arable agriculture, may be converted to arable and horticultural uses in the future. This change will mean a loss of soil organic matter, although this response may show a lagged response and may not be detectable for decades. Significant disturbance by tillage operations and changes to the above ground vegetation could change the microbial community composition. However, current microbial community profiles are similar in arable and improved grasslands in Wales (GMEP), indicating a conversion from improved grassland to arable may not have a significant impact on the microbial community structure. Soil erosion risk by water may also increase in areas converted to arable, particularly on erodible sandy and silty soils. Soil structural damage may also increase through increased trafficking, particularly if areas are used for late-harvested crops such as maize or potatoes.

Climate change may also expand areas of improved grassland into areas currently under unimproved grasslands. Trends in soil carbon specifically in Welsh soils between improved and unimproved grassland have not been reported to date. This data is necessary to ascertain the potential change in soil carbon as a result of grassland intensification. Intensification of grassland systems has been shown to influence soil biodiversity, with differences in community structure between improved and unimproved grasslands. However, current incentives to reduce inputs (e.g. fertiliser, lime) in grassland systems may negate these effects. Modelling indicates greater grassland productivity under climate change which could potentially increase stocking densities and also vehicle traffic associated with managed grasslands. This would increase the potential for structural degradation in grassland areas in Wales, which are currently sensitive to the number of machinery passes.

Expansion of woodland would potentially increase topsoil carbon, indicated by GMEP monitoring samples. However, it is uncertain whether the carbon stock within the whole soil profile would be increased as a result of woodland planting. Some evidence suggests that soil carbon is reduced in deeper parts of the profile after afforestation and may therefore offset any gains made in the topsoil through increased inputs. A significant shift in the microbial community composition would be expected after land use conversion to woodland. Woodland soils show unique microbial community profiles and there is evidence for increased connectivity between soil faunal groups in woodland soils. In commercial forestry, soil compaction can become an issue during stand establishment and harvest if not appropriately managed or ameliorated.

Soil lost to development is likely to have small extents in Wales but there are no current statistics to ascertain the current extent and rate of change. Protection of the very small extents of BMV land in Wales will become more relevant in the future as greater land is downgraded as a result of climate change. During and after development soil is exposed to increased handling and trafficking resulting in increased compaction. Depending on the urban land use post-development (e.g. ranging from soil sealed under a semi permeable layer to quasi-intact soil in green spaces) the consequences of changes in soil carbon and biodiversity will be variable and are currently not quantifiable.

11 Key knowledge gaps and recommendations

The following knowledge gaps and suggestions for further research and investment have been identified by the review process and also in consultation with the recent Defra soils evidence review. The focus will be on key gaps in general understanding of processes and implications for specific conditions relevant to Wales.

This report has focused on evidence published since a report of the state of Welsh soils in 2002 (CEH, 2002). Table 23 reviews the evidence and knowledge gaps in the original report and also highlights new evidence on severity and extents of each threat and additional knowledge gaps. Further detail of key knowledge gaps and recommendations is provided for each threat below. Knowledge gaps that have been addressed since the CEH are an extension of soil monitoring programmes for assessing change in soil carbon (GMEP programme) and UK scale soil erosion assessments (although these are unvalidated model outputs). The majority of knowledge gaps still remain (highlighted in italics) or relate to issues that are not specifically covered in this review (Table 23).

Table 23. A review of the CEH report and new evidence identified as part of the current review..

Threat	CEH 2002 Extent in Wales	CEH 2002 Knowledge gaps	New extent/evidence	New knowledge gaps
Loss to development	• *Extents of soil loss to development is not systematically collated at a national level*	• High grade agricultural land protected under Best and Most Versatile land ï (BMV) in planning policy. However, soils of lower quality agricultural land appear not to be as adequately protected (although may have significant ecological value)[1]	• Increased urban area in Wales (up to 2007)	• None
Erosion	• *Sources of large scale national data are limited* • *Site specific data available but limited rate (ie severity) of erosion available* • Focus on upland erosion with most extensive erosion found on peat soils • *The principal areas of arable cultivation in Wales, including Dyfed and Pembrokeshire, are likely to be subject to similar erosion pressures and patterns as those in England, such as channel erosion and rilling.* • Anecdotal evidence of	• *Comprehensive survey and monitoring scheme stratified by soil and land use type in Wales is required.* • *Inadequate or non-existent information on rates (severity) of erosion.* • No evaluation of the efficacy of current erosion control measures[1].	• National erosion risk maps (modelling only)	• Improvement in local scale modelling

Threat	CEH 2002 Extent in Wales	CEH 2002 Knowledge gaps	New extent/evidence	New knowledge gaps
	wind blow in small areas of sandy soils (e.g. Wrexham) • In lowland grassland erosion features are typified by poaching. However, results indicated that soil erosion was not a significant process on established, enclosed grassland.			
Soil structure	• *Virtually no data exists for the extent of structural degradation in Welsh soils.* • *Therefore it is impossible to determine if this is a significant threat to soil in Wales.*	• *Systematic survey of structural condition of Welsh soils is required.*	• Studies in similar soil/climates indicate potentially severe structural degradation in arable land under late harvested crops • Studies on grassland compaction indicate many sites in poor or moderate condition • Structural degradation worse on unimproved grassland compared with improved grassland by not reported for Wales specifically	• Data on soil structural condition is not reported for Welsh sites specifically
Soil organic matter	• Mean topsoil organic carbon decreased by 0.5 % under arable and permanent grassland between 1980 and 1996 • Mean organic carbon content of top 15 cm of soil is 10.8 % (data from	• More recent data on soil carbon stocks is needed • Difficulty in linking change in organic matter to soil function at a practical level[1] • Systematic data collection required through a national monitoring programme	• GMEP data expands timeseries of CS datasets in Wales • CS data indicates little change in soil carbon in Welsh soils overall (1978-2007, GMEP 2013) • Arable topsoils show soil C	• Welsh specific data not reported from CS and NSI surveys stratified by soil type and land use • Identify change between improved and unimproved grassland sites in Wales • Soil carbon stock changes for

Threat	CEH 2002 Extent in Wales	CEH 2002 Knowledge gaps	New extent/evidence	New knowledge gaps
	NSI) • Absolute total organic matter content of soils in Wales is unknown as most studies have only focused on top 15 cm of soil.		decline • Woodland topsoil shows increase in soil C	whole soil profile for key soil and land use types in Wales ï baseline data available for woodland sites (Vanguelova et al., 2013)
Climate change	• No information in report explicitly on extent	• Issues with uncertainties of the soil carbon stock impact on how CC can affect C dynamics in soils.	• Shift in seasonality of field capacity period • Evidence for increase in drought criteria impacting on ALC grade • Extent and duration of waterlogging decreases but only by 2080 • Bioclimatic envelope of uplands reduces	• Extent of ALC grade change for sites in Wales • Impacts of extreme events in catchments with slowly permeable soils that may experience excess surface and sub-surface runoff during field capacity periods
Loss soil biodiversity	• Not reported	• Not reported	• Baseline survey of soil microbial community structure in broad habitat types	• No knowledge of loss or change in soil biodiversity

11.1 Climate change

- Focus of research has been on upland areas as these are most likely to be sensitive to shifts in climate regime and thus impacting on the above ground vegetation and the organic soils. Impacts of changes in other more widespread areas such as loamy soils under grassland should be explored.
- It is unlikely that soil wetness regimes in Welsh soils will be significantly impacted in medium emission scenarios for 2020 and 2050. However, the seasonal shift in the water balance and specific period warrants further investigation, particularly where this will impact on areas with slowly permeable soils.
- Assessment of the shift in ALC grade for sites in Wales is required to determine the extent of downgrading and upgrading of land as a consequence of climate change.
- Specific hydrological characteristics of Welsh soils that influence their response to a) drier summers and wetter winters (e.g. duration of waterlogging and soil moisture deficits), and b) extreme weather events is required. This will also enable the assessment of catchment areas likely to be at greater risk to surface water flooding during extreme events.
- Better understanding of the effects of predicted climate change on the dynamics of soil biota (function, species composition, community diversity and resilience).

11.2 Loss of organic matter

- There are uncertainties and contradictory results from monitoring schemes on the rate of change in soil carbon in top soils, although an extended dataset (GMEP indicates no overall change in topsoil carbon in Wales. An analysis of monitoring data from CS +GMEP and NSI programmes should be extracted for sites in Wales specifically. Further analysis of topsoil carbon changes stratified by soil type and land use should be determined for this sub-set
- Studies indicate that significant carbon is stored below the topsoil (particularly in peat soils) and this needs to be taken into account in analysing carbon loss. A recent study indicated that carbon at depth is influenced by grassland land management and could affect the total carbon stock (Ward et al. 2016). This is not commonly taken into account in the monitoring data that concentrates on surface soils (ca. 0-15cm).
- Further work is required to ascertain changes in different fractions of soil carbon rather than the total carbon, which may provide a better indication of the rates of change in carbon cycling under different land uses.

- There are no critical thresholds of soil carbon content indicated for specific soil/land use types to identify where potential tipping points exist beyond which there are significant effects on ecosystem service delivery and function. This is hampered by the large spatial and temporal carbon values in soil and the complexity of climate, vegetation and soil interactions. Critical thresholds should be defined regionally given the environmental constraints on soil systems in Wales.
- The effect of grassland management (improvement and reversion) on carbon content of soils should be examined, with particular focus on soils with high carbon content.

11.3 Loss of biodiversity

- Building on the baseline survey, characterisation of microbial community structure should also be extended to key soil types within the broad habitats in Wales. This includes an assessment of dominant soil types such as loamy, freely draining soils and slowly permeable soils under different land uses (specifically intensive and extensive arable and grassland in addition to semi-natural habitats).
- Continued monitoring is required to ascertain any changes in soil biodiversity over time (GMEP programme). It would also be important to monitor areas where land use change has occurred to assess the effects on soil biota within Welsh specific land use change scenarios.
- There is incomplete understanding of the change in the functional response of soil biological communities and impacts on soil functions, although there is emerging evidence for shift in community complexity under different land use types at a European level.
- Change in interactions between functional groups as a result of climate change.
- Feedbacks between vegetation changes, soil biological community and other functions such as carbon storage are complex and likely to be regionally dependent.
- Better understanding of the effects of changes in land use and soil organic matter content, and in climate on the dynamics of soil biota (function, species composition, community diversity and resilience).

11.4 Erosion

- An understanding of the severity and spatial extent of soil erosion by water, wind, co-extraction and/or tillage across Wales, as currently no UK data exists. This could include a continuation of data collection from erosion monitoring sites assessed in Defra NT1004, SP0402 and SP0407. A pilot erosion monitoring network is currently being evaluated in SP1311 (due to report 2016/17).

- Modelled estimates of the severity and extent of different processes of soil erosion in Wales need field validation through surveys and monitoring.
- Better resolution of erosion prediction models, as current outputs are not suitable for local scale predictions.
- The efficacy of erosion control measures in Wales has not been evaluated (as stated in the CEH report, 2002). SP1318 (due to report 2016/17) is assessing developing a methodology to upscale the effects of erosion control measures from field to landscape to national scale.

11.5 Compaction

- Effect compaction in grassland and a loss of biodiversity ï a start has been made in BD2304, and BD5001 but further work is required.
- Wales was only used as part of a study in grassland (BD5001) ï a full study focusing on structural degradation on grassland soils should be undertaken. Current knowledge has been generalised from England and Wales data with a skew to data from English grasslands.
- Extent of utilisation and effectiveness of forestry compaction mitigation measures to ascertain the true extent and vulnerability of compaction from forestry operations.
- Systematic survey of structural condition of Welsh soils is required (as stated in the CEH report, 2002).
- A greater understanding of soil resilience to compaction, in key soil and land use combinations in Wales.

11.6 Loss to development

- Research on the effect of sealing and land-take on the wider soil ecosystem services delivery.
- An assessment should be made of the extent of land use change from non-urban to urban and the relative contributions of BMV land (and other soils on key habitat types) that have been lost to development in Wales.
- Research into the nature and condition of urban soils in Wales is needed.
- The extent of soil loss to development needs to be collected systematically at a national level.
- An understanding into the potential resilience of soil following loss to development.

12 References

12.1 Defra reports

Defra project number	Project title
AC0307	Climate change impacts on the livestock sector
BD2304	Scoping study to assess soil compaction affecting upland and lowland grassland in England and Wales
BD5001	Characterisation of soil structural degradation under grassland and development of measures to ameliorate its impact on biodiversity and other soil functions.
BD5003	Managing Grassland Diversity For Multiple Ecosystem Services
NT1004	Phosphorus loss from agriculture
SP0306	Critical levels of soil organic matter
SP0402	Research on the quantification and causes of upland erosion
SP0407	Arable and upland NSI erosion resurvey
SP0532	Vulnerability of organic soils
SP0538	The impacts of climate change on soil functions
SP0545	Spatial analysis of change in organic carbon and pH using re-sampled National Soil Inventory data across the whole of England and Wales
SP0570	Climate change impacts on soil biota - development of experimental methodology
SP0571	Modelling the impact of climate change on soils using UK Climate Projections
SP08005	The impact of subsoil compaction on soil functionality and landscape
SP08007	Scoping study of lowland soil loss through wind erosion, tillage erosion and soil co-extracted with root vegetables
SP08007	Scoping study of lowland soil loss through wind erosion, tillage erosion and soil co-extracted with root vegetables

SP08010	Unravelling the loss of Soil Carbon
SP1101	Comparison of soil carbon changes across England and Wales estimated in the Countryside Survey and the National Soil Inventory
SP1104	The impact of climate change on the suitability of soils for agriculture as defined by the Agricultural Land Classification
SP1113	Capturing cropland and grassland management impacts on soil carbon in the UK Land Use, Land Use Change and Forestry (LULUCF) inventory.
SP1311	Piloting a cost-effective framework for monitoring soil erosion in England and Wales
SP1316	Studies to support soils policy - waterlogging of agricultural soils in England and Wales, and the use of remote sensing and earth observations in soil monitoring
SP1317	How does a loss of soil depth impact on the ability of soils to deliver vital ecosystem services
SP1318	Scaling up of the benefits of field scale soil protection measures to understand their impact at the landscape scale
SP1501	Review of the weight that should be given to the protection of best and most versatile (BMV) land
SP1501	Application of Best and Most Versatile Land Policy by Planning Authorities
SP1601	Soil Functions, Quality and Degradation ï Studies in Support of Implementation of Soil Policy
SP1605	Studies to support future Soil Policy
SP1606	The total costs of soil degradation in England and Wales
SP1607	Defra research on soil protection 1990 - 2008: Synthesis of outputs
SP1609	Exploring the priority area approach
SP1620	Soil Evidence Review and Defra/ NERC/ BBSRC soil science coordinator

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