# The Second State of Natural Resources Report (SoNaRR2020)

# Assessment of the achievement of sustainable management of natural resources: Land use and soils

Natural Resources Wales

Final Report

# About Natural Resources Wales

Natural Resources Wales's purpose is to pursue sustainable management of natural resources. This means looking after air, land, water, wildlife, plants and soil to improve Wales's well-being, and provide a better future for everyone.

# Evidence at Natural Resources Wales

Natural Resources Wales is an evidence-informed organisation. We seek to ensure that our strategy, decisions, operations, and advice to Welsh Government and others, are underpinned by sound and quality-assured evidence. We recognise that it is critically important to have a good understanding of our changing environment.

We will realise this vision by:

- Maintaining and developing the technical specialist skills of our staff;
- Securing our data and information;
- Having a well resourced proactive programme of evidence work;
- Continuing to review and add to our evidence to ensure it is fit for the challenges facing us; and
- Communicating our evidence in an open and transparent way.

Title: **SoNaRR2020** Assessment of the achievement of Sustainable Management of Natural Resources: Land use and soils

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Restrictions: None

# The Second State of Natural Resources Report (SoNaRR2020) contents

This document is one of a group of products that make up the second State of Natural Resources Report (SoNaRR2020). The full suite of products are:

**Executive Summary.** Foreword, Introduction, Summary and Conclusions. Published as a series of webpages and a PDF document in December 2020

**The Natural Resource Registers.** Drivers, Pressures, Impacts and Opportunities for Action for eight Broad Ecosystems. Published as a series of PDF documents and as an interactive infographic in December 2020

**Assessments against the four Aims of SMNR.** Published as a series of PDF documents in December 2020:

SoNaRR2020 Aim 1. Stocks of Natural Resources are Safeguarded and Enhanced

SoNaRR2020 Aim 2. Ecosystems are Resilient to Expected and Unforeseen Change

SoNaRR2020 Aim 3. Wales has Healthy Places for People, Protected from Environmental Risks

SoNaRR2020 Aim 4. Contributing to a Regenerative Economy, Achieving Sustainable Levels of Production and Consumption

**The SoNaRR2020 Assessment of Biodiversity.** Published in March 2021

**Assessments by Broad Ecosystem.** Published as a series of PDF documents in March 2021:

Assessment of the Achievement of SMNR: Coastal Margins

Assessment of the Achievement of SMNR: Enclosed Farmland

Assessment of the Achievement of SMNR: Freshwater

Assessment of the Achievement of SMNR: Marine

Assessment of the Achievement of SMNR: Mountains, Moorlands and Heaths

Assessment of the Achievement of SMNR: Woodlands

Assessment of the Achievement of SMNR: Urban

Assessment of the Achievement of SMNR: Semi-Natural Grassland

**Assessments by Cross-cutting theme**. Published as a series of PDF documents in March 2021:

Assessment of the Achievement of SMNR: Air Quality

Assessment of the Achievement of SMNR: Climate Change

Assessment of the Achievement of SMNR: Energy Efficiency

Assessment of the Achievement of SMNR: Invasive Non-native Species

Assessment of the Achievement of SMNR: Land use and Soils

Assessment of the Achievement of SMNR: Waste

Assessment of the Achievement of SMNR: Water Efficiency

**Updated SoNaRR evidence needs.** Published as a data table on web in March 2021

**Acronyms and Glossary of terms.** Published as a PDF in December 2020 and updated in 2021 as a data table on the web

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# Contents

## Tables and Figures

# 1. Headline Messages

## Sustainable use and management of soils

The structure and function of the most important ecosystems and soils are fragile, finite, and under threat as land for food, fibre (timber and wood products), and infrastructure continues to be managed and altered. Protection measures, management regimes and investment choices require closer affinity with the soil and its supporting services (water cycling, nutrient cycling, soil formation and soil biodiversity) and ecosystems underlying such land uses. Natural soil fertility and natural nutrient cycles can be improved and maintained through the preservation or enhancement of soil organic matter. Where suitable, improved soil fertility can be attained through adaptation of management systems and practices. Nutrient cycles are best managed in integrated systems such as crop-livestock systems or crop-livestock-woodland systems.

## Adaptation to a changing climate

Climate change is the biggest threat to soils. From 2050, predicted changes to the extent and distribution of the agricultural land classification grade and the best and most versatile (BMV) agricultural land will be largely driven by seasonal drought risk through changes in soil wetness and water availability, especially in the south and east. This is similar for the distribution of native tree species and the productivity of main forest crops (see also Woodlands chapter). From 2050 (high emission scenario), the BMV area is predicted to decrease substantially. Increased water demand to maintain productivity at sufficient levels is likely to increase the pressure on water resources and water quality. Soils with high organic matter content and with good soil structure will retain and store more water for plant growth (see also Water Efficiency chapter).

## Adaptation of land management systems and practices

Resilient farm and forestry businesses require careful consideration of livestock, crop and tree species together with longer term decisions on genetic diversity and conservation. The choice of management system is a pivotal factor for achieving the sustainable management of natural resources. Using a wider range of farming, forestry and integrated management systems offers the best opportunity for medium to long-term delivery of public goods from management of the land. The need for innovation is amplified by an increasing incidence of extreme and unseasonal weather patterns. Precision farming, agro-ecological systems, agro-forestry, low-impact regular and irregular silvicultural systems and innovative horticultural systems – combined with collaboration and training in best practice – are key to achieving desirable outcomes.

## Sustainable land use change

Peatland restoration, renewable energy development and increased tree cover are required to meet decarbonisation and climate change adaptation policies. A decrease in provisioning services (food and fibre) may not meet the demands of the growing population. The extraction of raw materials for development, management of the waste produced, and the accelerated pace of renewable energy development all require a change in land use. This creates pressure on land to deliver a growing range of public goods and services. The challenge remains of making informed choices and decisions on land use change and to achieve the right balance, accepting some trade-offs, optimising outcomes where possible, and intelligent mitigation of the risks to the structure and function of ecosystems. Wales's ambitious policy frameworks do not yet provide a coherent and integrated approach to land use change priorities across national to community levels. A better land use change decision-making framework could help to support place-based delivery for Public Services Boards and via Area Statements.

## Sustainable standards for agriculture, forestry and development

To effectively balance the improvement of the structure and function of ecosystems alongside the provision of food, fibre, and places where people live and work (infrastructure), 'good' must be defined and described. The assessment and measurement of 'good' must be coherent, consistent, and well understood. 'Good' has to be responsive to monitoring and modelling if effective measures are to achieve sustainable management of natural resources (SMNR) and well-being benefit outcomes. For example, the implementation of good soil and nutrient management is essential for farmers to grow the food in demand and provide sufficient fodder and forage for livestock. Poor nutrient management is one of the biggest risks to the resilience of ecosystems. If farming and forestry is to be resilient and profitable, food and timber must be produced in a sustainable way which safeguards the natural resources on which future food and timber product depends. Most importantly, to do so, systems and standards of soil and nutrient management need to evolve.

## Meaningful implementation of Wales's national peatland restoration and woodland creation programmes

Most of the peatland resource is in poor condition, reducing the ability to mitigate climate change and benefit from the many regulating services that peatlands in good condition can provide. The Welsh Government peatland policy ambition is to develop a National Peatland Action Programme with costed proposals for the provision of a five-year restoration programme to "bring under sustainable management all areas of peat supporting semi-natural habitat" with the dual target to:

- Ensure all peatlands with semi-natural vegetation are subject to favourable management/restoration (a minimum estimated area of 30,000 ha).

- Restore a minimum of 25% (~c. 5,000 ha) of the most modified areas of peatland to functional peatland ecosystems.

Welsh Government has set out the need for increased rates of new woodland creation and the benefits from more tree planting in its Decarbonisation Plan, Natural Resources Policy, and Strategy for Woodlands and Trees. SoNaRR2016 identified that planting 'the right tree in the right place' can provide multiple benefits for SMNR and well-being as well as being a critical part of meeting Wales's emissions reduction targets. Welsh Government set out in Low Carbon Wales the target of at least 2,000 hectares of tree planting per year, rising to 4,000 ha per year as rapidly as possible. The location of tree planting is be for greatest ecosystem service benefit.

Both of these programmes, if done correctly, will safeguard soil from degradation processes such as erosion and soil organic matter loss, enhance soil carbon stock in the long term, and mitigate drought and flood risk. These aspirations will only be met with careful alignment of policy interventions: incentives; advice and guidance; standards; innovation, regulation and development of sector-led voluntary approaches (see Figure 20).

# 2. Introduction

In this chapter, the extent to which the sustainable management of natural resources are being achieved was assessed by considering the pressures and threats to soils within agriculture, woodland and urban land uses. The ecosystem services they generate and opportunities to manage land and soils more sustainably was considered in response to the climate and nature emergencies to better support resilience and well-being.

Soil is a key component of the earth's critical zone (Banwart et al., 2019) and has a profound effect on health and well-being (Steffan et al., 2018). Soil is a valuable and finite natural resource underpinning the delivery of ecosystem goods and services which support every aspect of the natural and built environment on which well-being depends. The way land and soils are used can deliver several functions or services at the same time and place, providing multiple benefits. However, it is important to recognise that some upstream land uses can have downstream positive and negative effects. An interdisciplinary and systematic approach is required to realise opportunities and address sustainable soil use and management challenges (see Haygarth and Ritz, 2009; Hou et al., 2020). Many Sustainable Development Goals cannot be achieved without healthy soils and sustainable land use (see EEA, 2019; Keesstra et al., 2018; Murphy and Fogarty, 2019; SSA, Visser et al., 2019).

Wales's soils and their climatic relationship largely determine the land use activities that can be supported sustainably. Society exerts pressure on soils and their supporting services (soil formation, nutrient cycling) through land use and environmental change, and more directly through threats like pollution, sealing by infrastructure, soil compaction and erosion. Land use, land management and planning should take account of changes to soil suitability and capability with predicted climatic change.

Agriculture currently accounts for the largest land use area in Wales (~80%) (Welsh Government, 2018), followed by forestry and woodlands (~15%) (Forest Research, 2019), then built environment uses with some integration of use and mosaics of land cover types. Farmed land comprises of four different ecosystems: enclosed farmland; semi-natural grassland; coastal margins and mountain; and moor and heath.

# 3. State and trends in land use and soils

## Summary Assessment and Forward Look

The following tables (Table 1 to Table 3) give a brief description of the past trends and future prospects for Land use and soils. These are assessed to be:

- Improving trends or developments dominate;
- Trends or developments show a mixed picture, or
- Deteriorating trends or developments dominate.

Further information is provided to put this in context.

Table 1 Summary Assessment and Forward Look – Woodland.

| Time period | Indicative Assessment | Description |
|---|---|---|
| Past trends<br><br>1970s-2019 | Mixed Picture | Woodland area in Wales has increased from approximately 303,000 ha in 2010 to approximately 309,000 ha in 2019. This is a positive trend, although it has fallen short of the level of ambition for new woodland creation to tackle the climate emergency during this period, and some of this increase is due to National Forest Inventory map changes and not tree planting. The condition of woodland soil carbon, total nitrogen, biodiversity and bulk density are stable with significant positive trends in soil pH. However, in the latest period (2013-16), there was a significant decline in soil mesofauna with no consistent long-term trends. |

| Time period | Indicative Assessment | Description |
|---|---|---|
| Future prospects<br><br>2020-2080 | Mixed Picture | There is considerable ambition around increasing the rate of new woodland creation (to the UKFS) to respond to the climate emergency, improve resilience, and maintain/enhance the flow of ecosystem services and well-being benefits. There are several ongoing programmes and initiatives to incentivise and advance more woodland creation. The extent of existing woodlands may be under threat from climate change, pests and diseases, and land-use change. Overall, the soil condition trends, except for soil mesofauna in woodlands have been improving.<br><br>As long as any new woodland created and existing woodlands continue to comply with the UKFS and the Glastir woodland creation verification process this trend could continue. The overall increase in carbon concentration since 1978 is now considered marginally non-significant. As more data is collected under Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP), this may emerge as a significant long-term positive trend. |

Note on robustness: The National Forest Inventory (NFI) on woodland extent is statistically robust and will be repeated providing trend data into the future. The soil results presented here are for topsoil (15cm) only and have changed from the Countryside Survey to Glastir Monitoring and Evaluation Programme (GMEP) and are subject to reduction in sample size in ERAMMP. It will also change as new data is received from ERAMMP monitoring and as statistical modelling methods improve. Repeated surveys of soil biodiversity may not continue under ERAMMP and rates of soil loss by erosion have not been directly measured. Soil formation is fundamental to the supporting ecosystem services and soil erosion, and biodiversity can provide an overall indication of soil resource stock and soil health.

Table 2 Summary Assessment and Forward Look – Agriculture.

| Time period | Indicative Assessment | Description |
|---|---|---|
| Past trends<br><br>1970s-2019 | Mixed Picture | A lower area of land was under Glastir in 2019 compared to 2018.Trends in resource management showed a decrease in the use of artificial fertilisers in Great Britain and a decrease in the overall nutrient balance surplus for nitrogen and phosphorus. There was a decrease in the rate and quantities of pesticide use but there may be an increase in the area treated. There's an overall increase in the UK farm productivity factor showing an improvement in resource efficiency.<br><br>The condition of agricultural soil showed topsoil carbon concentrations and total nitrogen were stable on improved land. The significant decline in topsoil nitrogen on habitat land is likely to be beneficial for native vegetation. However, topsoil carbon concentrations on habitat land in the uplands showed a significant decline. The reason for this decline requires further investigation.<br><br>Soil acidity declined on habitat land up until 2007 reflecting the rapid reductions in acidic deposition over the last three decades. This has now reversed in improved land with a recent significant increase in acidity. This may be due to a long-standing decline in lime use combined with continued fertiliser use, and has the potential to affect the productive potential of soils.<br><br>Topsoil phosphorus concentrations on improved land have been stable since 2007. Within GMEP, bulk density and soil mesofauna results were related to land use intensity and productivity. The reported decrease in bulk density on improved land may indicate reduced compaction of improved soils in Wales. However, the extent of damage by compaction from poaching and machinery remains a knowledge gap. In the latest period (2013-16) there was a significant decline in soil mesofauna on improved land and habitat land with no consistent long-term trends. |

| Time period | Indicative Assessment | Description |
|---|---|---|
| Future prospects<br><br>2020-2080 | Mixed Picture | There is no evidence to suggest that the area of agricultural land under the new scheme is likely to increase. The area of the best and most versatile land is predicted to change from 22% to 9% by 2080 in Wales according to the latest climate change high emissions scenario modelling, and is mainly driven by drought.<br><br>Extreme weather events such as more intense rainfall, prolonged periods of dry and cold weather, and more extreme and frequent flooding events are likely to increase in future due to climate change. More intense rainfall increases the challenge of preventing soil erosion and run-off. It creates greater instability on slopes leading to more widespread and frequent landslides.<br><br>More areas are likely to experience water deficits; drier conditions increases the incidents of wildfires on grassland. Drier weather conditions can reduce grass growth which may lead to reduced silage availability for livestock over the winter period. |

Note on robustness: The results presented here are for topsoil (15cm) only and have changed from the Countryside Survey to GMEP. They are subject to reduction in sample size in ERAMMP and will also change as new data is received from ERAMMP monitoring and as statistical modelling methods improve.

Repeated surveys of soil biodiversity may not continue under ERAMMP and rates of soil loss by erosion have not been directly measured. In addition, national monitoring to observe trends in soil pollutants have not been updated and are not currently included in ERAMMP.

To embed best practice for the sustainable management of soil and land resources requires it to be informed by monitoring trends in the ecosystems, management of soils, climatic regime, soil properties, carbon, a better understanding of the soil resource, the functional importance of soil biodiversity, and trends in macro-nutrients.

Soil formation, erosion, the nutrient cycle and soil biodiversity are fundamental to the supporting ecosystem services and can provide an overall indication of soil resource stock and soil health.

Table 3 Summary Assessment and Forward Look – Urban.

| Time period | Indicative Assessment | Description |
|---|---|---|
| Past trends<br><br>1939-2019 | Mixed Picture | The historic loss of agricultural land by soil sealing from urbanisation from 1939 to present day represents a loss of approximately 13% of the total soil stock for Wales; areas which are most versatile for agricultural activity and most suitable for horticultural cropping. Land that was previously industrial or used as landfill may be contaminated by metals, organic compound contaminants, hydrocarbons or pesticides. In Wales, the most common contaminants were benzo(a)pyrene, lead, and arsenic, all of which were identified at over 60% of contaminated land sites. Local authorities in Wales have undertaken detailed inspections on 800 potentially contaminated sites. From these inspections, 111 sites were subsequently determined as contaminated land with 97 sites being fully remediated and risks addressed at a cost of £4.9 million. |
| Future prospects<br><br>2020-2065 | Mixed Picture | According to the latest predictions on the cumulative loss of agricultural land to urbanisation under the different growth scenarios (hectares) since 2011, the base year is predicted to increase.<br><br>It is estimated by local authorities that 9,330 potential contaminated land sites are yet to undergo detailed inspection, and of these at least 414 sites are considered to be high priority. |

Note on robustness: The Agricultural Land Classification has recently been subject to refinement using an updated Soils of Wales map. These maybe be subject to future refinement as more records become available. Urban areas are not currently included in any national soils monitoring scheme to observe trends in soil quality and condition.

## Land use

Wales is characterised by significant areas of agricultural land classified (ALC) as grades 3b to 5 (80%), upland and mountainous topography (~20% of land) and is overall subject to a wetter climate than much of the UK. As a result, 80% (NAW, 2018) of agricultural land is designated as a 'less favourable area' (LFA) with a much smaller area of higher ALC grade best to deliver arable and horticultural crops. Welsh agriculture is dominated by permanent pasture grassland, which accounts for more than 64% (Welsh Government, 2019a) of the utilised area. Sole rights rough grazing account for 15%, while grass leys (under five years old) account for 10% and arable land for 6% of utilised agricultural area (Welsh Government, 2019a).

The main changes (2016-19) in land use area are an increase in tree cover on farms (Welsh Government, 2019a), more woodland (Forest Research, 2019), more permanent grassland, more arable land and more grass leys, whilst a decline in sole rights rough grazing and horticulture occurred (Welsh Government, 2019a).

Land used for renewable energy development has continued to increase to meet the target of 70% of Wales's electricity consumption from renewable energy sources by 2030 (48% in 2019). This includes wind, solar, hydropower, energy from waste and bioenergy projects plus the required electricity supply infrastructure. For example, solar generation requires 0.5MW/ha (National Assembly for Wales, 2015) and ground source heating requires 0.2MW/ha (Centre for Alternative Technology, 2020). Bioenergy requires the conversion of land to produce energy crops rather than food or fodder for livestock.

According to Forest Research, in 2017 there was estimated to be 92,700ha of tree cover (urban and rural) outside National Forest Inventory (NFI) defined woodlands. This is comprised of small woods less than 0.5 hectares in size (49,200ha), groups of trees (33,400ha) and lone trees (10,100ha). The total woodland as a percentage of land cover is 15%, including trees outside woodland brings the total land cover of woodlands and trees in Wales to 19.4% (Forest Research, 2017).

## Livestock

Livestock numbers and densities in Wales are driven by a combination of direct and indirect factors (see section 4).

Welsh Government's survey of sheep and lamb shows that:

- Numbers peaked in the 1990s with a gradual decline until 2010.
- From 2010, the number of sheep and lamb slowly began to rise reaching 10 million in 2017 (Welsh Government, 2019a).

Welsh Government’s survey of cattle and calves showed that:

- Combined dairy and beef herds in Wales was 1.1 million – a fall of 1.3% since 2018 (Welsh Government, 2019a).
- In 2018, there were 1,549 (Welsh Government, 2019b) dairy farms in Wales (Welsh Government, 2019c). There are 1,613 farms selling milk from cows, sheep and goats (June 2020) (AHDB, 2020a).
- Raw milk production in Wales exceeds the processing capacity; around 50% of milk is processed in Wales (mainly into cheese), and the rest is transported to England for processing (AHDB, 2018).
- Between 2004 and 2013, there was a gradual fall in dairy cows, but from 2014 to 2018 the numbers have increased (Welsh Government, 2019a). The latest estimates in numbers of dairy cows (females aged two years or more that have calved) is around 251,592 (as at June 2019). It has risen by 1.2% compared to 2016 and reduced by about 3,000 compared to 2018 (AHDB, 2020b).
- The number of beef females has fallen by nearly 50,000 since 2004, but this decline has become more gradual in the last five years (Welsh Government, 2019a).
- The south West area is the largest area, with a higher density of dairy cattle per hectare of grassland (HCC, 2019).

Welsh Government’s survey of poultry showed that:

- The total poultry in Wales was 8,489,800 in June 2019 – the majority of these were table chicken or broilers (4.9 million) and chicken kept for eggs (2.3 million) (Welsh Government, 2019a).
- Almost all of the birds are kept by a relatively small number of large producers (Welsh Government, 2019a).
- In recent years the number of birds kept for egg production has grown whilst the number of broilers has fallen (Welsh Government, 2019a).
- There are no steady long-term trends, although historical numbers were much lower (1927–1970) (Welsh Government, 2019a).
- There is a high density of poultry units in Powys. Most of these units are below the permitting threshold (Aazem & Bareham, 2015; CPRW, 2020; Bosanquet, 2019). The impact of intensive farming are discussed further in the Air quality chapter and Ecosystems chapters.

Urban and woodland land uses are discussed in the Urban chapter and Woodlands chapter. Arable land use is discussed in the Enclosed farmland chapter.

## Land use suitability and capability

Welsh Government’s Capability, Suitability and Climate Programme has modelled the changes in the Agricultural Land Classification (ALC) and the best and most versatile agricultural land (BMV) (Grades 1 to 3a). See the Woodlands chapter and SoNaRR2016 for more information on the predicted changes in tree species distribution. The models, using different climate change projection scenarios

(UKCP18) and a more refined Soils of Wales map, found the changes shown in Figure 1 and Table 4.

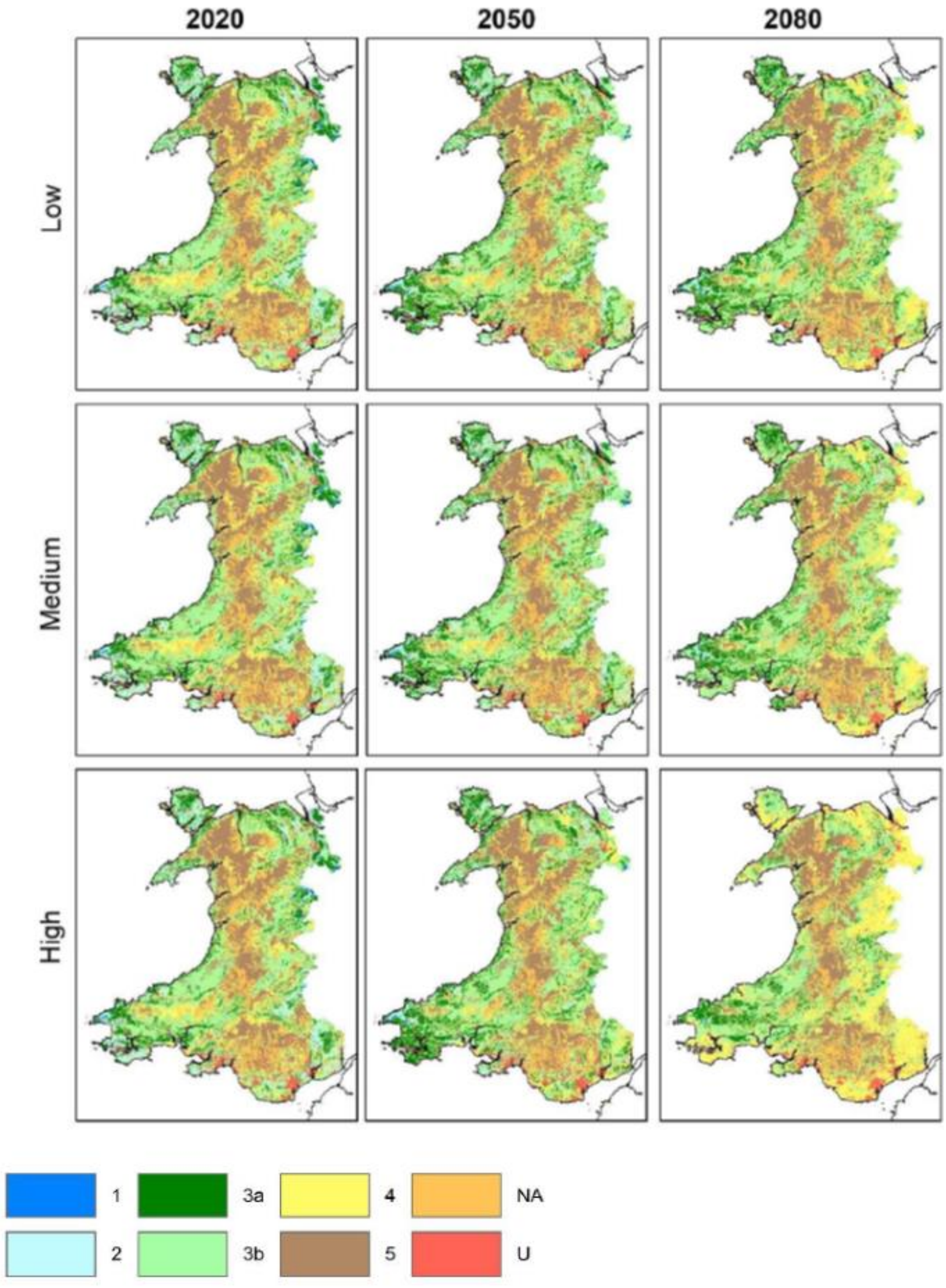


Figure 1 Predicted ALC grade using UKCP18 scenarios (Source: Keay C. A. and Hannam J.A. 2020).

Table 4 Changes in percentages of BMV and Not BMV land in Wales using UKCP18 scenarios (Source: Keay C. A. and Hannam J.A. 2020).

| | Current | 2020 Low | 2050 Low | 2080 Low | 2020 Medium | 2050 Medium | 2080 Medium | 2020 High | 2050 High | 2080 High |
|---|---|---|---|---|---|---|---|---|---|---|
| BMV | 20% | 23% | 24% | 18% | 23% | 24% | 16% | 23% | 22% | 9% |
| Not BMV | 80% | 77% | 76% | 82% | 77% | 76% | 84% | 77% | 78% | 91% |

Overall, the assessment shows predicted climate change impacts on soils with some soils improving and others downgrading, with potential changes in crop suitability, cropping and land use patterns in response to changing conditions.

The main limiting criteria for predictive ALC in 2080 medium emissions scenario is shown in Figure 2.

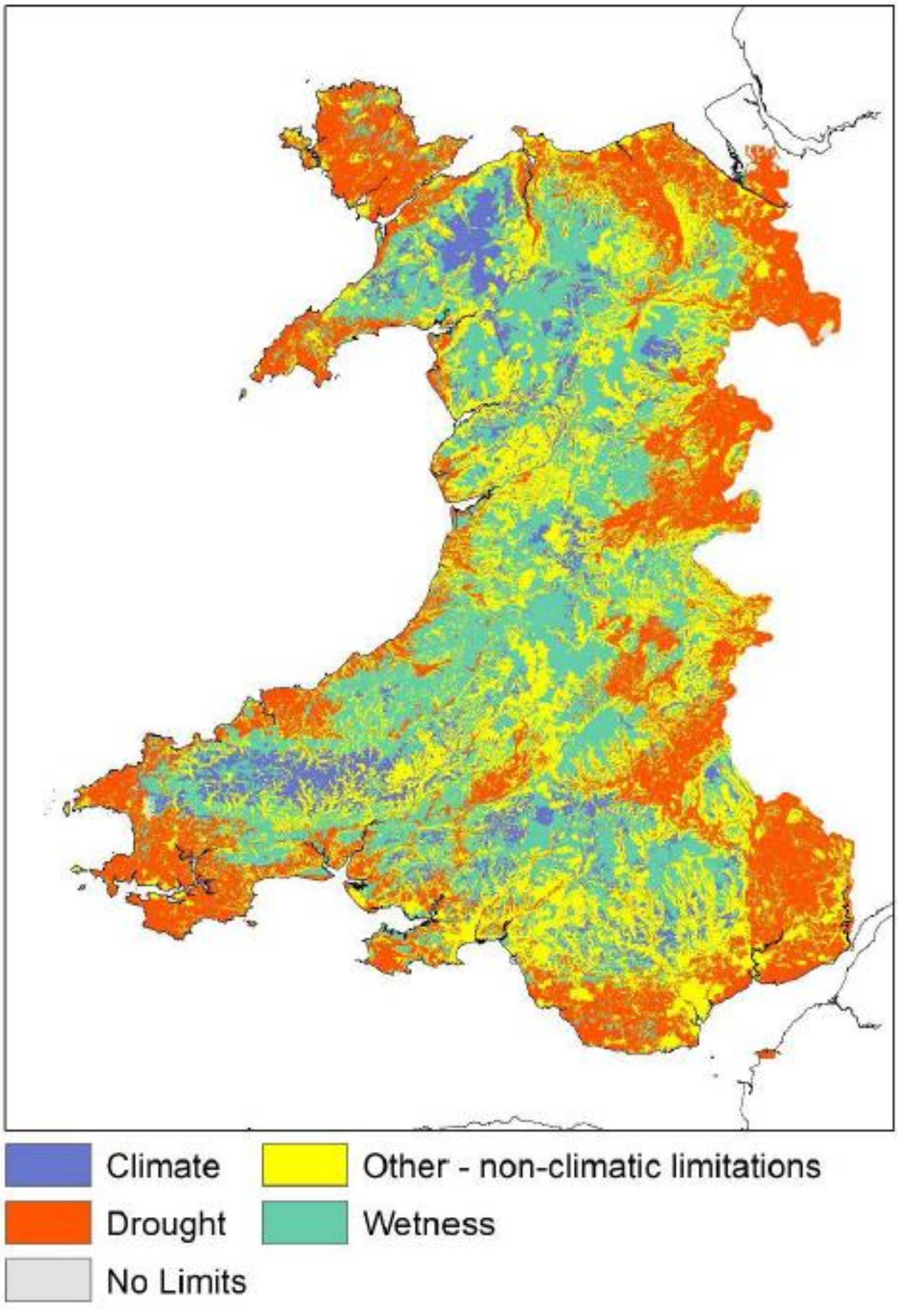


Figure 2 Main Limitations to Agricultural Land Classification (prioritised by climate, drought, wetness, other factors) for the Predictive ALC Map in 2080 under the medium emission scenario (Source: Keay C. A. and Hannam J.A. 2020).

Note: Other factors includes all other non-climatic ALC criteria such as soil depth, topsoil stone content and gradient.

Predicted changes in soil wetness classed between 2020 and 2050 improves the ALC grades but becomes a significant limiting factor by 2080 (Keay C. A. and Hannam J.A. 2020). The areas predicted to have improved productivity as a result of climate change may lead to intensification activities like conversion of grassland to arable or horticulture production, increasing the risk of soil erosion and compaction.

Most of Wales is not limited by drought in the baseline (the majority of the area is classified as Grade 1 for droughtiness). This is also the case for 2020, although some areas are starting to downgrade for the drought criteria. By 2050 and 2080, many areas in Wales (the Welsh border, Pembrokeshire, Anglesey and north Wales) are significantly downgraded due to drought constraints (Figure 3). This assumes that crops are not irrigated. The droughtiness criteria is based on water availability and moisture deficit for two reference crops (winter wheat and potatoes) and is influenced by temperature and summer rainfall. As the climate gets warmer and drier in the summer, the drought factor becomes more limiting to crop productivity (Keay C. A. and Hannam J.A. 2020).

In addition to summer drought, there is a risk from increasing winter flood events and sea level rise. According to the UK Climate Change Risk Assessment 2017 evidence report, approximately 9,000 hectares of Best and Most Versatile (BMV) land in Wales is at 1 in 75 year or greater risk from river flooding. A further 7,000 hectares is at a 1 in 75 year or greater risk of surface water flooding. The area of BMV land at a 1 in 75 year risk from all sources of flooding is projected to increase by 35% by the 2050s if global mean temperatures continue on the current trajectory. Welsh Government has commissioned work to re-assess the current fluvial flood risk (ADAS, 2020).

The long-term agricultural capability and suitability of Welsh soils to support different crop types (~120) in a range of future climate scenarios is currently being explored by Welsh Government through the Capability, Suitability and Climate Programme (CSCP) (ADAS, 2020). The long-term forestry capability and suitability of soils is supported via the UK Science and Innovation Strategy for Forestry (Forest Research; Read et al.,2009; Ray, 2008).

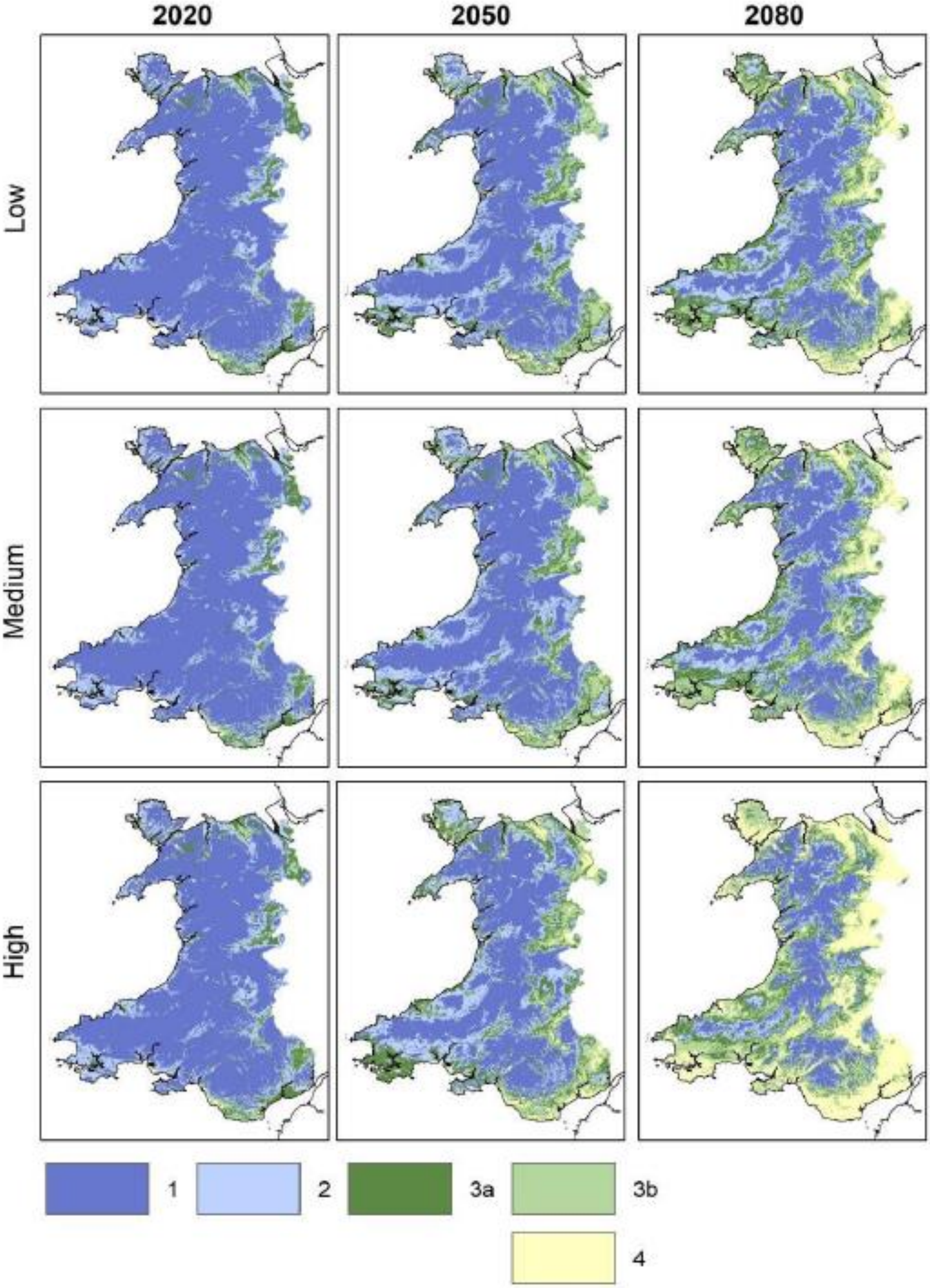


Figure 3 ALC Grade by Droughtiness under UKCP18 Scenarios (Source: Keay C. A. and Hannam J.A. 2020).

# Soils

## Soil Organic Carbon (SOC)

Topsoil carbon concentrations have been monitored across Wales as part of the ERAMMP monitoring (Alison et al., 2020). In general, they show a stable trend over the long term (Table 5). Recent, more in depth analysis of the GMEP data within the ERAMMP monitoring scheme showed topsoil carbon (0–15cm) was stable in woodlands and improved land (Table 5). Improved land in Wales was dominated by improved grassland rather than arable crops, while a significant decline in topsoil carbon occurred on habitat land restricted to the uplands from 2007 to 2016 (Alison et al., 2020). Further work is required to investigate the reasons for these changes (Alison et al., 2019a). See the Ecosystem chapters for ecosystem specific soil results.

Establishing a robust baseline for soil organic carbon stocks and monitoring change over time with confidence is a challenge (Rollett and Williams, 2020a; Ward et al., 2016), especially due to a number of potential sources of error in SOC measurement at sample, profile, plot and landscape scales (Vanguelova et al., 2016). An incomplete understanding of how SOC changes are influenced by climate, land use, and soil management factors adds complexity to designing appropriate monitoring (Smith et al., 2020).

Table 5 Trends in soil carbon concentrations in Habitat land, Improved land and Woodland between 1978 and 2016. (Alison et al., 2020).

| Variable | Year | Estimate of carbon concentration (g/kg) | *P*-value vs. 2016 | n samples |
|---|---|---|---|---|
| Habitat land | 1978 | 156.39 | 0.14 | 25 |
| Habitat land | 1998 | 146.55 | 0.41 | 31 |
| Habitat land | 2007 | 159.64 | 0.02 | 163 |
| Habitat land | 2016 | 132.48 | Not applicable | 322 |
| Improved land | 1978 | 59.83 | 0.45 | 43 |
| Improved land | 1998 | 56.77 | 0.98 | 43 |
| Improved land | 2007 | 53.00 | 0.20 | 216 |
| Improved land | 2016 | 56.66 | Not applicable | 249 |
| Woodland | 1978 | 134.93 | 0.09 | 15 |
| Woodland | 1998 | 151.98 | 0.52 | 17 |
| Woodland | 2007 | 145.97 | 0.21 | 62 |
| Woodland | 2016 | 166.91 | Not applicable | 88 |

Note: Habitat Land represents Semi-natural Grassland and Mountain, Moor and Heathland; improved Land represents Arable and Grassland while Woodland represents Conifer and Broadleaf.

Table 6 Long- and short-term trends in soil carbon concentrations in Habitat land, Improved land and Woodland between 1978 and 2016. (Alison et al., 2020).

| Habitat | Habitat Land | Improved Land | Woodland |
|---|---|---|---|
| Short-term | Decreasing trend | Non-significance in a trend, indicating stability and/or low sample size | Non-significance in a trend, indicating stability and/or low sample size |
| Long-term | Non-significance in a trend, indicating stability and/or low sample size | Non-significance in a trend, indicating stability and/or low sample size | Non-significance in a trend, indicating stability and/or low sample size |

Losses of soil organic matter (SOM) have been associated with a loss in soil quality and function, and reduced resistance and resilience to poor soil management (ADAS, 2019a). Land use and management factors likely to affect SOM and SOC levels include (see also the Climate change section).

- Loss by water erosion is accelerated by soil disturbance from tillage or cultivation, removal or changes to vegetative cover including some ground preparation for tree planting (ADAS, 2019a).
- Declines in SOM in both mineral and peat soil affects the vulnerability of soils to erosion and soil compaction and have negative effects on soil biodiversity (ADAS, 2019a).
- Land use change (such as afforestation, deforestation or ploughing of grasslands for arable cultivation) has a major impact on SOM levels. The above ground inputs of organic matter to the soil are significantly reduced when arable crops are harvested (ADAS, 2019a; Alison et al., 2019a).
- Mineralisation or oxidation and erosion of peaty soil reduces organic matter stocks (ADAS, 2019a). Shallow peat soils are likely to be vulnerable to carbon losses during tree planting and harvesting (Berdeni et al., 2020; Crane et al., 2020; Matthews et al., 2020).
- Higher temperatures and reduced soil moisture reduce SOM levels. Soils of wetland habitats, such as peat bogs and fens, are particularly sensitive to changes in soil wetness; the degraded condition (such as through drainage, extraction or over-grazing) of the majority of these habitats increases the vulnerability of their soils (ADAS, 2019a).
- Uncontrolled burns due to poor management, extreme weather events and illegal activities lead to greater SOC losses compared to controlled burning (Alison et al., 2019a). There were 4,015 grassland, woodland and crop fires in 2018–19, almost double the number in 2017–18 and the highest since 2011–12 (Welsh Government, 2019d).
- Habitats with high SOC stocks are generally most threatened with SOC declines, especially in the uplands which have high existing C stocks (Alison et al., 2019a).

The relative risk of SOM declines associated to land use and soil type are shown in Table 7.

Table 7 The probability of soil degradation in each land use and soil type category (Source: ADAS, 2019a)

| Land use type | Soil type: Clay | Soil type: Silt | Soil type: Sand | Soil type: Peat |
|---|---|---|---|---|
| Urban | High | High | High | High |
| Horticulture | High with small differences between soil textures | High with small differences between soil textures | High with large differences between soil textures | High |
| Arable intensive | High with small differences between soil textures | High with small differences between soil textures | High with large differences between soil textures | High with large differences between soil textures |
| Arable extensive | Moderate | Moderate | Moderate | Moderate |
| Grassland improved | Moderate | Moderate | Moderate | High |
| Grassland unimproved | Low | Low | Low | |
| Rough grassland | Low | Low | Low | Low |
| Forestry | Low | Low | Low | |
| Woodland | Low | Low | Low | |
| Wildscape | Low | Low | Low | Low |

## Soil Nutrients

The nutrient status of soils underpins the delivery of regulating and provisioning services. Soils provide plants with 17 nutrient elements essential for plant growth, including carbon, oxygen and hydrogen from the air (Udall et al., 2015). Macronutrients that are needed in relatively large amounts include nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulphur (S), carbon (C), oxygen (O) and hydrogen (H). Micronutrients which are needed in smaller amounts include manganese (Mn), iron (Fe), boron (B), zinc (Zn), copper (Cu), molybdenum (Mo), chlorine (Cl) and cobalt (Co). Cobalt has only recently been recognised as a potentially essential nutrient for plants and is necessary for nitrogen (N) fixation occurring within the nodules of legume plants.

Deficiency of any one of these elements is likely to limit plant growth and reduce yield. Optimum management of all essential nutrients is required to deliver sustainable agriculture (Goulding et al., 2008). Managing nutrient applications to optimise nitrogen and phosphorus supply is important to minimise losses to the environment. The pH of a soil affects the bioavailability of plant nutrients, which will also impact on plant growth (PDA, 2011).

Soil data from across the UK in 2018/19 provided by participants in the Professional Agricultural Analysis Group indicated that only 9% of samples were at target indices for both phosphate and potassium, which has been unchanged since 2009. Meanwhile, 16% were below the targets and 21% were above the targets indices for optimum crop growth. This indicates the need to base fertiliser use on regular soil analysis and nutrient planning (PAAG, 2019).

There are no national level data available for other essential nutrients such as sulphur.

Table 8 Trends in topsoil pH and nutrients in improved land (arable and grassland) between 1978 and 2016. (Alison et al., 2020).

| Variable | Year | Estimate | P-value vs. 2016 | n samples |
|---|---|---|---|---|
| pH | 1978 | 5.35pH | <0.01 (significantly different to 2016) | 50 |
| pH | 1998 | 5.75pH | 0.71 | 46 |
| pH | 2007 | 5.99pH | <0.01 (significantly different to 2016) | 230 |
| pH | 2016 | 5.78pH | Not applicable | 323 |
| Total nitrogen | 1998 | 0.52% | 0.14 | 45 |
| Total nitrogen | 2007 | 0.53% | 0.08 | 43 |
| Total nitrogen | 2016 | 0.47% | Not applicable | 321 |
| Olsen-phosphorus | 1998 | 41.31mg/kg | <0.01 (significantly different to 2016) | 33 |
| Olsen-phosphorus | 2007 | 23.56mg/kg | 0.98 | 43 |
| Olsen-phosphorus | 2016 | 23.62mg/kg | Not applicable | 321 |

Table 9 Long- and short-term trends in topsoil pH and nutrients in improved land between 1978 and 2016. (Alison et al., 2020).

| Habitat | pH | Total nitrogen | Olsen-phosphorus |
|---|---|---|---|
| Improved land short-term | Decreasing trend | Non-significance in a trend, indicating stability and/or low sample size | Non-significance in a trend, indicating stability and/or low sample size |
| Improved land long-term | Increasing trend | Non-significance in a trend, indicating stability and/or low sample size | Decreasing trend |

Table 10 Trends in topsoil pH and nutrients in habitat land (semi-natural grassland and mountain, moorland and heath) between 1978 and 2016. (Alison et al., 2020).

| Variable | Year | Estimate | P-value vs. 2016 | n samples |
|---|---|---|---|---|
| pH | 1978 | 4.48 (significantly different to 2016) | <0.01 (significantly different to 2016) | 23 (significantly different to 2016) |
| pH | 1998 | 5.10pH | 0.93 | 28 |
| pH | 2007 | 5.02ph | 0.27 | 150 |
| pH | 2016 | 5.11pH | Not applicable | 248 |
| Total nitrogen | 1998 | 1.14% (significantly different to 2016) | <0.01 (significantly different to 2016) | 28 (significantly different to 2016) |
| Total nitrogen | 2007 | 1.13% (significantly different to 2016) | <0.01 (significantly different to 2016) | 26 (significantly different to 2016) |
| Total nitrogen | 2016 | 0.87% | Not applicable | 248 |

Table 11 Long- and short-term trends in topsoil pH and nutrients in habitat land between 1978 and 2016. (Alison et al., 2020).

| Habitat | pH | Total nitrogen | Olsen-phosphorus |
|---|---|---|---|
| Habitat land short-term | Non-significance in a trend, indicating stability and/or low sample size | Decreasing trend | Not applicable |
| Habitat land long-term | Increasing trend | Decreasing trend | Not applicable |

Table 12 Trends in topsoil pH and nutrients in woodland (conifer and broadleaf) between 1978 and 2016. (Alison et al., 2020).

| Variable | Year | Estimate | P-value vs. 2016 | n samples |
|---|---|---|---|---|
| pH | 1978 | 4.07pH (significantly different to 2016) | <0.01 (significantly different to 2016) | 15 (significantly different to 2016) |
| pH | 1998 | 4.64pH | 0.84 | 17 |
| pH | 2007 | 4.70pH | 0.84 | 64 |
| pH | 2016 | 4.68pH | Not applicable | 88 |
| Total nitrogen | 1998 | 0.97% | 0.18 | 16 |
| Total nitrogen | 2007 | 0.72% | 0.25 | 16 |
| Total nitrogen | 2016 | 0.81% | Not applicable | 88 |

Table 13 Long- and short-term trends in topsoil pH and nutrients in woodland between 1978 and 2016. (Alison et al., 2020).

| Habitat | pH | Total nitrogen | Olsen-phosphorus |
|---|---|---|---|
| Woodland short-term | Non-significance in a trend, indicating stability and/or low sample size | Non-significance in a trend, indicating stability and/or low sample size | Not applicable |
| Woodland long-term | Increasing trend | Non-significance in a trend, indicating stability and/or low sample size | Not applicable |

The optimum range for soil pH to increase the availability of nutrients by plant uptake and to minimise the build-up of soil phosphorus and leaching of nitrate on improved grassland is pH 6.0 for mineral soils and pH 5.7 for intermediate organic soils (AHDB, 2020c). In the latest GMEP monitoring period, topsoil pH on improved land has declined significantly (Table 5). This may be due to a decline in liming and continued fertiliser use; however, the long-term trend is a significant increase in soil pH across all land uses since 1978 (Maskell et al., 2019), an observation other studies support (Kirk et al., 2010; Reynolds et al., 2013).

Phosphorus levels (Table 8) on improved land within the latest period have stabilised after an overall period of significant decline (Defra, 2018a; Maskell et al., 2019). Estimated data on nutrient cycling of soils showed some surpluses of nitrogen and phosphorus balances, taking into account inputs and offtakes (Table 8). A soil nutrient balance estimate, expressed as a loading of nitrogen or phosphorus per hectare of managed agricultural land, can be used as an indicator of the environmental risks. While a shortage of nutrients can limit the productivity of agricultural soils, a surplus of these nutrients lowers the profitability of production and poses a serious environmental risk. Losses of nutrients to the environment can impact air quality (ammonia emissions), water quality (nitrate and phosphate levels in run-off and rivers), and climate change (nitrous oxide emissions). It provides a high-level measure which can be used to monitor long-term trends and to make meaningful comparisons between countries. A summary is shown below for UK and Wales.

Table 14 Nitrogen (N) and phosphorus (P) balance for 2017 (Source: Defra 2018b, pers.com)

| UK Nitrogen balance (kg/ha) | Wales Nitrogen balance (kg/ha) | Wales N balance compared to 2000 | UK P balance (kg/ha) | Wales P balance (kg/ha) | Wales P balance compared to 2000 |
|---|---|---|---|---|---|
| 90 | 85 | -37.9 | 6.2 | 6.5 | -3.1 |

Other estimates of annual nutrient losses from Welsh agriculture are around 37,000 tonnes of nitrate-N and 700 tonnes of phosphorus to water, and 20,000 tonnes of ammonia and 8,000 tonnes of nitrous oxide to air (Williams et al., 2019). Poorly managed applications and rates of application of manufactured fertilisers and organic materials to land represent a significant risk to water and air quality as well as impacting on farm business performance (Williams et al., 2019). This can have negative impacts on semi-natural ecosystems, all of which are very vulnerable to high nutrient levels, which typically cause lower diversity, poor condition, and even habitat loss (see Ecosystem chapters).

There are increasing concerns regarding the impact of pollution to water from the use and management of organic manures (slurries and manures). The Wales Land Management Forum sub-group on agricultural pollution was established to work in collaboration with stakeholders and the agricultural industry to tackle agricultural related pollution to water, and has produced a progress report with a number of recommendations. (see Freshwater chapter).

Other forms of organic materials spread to land, such as biowastes, can have a positive effect on soil by increasing organic matter and essential nutrients. However, it must be ensured that the use of biowaste to land does not impact on future soil health. Better evidence is required to ensure clear identification of what landbank is available in Wales in terms of the scale and suitability to receive biowastes to land, and identify and assess emerging risks such as chemicals, microplastics and anti-microbial resistance. Work is already under way on understanding and assessing these risks in biosolids through the latest Chemicals Investigation Program (CIP3) and The Waste and Resources Action Programme on compost and digestate.

A wider understanding of assessing further positive and negative impacts on soil health from the application of biowastes to land is required. Current assessment focuses on the demonstration of nutrient benefit to the receiving soil and crop. Greater understanding of the potential impact that applications have on soil health, function, and biodiversity is required.

## Soil Biodiversity

Soil biota accounts for ~25% of global biodiversity and is vital for nutrient cycling and plant growth (George et al., 2019). Moreover, often overlooked biomedical resources like antibiotics are isolated from soils contributing to human and animal well-being. Soil biodiversity is often reported in microbial, mesofauna and macrofauna groups. The ERAMMP monitoring programme has measured the microbial and mesofauna groups.

Soil mesofauna results from GMEP (Emmett et al., 2017) showed a decline across all land uses in the latest period (2013–16); they are below the CS national average returning to that observed in 1998. According to GMEP, there is no consistent pattern in soil mesofauna numbers. However, work suggests that certain groups of mesofauna show sensitivity to disturbance and moisture regime such as mesostigmata (mites) and collembola (springtails) that may prove useful for understanding change in cultivated and upland heath and bog habitats (George et al., 2017). Further work is needed to understand inter-annual variation together with an analysis of the species present.

A national-scale metabarcoding analysis of soil biodiversity across 436 locations in Wales within seven different vegetation classes (crops/weeds, fertile grassland, infertile grassland, lowland wood, upland wood, moorland grass mosaic and heath/bog) was undertaken by GMEP. The results showed that animal richness is negatively influenced by intensive land use and unaffected by soil properties, while microbial richness was driven by environmental properties in addition to land use (Figure 4) (George et al,. 2019).

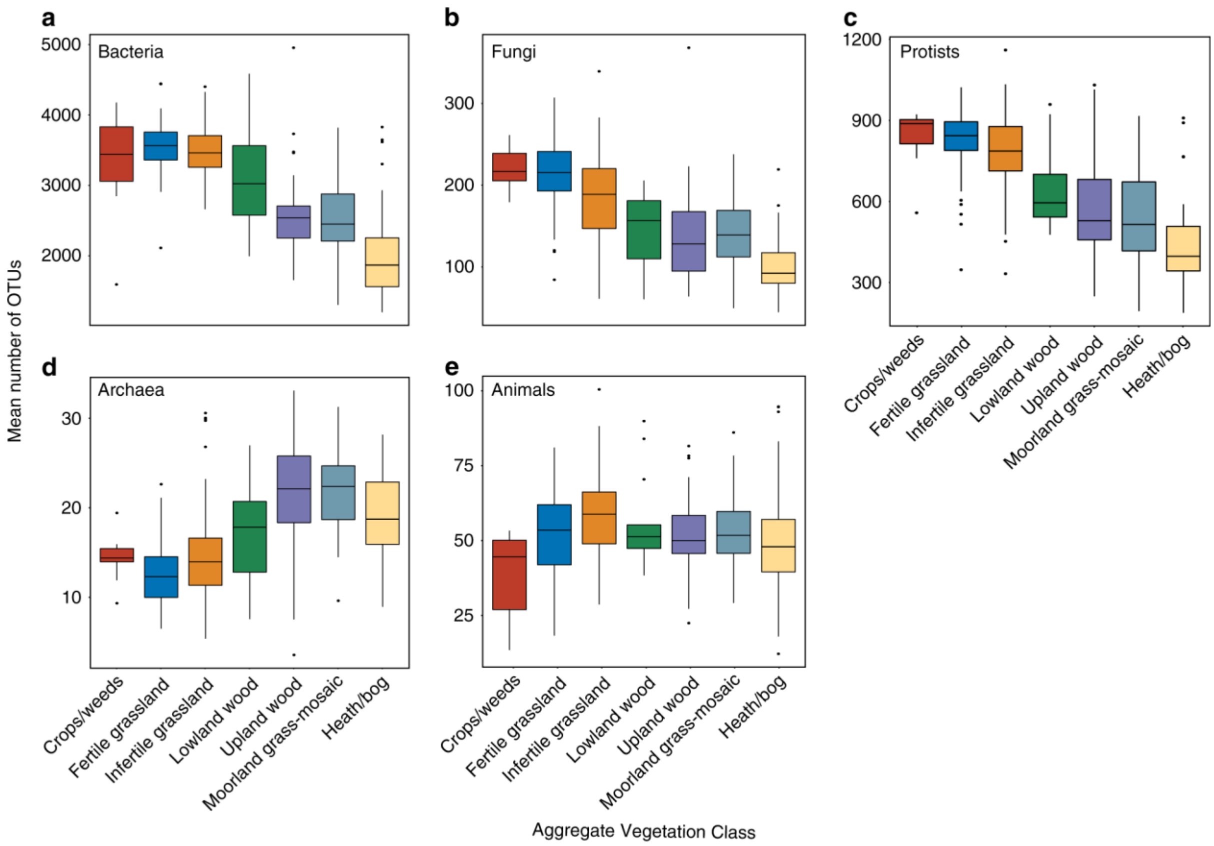


Figure 4 Boxplots of OTU richness for each organismal group. (Source: George et al., 2019, licensed under CC BY 4.0).

Note: Richness of a bacteria; b fungi; c protists; d archaea; e animals are plotted against Aggregate Vegetation Class ordered from most (crops/weeds) to least (heath/bog) productive. Boxes are bounded on the first and third quartiles; horizontal lines denote medians. Black dots are outliers beyond the whiskers, which denote 1.5x the interquartile range.

Mycorrhizal fungi form a symbiotic relationship with plant roots essential to plant growth and health and, as they are highly affected by fertilisers and land management practices, help us understand the health of soils. A study across large geographical scales showed that a higher cover of ectomycorrhiza vegetation (extra-cellular fungi) was broadly associated with greater soil C stocks in both topsoil and subsoil, while arbuscular mycorrhiza vegetation (intra-cellular fungi) was more variable, weaker and mostly had negative relationships (Soudzilovskaia et al., 2019). However, other variables such as climate, soil nutrients, especially nitrogen availability, and soil texture may affect both soil carbon and mycorrhizal plant distributions (Soudzilovskaia et al., 2019).

In 2015, soils from 11 EU Member States (including Wales) and six of the tested soils contained pesticide residues (25% of samples had one residue, 58% of samples had mixtures of two or more residues), in a total of 166 different pesticide combinations. Glyphosate and its metabolite AMPA, DDTs (DDT and its metabolites) and the broad-spectrum fungicides boscalid, epoxiconazole and tebuconazole were the compounds most frequently found in soil samples and the compounds found at the highest concentrations (Silva et al., 2019). These compounds occasionally exceeded their predicted environmental concentrations in soil but were below the respective toxic endpoints for standard in-soil organisms.

Recent research suggests that herbicide glyphosate persists in soil for longer than previously thought and negatively affects soil organisms that are responsible for nutrient cycling and maintaining soil structure, including earthworms (Soil Association, 2016).

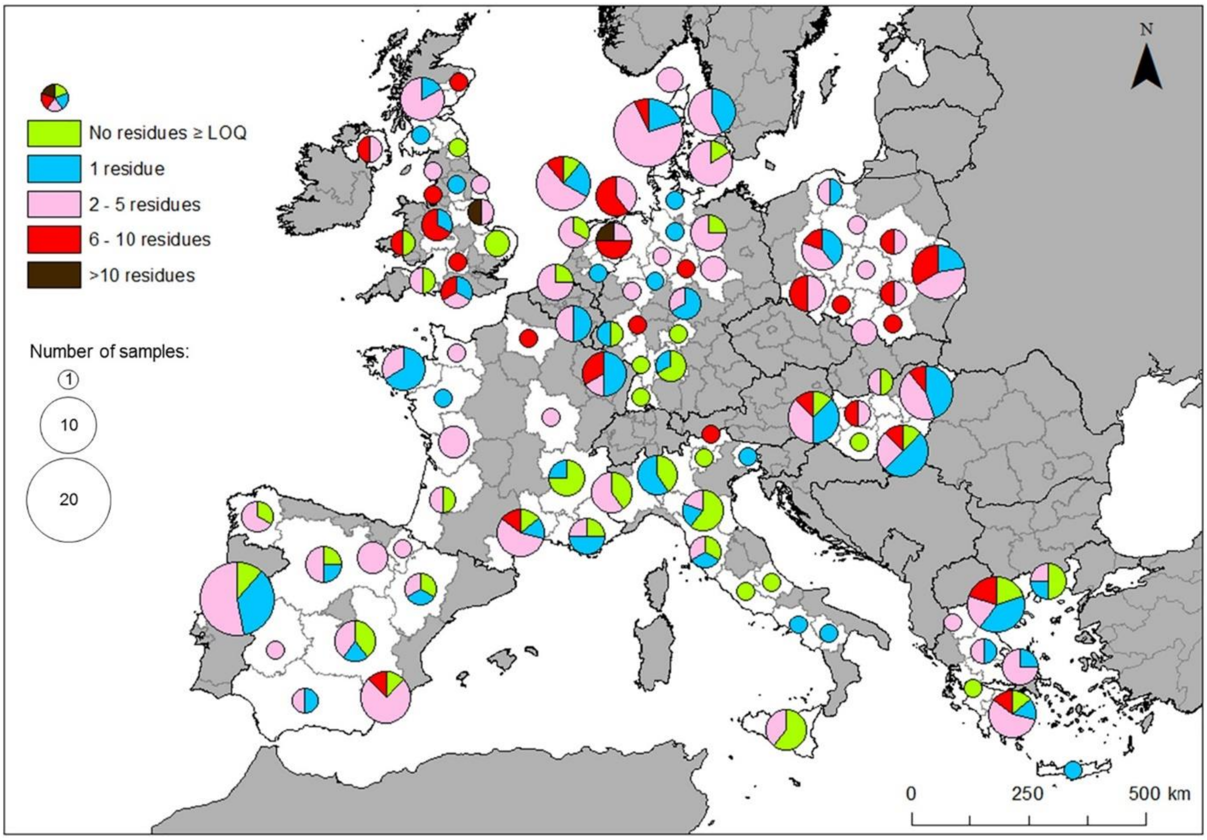


Figure 5 Number of pesticide residues in EU agricultural topsoils (0–15/20 cm) at the NUTS 2 level. Source: Silva et al., 2019, licensed under CC BY 4.0).

The main pressures and threats to soil biodiversity are the intensification or higher productivity systems using higher inputs (such as fertilisers, pesticides, sewage sludge and herbicides). Inorganic mineral fertilisers tend to lead to lower animal richness and biodiversity and favour the bacterial pathway of decomposition, while lower inputs tend to conserve biodiversity (George et al., 2019; IPBES, 2016). Land use change in the form of urbanisation leading to soil sealing can result in even more dramatic reductions in levels of soil biodiversity (ADAS, 2019a; Jeffery et al., 2010).

## Soil Erosion

Soil erosion by water is an important degradation process that occurs naturally but can be accelerated by inappropriate land management. The reviews of soil erosion in England and Wales (Boardman and Evans, 2006, Morgan, 1985, Rollett and Williams, 2020b) indicate that soil erosion in Wales is mainly attributable to upland erosion processes, landslips, stream bank erosion and water erosion along the border with England. A survey of the extent of erosion features in England and

Wales presented by McHugh et al. (2002) showed that erosion of peaty soils is the most widespread form of erosion in the uplands. The erosion of peaty soils can occur through a number of different processes, such as weathering (frost action, desiccation), sediment transport (water erosion, wind erosion, ditch erosion, gully erosion, mass movement, in stream transport processes) and the interactions between them (Li et al., 2018). Large areas of Wales are assumed to have low erosion rates due to the predominance of grassland and rough grazing, although this has not been quantified by measurements or observations (Cranfield University, 2016). A report found that 80% of erosion events were associated with land cropped to winter cereals (Chambers et al., 2000). However, coarse scale national assessments do not capture local scale factors that are commonly responsible for most erosion events. Monitoring soil erosion has not been conducted under the ERAMMP project to date; however, information on river bank condition was collected as part of the head water stream assessment and will be analysed along with a new assessment of erosion and soil damage features in future ERAMMP monitoring (Robinson*, pers. comm*).

Typical soil formation and erosion rates specifically in Wales have not been directly measured and quantified. A number of literature reviews that have reported estimated rates of soil erosion for England and Wales (such as Owens et al., 2006; Knox et al., 2015; Rickson et al., 2016; Nicholson et al., 2020) for ‘natural’ (background) rates of erosion are estimated to be generally <0.5 t/ha/yr (Nicholson et al., 2020). This mostly ranges from 0.1-1.0 t/ha/yr based on sediment yields (Evans, 2006), although a portion of this can be attributed to river channel erosion. Higher erosion rates occur most commonly on sandy and light silty soils on sloping land, often when the surface roughness is low and vegetation cover is less than 25-30% (Evans, 1990). Accelerated soil erosion rates are in the order of 1-10 t/ha/yr in England and Wales (Chambers et al., 1992; Chambers et al., 2000; Evans, 2005; Environment Agency, 2002). Estimates of annual rates of erosion were 0.54 – 1.37 t/ha/yr in UK grassland, 0.1-10t/ha/yr on UK cultivated land and 10-200t/ha/yr on UK bare soils (Nicholson et al., 2020) and require further validation before they can be assumed to be applicable to Welsh soils. As long as soil formation rates exceed soil erosion rates, soil will not be lost to future generations. Soil losses exceeding 1 t/ha/year are considered irreversible and unsustainable within a time span of 50-100 years (Rollett and Williams, 2020b).

There is currently little information specific to Wales on other potential ‘hotspots’ of soil erosion including roadside verges and footpath erosion, which may be a significant or important localised source of sediment in some Welsh catchments (Nicholson et al., 2020). Soil can be transported ‘out of field’ when it is co-extracted on the roots of crops and/or on the wheels and implements of farm machinery (Owens et al., 2006), causing a significant loss of soil from fields. No data on the magnitude of such losses specific to England and Wales have been reported. However, Frost and Speirs (1996) assessed soil loss for a site in East Lothian, Scotland with a harvest of (mainly) potatoes and carrots at 1 t/ha/harvest. In 94% of the studied area, this was greater than the soil loss resulting from water erosion caused by a severe storm with a 20-year return period.

Modelled soil erosion rates to water are discussed in the Freshwater chapter.

## Landslips and Landslides

A landslip is a natural process that enables a hill slope to reach equilibrium and can affect both natural land forms and artificial ones such as mine spoil heaps. Although colliery sites (2000+) are well known, there are also many thousands of other spoil heaps associated with Wales's extractive industry legacy. These sites can pose a landslip risk in much the same way as former colliery sites and some spoil heaps with fine materials when dry can be liberated by wind erosion. It can take decades for a slope to become stable, and if the controlling features change, the slope may need to adjust. Many of these sites have been categorised as regionally important geodiversity sites (RIGS) and some have been designated as Sites of Special Scientific Interest (SSSIs). Local authorities have a key role in monitoring and assessing some sites, particularly where they affect local communities (such as the Pantteg Landslide in Ystalyfera).

In summary, there are five main observations:

- Increased frequency and intensity of extreme rainfall leading to greater pore water pressure within hillside soils and subsoils and liquefaction of the material (like the landslip at Tylorstown, Rhondda in February 2020).
- There are a number of slow "geological" landslips sites (like Pantteg, Ystalyfera). They are often very slow moving incidents but every now and again can move considerably.
- Regular inspection is required to continue classification of high and low risk spoil heaps rather than assumption of a 'steady-state'.
- Other instability issues have occurred on hill sides where no known mining or quarrying has occurred. These are usually a result of land use and vegetation change alongside the impact of the changing climate. These sites are widespread and create risks primarily to transport links, water supply and water quality.
- In recent years, landslips have led to increased sediment erosion which has polluted water supply reservoirs in South Wales (so called "Red Events"). As a result of these events, Dŵr Cymru has commissioned research into identifying the causes of the likely locations for slips in upstream catchments. Natural Resources Wales, alongside other local stakeholders, has worked closely with Dŵr Cymru in identifying slip sites and investigating mitigating actions, such as tree planting and *Molinia* removal/control to restore heath and bog habitats.

## Soil Sealing

A recent study into the loss of soils by sealing to urbanisation in Wales from 1939 to present day found 29,000ha (13%) of a total predicted 226,000ha of the best and most versatile (BMV) agricultural land has been urbanised. These areas are most versatile for agricultural activity and most suitable for horticultural cropping (ADAS, 2019b).

- High Quality Land Loss: 29,000ha (ALC Grades 1, 2 & 3a)
- Moderate Quality Agricultural Land Loss: 35,000ha (ALC Grade 3b)
- Poor & Very Poor Agricultural Land Loss: 21,000ha (ALC Grades 4 & 5)

Further assessments will be undertaken to assess:

- High quality agricultural land loss due to sealed areas – hard surfaces outside urban boundaries such as roads.
- High quality agricultural land loss due to other uses such as woodland and protected sites.
- High quality land loss under Welsh Government population growth scenarios (2020-80).
- The significance of agricultural land loss and what it means.

Further predictive modelling shows that the expansion of urban areas will have minimal impact on future agricultural productivity in Wales. Overall, the area of BMV land in Wales is projected to decline by 0.40% by 2065 under a high urban growth scenario. This represents a cumulative estimated loss of 6,746 hectares over the period 2018 to 2065 (approximately 125 hectares, on average, per annum) (ADAS, 2020)

Table 15 Cumulative loss of agricultural land to urbanisation under the different growth scenarios (Low, Medium and High) in hectares from 2011 base year predictions (ADAS, 2020).

| Growth scenario | Year | BMV Land (1, 2 & 3a) | Grade 3b | Grade 4 & 5 |
|---|---|---|---|---|
| Low | 2035 | 2273 | 2660 | 2851 |
| Low | 2050 | 2674 | 2948 | 3380 |
| Low | 2065 | 2705 | 2988 | 3428 |
| Medium | 2035 | 3731 | 4278 | 4274 |
| Medium | 2050 | 4395 | 5043 | 5051 |
| Medium | 2065 | 4475 | 5144 | 5164 |
| High | 2035 | 4791 | 5539 | 5519 |
| High | 2050 | 6555 | 7615 | 7691 |
| High | 2065 | 6746 | 7858 | 7971 |

There is potential for BMV land loss in areas close to urban fringes which could be impacted by unexpected spikes in population.

SoNaRR2016 identified the trend of paving over our gardens has increased the impermeable areas and soil sealing. A study of an area in Cardiff showed that from 1984 to 2009 the impermeable area had increased by 20% through home extensions, conservatories and paving of gardens. Due to these changes, and the increasing rainfall intensity and run-off predicted from our changing climate, sewer flows in Wales are projected to increase by over 1% a year. The original drainage was not designed to deal with both the increased run-off and the increased storminess. As such, the risk of local flooding in urban areas has increased. Applying SuDs techniques to new developments will not address flooding on existing sites. To do this, SuDS techniques need to be implemented on existing sites or the risk of surface water and sewer flooding will inevitably rise (NRW, undated).

## Soil Compaction

The ability of soil to deliver benefits is linked to its structure (The Royal Society, 2020). Soil structure can be easily damaged by poor land management, which in turn negatively affects soil functions and the provision of benefits, such as biodiversity, agricultural productivity, clean water and flood prevention, and climate change mitigation.

Analysis of bulk density (an indicator of compaction) shows stability on woodland since 2007 (Alison et al., 2020). Within GMEP, data of improved land bulk density increases with land use intensity. However, the reported significant decrease in bulk density on improved land, underpinned by a decrease on improved grassland, could indicate reduced compaction of improved soils in Wales (Table 16). Average reported bulk density values for topsoils are below levels where grasslands are liable to suffer from compaction; 1.3 g/cm3 for mineral soils and 1.0 g/cm3 for peat soils (Black et al., 2008).

Table 16 Trends in bulk density in Habitat Land (Semi-natural Grassland & Mountain, Moorland & Heath), Improved Land (Arable & Grassland), Woodland (Conifer & Broadleaf) (Alison et al., 2020).

| Habitat | Year | Bulk density estimate (g/cm3) | P-value vs. 2016 | n samples | Short Term Trend |
|---|---|---|---|---|---|
| Improved Land | 2007 | 0.95 | <0.01 (significantly different to 2016) | 228 | Not applicable |
| Improved Land | 2016 | 0.85 | Not applicable | 323 | Decrease |
| Habitat Land | 2007 | 0.55 | 0.76 | 145 | Not applicable |
| Habitat Land | 2016 | 0.54 | Not applicable | 247 | Stable |
| Woodland | 2007 | 0.58 | 0.06 | 59 | Not applicable |
| Woodland | 2016 | 0.49 | Not applicable | 88 | Stable |

Compaction from machinery or livestock, based on modelling assessments of soil wetness classes, affects 25% of the total grassland area. Compaction by livestock is a function of the timing and intensity of grazing activities and the risks are much higher with wet soil and low plant density (i.e. in early spring and late autumn or early winter). The same modelling assessments suggest that <5% of arable soil and <1% of forest soils in Wales are at significant risk of compaction, mainly from cultivation and harvesting operations.

Land use change, such as increased cultivation for arable and fodder production and climate change, present further potential risks to grassland soils through changes in rainfall intensity/distribution and associated changes in soil moisture regimes. The problem is growing due to the increasing size and weight of field machinery; between 1960 and 2010, wheel loads from machinery increased by almost 600% (Schjønning et al., 2018). In addition, the increased use of contractors may lead to more field operations being carried out under unsuitable conditions as the farmer is no longer in control of the timing of the fieldwork or the machinery that is used (ADAS, 2019a).

Compaction reduces soil pore spaces and causes the bulk density to increase. High bulk densities affect root penetration, soil pore volume, water infiltration and air diffusion rates, as well as reducing overall pore space habitat for soil organisms.

Generally, increased compaction leads to a reduction in soil biodiversity and leads to soil becoming anaerobic, which can have large impacts on the types and distribution of soil organisms present (Jeffery et al., 2010). Compaction can vary hugely in severity and permanence and can be remediated by machinery. The type of machine needed depends on the soil type, soil texture and depth of compaction. Good soil structure and modern grass varieties can increase the efficiency of nitrogen fertiliser from 60% to 75%. Poor soil structure can reduce this to 40% or less (HCC and NRW, 2015).

## Soil Pollution

Land that was previously industrial (metal works, coal or lead mines, gas works etc.) or used as landfill may be contaminated by metals, organic compound contaminants (such as polycyclic aromatic hydrocarbons-PAHs), hydrocarbons or pesticides (ADAS, 2019a). In Wales, the most common contaminants are benzo(a)pyrene, lead and arsenic, all of which were identified at over 60% of contaminated land sites (NRW, 2016a). Contaminants may decrease pH, which can affect nutrient availability and biomass production; pH is also an important determinant of soil biodiversity (ADAS, 2019a).The effects of a given pollutant on the soil biota can be highly variable depending on the pollutant (Jeffery et al., 2010).

Land affected by contamination can pose a risk to both human health and the wider environment. It is an issue jointly regulated by local authorities and NRW, with responsibility for human health and controlled waters primarily falling to each respectively. The planning process is regarded as the main mechanism for providing the opportunity to remediate land contamination as part of the cycle of land redevelopment and regeneration, bringing land previously affected by contamination back into beneficial use. However, some potentially contaminated sites cannot be dealt with in this way and may continue to pose a risk to health and/or the environment. These sites need to be dealt with by the local authority or Natural Resources Wales through Part 2A of the Environmental Protection Act 1990. Under Part 2A EPA 1990, local authorities in Wales have undertaken detailed inspections of 800 potentially contaminated sites. From these inspections, 111 sites were subsequently determined as contaminated land, with 97 sites being fully remediated and risks addressed at a cost of £4.9 million (NRW, 2016). It is estimated by local authorities that 9,330 sites are yet to undergo detailed inspection, and of these, at least 414 sites are considered to be high priority.

Funding for contaminated land inspection has primarily come from Welsh Government's Contaminated Land Capital Fund Scheme. The scheme has accounted for over 70% of funds, with the remainder coming from the original owner/polluter and voluntary contributions. The annual fund scheme was withdrawn in 2010/11, with only one additional year of funding in the time since (during 2017–18). The 2017/18 fund of £1 million was fully allocated to several local authority contaminated land investigations and to a treatment trial and capping scheme at two metal mines sites led by NRW. Securing future funding from Welsh Government for this annual fund or a similar scheme is a clear opportunity for dealing with the historic legacy of contaminated land in Wales. Without it there is an overreliance on the planning regime to deal with historic contamination which tends to target commercially viable sites, leaving others to continue to pose risks.

Some heavy metal contaminated land is of high biodiversity value, supporting particularly rare habitats (such as calaminarian grassland) or species restricted to soils or rocks with high heavy metal content. Such land needs to be evaluated for its biodiversity and the habitat or species interest taken into account before and during remediation measures.

## Summary of key messages and broader context

Historical soil carbon concentrations declined significantly in arable systems as reported by all monitoring programs (Bellamy et al., 2005; Reynolds et al., 2013; Chapman et al., 2013). This was consistent across Great Britain and is consistent with findings from France (Saby, 2008) and Belgium (Goidts, 2007) where similar monitoring has been conducted. This may have recently stabilised in Wales (Alison et al., 2020); see Enclosed farmland chapter.

In Woodlands, excluding those on deep peats, National Soil Inventory of Scotland (NSIS) (Chapman et al., 2013) found a significant increase in soil carbon in Scotland consistent with the findings of the Countryside Survey (Emmett et al., 2010). The Woodland Survey of Great Britain (Kirkby et al., 2005) had identified a similar but non significant trend in soil organic matter.

The evidence for a change of soil carbon in grasslands is mixed over the long-term which is also the case in other European countries (Alison et al., 2019a; Reijneveld et al., 2009; Lettens et al., 2005; Poeplau et al., 2015).

Soil pH has provided a strong signal picked up consistently by all monitoring programs (Kirk et al., 2010; Reynolds et al., 2013). Soil pH has consistently increased in most habitats in what is considered to be the response of soils rebounding from acidification from air pollution (Kirk et al., 2010; Reynolds et al., 2013). Recently, ERAMMP has reported a short-term decline in this trend on improved land (Alison et al., 2020); see Enclosed farmland chapter.

Soil nutrients such as phosphorous and nitrogen have shown significant decreases across many broad habitats according to the Countryside Survey (Emmett et al., 2010), bringing P especially to more sustainable levels. However, P levels in mesotrophic (neutral pH) grasslands remain high (Seaton et al., 2020).

At a national level, soils do not appear to show evidence of widespread compaction. A short-term decline of bulk density on improved land is encouraging and may indicate less pressure on these soils (Alison et al., 2020).

ERAMMP and other work has identified important links between soil hydraulic properties and climate that may help us better understand the resilience of soils to climate change and how to manage this; see Climate change chapter.

Maintaining healthy soils is an important goal of environmental management, good farm husbandry, and forest management (CPRE, 2018; UKFS 2017). The new baseline developed by ERAMMP is summarised by Seaton (2020). Research and innovation activities will take place at a variety of spatial scales: plot and field; farm; landscape; regional and country; global; and food system scale (Veerman et al., 2020).

# 4. Drivers of Change

## Indirect Drivers

### Land Ownership

The motivations and goals of individual land owners and the objectives of those with controlling interests highly influences the extent to which SMNR can be achieved. A recent UK study into the sale of land in the last 40 years showed the appropriation of public land by the private sector was two million hectares (10% of UK land, which is almost the size of Wales), worth an estimated £400 billion today. This ownership now forms the largest component of wealth in Britain and is the largest privatisation of a public resource in European history. These have mostly comprised small plots of land sold by local authorities, the MoD, Forestry Commission, NHS and school playing fields. The buyers are mainly those who have corporate interests with shareholders such as developers, financial institutions, and supermarkets (BBC, 2019).

In Wales, it is estimated that land ownership in 2018 by Basic Payment Scheme (BPS) and Glastir applicants was about two-thirds owned and a third rented. Farmers renting land may be put at a disadvantage by rising land prices if this also increases rent. Renting land for pasture was on average more expensive in Wales in the first half of 2018 than it was in England. Average farm size in Wales is generally small (45 hectares) in comparison to most other parts of the UK and just over half of the farms in Wales are very small farms (59% of the total) and account for 5% of total turnover, from 15% of the farmed land (Figure 6) (Welsh Government, 2019c).

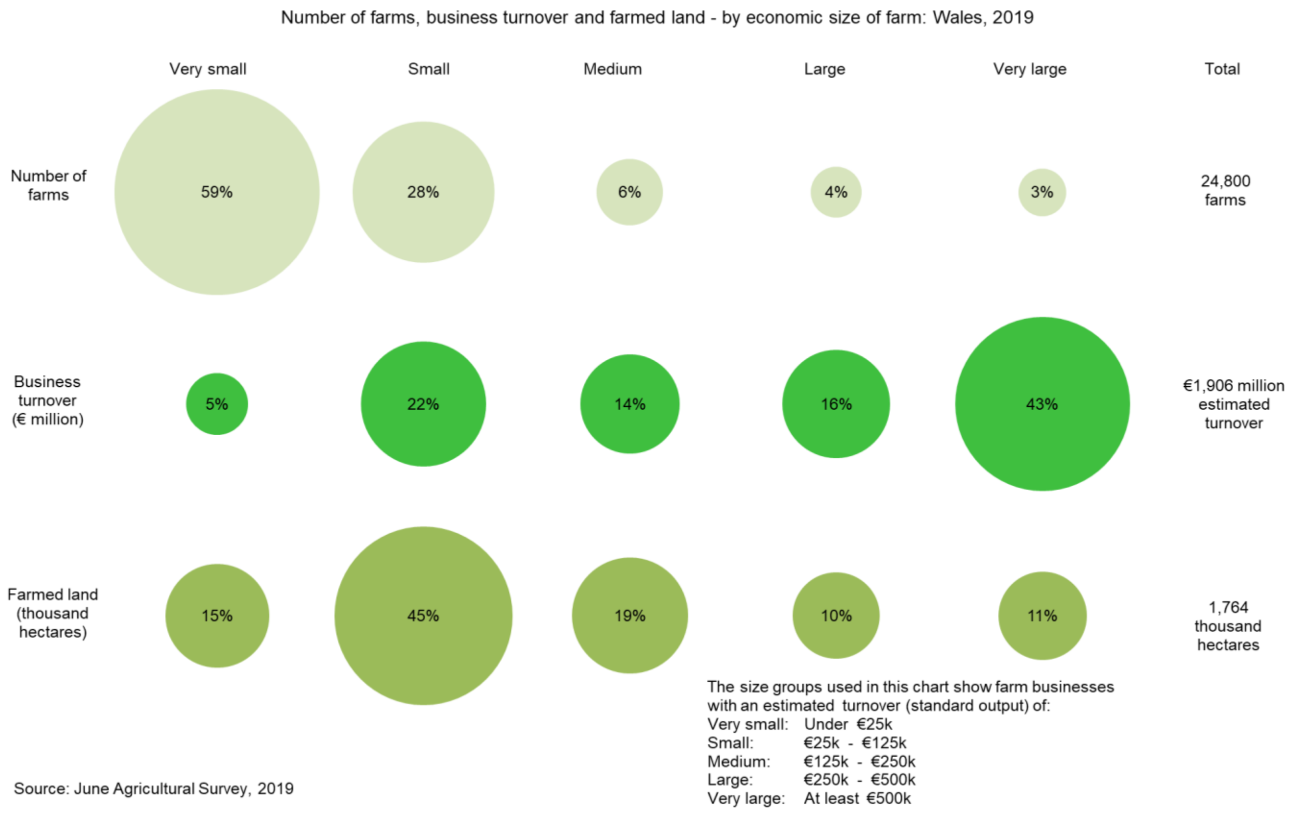


Figure 6 Number of farms, business turnover and farmed land, by economic size of farm (Welsh Government, 2019c).

An estimated 9.7% of agricultural land in Wales is ‘common land’ (approx.180,000 ha) and two-thirds of this is currently in ‘active management’ under Glastir Commons. Most of the common land in Wales is used for agricultural purposes with half having grazing rights for sheep and around a third for cattle (Welsh Government, 2019c).

The 2019 total NFI Woodland area in Wales is mainly owned by the private sector (62%), while the rest is the public forest estate managed by NRW on behalf of Welsh Government and the nation. The private sector woodland area mainly comprises of broadleaf woodland, whereas the Welsh Government Woodland Estate (WGWE) area mainly comprises conifer plantation with some mixed woodland (Forest Research, 2019).

## Economic and Market Changes

The most immediate pressure on the current pattern of land use, provisioning services and SMNR is the uncertainty in future policies relating to funding and market access following Brexit. Around 5% of lamb from Wales is consumed in Wales, approximately 60% is consumed in the rest of the UK, and 35% is consumed in export markets. Whilst 5% of beef from Wales is consumed in Wales, approximately 80% is consumed in the rest of the UK, and 15% is consumed in export markets (HCC, 2020a). Some sectors like the lamb sector are more reliant on export markets. Overall, however, 73% (Welsh Government, 2019d) of Welsh food and drink exports value are to the European Union, highlighting the importance of this market to the overall food production system.

Key findings from an estimated assessment of the potential impact under different trading scenarios (assuming basic payments continue at current rates) were:

- The potential agricultural land use conversions (following the rule based decisions) vary in magnitude and location across Wales under the three different Brexit trade scenarios. Total agricultural land area potentially affected ranges from 56,779 to 284,592 ha depending on the scenario (Cosby et al., 2019).
- The sheep sector is more negatively affected under No Deal and Multiple Free Trade Agreements (MFTA) scenarios due to reliance on exports relative to the dairy and beef sectors (Cosby et al., 2019).
- The total area potentially affected by the Brexit trade scenarios is 3 to 17% of current farmland depending on the scenario (Emmett et al., 2019).
- The total area potentially changing to non-agricultural uses is 2 to 15% of current farmland, depending on the trade scenario (Emmett et al., 2019).
- Environmental outcomes of the trade scenarios have been explored in terms of magnitude and spatial distribution across Wales for greenhouse gas (GHG) emissions, water quality, air quality, and bird abundance and diversity. The results emphasise the improvement in environmental outcomes for some regions but a risk of degradation in others. Further details can be found in ERAMMP Adroddiad-12/Report-12.
- Potential change in farm jobs was also explored, showing North West and Mid Wales as the areas potentially most affected by the MFTA modelled scenario. Further details can be found in ERAMMP Adroddiad-12/Report-12.

It should be noted there were a large number of assumptions, limitations and uncertainties with this modelling.

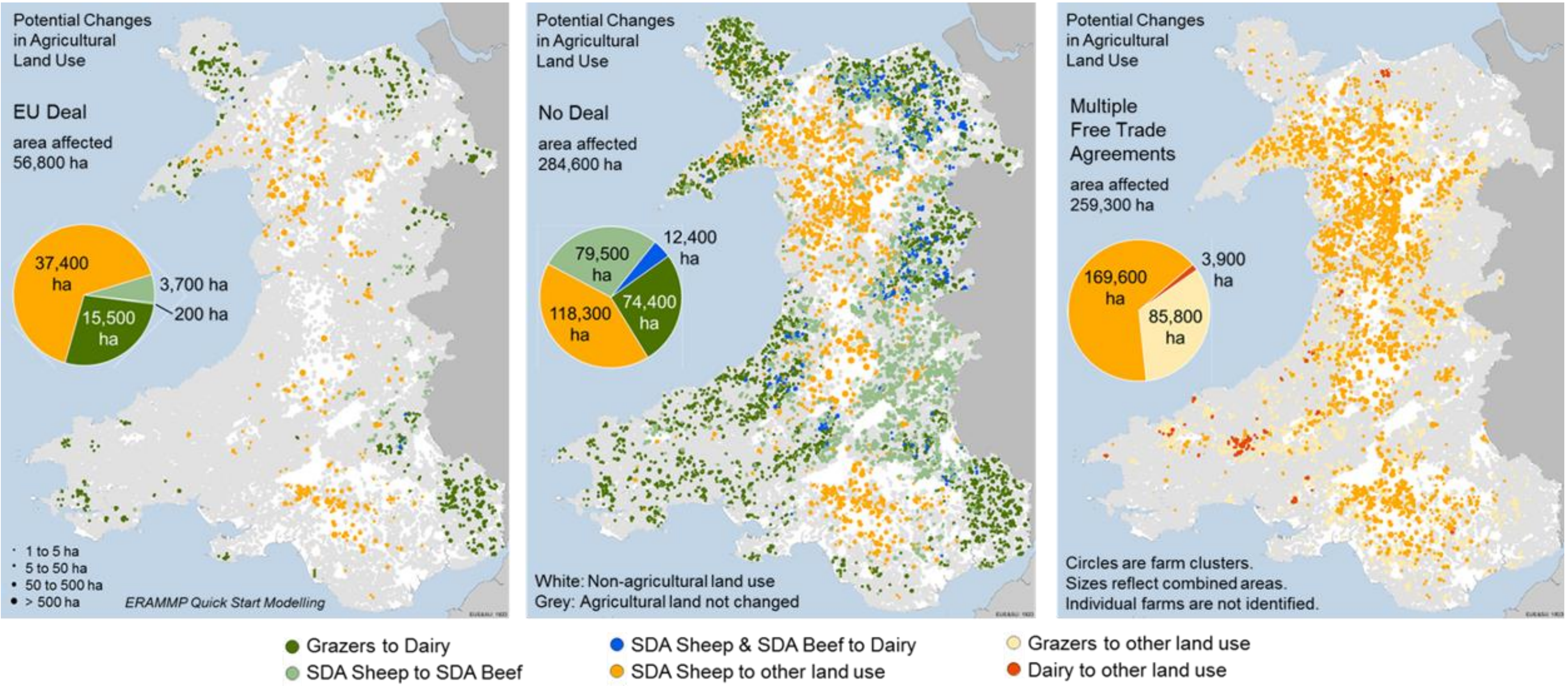


Figure 7 Potential agricultural land use change for the three Brexit scenarios.

Note: (Contains data from the Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP), reproduced from Cosby, B.J., Thomas, A., Emmett, B.A., et al. (2019) ERAMMP Report 12: QuickStart-1. Report to Welsh Government (Contract C210/2016/2017) (CEH NEC06297) under the Open Government License 3.0).

## Policy Changes

The Common Agricultural Policy (CAP) has had a significant influence on agricultural land use and management since its introduction in 1974. It was primarily designed to increase food production and to provide price support against fluctuating global markets, commodity prices and cost of inputs (Defra, 2019; AHDB, 2018).

Since the late 1990s, reforms to CAP have increasingly supported more environmentally sustainable practices through agri-environment schemes (see below). This will change following the exit from the European Union in January 2021. Areas of land under schemes have varied over time, and the total land area under Glastir reduced from approximately 1,041,000ha in 2018 to 849,000ha in 2019 (Welsh Government, 2020a pers comm). This is likely to be due to a reduction between the amount of active contracts areas in 2018 and 2019 as the main Glastir Schemes (Commons, Entry/Advanced and Organic) are coming to an end (5 years + 2 yr extension) and some contract holders declined their extension offers (Welsh Government, 2020 *pers comm*). Expansion of woodland has been low since the large expansion seen up to the 1990s as tax incentives, for example, have been removed.

The Farm Practice Survey (FPS) 2016 highlights "lessons learned" from previous agri-environment schemes. For farms that had not participated in any scheme, perceived complexity (42%) and a lack of fit with the farming system (53%) were cited most frequently as reasons. A general lack of interest was cited by 35% of respondents (Anthony et al., 2016). The economic incentive to participate in future schemes may be the core driver for uptake. However, it will be important to incentivise scheme participation and to improve the uptake of specific options to deliver "public goods" outcomes for land use and soils**.** Self-monitoring and reporting could have a transformative role in achieving environmental outcomes (Arnott et al., 2019). Self-monitoring should be backed up by independent local, regional and national scale monitoring to understand, interpret and confirm patterns in soil resource stocks and condition.

Future policy proposals and recommendations relating to Land Use, Land Use Change and Forestry (LULUCF) sectors include Welsh Government's Prosperity for All: A Low Carbon Wales (Welsh Government, 2019f), the Land use: Policies for a Net Zero UK by the Committee on Climate Change (2020), climate change adaptation in the Prosperity for All: A Climate Conscious Wales (Welsh Government, 2019g), and Shoreline Management Plans and the Draft National Development Framework (Welsh Government, 2019h). These reports and plans could have a significant influence on future land use and management including:

- Post Brexit support for farmers and land managers to replace CAP (Sustainable Farming and our Land)
- Emission reductions and low-carbon farming practices
- Increase tree planting to at least 2,000 hectares per year, aiming to increase this to 4,000 hectares, including agro-forestry, hedge creation and broadleaf management
- Upland and lowland peatland restoration ensuring that all peatlands supporting semi-natural habitats are restored and sustainably managed

- Potentially reduce consumption of the most carbon intensive foods
- Tackling land management that contributes to increased flood risk
- Address risks to ecosystems and agriculture through the Capability, Suitability and Climate Programme, Woodlands for Wales Strategy and the National Forest
- Cross-cutting actions through the Natural Resources Policy, Area Statements, Planning Policy, renewable energy and urban growth as contained in the Draft National Development Framework

The types of existing land use and the types of land use change recommended to deliver land contribution to the net-zero target is shown below (Figure 8). In Wales, the main recommended land use changes are from grassland to woodland cover, increased renewable energy development, agroforestry and hedges, bioenergy and restoration of peatland.

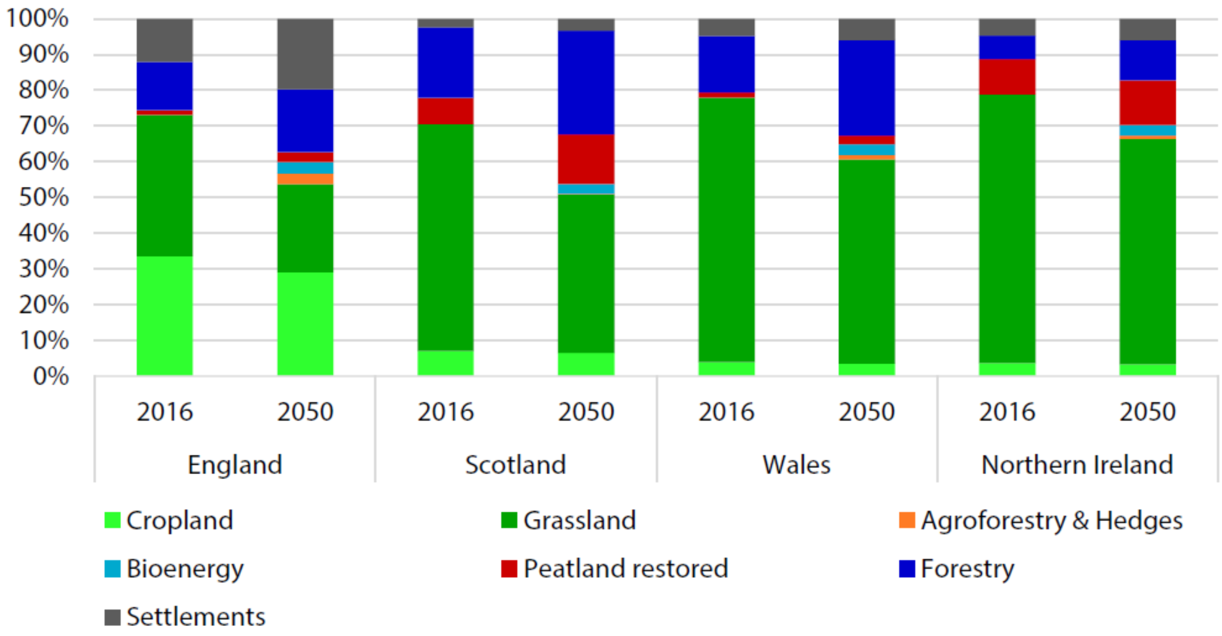


Figure 8 Land use change to contribute to the net zero UK (Source: CCC, 2020).

## Population, cultural and behavioural changes

The world's population continues to grow, albeit at a slower pace than at any time since 1950, with projections estimating further growth from an estimated 7.7 billion people worldwide in 2019 to around 8.5 billion in 2030 (UN, 2019). The population of the UK is projected to increase. The population in England is projected to grow more quickly than the other UK nations: 5.0% between mid 2018 and mid 2028, compared with 3.7% for Northern Ireland, 2.7% for Wales and 1.8% for Scotland (ONS, 2019). The population of Wales is projected to increase by 2.7% to 3.22 million by 2028, and by 3.7% to 3.26 million by 2043 (NS, 2019). As such, there may be an increase in the demand for food. As the UK imports around 45% of its food, our food system affects countries around the world (Defra, 2020b).

Recent research conducted by Agriculture and Horticulture Development Board (ADHB) into consumer environmental concerns regarding the food production system and when purchasing food showed the following results:

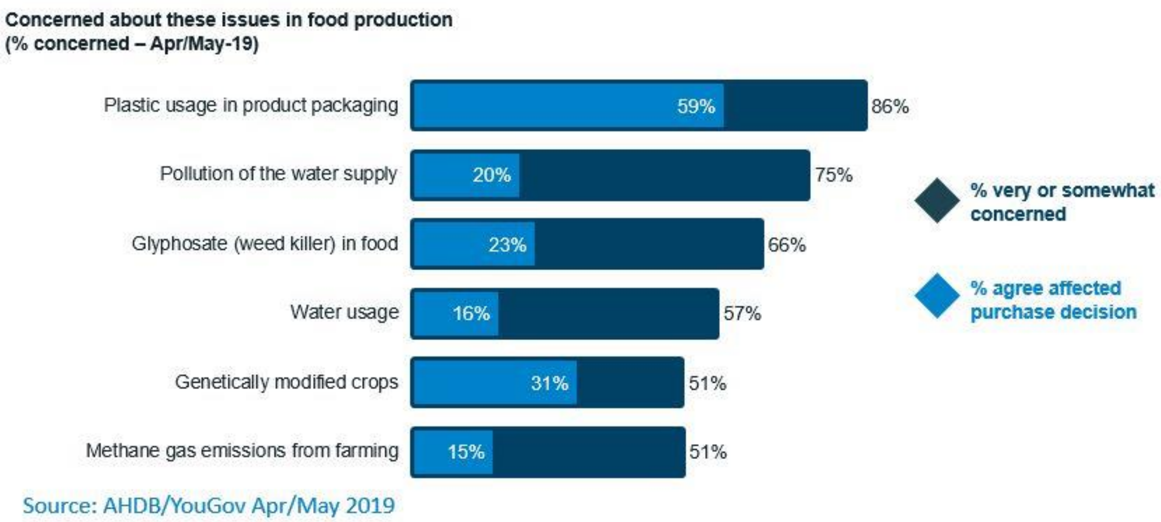


Figure 9 Consumer concerns about issues in food production results in April and May 2019, (Source: AHDB, 2019a).

According to the AHDB (2019) survey results (Figure 9):

- Plastic usage was the main concern cited by consumers.
- Eighty percent of people are trying to cut down on the amount of packaging they buy, and half would be willing to pay more for eco-friendly packaging.
- Consumer demand to minimise plastic has led to many retailers releasing statements or plans to reduce the amount of plastic.
- Methane gas emissions from farming came out as the lowest priority for consumers and are more of a driver for vegetarians, pescatarians and vegans, with 74% of this group being concerned.
- Water pollution and glyphosate usage came out as more of a concern than methane gas.
- People citing the environment as a reason for becoming vegan or considering veganism increased by 28%.

See the Waste chapter for more information about waste and the circular economy.

Other studies have shown a trend in ethical drivers in food choice with food produced locally as the main driver in 2009 (Welsh Government, 2010). This is reflected in more recent evidence in Wales showing there is a strong preference for Welsh products and supporting the local economy, with 84% of shoppers likely to support Welsh food and drink producers and 78% saying that buying Welsh produce helps the local economy and would like to see more Welsh products (Food and Drink Wales, 2017).

A recent nationwide survey of land managers (11%), land owner-managers (72%) and tenant farmers (17%) about sustainable soil management (SSM) practices on mixed (36%), livestock (33%) and cropping (31%) farms across the UK was undertaken by Outhwhite and Krzywoszynska (2020). It showed the majority of farmers were concerned about soil degradation within agriculture with 15% of those questioned extremely worried. Overall, Welsh farmers perceived their land to be less degraded than land within the UK, or land globally. Over 50% of respondents ranked preventing flooding, ensuring clean air as important and securing food supply, improving farm productivity, mitigating climate change, enhancing biodiversity and ensuring clean drinking water as extremely important for managing soils sustainably. It found there was a wide uptake of a diversity of Sustainable Soil Management (SSM) practices of 4.5 practices on average per respondent (3.5 if manuring is excluded). There were a significant number reporting using cover crops (44%), min-tillage (37%) or no tillage (32%) (Outhwhite and Krzywoszynska, 2020).

Those participating in farming networks, agri-environment assurance schemes or farming certification schemes used a higher number of SSM practices. There was also a wide use of soil assessment methods and field walking; nutrient testing and visual soil and crop assessment were the most popular (Outhwhite and Krzywoszynska, 2020).

The UK farming community is innovative and experiments with a variety of SSM practices. However, there was a weak uptake in SSM as a systematic practice within the UK and a lack of understanding about the need for a systematic approach. Participating in formal farming networks does not influence the adoption of SSM as a system and advisors do not seem to have a strong influence. This suggests a need for more communication and education about the systematic approaches to soil health (Outhwhite and Krzywoszynska, 2020).

Barriers to SSM were considered to be capital cost investment, limited knowledge, lack of evidence, availability of expertise, peer pressure (from family, land owner etc.), farm economic viability, time constraints, infrastructure and typological factors. However, 18% of respondents considered there were no barriers. Enablers to SSM practice were considered to be economic support, knowledge support, evidence, infrastructure and equipment, community support, policy and regulatory support (Outhwhite and Krzywoszynska, 2020).

A survey conducted by Farming Connect in 2018 of 911 farming businesses (10% of Farming Connect registered farms in 2018) and 705 in 2019 into Farming Connect advice and support showed out of the responses received soil sampling or nutrient management planning and animal health monitoring were the most popular single activities carried out and that a combination of activities were mainly carried out.

The surveys also included an assessment into the importance of management for biodiversity and habitat, soil quality, water quality, landscape, water, air quality was to the farm business on a score of 1 to 6 for importance and whether farm businesses had considered planting trees. Out of the responses received, the results showed for:

- Habitats and biodiversity – Responses between 2018 and 2019 show some changes, with 86% of responders selecting 5 or 6 on the scale in 2018, compared to 65% in 2019.
- Soil quality - Survey results from 2018 suggest that soil is of some concern, as around half of responses (54%) rate it at a 4 or 5 on the scale. However, in 2019, 71% of answers indicated that soil was a top priority, ranking this issue at 6 on the scale.
- Water quality – In 2018, 87% of respondents indicated that the management of water quality was at the higher end of the scale (five and six). In 2019 this was similar.

- Water management – The importance of managing water to participants in 2018 and 2019 was fairly similar, although there was an indication of higher concern in 2019.
- Landscape - in both the 2018 and 2019 survey was very similar. Results suggest that participants are moderately concerned with maintaining the landscape, although it is not as important as soil or water quality.
- Air Quality - in 2018 and 2019 was again comparable. In both years the majority of responses fell at the upper-middle end of the scale with most selecting ‘5’
- Planting trees - No clear inclination was shown to planting trees on the farm.

A good level of engagement by farmers with Farming Connect activities is indicated in the survey responses and it showed they are utilising the opportunities on offer and making practical changes to their businesses. The most popular change that respondents made on their farms in both 2018 and 2019 was in relation to managing nutrients and regularly sampling. Supporting farmers in engaging with schemes such as planting trees on their land was indicated as valuable. The farmers surveyed indicated a strong concern about biodiversity and habitats on their farms and expressed an interest in improving sustainability. Further details on benchmarking and how that has influenced a change in practices is also contained in the report along with additional survey questions (Williams, 2019).

## Direct Drivers

The main direct drivers affecting the pressures and threats to soils in Wales are climate change, land use change, and land management. Figure 10 shows the main drivers influencing soil processes driving stock change (except salinization). How the processes influence each other is discussed in Section 3 and 5.

Ecosystem services are discussed further in Section 5.

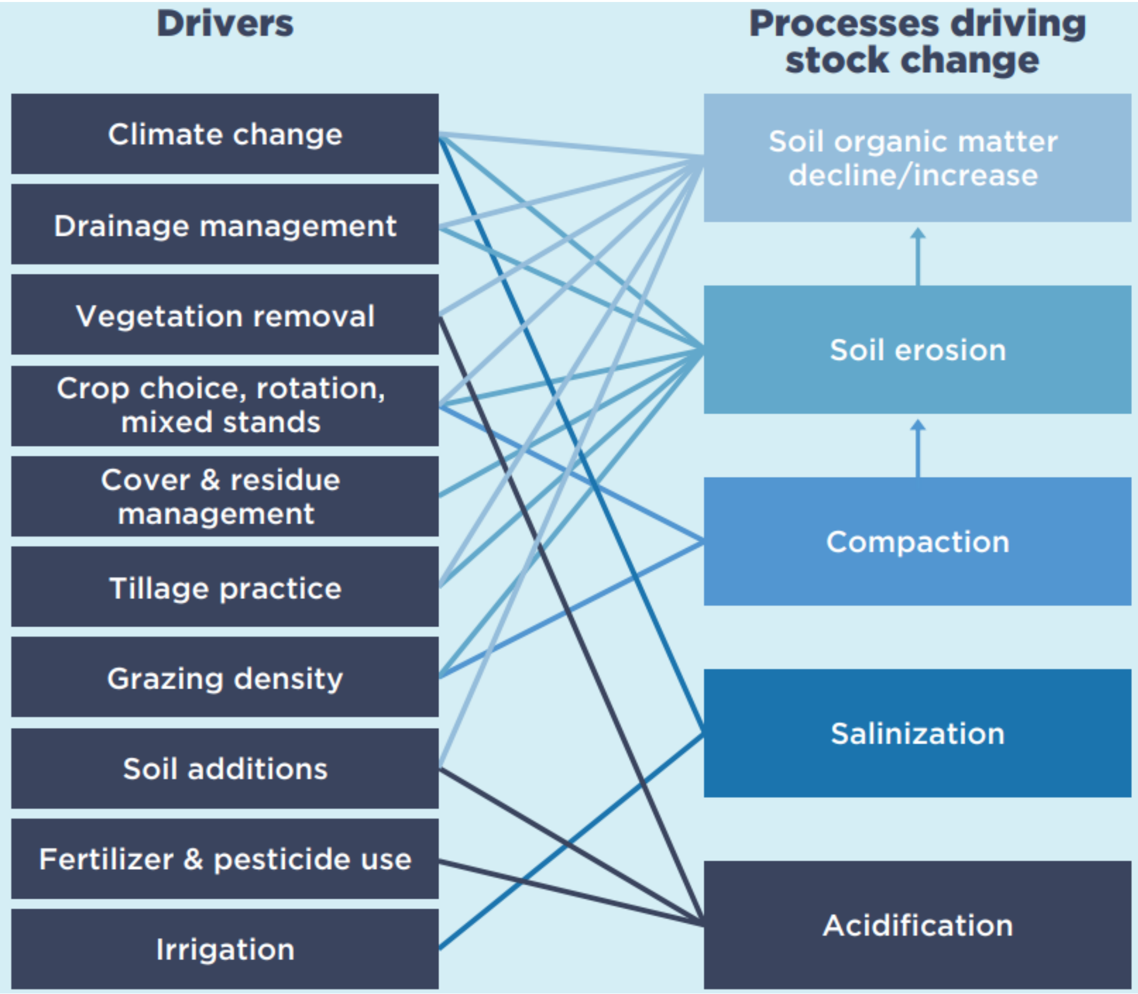


Figure 10 Key drivers of soil change (Source: Janes-Bassett and Davies, 2018, licensed under CC BY-SA 4.0).

## Climatic Change

The UKCP18 climate change impact predicts wetter winters, warmer summers, increased incidence of storms, extreme weather and rising sea levels. Sea level rise caused by climate change, along with a higher incidence of storms, increases the risk of erosion, flooding and flooding of coastal communities (Met Office, 2019).

Climate change has already resulted in, and is predicted to have, an increasingly significant impact on land use and soil in Wales as some of the evidence in the soil state and trend section indicates. Agricultural crops, animal and plant health and tree suitability, tree species distribution and productivity levels will be impacted (see SoNaRR2016). The main predicted changes to natural resources are:

## Changes to bioclimatic environments currently storing high levels of soil carbon (peat soils and organo-mineral soils with peaty topsoils)

Areas with peat and peaty soils (organo-mineral soils) currently accumulate and maintain soil carbon as they are under specific (bio)climatic conditions (low temperatures and high rainfall). These areas may be vulnerable to carbon loss due to increased temperatures, reduced soil wetness, and increased dry periods with a potential increase in GHG emissions (Keay and Hannam, 2020). Losses of carbon in organic soils may be most closely correlated with increasing temperature and changes in vegetation communities, but this requires further investigation (Alison et al., 2019b; Barraclough et al., 2015; Brown et al., 2016). Areas with peat and peaty soils can and do support a range of specialised habitats. Organo-mineral soils are an important soil type for Welsh conservation areas with 23% of the organo-mineral soil area of Wales designated as land supporting Sites of Special Scientific Interest (SSSI) (Bol et al., 2011). Furthermore, 40–45% of the total area of Welsh Sites of Special Scientific Interest (SSSI), Special Protection Areas (SPA) and Special Areas of Conservation (SAC) are on organo-mineral soils (Bol et al., 2011). The climatic shift may change soil conditions. In particular, there may be feedbacks resulting in state shifts not yet understood, and therefore, limits capabilities for planning and projecting impacts on condition and function of these habitats in the future (Robinson et al, 2019; Van der Putten, et al., 2013). See the Mountains Moorlands and Heaths chapter for more information on peatlands.

Results from the ERAMMP monitoring showed high degrees of soil water repellency in Welsh soils. It found that 92% of soils across Wales show some degree of water repellency across a large-scale gradient of soil, vegetation and land-use (Seaton et al., 2019). A link was found between a wetter climate and low nutrient availability, which alters plant, bacterial and fungal community structure. This indicates a link between environmental stress, the behaviour of the soil biological community, and the hydrological behaviour of soils. In the long run, this will help us understand the resilience of ecosystems to climate change.

In addition, results from a long-term (20 years) climate change study in North Wales identified that persistent drought combined with extreme drought events lead to soil structural change (Robinson et al., 2016). Cracking the subsoil released perched water from the topsoil, reducing the topsoil moisture content, which has not recovered to date. High levels of soil moisture are associated with high carbon levels, therefore dewatering may increase carbon loss as observed in the experiment. A soil moisture state change related to climate is supported by observations from Plynlimon for podsols under forestry behaving in the same way following extreme drought. The results of this work suggest that an understanding of how climate change will impact soil moisture relations and the potential of these mechanisms to result in alternative soil moisture states is needed (Robinson et al., 2019), as well as their implications for soil resilience, crop and water resource management. Consideration should be given in increasing the capacity to monitor the impact of climate change to support measuring long-term change and climate predictions. Remote sensing can be challenging in the Welsh topography and the use of ground based sensor networks should be explored (Robinson, *per comm*).

## Agricultural (and forestry) potential will improve in some areas

Some areas may see a shift from grassland to arable systems as areas become more climatically suitable for horticultural or a combination of crops. Land that is currently not graded as Best and Most Versatile (BMV) may improve sufficiently in grade in the future to be included in BMV. Consideration should be given to these areas under planning policy to protect future potential (Keay and Hannam, 2020). Changes in land use may increase the risk of soil threats such as erosion by converting from grass to arable land with periods of bare soil over a growing season. Tree species suitability will change in range and productivity with most species' flexibility and productivity gains in the north and west of Wales.

## Agricultural (and forestry) potential will decrease in some areas

In these areas the changes in overall Agricultural Land Classification grade are primarily driven by an increase in the drought criteria. This is a result of increased temperatures over the growing period and reduced summer rainfall. These areas will need to be irrigated in the future if they are to maintain productivity, particularly if they are used for higher value arable and horticultural crops. Crop selection and agricultural practices may need to change in the future, and will subsequently increase competition for water resources. Water capture during winter may need to be implemented to compensate for the water deficit in the summer months. Soils need to be high in organic matter and structurally in their best condition to be able to retain as much moisture as possible and allow unimpeded drainage (Keay and Hannam, 2020). Tree species like beech and sitka spruce will become increasingly less suitable in the east and south of Wales.

## Changes in the seasonal distribution and intensity of rainfall

Some areas show a reduction in the number of field capacity days (FCD) in the future, however most areas in Wales will have a similar number of FCD to the baseline period. In areas where there is little change in FCD in the future, there would be limited capacity for the soil to cope with the additional winter rainfall and increased frequency of intense winter rainfall events. These extreme rainfall events are projected to be similar to winter rainfall in the UK during the winter of 2019/2020, which resulted in widespread flooding. With the shift to the field capacity period later into autumn/early winter, there could be greater opportunity for autumn sown crops. The soils may take longer to dry out in the spring due to an increased winter rainfall, potentially reducing the opportunity for access to land for spring cropping, cultivations or grazing. The successful preparation for, and establishment of, newly planted trees is likely to be more difficult with changing rainfall patterns with an increased risk of soil erosion with clearfelled areas prior to any re-stocking (Keay and Hannam, 2020).

The LANDMAP, Landscape and a Changing Climate report (2019) shows how the landscape may change to a greater or lesser degree, in the short or long-term (Berry et al., 2019).

There has been much debate over the reason for measured declines in UK soil carbon concentrations over the last few decades. Are they a result of climate change or other factors such as changes in land management or recovery from acidification? Given the predicted increases in temperature and changes in the seasonality and magnitude of rainfall events, changes to soils and the services they provide are highly likely, particularly if land-use patterns also change (Rollett and Williams, 2020b).

The effects of climate change on soil microbial and soil microbial-plant interactions could have ramifications for the composition and function of ecosystems (Classen et al., 2015). A study based on Demonstration Test Catchments in England reported that the underlying trend of increasing P losses under climate change is larger than the theoretical reduction predicted for maximum uptake of farmer-preferred mitigation options (Ockenden et al., 2017).

## Land Use Change

See sections 3 and section 5

## Land management systems and practices

Permanent grasslands are the main component of agricultural land and can be improved, semi-improved or unimproved (semi-natural) depending on the management practices. Improved grasslands are subject to more intensive management practices compared to semi-improved grasslands as they receive more inputs (see Enclosed farmland chapter for further information). Unimproved grasslands are discussed in the Semi-natural grasslands chapter

Productivity provides a measure of how well inputs are converted into outputs with UK trends showing that:

- Total factor farm productivity decreased by 2.1% between 2017 and 2018 driven by a fall in production volumes combined with a slight increase in volumes of inputs (Defra, 2019).
- Since 1973 total factor productivity has increased by over 53% driven by a 36% increase in the volume of outputs and a 12% fall in the volume of inputs (Defra, 2019; Welsh Government, 2019c).
- Animal feed is the single largest input and showed an increase of 2.4% overall (Defra, 2019; Welsh Government, 2019c).
- The largest decrease in inputs was from fertilisers. This input decreased by 9.7% in volume between 2016 and 2017 (Welsh Government, 2019c).

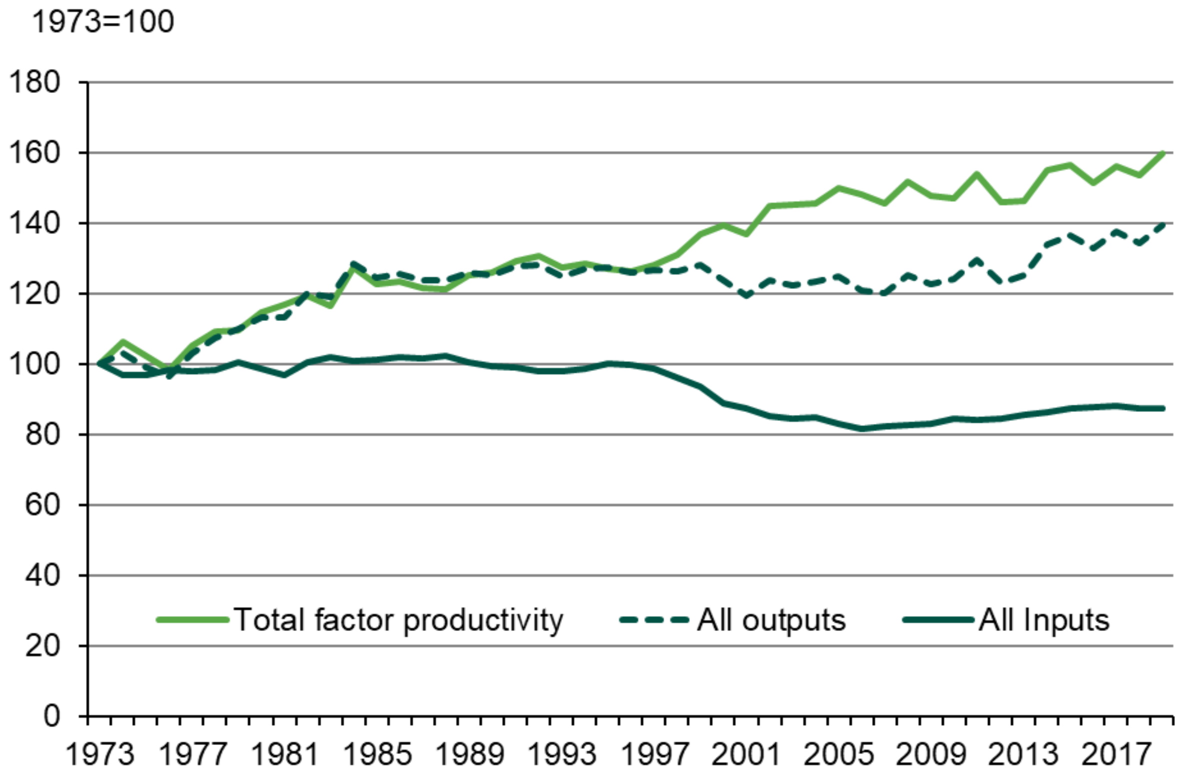


Figure 11 Total factor farm productivity in the UK 1973–2018 (Source: Defra, 2019; Welsh Government, 2019c).

Total factor productivity in UK agriculture is not measured at a regional or country level. In Wales, although the overall weight and rate of plant protection products or pesticides have declined, the area of use has increased (see Enclosed farmland chapter).

The drive to increase profits, efficiency and production using fewer inputs risks an increase in specialisation which could lead to a reduction in genetic diversity, cropping type, habitat and species diversity and underlying ecosystem condition. High biological diversity and better ecosystem condition is positively related to improved ecosystem resilience and provision of many ecosystem services (see Ecosystems chapters, Biodiversity chapter and Aim 2 chapter). Choices in silvicultural management system, tree species diversity and genetic diversity and its conservation are known to influence woodland condition and ecosystem resilience (see Woodlands chapter).

# 5. Ecosystem services for well-being

Soils play a pivotal role in major global biogeochemical cycles (carbon, nutrient, and water), while hosting the largest diversity of organisms on land. Because of this, soils deliver fundamental ecosystem services and management to change a soil process in support of one ecosystem service; this can either provide co-benefits to other services or result in trade-offs (Figure 12) (Smith et al., 2015).

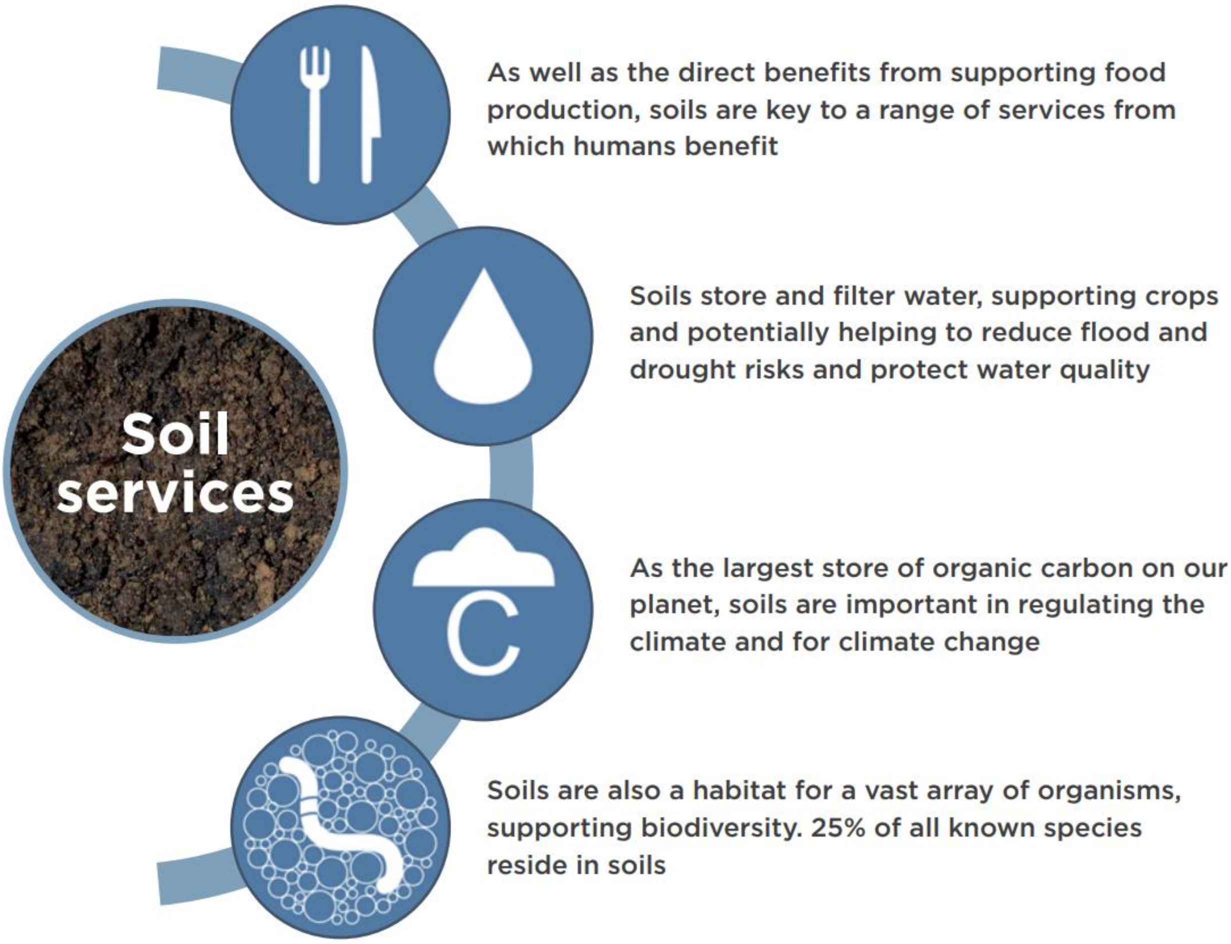


Figure 12 Soil services and benefits (Source: Janes-Bassett and Davies, 2018, licensed under CC BY-SA 4.0).

# Assessment: Healthy places for people protected from environmental risks (Aim 3)

## Cultural services: landscape quality

As well as producing food, the agriculture sector is positively contributing to the delivery of highly valued landscapes. More than 50% of the Welsh landscape are nationally and regionally evaluated as outstanding (11%) or high (40%) for their distinct and recognisable landscape patterns, scenic quality, character, and qualities (White, 2018). Collectively, these valued landscapes provide multiple aesthetic, mental and physical well-being benefits for rural communities and visitors. Visual and sensory data identified that 57% of landscapes remained constant, 34% were regarded as in decline and 9% were considered to be improving (Welsh Government, 2020b). SoNaRR2016 reports on key pressures and threats to landscapes (NRW, 2016b).

National Parks and Areas of Outstanding Natural Beauty are the most cherished landscapes, covering 25% of Wales, and these provide vital cultural services for residents and visitors. Snowdonia has seen a 15% rise in visitor numbers over five years (2015–2020) and across all National Parks, the visitor economy generated over £1.2 billion in 2018. With increasing visitor numbers come economic and health benefits. However, risks of ‘over-tourism’ in certain locations can have a negative impact on biodiversity and requires careful management and investment to respond to the pressure. Land uses with low light pollution benefit sensitive biodiversity sites, human health, and enjoyment of natural and cultural environments.

Starlight tourism is increasing and 46% of Wales was associated with negligible levels of night-time light pollution in 2009, although increasing lighting is threatening the benefits of dark skies. In Wales, the Brecon Beacons National Park, Snowdonia National Park, Elan Valley, and the Gower all have Dark Sky status and three other Areas of Outstanding Natural Beaty are looking at community dark sky designation. There is an all-Party Parliamentary Group for Dark Skies recently established in January 2020. New analysis in 2020 will identify the scale of this pressure and its impact on tranquillity.

## Access and health

The Wales Coast Path and National Trails enable health benefits and enjoyment of many highly valued and designated landscapes. Access for people to terrestrial, non-urbanised ecosystems is primarily via the Public Right of Way (PRoW) network and designated Open Access land, the majority of which are on/through agricultural land. There are approximately 33,000km (20,750 miles) of PRoW in Wales and almost all the land contained within the Mountain, moor and heath ecosystem and Common Land is designated as Open Access land. Over half of UK day visitors (54%) and around two thirds (67%) of staying visitors to Wales listed the landscape as a reason for visiting in 2016 (Welsh Government, 2019c). Of the outdoor activities listed by staying visitors, walking (75%) was the main activity. Walking generated an estimated £562 million of additional demand in the Welsh economy and £275 million of GVA in 2009 (Engledew et al., 2019). The Wales Coast Path contributes £84 million a year to the Welsh economy (Engledew et al., 2019). The total spend in Wales on tourism in 2018 was £6.3 billion; tourism overall accounts for 9.5% of employment in Wales, but in some counties like Pembrokeshire and Gwynedd, the share of the employment is as much as 14% (Welsh Government, 2020b). Wales has some of the most varied geology in the world and provides evidence from the earth's early history from the last Ice Age to the present day – covering some 1.4 billion years. There are two UNESCO Geoparks in Wales (GeoMôn on Anglesey and Fforest Fawr in the Brecon Beacons). Work by UNESCO has found that on average the UK Geoparks add approximately £2million to the local economy. See also the Woodlands chapter.

## Decarbonisation

The way land is used and managed provides important regulating services (climate regulation, air quality, and flood and drought mitigation) that benefits well-being. Modelled results for the Land Use, Land Use Change and Forestry (LULUCF) accounts showed a net reduction (-0.44 Mt$CO_2$e) in GHG emissions in 2018 in Wales (Figure 13) (NAEI, 2020). This was mainly due to the action of forest land removing carbon dioxide from the atmosphere (Table 14). The sector comprises both sinks (-2.15 MtCO2e) and sources (1.71 MtCO2e) of emissions (Table 14 and Table 15)(NAEI, 2020).

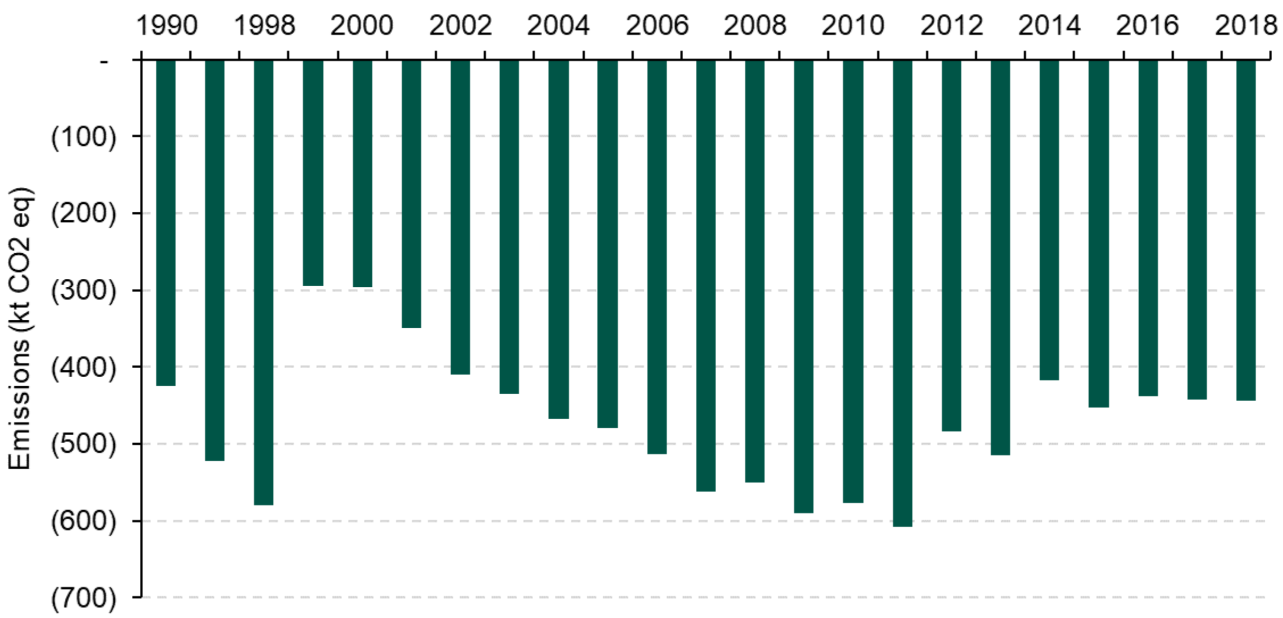


Figure 13 LULUCF Sector GHG balance (Source: NAEI, 2020).

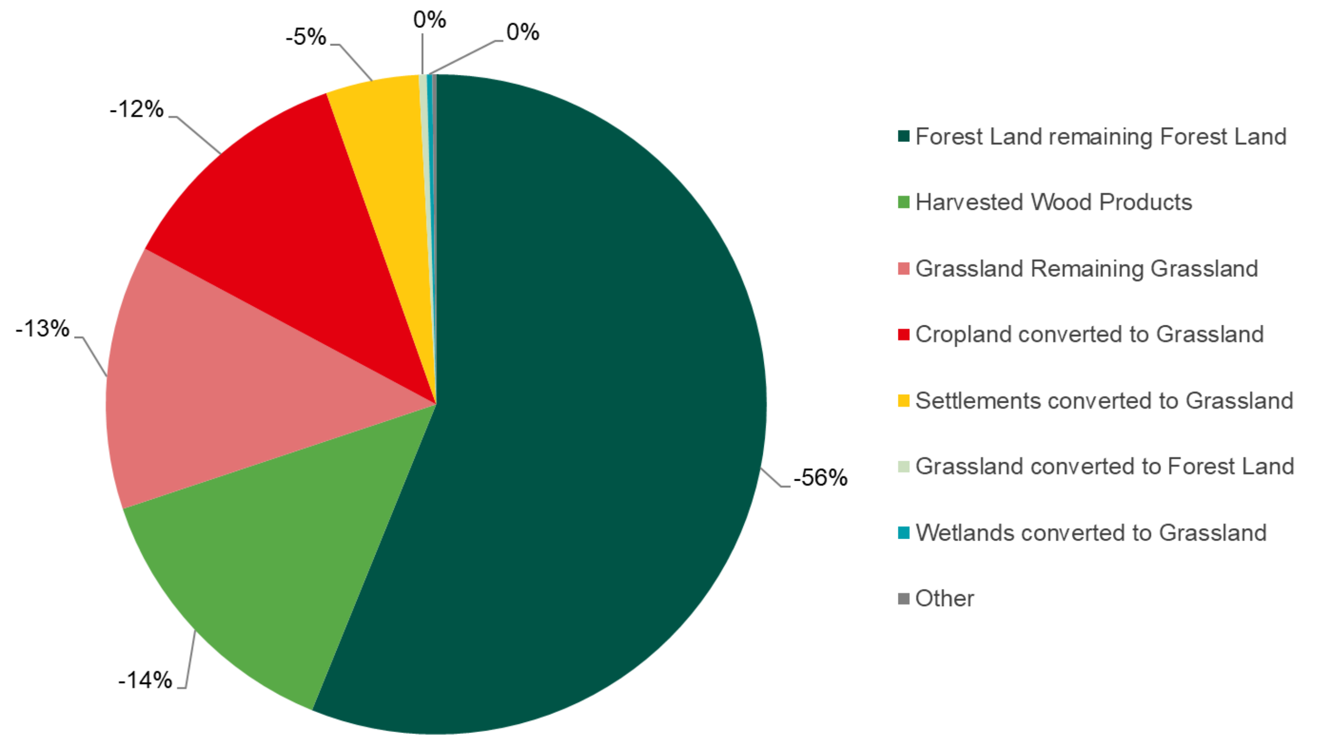


Figure 14 LULUCF Sector Sinks 2018 (Source: NAEI, 2020).

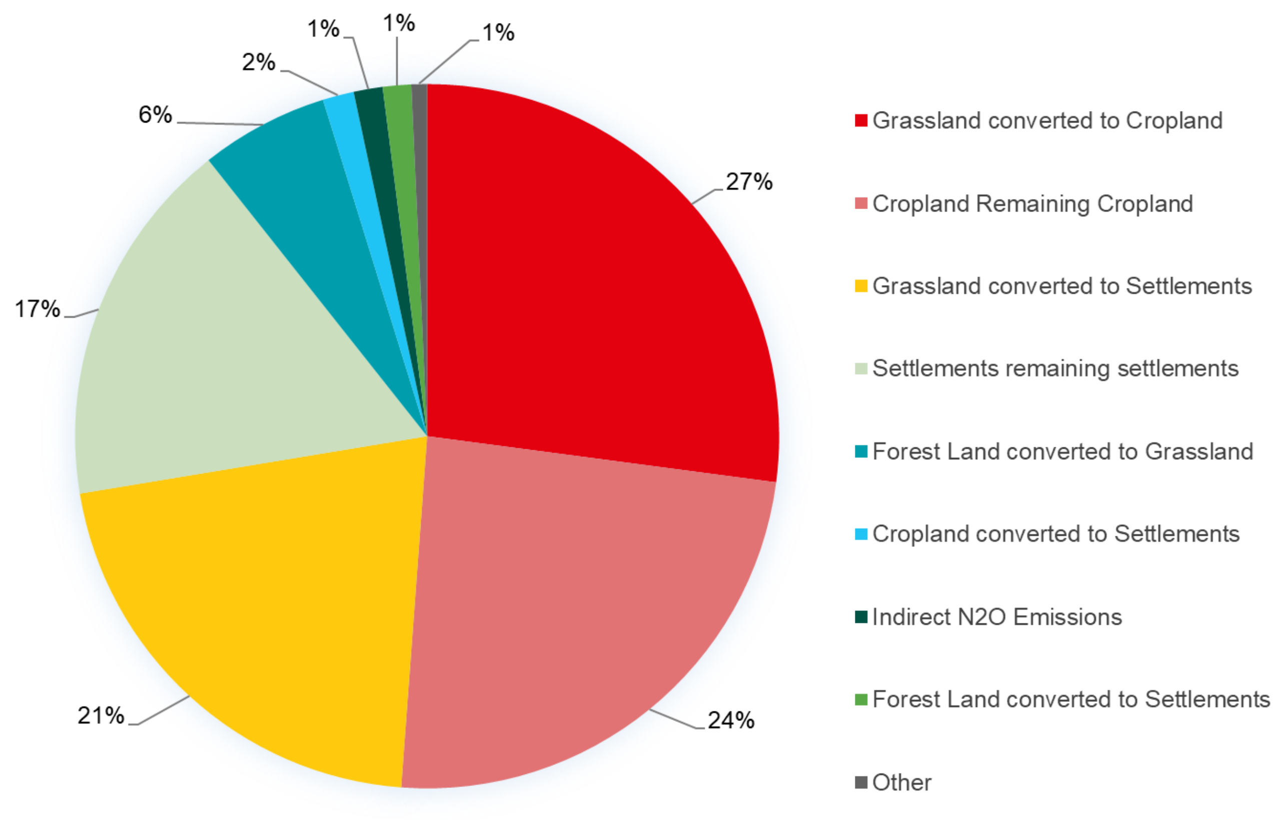


Figure 15 LULUCF Sector Sources 2018 (Source: NAEI, 2020).

The aim for a low carbon Wales is to significantly increase the LULUCF sink in Wales by the year 2030 by increasing tree cover, reducing carbon loss from peatlands, and building carbon stores within soils and biomass.

Semi-natural peatlands cover approximately 66,000ha and, if restored, emissions reductions of approximately 70 kt $CO_2$-eq yr-1 would be achieved; however, the most intensive emissions are from intensively managed grassland and arable land (not semi-natural habitats) (Welsh Government, 2019f). If all Welsh peatland were brought into sustainable management, it would secure a further 230 kt $CO_2$-eq yr-1 of emission reductions (Welsh Government, 2019f).

Peatland is not well represented in current carbon budgets as it only considers emissions from peatland extraction for fuel or horticultural use, which is a small component in Wales. It is expected that a new methodology will be introduced which will take account of a wider range of emissions from peatland. This will alter the overall LULUCF inventory for Wales (Welsh Government, 2019f).

The estimated carbon sequestered by agricultural and woodland land use in Wales is shown in Figure 16.

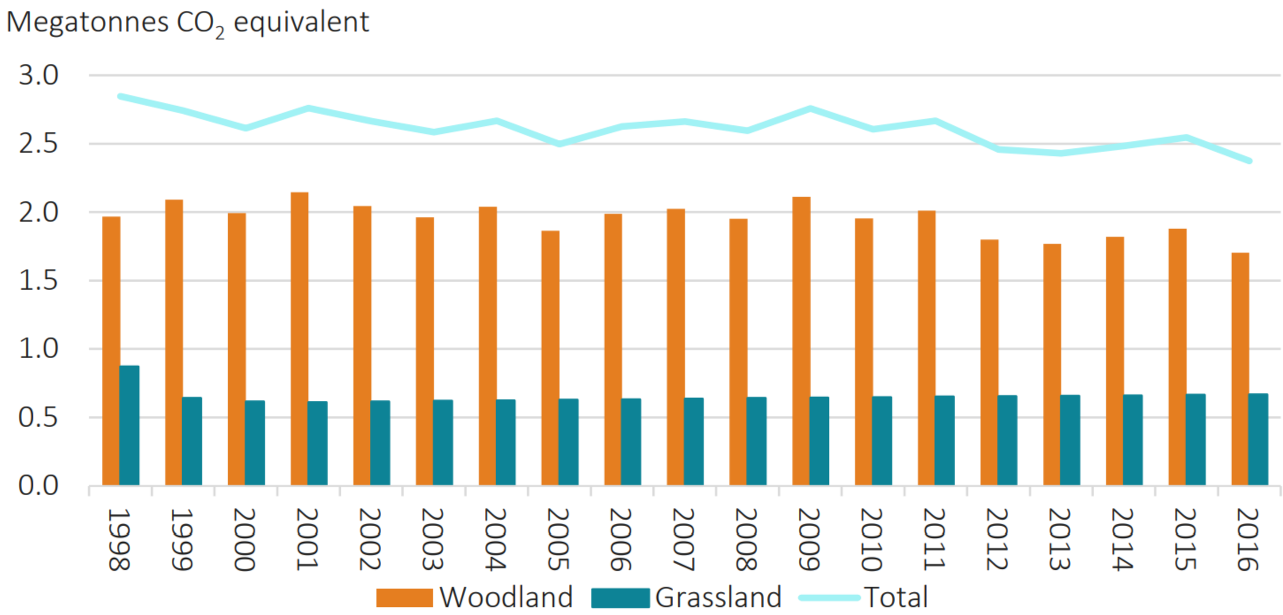


Figure 16 Carbon sequestered by wFoodland and grassland in Wales 1998–2016 (Source: Engledew et al., 2019).

## Air Quality

Land use and air pollution removal depends on the vegetation type and pollutant (Figure 17). Absolute air pollution (PM2.5, PM10, $NO_2$, $NH_3$ & $SO_2$) removal by vegetation was on average 64% on farmland and 33% on woodland. However, this reflects the extent of habitats more than the habitat's effectiveness at removing pollution as farmland, on average, removed 52.0 kilograms of pollutant per hectare over the time series (2007–2017) in comparison to 101.3 kg/ha for woodland (Engledew et al., 2019). See the Air quality chapter for further information.

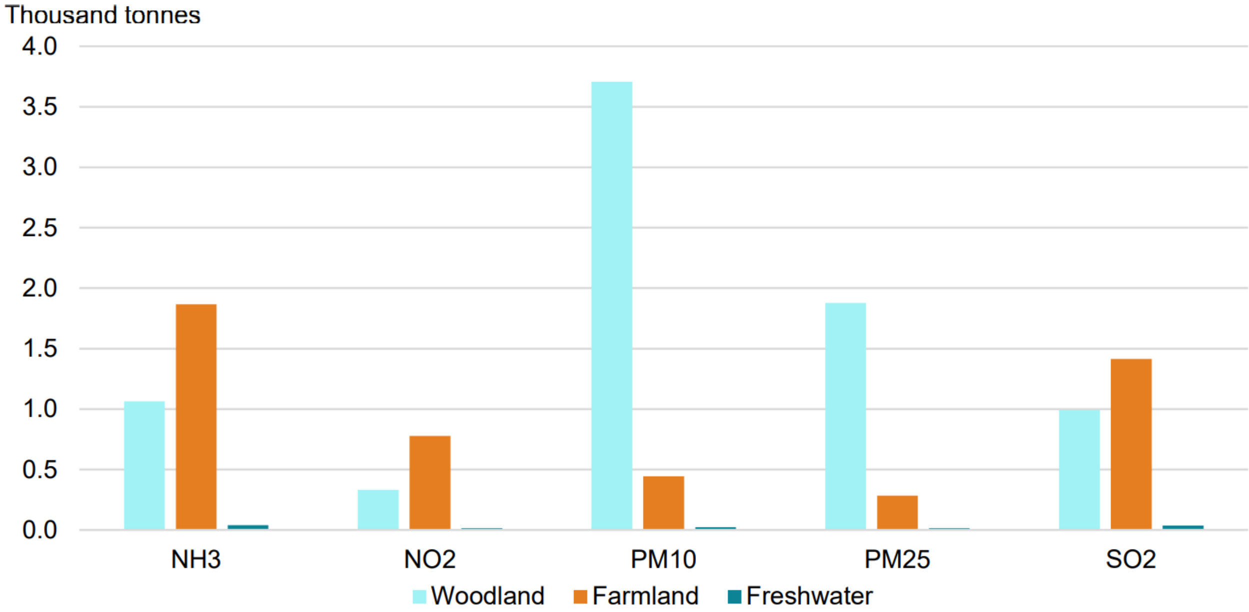


Figure 17 Air Pollution removal by woodland and farmland (Source: Engledew et al., 2019).

## Catchment management solutions

SoNaRR2016 highlighted the need to maintain, enhance and restore flood plains and hydrological systems to deliver ecosystem resilience and multiple benefits such as reduced risk of flood and drought and improved water quality and supply.

Natural sustainable drainage approaches to flood and drought risk management intend to protect, restore, and emulate the natural processes in catchments. It does so by storing and slowing water, increasing flow connectivity, and increasing soil infiltration and storage capacity. By slowing the flow of water in the uplands, this can lead to reduced flooding, balance flows in smaller watercourses, provide a lag and reduction in peak flows downstream giving more time to implement flood mitigation measures. There are many research projects assessing the impact of and options for natural catchment management to reduce the impact of flooding and droughts. These include Pontbren, sustainable drainage systems, LANDWISE, Protect-NFM and Q-NFM with associated case studies and rural sustainable drainage systems (Environment Agency, 2012) including the restoration potential of semi-natural habitats in Welsh flood plains – using the Wye catchment as an example (Rothero et al., 2018).

The National Strategy for Flood and Coastal Erosion Risk Management in Wales identifies the opportunity for farming and land management policy to widen the implementation of natural flood management (NFM) to those without direct responsibility for managing flood risk management. The Sustainable Farming and our Land consultation (Welsh Government, 2019i) contain a number of proposals relating to NFM.

Further research continues into these approaches to better understand their impact, costs and long-term maintenance needs. At the same time the barriers to further uptake of such schemes needs to be considered and ways to ensure their longevity must be developed on a parity with engineered defences to help alleviate local flooding and identify the benefits that natural approaches delivers. It is clear from recent flooding experienced in Wales (February 2020) and future climate change projections that land use change, and where houses are built and infrastructure designed, are key considerations as weather patterns change and the frequency and intensity of storms and droughts increase.

## Assessment: Towards a sustainable economy with more efficient use of natural resources (Aim 4)

The main provisioning benefits from land uses and soils, are food, water, fibre and timber. See the Woodlands chapter for timber, Enclosed farmland for arable and horticulture and the Water Efficiency chapter and Freshwater chapter for water supply.

Soils are a key natural resource asset for food production as it provides nutrients, water and physical and biological support for plants, which is critical to agricultural productivity. Agricultural soils also provide a range of other services and public benefits (Janes-Bassett and Davies, 2018) including directly and indirectly a source of livelihoods for rural communities and the wider economy (FAO, 2020). The food and drink supply chain in Wales (primary production, manufacturing, retail, wholesale, and non-residential catering) contributed a total Gross Value Added (GVA) of £4.7bn in 2016. It employs 217,000 (2017) people, down from 232,000 (2016) (Welsh Government, 2019j).

Beef, sheep, poultry, and dairy produce collectively made up 80% of Welsh agricultural forecasted output in 2018 (Welsh Government, 2019b). Overall UK meat and milk production has been increasing in the UK from 2016 to 2018 (Defra, 2020). Beef, pork and sheep meat production estimates in Wales are lower in 2019 than in 2016. Beef and sheep meat production increased in 2019 compared to 2017 and 2018. There was no change in pork production over this time (HCC, 2020b, pers comm). Milk production in Wales was estimated at 1,976 million litres for 2019/20, just 0.2% higher than the level estimated in 2018/19 (AHDB, 2020d) and was 1,971m litres in 2018/19, up 7% since 2016/17 (AHDB, 2019b). There has been significant restructuring in the last 20 years; the number of dairy farms has halved but the Welsh dairy herd has expanded such that average herd size has doubled (Welsh Government, 2019c). Provisional UK overall meat and milk production for 2019 shows a provisional increase (Defra, 2020). However, more recently the impact of the global pandemic had an immediate impact on the dairy sector with the closure of the food service and hospitality sectors leaving some processors without a viable outlet for their milk and milk products. A marketing campaign and other measures were launched to boost consumer demand for milk and to enable more collaboration to resolve the issues (Welsh Government, 2020b).The latest Welsh meat industry statistics and a breakdown of the dairy and meat trade flow in Wales and the importance of the EU export market are available online.

Modifying and innovating current practices and supply chains could improve the productivity and resilience of agricultural production systems in a way that safeguards and enhances the environment and ecosystem resilience. Water and climate-smart production systems will become increasingly important as water scarcity is predicted to increase and as agriculture seeks new ways to reduce the emission of greenhouse gases, ammonia emissions and the associated use of fertilizers and other agricultural inputs (FAO, 2020). Extreme weather events, market volatility and uncertainty over future trade all impair stability and production. Policies, technologies, and practices that build producers' resilience to threats would also contribute to sustainability. Resilience therefore becomes central to the transition towards a sustainable agriculture and must address both the natural (ecosystem) and the human dimensions (well-being) (FAO, 2020).

Potential pathways for safeguarding the stocks of soils and building ecosystem resilience to safeguard and enhance the soils supporting services are shown in Figure 18.

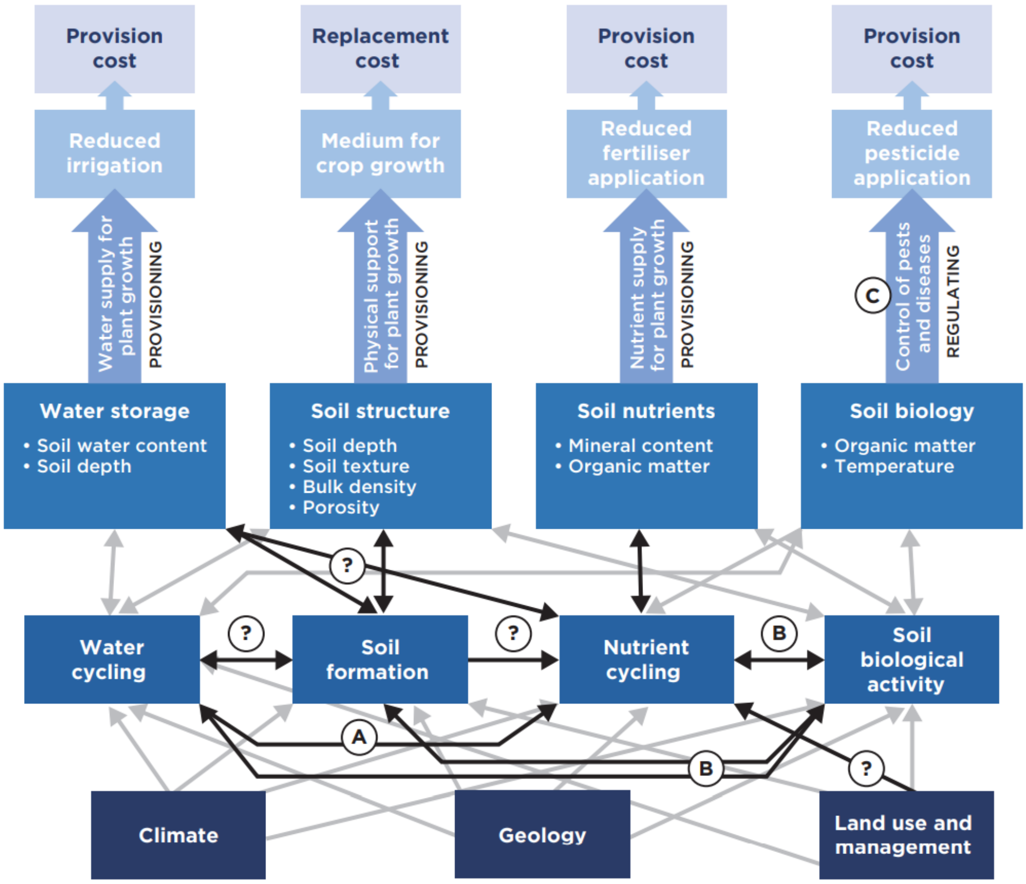


Figure 18 Ecosystem services for food productivity and well-being benefits (circles show key gaps in knowledge or modelling capabilities) (Source: Janes-Bassett and Davies, 2018, licensed under CC BY-SA 4.0).

## Soil formation and soil carbon (Supporting Service SMNR Aims 1 and 2)

Soil formation is a fundamental supporting ecosystem service. The nature and properties of the soil that form and develop at any location are dependent on the interaction over time of: climate, topographical relief (elevation, orientation and slope of terrain), parent materials (geology), past geomorphological processes, land use, and the ecosystem within which the soil forms. Soil formation rates (by weathering) in Europe under current conditions are estimated to vary between 0.3 and 1.2 t/ha/yr (ADAS, 2019a).

Accumulation of soil organic matter (SOM) is important for soil formation as the relatively cool and wet climate of Wales encourages the formation of organic rich soils. On the whole, soil C contents are close to equilibrium with soil type and land use in Wales (Adams, 2015; Detheridge et al., 2014), peaty soils have a high carbon (>12%) and organic matter content (>20%), while Welsh soils are estimated to contain 410 million tonnes (NRW, 2016b; UKNEA, 2011).

The total area of deep peat soils in Wales is more than 90,000ha (circa. 4%). Peatland is discussed in the Mountain, Moorland and Heath chapter. Shallow peaty soils (organo-mineral soils) cover an additional area of 359,200 ha (17.3%) (UKNEA, 2011). SoNaRR2016 reported that maintaining the carbon content of these soils is a key priority in limiting overall greenhouse gas emissions in Wales as well as managing water resources in the face of inevitable climate change (NRW, 2016b). A good understanding of how land use and management has impacted the extent or condition of organo-mineral soils across Wales which are an important carbon store and habitat is currently not available (Robinson *pers. comm*; Berdeni et al., 2020).

In 2016, the Office for National Statistics (ONS) published preliminary estimates of carbon stock accounts for geocarbon (coal, oil and gas) and biocarbon. These partial accounts estimated there were 4,266 million tonnes (MtC) of recorded biocarbon in the UK in 2007, of which 94.2% (4,019 MtC) was contained in soil stocks and 5.8% (247 MtC) in vegetation stocks (ONS, 2016).

Soil organic carbon (SOC) and soil organic matter (SOM) underpin many important soil functions and services, such as:

- Nutrient cycling by providing food sources and habitat for the soil biological falison
- Soil water retention, storage, infiltration and reducing the rate of surface run-off and increasing groundwater re-charge (ADAS, 2019a; Alison et al., 2019a).
- The maintenance of soil structure and reduced susceptibility to erosion (ADAS, 2019a; Alison et al., 2019a).
- Increase in yields, especially of non-legume crops on organic farms (Alison et al., 2019a).
- Increased workability of soils (ADAS, 2019a; Alison et al., 2019a).
- Ecosystems in good condition contribute to biodiversity, carbon storage and sequestration, regulation of stream base flows, surface water run-off and downstream flood peaks (IPBES, 2016).

- Climate change mitigation (ADAS, 2019a; Alison et al., 2019a). This has been promoted by the 4 per mile or 4 in a thousand initiative highlighting that a significant decrease in the level of $CO_2$ in the atmosphere can be achieved by the marginal increase in C stocks of 0.4% on all soils globally (Alison et al., 2019; Minasny et al., 2017).

## Soil Biodiversity (Supporting Service SMNR Aims 1 and 2)

Soil biota accounts for ~25% of global biodiversity and is vital for nutrient cycling and plant growth (George et al., 2019). Essential ecosystem services provided by soil biota include (Jeffrey et al., 2010):

- Decomposition and cycling of organic matter and carbon to maintain soil fertility and health and recycling of organic waste materials (UKNEA).
- Regulation of nutrients' availability and uptake through biological nitrogen fixation (BNF). This includes phosphorus (mycorrhizal associations) and sulphur cycles (Chen et al., 2019).
- Regulation of nutrients' availability and uptake by nitrogen mineralisation.
- Mineral weathering of inorganic nutrients.
- Suppression of pests and diseases.
- Maintenance of soil structure and regulation of soil hydrological processes.
- Gas exchanges and carbon sequestration.
- Soil detoxification of pollutants.
- Plant growth control through the regulation of nutrients' availability and above ground biodiversity.
- Contributing to pollination service by providing a habitat for pollinators.

## Nutrient Cycling (Supporting Service SMNR Aims 1 and 2)

The benefits provided by nutrient cycling are:

- Nitrogen makes up almost 80% of the gases present in the atmosphere and this can be transformed into plant-available form through the process of biological nitrogen fixation (BNF) (Jeffrey et al., 2010).
- Estimates of global BNF range from 100 to 290 million tonnes of N per year, of which 40–48 million tonnes are estimated to be biologically fixed in agroecosystems (Jeffrey et al., 2010).
- Nitrogen fixation from symbiotic microorganisms can range between 30 and 300 kilograms of nitrogen per hectare per year (Jeffrey et al., 2010).
- Earthworms play an important role in soil nutrient cycling by modifying the soil structure, rates of decomposition, and microbial communities. It has been estimated that earthworm populations in agroecosystems can beneficially affect soil nitrogen by 10 to 74 kgN per hectare per year (Jeffrey et al., 2010).

Organic materials such as crop residues, manures, and slurry are often used on agricultural land. They are a source of organic matter and nutrients to maintain or improve soil fertility, including materials that are regulated as waste. Sewage sludge (biosolids) and waste derived products will be referred to as biowaste in this section – see the Waste chapter for further information.

Organic matter is critical as it:

- Is a source of major plant nutrients such as nitrogen, phosphorus, potassium, sulphur, and magnesium;
- Reduces the need for artificial fertilisers;
- Contributes to maintaining good soil structure, enabling roots to penetrate through the soils more easily and retain more moisture;
- Provides binding sites for nutrients held weakly that become readily available to plants or in the organic form which becomes available by microbial activity (Defra, 2010)
- Increases organic carbon, aggregate stability, decreasing soil bulk density and improving the soil physical quality compared to soils using only inorganic fertilisers (Herencia et al., 2010)
- Has a higher functional diversity index in soil microbes compared to artificial fertilisers as a result of a higher number and diversity in soil microbes, organic carbon content and soil fertility (Sradnick et al., 2013)
- Can significantly increase microbial biomass and abundance of bacteria and fungi (Malik et al., 2012)
- Provides a long-term slow release of available phosphorus (Malik et al., 2012)
- Can bind toxic substances such as heavy metals to humus (mineralised from organic matter) and prevent them from entering the wider ecosystem (Jeffrey et al., 2010)

## Water Quality and Quantity

The types of soils and the geological formations that underlie soils have a significant influence on the supply and transfer of water. Groundwater contributes to river baseflows and supplies water to springs, aquifers, wells, and boreholes, which will be more prone to drying up without the supply of stored water in soils and groundwater. Wales is also a major exporter of water to England. The quality and quantity of water are intrinsically linked to soil management and has a significant influence on compliance with the Water Framework Directive standards, such as from diffuse water pollution, soil erosion and surface run-off, as soils can contain sources of nutrients, pathogens, sediments and chemicals. Managing soils sustainably can help mitigate flood flows through attenuation, for example by reducing levels of soil compaction (see 3.2) and mitigate pollutant transfers. See the Freshwater chapter, and Figure 19 for further information.

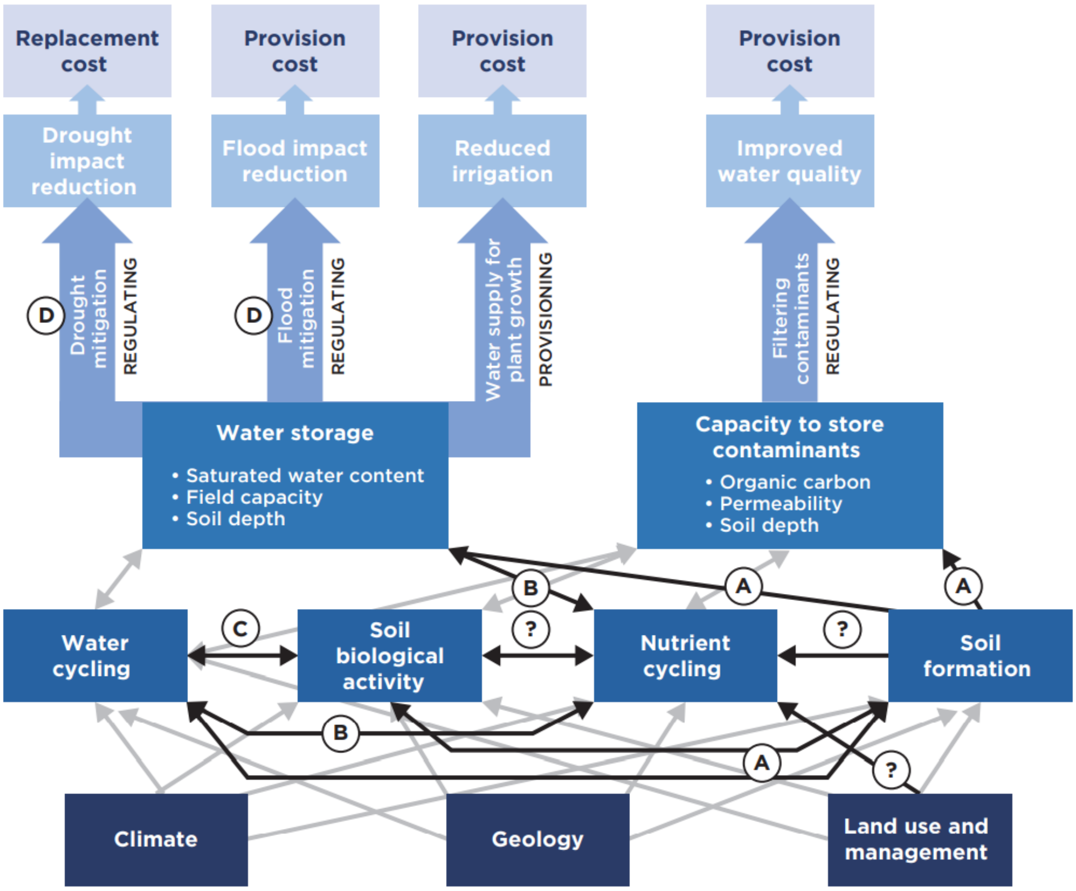


Figure 19 Water regulation natural capital pathway (Source: Janes-Bassett and Davies, 2018, licensed under CC BY-SA 4.0).

As soils are a managed resource that are fundamental to biomass production, they play an important part in the economy. Understanding this contribution and how use and degradation impacts the economy is challenging. Global efforts are under way to incorporate soils into environmental accounting (Hein et al., 2020). The UK is contributing to this effort through the development of natural capital accounts by the Office for National Statistics. However, valuing soils and accounting for them is a challenge, as demonstrated by Obst (2015) and Robinson (2017). A recent analysis of the economic impact of degradation on the soils of England and Wales (Graves et al., 2015), was estimated at ~£1.2 billion. Of this, about 20% represents a direct cost to productivity or onsite costs, while 80% is attributed to off-site costs and a loss of ecosystem services. This helps to understand why there is little financial incentive to correct soil degradation for landowners.

# 6. Making a change – discussion of trade-offs and synergies

Land use change to increase tree cover, more sustainable management of soil, peatland restoration and renewable energy have been identified to contribute to decarbonisation policies, nature recovery, flood and drought mitigation and the supply of clean air and water. SoNaRR2016 indicated that two changes in particular would make the biggest impact on well-being: more tree planting and peatland restoration. The following options illustrate where focusing on different approaches can provide the simultaneous supply, or a reduction of other services in terms of land use change and management to tackle the climate and nature emergencies, sustainable soil management, and continued food and fibre production.

## More peatland restoration

Two-thirds of Wales's peatland resource requires action to improve the delivery of critical ecosystem functions supporting biodiversity, carbon storage and sequestration, regulation of stream base flows, water run-off and downstream flood peaks. It also contributes to nutrient regulation and retention. Peatlands are sinks and sources of natural greenhouse gases, particularly carbon dioxide ($CO_2$) and methane ($CH_4$). Peatlands in poor condition may be drying and oxidising, which will cause them to emit carbon, whereas peatlands in good condition are usually waterlogged, will be peat forming and therefore sequester carbon due to retarded decomposition rates and colonisation of peat forming species, notably *sphagnum* (ASC, 2016).

## More renewable energy development

The Welsh Government's draft Future Wales 2040: the national plan identifies a strategic need for more, large-scale renewable energy developments, including wind and solar voltaic. The current draft includes supportive text for such development (Policies 17 and 18) with an acceptance of some landscape change. However, the policy also says that such developments are not permitted in National Parks and Areas of Outstanding Natural Beauty (which make up 25% Wales). This change may also alter the composition, pattern and proportion of existing land for other production such as growing food, fibre or timber, and on a wider scale change landscape character. However, renewable energy sources that are managed sustainably are able to use the same land for repeated energy extraction, whereas non-renewable sources require expansion as resources are depleted (Parish et al., 2013; Trainor et al., 2016). Innovative deployment of renewables, like solar roof tiles, wind integration with agriculture and forestry, can reduce land use pressures and avoid landscape disturbances caused by fossil fuels and nuclear energy (Lovins, 2011; Fritsche et al., 2017).

## Increase in woodland cover

The benefits of more trees can be wide-ranging including habitats for wildlife, places for recreation and well-being, diffuse pollution control, slope stability, erosion control, climate mitigation, flood and drought mitigation and protection, urban and livestock cooling, riparian cooling for fish, air pollutant removal, and water filtration. Woodlands can provide a range of benefits in varying amounts depending on their location, type, and management. More woodland is likely to mean less land area for food production, although a 5% increase in woodland cover at Pontbren did not affect farm productivity (Welsh Parliament, 2020). Conversion of land to tree cover can be seen to compete for space with the expansion and restoration of other habitats providing a wide range of ecosystem benefits such as semi-natural grasslands and notably mountain, moorland and heathland (see the Semi-natural grasslands chapter and Mountain Moorland and Heath chapter).

## More trees on farms

More trees and hedgerows on farms can provide multiple benefits to food production and carbon stocks, especially if they are incorporated as part of agroforestry and provide nature-based solutions. The benefits to food production and society include shelter and shade for livestock, supporting pollinators and enhancing crop yields, source of timber/fuel/fodder/fruit/nuts/berries, stock enclosures, reducing pests and diseases, supplement to livestock diet, habitat and cover for game, enhancing output for free-range poultry farms and source of biofuels (Soil Association, 2019). The trade-offs depend on the extent of planting, intensity of management, and the conversion of existing land use type (i.e. improved or habitat land).

Reluctance to plant woodland is often attributed to many factors including low financial attractiveness, long-held cultural views on changing land use and perceptions of the urgency of tackling climate change (Moseley et al., 2011). Other more recent factors include physical availability of suitable land, reduction in land value when converting agriculture land to woodland, and access to grants which incentivise a change in land use (The Royal Forestry Society, 2020). The main motivations for creating woodlands were to increase biodiversity, enhance landscape (The Royal Forestry Society, 2020, Lawrence et al., 2010) and capture carbon (Royal Forestry Society, 2020). Insights from behavioural economics indicates that certain ‘nudges’ may help direct choices in a particular direction and should be tailored towards different landowners with different attitudes, motivations and willingness to plant trees. These include addressing perceived barriers to woodland creation by highlighting successes and the public sector leading by example (Moseley et al., 2011). The Wales Land Management Forum Task and Finish Group on Woodland Creation is currently exploring the barriers to woodland creation in Wales and will report on this in 2021. This could provide new insights into the barriers to woodland creation and how to overcome them.

## Less intensive food and fibre in places

To increase ecosystem structure and function, less food, fibre, and timber output per hectare of land must be produced. Risks to regulating and cultural services are generally reduced but may increase the need to import goods or intensify management elsewhere. More extensive grazing regimes and continuous cover forestry systems are generally seen as synonymous with enhanced sustainability and reduced profitability. This is not necessarily the case, especially where high value niche markets can be supplied. A wide range of agro-ecological and low impact silvilcultural systems can be employed alongside best practice measures for sustainable management.

## More intensive food and fibre in places

Increasing the intensity of management and gaining higher yield per hectare of land could off-set the reduction of food and fibre production elsewhere. This is highly dependent on the climate, suitability and capability of the soils, genetic material and cropping cycle employed. Risks to regulating and cultural services are generally increased. Animal health and welfare and plant health can be adversely affected. Intensive production systems can be undertaken to sustainable standards. A wide range of precision farming and high productivity silvilcultural systems can be employed alongside best practice measures for sustainable management.

## Balance, trade-off or optimisation

Fully functioning soils provide rich biodiversity, sequester, and maintain carbon, slow the flow of water, help to regulate the climate and air quality, and produce a sustainable supply of food, fibre and timber. Making soil management and land use change decisions which balance all ecosystem services is not a straightforward equation – indeed they are classic conflicts of interest. A combination of the challenges and estimated impact on services are shown in Table 17, Table 18 and Table 19.

It should be noted that this does not take account of the impact of any required increase in imported food, fibre, and timber to meet societal needs. International systems do exist for some goods, such as timber verified to the Forest Stewardship Council and Programme for the Endorsement of Forest Certification schemes. This provides assurance that the products imported have been produced sustainably and on a par with domestic standards.

Synergies can be identified, some services can be optimised and trade-offs can be minimised by careful planning, site verification, using spatial evidence and monitoring. A fresh appraisal of Wales's land use change framework and more SMNR guidance would help such complex decisions to be made in the context of SMNR and the climate and nature emergencies.

In addition, a greater understanding of the location and vulnerability of stocks of carbon stored in soils and the impact of any land use and management change could help inform further decisions to safeguard and increase carbon stores in soils and biomass. The latest Natural Capital Committee Report on Nature Based solutions (NCC, 2020) has suggested a number of recommendations including the importance of maintaining existing biocarbon stocks.

Table 17 Provisioning services prioritised (Turkelboom et al.,2016; Howe et al., 2014).

| Provisioning Services Demands | | |
|---|---|---|
| Trade off / risk – supply of one Ecosystem Service directly decreases another ES | | |
| Synergy / control – use of one ES directly increases benefits of another ES | | |
| **Provisioning services** | **Regulating services** | **Cultural services** |
| **Provisioning services demands**:<br><br>Food<br><br>Fibre<br><br>Infrastructure<br><br>More intensive food and fibre, more development, and more trees in some places | **Potential risk**<br><br>Increased risk to soil, water and carbon from intensive land management regimes that can also decrease future potential for food and fibre supply.<br><br>Decreased pollinators. Increased risk of pests.<br><br>Sub-optimal supply in order to balance all demands. | **Potential risks**<br><br>Can reduce access to green space lowering quality of life<br><br>Can fragment deep human connection to place and history<br><br>Employment can become too specialised/low skilled for local supply |
| **Provisioning services demands:**<br><br>Food<br><br>Fibre<br><br>Infrastructure<br><br>More intensive food and fibre, more development, and more trees in some places | **Potential controls**<br><br>Able to produce more food and fibre from less land / or to meet increased domestic supply and demand.<br><br>Sustainable management systems and standards, investment and innovation to protect air, soil, water and carbon.<br><br>Recognition that to meet some challenges critical to well-being that optimising one service over others may be required. | **Potential controls**<br><br>Active sustainable land management provides jobs, skills and revenue can help pay for provision of recreation opportunities, landscape quality improvements, historical records and interpretive materials<br><br>Frameworks for development that benefit landscape and nature such as sustainable drainage<br><br>Investment and innovation supporting sustainable local supply chains. Green marketplace innovation |

Table 18 Regulating services prioritised (Turkelboom et al.,2016; Howe et al., 2014).

| Regulating Services Demands | | |
|---|---|---|
| Trade off / risk – supply of one Ecosystem Service directly decreases another ES | | |
| Synergy / control – use of one ES directly increases benefits of another ES | | |
| **Regulating Services** | **Provisioning services** | **Cultural services** |
| **Regulating services demands:**<br>Air quality<br><br>Soil conservation<br><br>Water quantity and quality<br><br>Carbon storage<br><br>Pollinators<br><br>Wild diversity<br><br>Peatland restoration and conservation<br><br>More trees, less improved grassland | **Potential trade off**<br>Soil sealing or permeable surface?<br><br>Trees (fibre) or grassland (food)?<br><br>Peat habitat protection (no or little food or fibre).<br><br>Other ecosystem protection (no or little food or fibre).<br><br>Supply of food and fibre to meet demand met by increasing imports. | **Potential risks**<br>Farming practice rural economy and culture undermined as land use changes/soil, water and carbon incentivised over food and fibre.<br><br>Unequal access to clean air and water.<br><br>Some properties and businesses protected from flood risk, others are not.<br><br>Spatial variation in climate impacts such as greater risk from ecological change in south and east than north and west. |
| **Regulating services demands:**<br><br>Air quality<br><br>Soil conservation<br><br>Water quantity and quality<br><br>Carbon storage<br><br>Pollinators<br><br>Wild diversity<br><br>Peatland restoration and conservation<br><br>More trees, less improved grassland | **Potential controls**<br>Sustainable drainage systems<br><br>Trees are a nature-based solution for most regulating services.<br><br>More trees on farms to diversify business model and improve livestock health and welfare.<br><br>Renewable energy on farms/in forests alongside food and fibre production.<br><br>Peat restoration and conservation within farm and forest management systems. | **Potential controls**<br>Guidance and advice on 'best' land use and management system choices (sustainable choice, what good looks and feels like).<br><br>Sector adaption strategies that reflect spatial variation across the country.<br><br>Incentives for sustainable choices in development, farming, and forestry management systems.<br><br>Increased consumer confidence in goods produced that make soil, water and carbon sense allowing sufficient return in a virtuous/circular economy. |

Table 19 Cultural services prioritised (Turkelboom et al.,2016; Howe et al., 2014).

| Cultural Services Demands | | |
|---|---|---|
| Trade off / risk – supply of one Ecosystem Service directly decreases another ES | | |
| Synergy / control – use of one ES directly increases benefits of another ES | | |
| **Cultural Services** | **Provisioning services** | **Regulating services** |
| **Cultural services demands:**<br><br>Landscape quality<br><br>Places for recreation<br><br>Heritage and sense of place<br><br>Trade skills<br><br>Employment | **Potential trade-off:**<br><br>Jobs or nature?<br><br>Conservation or development?<br><br>Protection or active management?<br><br>Sharing or sparing space?<br><br>Resistance to change in land use or management regime reducing resilience of business and potential to meet future demand for food, fibre, energy, waste management etc.<br><br>Broader micro (often public, local) interests conflict with narrow macro (often private, strategic) interests. | **Potential trade-off:**<br><br>Landowner bears the burden (costs & complexity increased) and wider society receives the benefit (without paying)<br><br>Unresponsive to ecological change reducing adaptive potential of ecological system.<br><br>Resistance to change in land use or management regime, such as society placing little value on actions required such as peat restoration in uplands to reduce downstream flood risk |
| **Cultural Services demands:**<br><br>Landscape quality<br><br>Places for recreation<br><br>Heritage and sense of place<br><br>Trade skills<br><br>Employment | **Potential synergy:**<br><br>Sustainable management systems and standards, investment and innovation to meet local food and fibre demand in local supply chains<br><br>Increased co-operation between stakeholders at all scales. | **Potential synergy:**<br><br>Link the action and the outcome with incentive, new markets and innovation.<br><br>Sustainable management systems and standards, investment and innovation to protect soil, water & carbon |

# 7. Opportunities for action for achieving the sustainable management of natural resources

There are five main areas, summarised in Figure 20, where policy, systems and practice can help improve the sustainable use and sustainable management of natural resources:

- Protect and conserve the current land cover.
- Alter land management regime (systems and practices).
- Provide ‘nudges’ to change use or management such as standards or incentives.
- Change the land use.
- Innovate the market to trade in the provision of well-being benefits.

There needs to be alignment between the five types of intervention if the challenges of the climate and nature emergencies, decarbonisation targets, and positively invest in the stock and flow of well-being benefits.

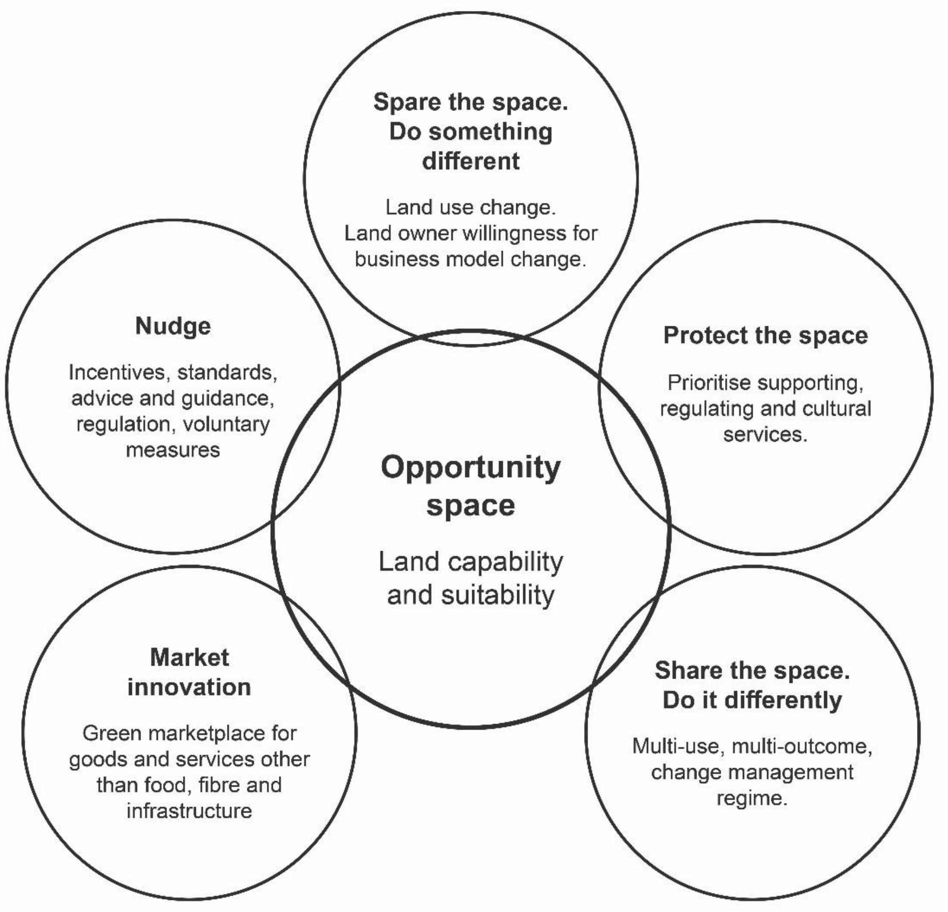


Figure 20 Summarised land management and land use interventions for SMNR (Source NRW).

From the evidence in the chapter the following are considered to be top priorities to address through a combination of the five main types of intervention:

## Protect Wales's network of special places for nature and landscape

The network of terrestrial and freshwater SSSIs provides a haven of wild diversity alongside Wales's treasured landscapes. Considerations should be made to giving soils more of a prominent role in existing terrestrial SSSI site descriptions. It has been long known that by protecting these patches and taking action to restore habitat 'stepping stones' between these special sites increases the resilience of all of Welsh ecosystems. Some of these sites will evolve along with the changing climate but taking action to better connect Wales's special sites will help some species and habitats adapt and move.

## More sustainable soil and water management – systems and practices

A focus on land use and soil management can lead to water, greenhouse gases, air quality and biodiversity benefits that have value for both business and the wider community well-being (Newell-Price et al., 2011; Janes-Bassett and Davies, J. 2018). Soil underpins the supply chain, and if it becomes degraded, the business is at risk. Recognising and valuing the ecosystem services provided by soils can help motivate changes to practices that provide wins for soil sustainability and improved input efficiency (water, fertilizer and pesticide usage) and to improve overall soil health and function, including carbon storage, providing and cycling nutrients, and controlling the drainage, flow and storage of water (see such as AHDB, 2019c; Janes-Bassett and Davies, J. 2018). Continuing professional development and compliance with regularly updated best practice frameworks, such as the Code of Good Agricultural Practice, UK Forestry Standard, and Planning Policy Wales, is key. Maintaining healthy soils can increase resilience to the effects of climate change and encouraging more agroecological and low impact silvicultural principles (Lampkin et al., 2012; Poux and Aubert, 2018; FAO, 2018) as part of agronomic and forestry decision-making and nutrient management can replace or minimise the use of inputs. Natural soil fertility and natural nutrient cycles can be improved and maintained through the preservation or enhancement of soil organic matter based on soil analysis and nutrient planning and can minimise or replace the use of artificial fertilisers on improved land (such as crop rotations with legumes, green or animal manures), and meet crop requirement with reduced herbicide use (FAO, 2017). Precise and appropriate application methods of organic manures will minimise the risk of causing diffuse pollution (air and water), soil erosion, promote soil biodiversity and increase ecosystem resilience whilst reducing emission of greenhouse gases (Newell-Price et al., 2011; AHDB, 2020e; Williams et al., 2019; see the Ecosystem chapters).

## Evolution of ‘public goods’-based schemes, initiatives and incentives

More sustainable agricultural and forestry land management must be supported as part of an integrated approach to increase SMNR, the provision of ecosystem benefits, and enhance future well-being. The ability of land managers to work collaboratively and at scale to share and build knowledge and skills and deliver shared outcomes is needed - this is essential for landscape or catchment scale outcomes. In addition, incentives to adopt systematic approaches to sustainable soil management to improve overall soil health are needed; profitability and business resilience go hand in hand with sustainability and ecosystem resilience. New market-based measures are required to value and trade well-being and environmental benefits that society needs alongside the traditional monetised commodities of food, fibre, and built infrastructure. Innovation in market-based mechanisms to trade in other well-being benefits could help transform the ability of public money to steer private investment to deliver well-being benefits, as well as profit in the traditional sense. Sustainable production can only take place when there is the right balance between private and public sector initiatives, as well as accountability, equity, transparency, and regulations. Farmers and land managers need to be provided with the right incentives that support the adoption of appropriate practices on the ground (FAO, 2020; WLMF sub-group, 2018).

## A better land use change decision-making framework

Clear direction on land use change and sustainable land management priorities at a national, regional, and local level could support better delivery of SMNR through Area Statements and other place-based delivery mechanisms. Wales’s policy frameworks for natural infrastructure and long-term climate change mitigation and adaptation requires land use change. There are calls for a whole system land use framework to help bring together all the interests, from environment and farming, town planning and housing, public services, transport and infrastructure, and business investment. It must work with people in their communities, both shaping a national framework and informed by it (RSA, 2018; RSA, 2019; Foresight Land Use Futures Project, 2010). Debate continues around the merits of land sparing (single or optimised benefit) versus land sharing (multi-purpose use which seeks to balance all possible benefits), but it is individual businesses that make decisions about land use (RWAS 2020; FCRN, 2018). More co-operative approaches between landowners and managers could support the shifts we know are required. Innovation in green market-based mechanisms to trade in other well-being benefits could support sustainable land use change and management decisions (CCC, 2020). A new coherent and integrated framework may help such complex decisions to be made in the context of SMNR, the climate and nature emergencies.

## Implement the National Peatland Restoration Programme

Bringing upland and lowland semi-natural deep peat into favourable condition and bring more tree covered, grassland, and arable deep peat into sustainable management to help meet Wales's decarbonisation targets. This would increase sustainable drainage across peaty soils contributing to catchment-based flood and drought risk management strategies. Peatlands in good condition support a characteristic and significant suite of habitat types and animal and plant species, as well as performing a range of critical ecosystem service functions: carbon accumulation, carbon storage, the regulation of greenhouse gas emissions, and other hydrological and hydrochemical processes.

## Increase the rate of new woodland creation and plant more trees

Wales must tackle the climate and nature emergencies to improve ecosystem resilience and generate future well-being benefits. SoNaRR2016 identified that planting 'the right tree in the right place' can provide multiple benefits for SMNR and well-being. There are opportunities for natural catchment management to reduce flood and drought risk to slow down surface water flow by creating or restoring riparian and/or flood plain woodlands. This would provide land for upstream winter overflow and improve riparian habitats throughout water catchments to collectively reduce the risk of flooding and drought to downstream communities. Tree shelterbelts established at Nant Pontbren catchment in pastures of land used for sheep grazing showed water infiltration rates were up to 60 times higher in areas planted with young trees than in adjacent grazed pastures (See the Nant Pontbren case study). This demonstrates that farm trees could represent a key landscape feature, reducing run-off even when only present as a small proportion of the land cover (Carroll et al., 2006). Trees in towns and villages can significantly help society adapt to the predicted impacts of the changing climate through shade, cooling, and air quality improvements. Woodland creation on suitable derelict brownfield sites can bring them back into beneficial use (See The Spirit of Llynfi and Spirit of Llynfi Woodland, near Bridgend case study web pages).

## Using a decision train approach to tackle issues at source

A major failing within resource management is trying to tackle problems at the point where the impact is felt. This is simply too late; there is a need instead to look at the root cause of problems and develop approaches which can tackle them at source. The "decision train" approach can be used to consider additional or complementary solutions in a sequential manner as shown in the diagram below.

In the case of erosion, for example, it is very difficult to tackle surface run-off across a catchment. However, it is possible, through legislation or other motivations, to tackle the sources of the issue. Modified vehicle emission standards improve air quality and with cleaner air there is less pollution deposited over the countryside. This in turn reduces the amount of polluted run-off.

The following four-step approach provides a framework for solving problems as close to their source as possible (Figure 21).

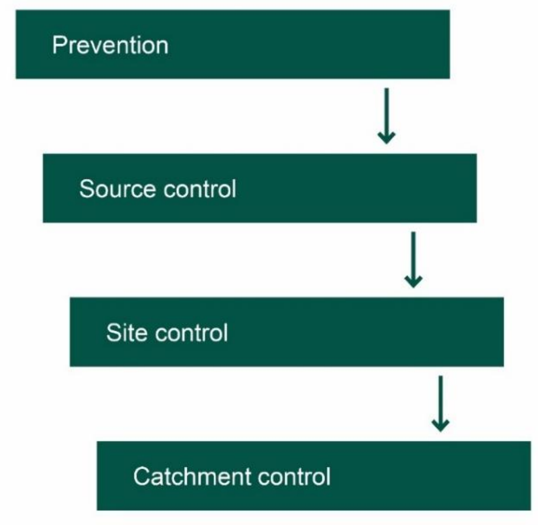


Figure 21 Four-step decision train approach (Source: NRW).

When seeking to address issues such as catchment erosion, the nature of the existing challenges must be looked at. All too often prevention or dealing with the source of the issue is ignored, and solutions are applied at the very last stage where the impact is most heavily felt. Such late stage interventions are important, however ignoring “upstream” solutions can end up being more costly and inflexible.

# 8. Evidence Needs

The land use and soil evidence needs in SoNaRR are broad due to remaining questions on the impact of climate change, land use change, soil pollution and the extent to which soils in Wales are managed and used sustainably across all land uses (agriculture, woodlands & urban) and all ecosystems.

Soils are a key component of ecosystem resilience through the supporting services they provide. Soil formation, erosion, the nutrient cycle and soil biodiversity are fundamental to the supporting ecosystem services to provide an overall indication of soil resource stock and soil health. However, repeated surveys of soil biodiversity may not continue and rates of soil loss by erosion and rates of soil formation have not been directly measured to assess if rates of soil loss exceed soil formation rates in Wales. National monitoring to observe trends and to assess the potential impact of soil pollutants have not been updated and are not currently included in national monitoring. While Urban and Coastal Margins Ecosystems are not currently represented in national monitoring.

Where soil data and evidence is collected it is not easily shared or combined. As such, establishing a minimum indicator set for soil properties and chemistry would be useful and ensure compatibility with other monitoring programmes across all land uses along with improved information on land use and it’s management regime. Soil condition is mostly a function of the management system in place and so any changes to land use and land management systems need to be monitored. As such, a better understanding and monitoring of shared land uses would also be useful where primary use is for woodland or agriculture but also may support renewable energy development for example.

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