The Second State of Natural Resources Report (SoNaRR2020)

Assessment of the achievement of sustainable management of natural resources: Climate Change

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: Climate Change

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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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1. Headline Messages

Wales will see higher temperatures and higher sea levels over the coming decades, and very likely more drier summers and wetter winters along with greater frequency and intensity of heavy rainfall events as a result of climate change.

Much of Wales is projected to be less impacted by drought and heatwaves compared to much of southern England, making Wales better placed to adapt to this change. However, the high rainfall and steep-sided valleys across much of Wales will exacerbate the risks associated with heavy rainfall events.

Climate change is already having a substantial effect on Welsh biodiversity and ecosystems, such as loss of inter-tidal habitats due to sea-level rise. Climate change will increasingly affect all Welsh ecosystems but almost all impacts can be reduced by urgent, stringent global mitigation to limit global temperature rise to well below 2°C.

Action to limit and adapt to climate change is urgent. Adaptation measures, such as coastal realignment; increasing carbon storage, particularly through increased woodland creation; and reducing emissions, especially peatland restoration, will be key to responding to the threat of climate change and creating a more resilient Wales.

A whole systems approach, integrating adaptation and mitigation measures across sectoral policy areas, is required to help achieve net zero emissions and biodiversity goals.

2. Introduction

An overview of the effects of climate change on natural resources and ecosystems in Wales will be provided in this chapter. Changes in climate threaten ecosystem resilience and ecosystem services through shifting species ranges, localised extinctions, changes to life-cycle events and other impacts on ecosystem function. Climate change also interacts and exacerbates other environmental stressors, such as the increase in invasive species and disease vectors. Climate change is also projected to increase the frequency and intensity of droughts, fluvial and coastal floods and heatwaves, which are projected to further reduce ecosystem resilience. Globally and within Wales, some of the impacts of climate change including sea level rise and coastal erosion will be irreversible (IPBES, 2019).

Through the Intergovernmental Panel on Climate Change's Special Report on the impacts of 1.5°C warming (IPCC, 2018), the urgency of a transformative response to climate change was emphatically stated by the global scientific community. The 1.5°C report was a response to the United Nations Framework Convention on Climate Change (UNFCCC) Paris Agreement 2015 goal to limit warming to well below 2°C above pre-industrial levels, and to pursue efforts to limit warming to 1.5°C, in order to avoid the more severe impacts of climate change. The report reinforced the need for ambitious climate mitigation and adaptation policies and targets.Through the Environment Act (Wales) 2016, five-yearly carbon budgets and

decadal targets for emission reduction have been established to drive decarbonisation. In April 2019, Welsh Government declared a climate emergency with the intention of prompting ‘a wave of action (Welsh Government, 2019) and many Welsh Councils have made similar declarations and local decarbonisation goals.

3. Emissions, Current Climate and Future Trends

Emissions trends

Wales’s greenhouse gas emissions have fallen by a quarter since 1990 (NAEI, 2020). In 2018, energy supply contributed 29% of Welsh emissions and the business sector 22% of the total. Other sectors contribute much less: transport (16%), agriculture (14%), residential (10%), industrial process (5%), waste management (3%) and public (1%) (Figure 1).

It is important to recognise that these sectoral figures represent only direct emissions and that in reality their overall significance may be very different. For example, the emissions that the public sector is responsible for are much greater than the heating and vehicle fuel emissions included in the inventory: assessments of the carbon budgets of many Welsh public-sector organisations show that procurement represents the majority of emissions. Land use, land use change and forestry as a sector is a net sink of 1% of Welsh emissions predominantly through sequestration in woodland. While Welsh peatlands store large quantities of carbon, the majority of them emit carbon due to their poor condition (Evans et al., 2015).

Although greenhouse gas emissions produced in Wales are declining, greenhouse gas emissions embedded in imported goods and services represent around one-third of total territorial emissions (SEI and GHD, 2015) and have shown limited reductions since 2007. China is the largest source of both imported goods and emissions in the UK.

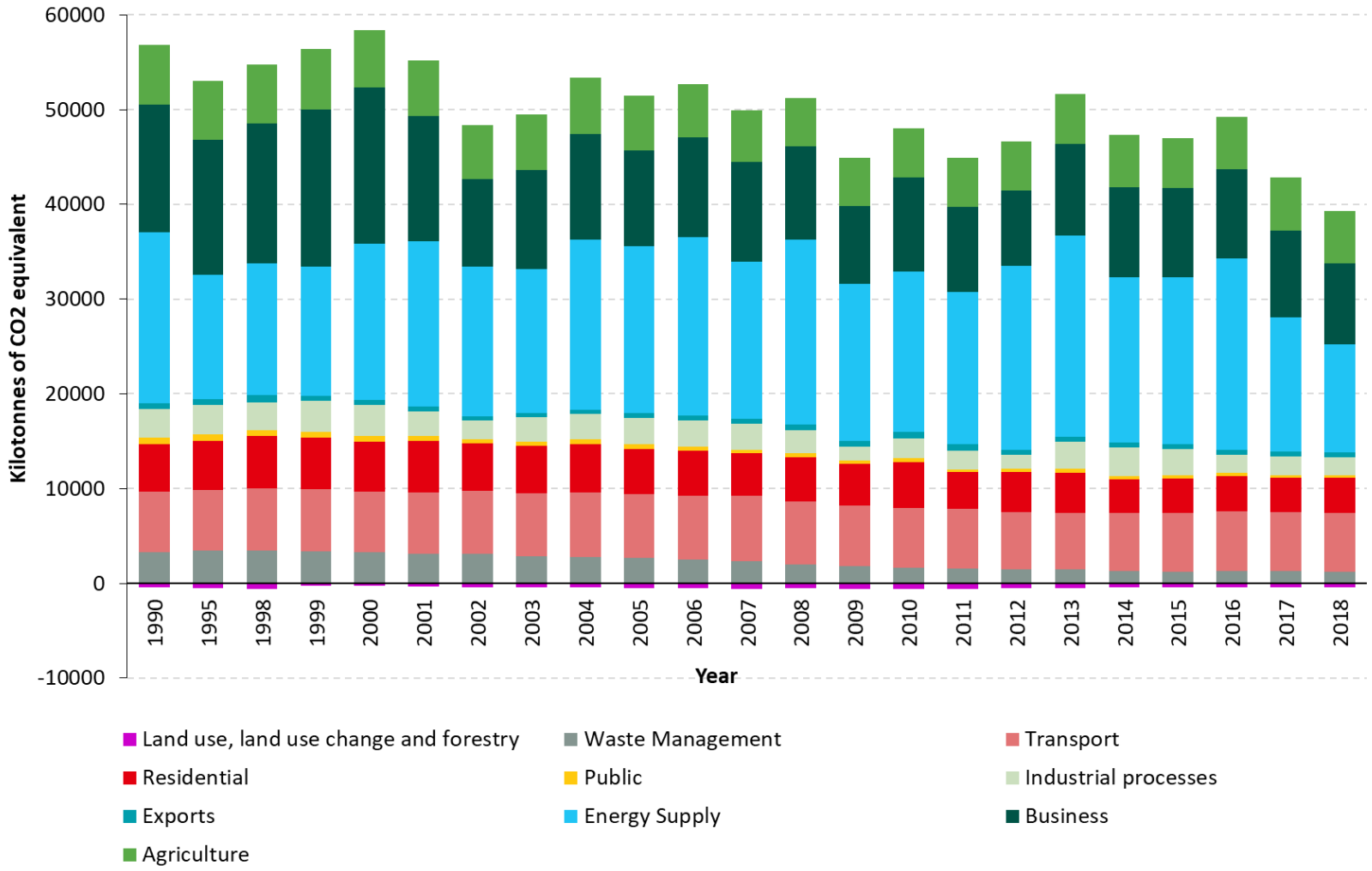

Figure 1 Wales Greenhouse Gas Emissions by sector

Source: National Atmospheric Emissions Inventory 2020

Climate and sea level trends

Global warming has already reached around 1°C above pre-industrial levels and the rate is increasing (IPCC, 2018). In Wales, the most recent decade (2008-2017) was 0.8°C warmer than the average temperature experienced in 1961-1990 (Met Office, 2018). To date, the average annual rainfall across Wales has not changed markedly. However, there is some evidence of seasonal changes and more heavy rainfall events. In the past 10 years, UK winters have been 5% wetter on average than 1981-2010. Summers have been 11% wetter during the same period (Met Office, 2018).

The UK also experiences heatwaves, which can lead to droughts and wildfire. 2018 was the joint hottest summer on record, with the Met Office reporting an average air temperature of 1.5°C above the long-term average (Kendon et al., 2019). In Wales, June 2018 was the warmest on record dating back to 1884. All of the 10 warmest years on record in the UK have occurred since 2002, with half of these occurring since 2010. High temperatures and low rainfall, along with increased demand for water, led to drought across Wales during 2018, with rainfall widely less than 75% of average.

Although average annual rainfall has not changed markedly, there is evidence of more heavy rainfall events. Since the last SoNaRR (NRW, 2016), Wales has experienced some significant storm events, including Storm Brian in October 2017, Storm Bronagh in September 2018, where around half a months' worth of rain fell on Sennybridge, Powys, in 24hrs, and Storm Callum in October 2018 where flooding in parts of Carmarthenshire was the worst in over 30 years. More recently, Storm Ciara (8-9 February 2020) and Dennis (15-16 February 2020) were two of the most severe and widespread flooding incidents experienced in Wales in many years. These events are consistent with projections of increased heavy rainfall days and storminess. However, due to the highly variable climate of the UK, these storms cannot be individually directly attributed to climate change (MCCIP, 2020).

Mean sea-level rise around the UK (driven principally by thermal expansion of the oceans but also a range of other factors) has risen by around 16cm since the start of the 20th Century (Met Office, 2018) and will continue to rise over the next century even if global warming is restricted to below 2ºC. It is difficult to derive a good estimate of historical sea-level rise for Wales alone due to data limitations.

Future climate and sea level trends in Wales

The Met Office released new climate projections in 2018 known as UKCP18. These are the most up to date climate projections for the UK. Projections indicate higher temperatures, a reduction in summer rainfall, and an increase in winter rainfall across the UK, including Wales, along with less snow and frost (Met Office, 2018). Temperature change after the 2050s is highly dependent upon the level of global emissions. Before this, under most scenarios, temperatures in Wales are expected to rise by 1.2-1.6°C (median estimate) (Table 1). Warming is expected to be greater in the summer than the winter. The mean winter temperature rise in Wales by 2050 is likely to be 1.1-1.6°C. In summer, the temperature rise is likely to be 1.6-2°C (median estimate). While there is a general trend towards warmer weather winters,

some cold periods will still occur due to climatic variation. Nevertheless, UKCP18 snowfall projections show a significant decrease in both falling and lying snow across the UK compared to 1981-2000 (Met Office, 2018).

Table 1 Projected Annual temperature change (median estimates) for Wales from 1981-2000 to two future time periods. From UKCP18 (Met Office, 2018).

Representative Concentration Pathway (RCP) as presented in UKCP18. See IPPC for definition **and** CoastAdapt **for explanation**	Temperature change (degress C) **2041-2060**	Temperature change (degress C) **2080-2099**
RCP2.6	1.2	1.3
RCP8.5	1.6	3.9

There is still uncertainty over how climate change will affect seasonal rainfall in the UK, but projections for Wales show a 6-9% increase in average winter precipitation by the 2050s and a reduction in average summer precipitation of 15-19%. By the end of the century, summer precipitation could decrease by 20-38% (median estimates) (Met Office, 2018). (Table 2).

Table 2 Projected Annual precipitation change (median estimates) for Wales from 1981-2000 to two future time periods. From UKCP18 (Met Office, 2018).

Representative Concentration Pathway (RCP) as presented in UKCP18. See IPPC for definition **and** CoastAdapt **for explanation**	**Winter Precipitation Change (%)** **2041-2060**	**Winter Precipitation Change (%)** **2080-2099**	**Summer Precipitation Change (%)** **2041-2060**	**Summer Precipitation Change (%)** **2080-2099**
RCP2.6	6	6	-15	-20
RCP8.5	9	23	-19	-38

As well as changes to the average climate, Wales will be affected by a likely increase in the frequency of severe weather events, including heavy rainfall and heat waves. By mid-century, the chance of hot summers resembling the 2018 heatwave will be significantly more common.The Urban Ecosystem Chapter provides details on overheating and the increase in the intensity of heatwaves. As warmer air is able to hold more moisture, higher temperatures are likely to lead to more intense rainfall, including thunderstorms.

Sea levels will continue to rise around the UK driven by rising temperatures (Met Office, 2018). The magnitude and rate of this rise depend on future emissions (IPCC, 2018). Sea level around Cardiff, for example, is projected to increase by 15-32cm under a low scenario and 20-39cm under a high scenario by 2050. By the end of the century, sea level around Cardiff is projected to increase by 27-69cm under a low scenario and 51-131cm under a high scenario (Met Office, 2018). Sea levels will continue to rise beyond 2100 but the amount is very uncertain. All scenarios predict sea level rise. Sea level rise will be greater in south Wales than the north (Figure 2), largely due to the rise of land masses following the removal of the heavy weight of ice sheets during the last glacial period. This is known as isostatic rebound.

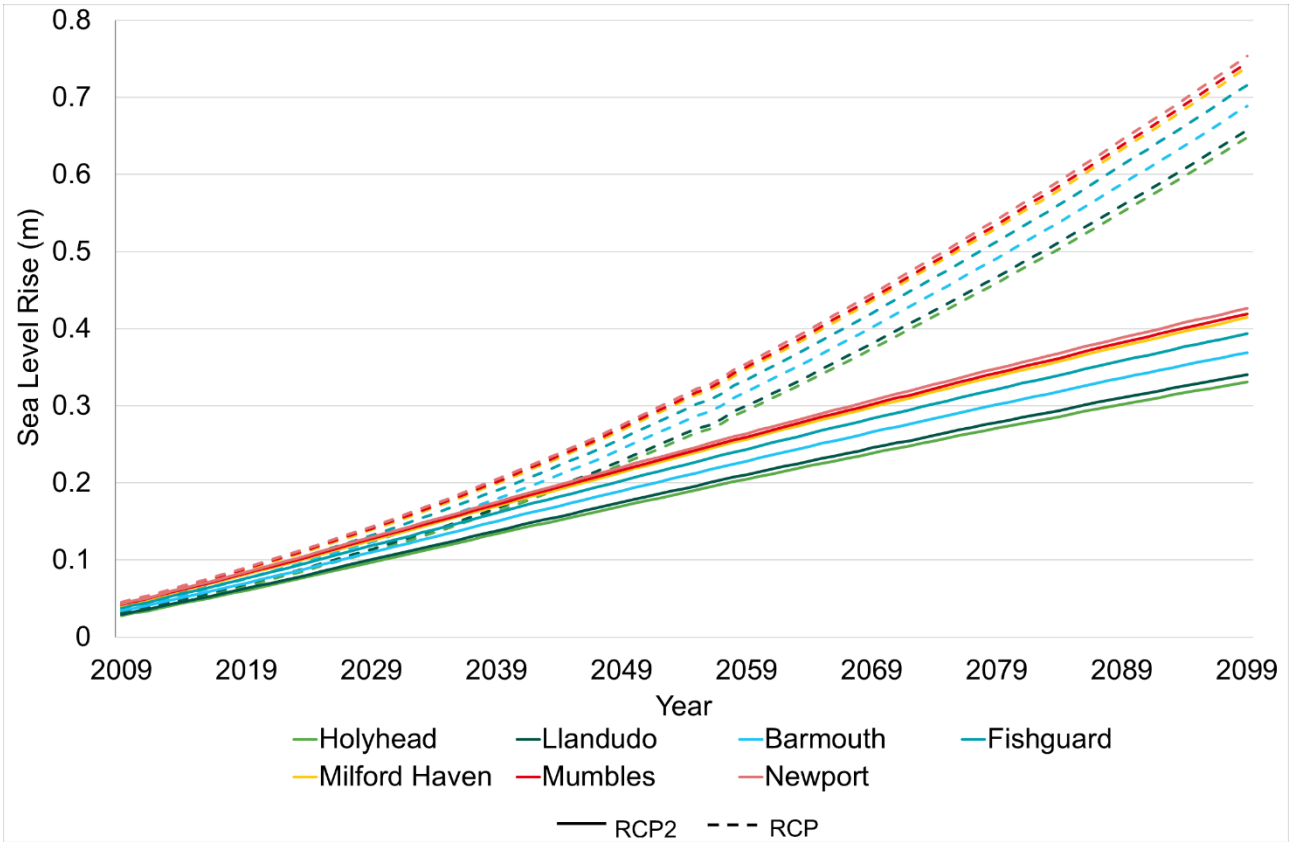

Figure 2 Projected sea level rise at tidal gauges around the Welsh coast under RCP2.6 (low emissions) and RCP8.5 (high emissions) scenarios.

Values are the 50th percentile.Data source: UKCP18 projections (Met Office, 2018*)*

Future risks from climate change depend on the speed, peak and duration of warming (IPCC, 2018). Even with stringent mitigation, global temperatures are projected to continue to rise by at least another 0.5°C by 2100 (if the more stringent 1.5°C ambition of the Paris Agreement is met), with previous global commitments only constraining the warming to around 3°C (UNEP, 2019). Even if temperatures subsequently were to return to a level of 1.5°C or less above pre-industrial levels, the impact would be greater than if they had successfully been limited to this level (Hoegh-Guldberg et al., 2018).

4. Key Policies on Climate Change Adaptation and Mitigation

International agreements

In November 2016, the UK Government ratified the UNFCCC 2015 Paris Agreement, which aims to keep global mean temperature rise 'well below' 2°C with a target of limiting mean temperature rise to 1.5°C above pre-industrial levels (United Nations, 2015). Countries also agreed to a long-term goal of adaptation to minimise the impact of the warming caused by past and current emissions.

Responding to climate change and ensuring ecosystem resilience is also covered in the Convention on Biological Diversity, with an objective to improve carbon stocks through ecosystem restoration and conservation. The role of both marine and terrestrial ecosystems in maintaining existing carbon stores and, where possible, sequestering additional carbon is now well accepted as an essential component of climate policy.

United Kingdom and Welsh policies

A combination of UK and Welsh legislation provides the statutory framework for addressing climate change in Wales. The Climate Change Act (2008) provides the original underpinning policy establishing an approach to setting UK emission reduction targets and budgets and a framework for reviewing climate change risks and setting out adaptation action. It legally binds the UK to reducing emissions to achieve a net zero status by 2050 and sets interim 5-yearly carbon budgets along the way. The Act established an independent body, the UK Committee on Climate Change (UKCCC), to advise the UK and devolved governments on Greenhouse Gas accounting approaches, emissions targets and budgets, climate risks, along with assessing progress and recommending measures for delivery of mitigation and adaptation.

The Climate Change Act requires the UK Government to publish a Climate Change Risk Assessment every 5 years that reviews both risks, opportunities and the need for further action to address them. It provides the evidence base for Government-led national adaptation programmes in the UK nations, including Wales. The first report was published in 2012 (Defra, 2012a) and the second assessment (CCRA2) in 2017 (UKCCC, 2016). For the next iteration, a suite of research projects covering water resources, flood risk, socio-economic dimensions, behaviour change, thresholds in the natural environment and interacting risks have been commissioned by the UKCCC to inform the CCRA3 report.These were published in spring 2020 – see https://www.ukclimaterisk.org/ccra-research/. The CCRA3 evidence report will be published in 2021 setting out 65 risks based on similar analysis as in CCRA2.

The Intergovernmental Panel on Climate Change Special Report on Global Warming of 1.5°C, published in October 2018, was a landmark report stating that 'limiting global warming to 1.5°C with no or limited overshoot, would require rapid and far-reaching transitions … and imply deep emissions reductions in all sectors' (IPCC,

2018). In response to the IPCC report, the UKCCC produced advice recommending a UK net-zero GHG target for 2050 that will deliver on the commitment that the UK made by signing the Paris Agreement (UKCCC, 2019). Owing to Wales facing greater challenges to achieve decarbonisation than other nations in the UK, particularly due to large agricultural and industrial sector emissions, the UKCCC recommended that Wales targets a 95% reduction in emissions by 2050. This recommendation has been accepted by Welsh Government (WG) but with an ambition for net zero emissions by 2050.

Until recently, the UK's policy commitments were insufficient to meet its own climate targets (Climate Action Tracker, 2020). However, in advance of the postponed UNFCCC Conference of the Parties in Glasgow (CoP26), the UK Government has revised its decarbonisation policy to produce its first separate Nationally Determined Contribution for the UNFCCC following Brexit. This sets out the target to reduce the UK's emissions by at least 68% by 2030, compared to 1990 levels (UKGov, 2020). The policy objectives to deliver this challenging emission reduction target are outlined in a *Ten Point Plan for a Green Industrial Revolution* (HM Government, 2020). Amongst the policy areas included are the expansion of offshore wind, hydrogen, nuclear power, zero emission vehicles, active travel, low carbon buildings, carbon capture technology and green finance.

The Environment (Wales) Act (2016) provides the legal framework for Welsh emissions and currently sets a target of an 80% reduction in GHGs in Wales by 2050 (Welsh Government, 2016). However, in line with the advice from UKCCC, regulations to revise the target to 95% reduction by 2050, with amended interim GHG reduction targets for 2030 and 2040, will be introduced early in 2021. In 2019, WG published the first Low Carbon Delivery Plan for Wales *Prosperity for All: A Low Carbon Wales* (Welsh Government, 2019a), which brings together 76 existing pieces of policy from across the Welsh Government, UK Government and the EU along with 24 proposals to explore and develop future policy actions. In addition to these climate change specific policies, decarbonisation has been added as a sixth priority area in the Prosperity for All Strategy. This is a critical step in embedding consideration of climate change within Welsh policy. The achievement of decarbonisation across Wales is also implicit within the Well-being of Future Generations Act (2015) and its goals. The goals ' *A prosperous Wales'* and '*A globally responsible Wales'* include reference to transition to a 'low carbon society' and 'make a positive contribution to global well-being' respectively (Welsh Government, 2015).

The climate change adaptation plan for Wales - *Prosperity for All: A Climate Conscious Wales* (Welsh Government, 2019b) was published in November 2019, setting out 32 actions for 2020 - 2025 to achieve a more resilient Wales through increasing knowledge, capacity and resilience. The main risk areas set out in the Plan are largely informed by the CCRA2 and the identified risks to people, communities, buildings and infrastructure from flooding; risks to water resources from drought and low river flows; and risks to ecosystems and agriculture from climatic changes as urgent priorities. In relation to the natural environment, the adoption of the following nature-based solutions are key to delivery of actions:

- Developing resilient ecological networks of habitats;
- Increased woodland cover, well located for ecosystem service benefits;
- Maintaining, enhancing and restoring flood plains and hydrogeological systems to reduce flood risk and improve water quality;
- Restoration of uplands, particularly peatlands, to manage them for biodiversity, carbon storage, water resources and flood risk, renewable energy and recreation benefits.

The Natural Resources Policy (Welsh Government, 2017), which used evidence from the assessment of SMNR in SoNaRR2016, outlines three national priorities for Wales: delivering nature-based solutions, increasing renewable energy and resource efficiency, and taking a place-based approach. All three of these goals will be crucial to addressing climate change mitigation and adaptation. The seven regional Area Statements for Wales recently published by NRW will help translate these priorities and the need for climate change action into place-based action.

5. Impacts on Ecosystem Resilience and Ecosystem Services

Biodiversity

Observed Changes

There is strong evidence that climate change is already affecting biodiversity in Wales. Many species such as birds and butterflies are shifting their geographical ranges northwards as the climate warms (Morecroft and Speakman, 2015). Climate change has been cited as one of the primary causes of a higher proportion of surface feeding seabirds experiencing frequent, widespread breeding failures in the Celtic Sea (MCCIP, 2020). Migratory birds are no longer travelling as far in the non-breeding season (ASC, 2016) and some are arriving earlier in the spring and leaving later in the autumn.

Climate change has already led to new species colonisations in the UK, including species that are currently of conservation concern. The Greater Horseshoe Bat has spread into North Wales over recent decades while previously it was restricted to the south and west of the country. Similarly, recent intertidal monitoring has found newly recorded non-indigenous kelp species (Mieszkowska, 2019). Some shifts in marine species have also already been observed. (MCCIP, 2020).

Spring life-cycle events, such as leafing, flowering and egg laying, have occurred on average nearly 2 weeks earlier over recent decades in most species monitored (Morecroft and Speakman, 2015). The earlier emergence of leaves and caterpillars is negatively affecting migratory birds like the pied flycatcher in Snowdonia, which rely on the caterpillars for food. Pied flycatchers do not overwinter in Wales and cannot easily respond to earlier warming in spring (Burgess et al., 2018).

Projected Changes

Climate change will continue to alter the abundance and distribution of biodiversity (IPBES, 2019). Both globally and in the UK, certain groups of species have been found to be more at risk, particularly plants (Hoegh-Guldberg et al., 2018; Morecroft and Speakman 2015). Such change will have knock-on effects for whole ecosystems. Plant losses will affect all species that rely on them for food and shelter. Key ecosystem services may also be reduced, including the potential reduction in crop yields due to loss of pollinating insects. These impacts will be worse with greater warming (Hoegh-Guldberg et al., 2018; Morecroft and Speakman 2015). In Wales, montane habitats, due to their isolation on mountain tops at the southern edge of their range, are at high risk. Additionally, coastal inter-tidal habitats due to sea-level rise and erosion, along with wetland communities due to their vulnerability to drought will be particularly sensitive to climatic changes. Some species, particularly those at their edge of range in Wales, are also likely to be at greater risk of decline, such as the gwyniad (arctic char).

There is a general trend towards species moving northwards and upslope as the climate warms. Higher sea temperatures will affect marine ecosystems, which could lead to further changes in species distributions, with cold water adapted species most affected (MCCIP, 2020). Changes to species' ranges will also alter the spread of invasive species, pests and diseases [see INNS Chapter]. As a result, damage from pests and diseases will also increase due to climate change (IPBES, 2019). It is likely that the Pacific oyster, which was introduced to southern England to supplement the shellfish industry, will be able to successfully spread to Wales by 2040, as sea temperatures increase.

Where species are unable to disperse and shift their range, either due to barriers to movement or being unable to disperse at the pace of warming, they will be at risk of localised extinctions (IPBES, 2019). This is likely to be a particular problem for species which have lower dispersal rates or face fragmented habitats. Rarer species of conservation concern by their nature often have more specific environmental and habitat requirements which mean they face greater challenges to disperse than widespread species. For instance, lowland semi-natural grasslands in Wales are very fragmented, which could limit species' ability to move as the climate changes, increasing their risk of extinction. See semi-natural grasslands chapter for more information. Scarce arctic alpine plants in the Welsh mountains are also extremely vulnerable as they may run out of higher locations to move to and will face competition from species that have previously been found at lower elevations as these move higher to track the changing climatic conditions. There is good evidence from long-term monitoring of montane vegetation across Europe that accelerating increases in species richness on summits is a climate-induced change likely to threaten rare mountain species (Steinbauer et al., 2018). Localised extinctions could have knock-on effects, particularly for species that depend on a limited number of species as a pollinator, disperser or as a source of food.

Changes to the timing of events such as budding and flowering in plants, egg laying and hatching in birds, breeding in mammals and the emergence of insects will continue to change further (IPBES, 2019). For example, the migration of both the Palmate Newt and Smooth Newt has been shown to be earlier at a site in mid-Wales

(Chadwick et al., 2006). However, monitoring of the timing of flowering of 80 species on Snowdon has resulted in a variable response with some species showing earlier flowering while others were later or showed no change (Turner and Bowmaker, 2016).

Extreme weather events, such as floods, droughts and heatwaves, will also affect biodiversity, through direct mortality or reduced reproductive success. Depending on the frequency of these events, species may or may not recover. Recent intertidal monitoring surveys found heat damage to high shore fucoid seaweed species in Wales and across the UK during the 2018 summer (Mieszkowska, 2019). Heat stress will also affect livestock and has been shown to negatively affect dairy production (Polsky and von Keyserlingk, 2017). Community composition changes in macro-invertebrates have been identified in headwater streams in Wales. Studies over many decades show their sensitivity to climatic changes in terms of changing precipitation, thermal regimes and oxygen concentrations in combination with the historical legacy of acidification e.g. Durance and Ormerod, 2007.

Ocean waters around the UK are also likely to become more acidic and contain less dissolved oxygen with climate change (MCCIP, 2020). This could have a particularly significant impact on shellfish fisheries in Wales (MCCIP, 2020).

People and the built environment

Observed Changes

In the UK, the number of cold days has decreased, while the number of warm days has increased (UKCCC, 2016). Despite this, cold weather is still a significant health problem in the UK. There were approximately 23,200 excess winter deaths in England and Wales in the 2018 to 2019 winter. Winter deaths across the UK declined significantly from the years 1950 to 2000 but with no clear trend since then until Covid-19. Excess winter deaths In Wales in the 2018 to 2019 winter were significantly lower than all years since the 2013 to 2014 winter (ONS, 2019). Recent excess deaths data has been complicated by the impacts of Covid-19. For the most up to date statistics on excess winter deaths see the ONS website.

There are around 2,000 heat-related deaths per year in the UK (Hajat et al., 2014). But in the hot summer of 2018, there were an estimated 8,500 heat-related deaths among the over-65s in the UK, which is over twice the average for the years 2000 to 2004 (Watts et al, 2020).

Projected Changes

Climate change will marginally reduce the risks associated with cold weather. However, higher temperatures will have a significantly increased impact on human health and well-being, including heat stress and an increased need for cooling. The number of heat-related deaths in the UK are projected to increase by over 250% by the 2050s, due to a combination of climate change, projected population growth, and ageing (Hajat et al., 2014). The percentage increase in Wales is expected to be slightly greater than the UK average due to the relatively older demographic. Overheating of buildings particularly affects urban areas. Climate

change is likely to exacerbate urban heat island effects which could lead to buildings overheating in the summer, particularly during heatwaves (Kovats and Osborn, 2016). Hotter summers are likely to exacerbate ozone pollution episodes that can have significant impacts on human health and the environment. [see Urban chapter and Air Quality chapter]

Warmer temperatures could provide greater opportunities for outdoor activities and increase the length of the tourist season in Wales. However, changes to water resources have been identified as a risk to this opportunity. Demand for water quadruples in coastal areas in the summer. With projected drier summers, this demand might not be met and could instead limit the Welsh tourist capacity (ADAS, 2010).

Extreme events and sea level rise

Observed Changes

Evidence suggests that there has been an acceleration of sea level rise in recent years of up to 4 mm per annum (IPCC, 2014). This has already led to the loss of some coastal habitats and damage to coastal communities and infrastructure. While it is not possible to confidently attribute individual recent extreme weather events like floods and droughts to climate change rather than inter-annual variability, there is increasing research that shows that the likelihood of many recent climatic extremes such as the 2018 heatwave have been significantly increased by anthropogenic climate change. Moreover, the recent pattern of global extreme events is consistent with future climate change projections.

Projected Changes

More intense rainfall and rising sea levels will increase the risk of flooding in Wales. It is projected that mean winter precipitation in Wales will be on average +9% by the 2050s compared to a 1981-2000 baseline based on a 'high' RCP8.5 scenario (Murphy et al., 2018). A greater proportion of warmer, wetter and windier weather resulting in more wet days in winter underlies this expected change. The most recent downscaled climate models provide clear evidence of a shift to more intense hourly rainfall in all seasons that may drive increased frequency of flash flooding events. The risk to the population will be particularly great in urban areas [LINK TO URBAN CHAPTER]. Managing the risk from flooding is a priority for the Welsh Government and current estimates show that over 245,000 properties in Wales are at risk from all sources of flooding (NRW, 2019). Flooding has a wide range of impacts on communities, including loss of homes, income and negative effects on mental health and well-being over long periods of time [see Aim 3 Healthy Places assessment and Urban chapter]. As well as the impact on urban areas, flooding could damage valuable farmland (Keay, 2020), cause detriment to water quality, and subsequently impact on biodiversity and ecosystem resilience. [see Enclosed Farmland chapter]

Sea level rise will continue to cause increased erosion of coastal habitats as well as threatening infrastructure such as railways. For example, by 2050 (based on a 'high' RCP8.5 scenario) sea level rise in Cardiff is projected to be between 20 – 39cm higher (Palmer et al., 2018). Increased erosion rates due to greater wave

action could lead to some coastal ecosystems being lost. Saltmarsh in particular is an important means of flood mitigation as it absorbs wave energy and can reduce impacts of storm surges. [see Coastal Margins chapter]. Increased erosion will also result in the loss of productive agricultural land and poses a significant threat to historical assets that are located along the coastline of Wales. Where the coastline is defended, erosion and sea level rise coupled with competing pressures such as development results in loss of habitat such as saltmarsh due to coastal squeeze. Most, though not all, human communities are likely to be defended, at least in the medium term. The impacts of sea level rise are also linked to the potentially increased incidence of storms (Welsh Government, 2019b). Sea-level rise also presents a low risk of saline intrusion into aquifers and agricultural land in Wales. Shoreline Management Plans provide a mechanism to coordinate the planned management of the coast (SMP2).

Drier summers could lead to increased pressure on water resources and the natural environment, leading to more frequent droughts. Mean summer precipitation is projected to be -19% by the 2050s based on a 'high' scenario defined as rainfall occurring on fewer days but with greater intensity (Murphy et al., 2018). Some ecosystems will be more vulnerable than others. Enclosed farmland is likely to be more vulnerable to summer droughts than semi-natural grasslands. Wetland ecosystems are also at risk from drier summers as they contain many species that are adapted to saturated conditions. Summer river flows are likely to decrease across the UK (Watts and Anderson, 2016). Changes to water availability are likely to lead to changes to the energy generated through hydropower.

Freshwater species are particularly sensitive to low flows, as there is less dissolved oxygen available for them. This problem is likely to be exacerbated by climate change with warmer river water having lower dissolved oxygen concentrations. However, these impacts can be managed through reducing pollution to improve water oxygenation and enhance their resilience (Verberk et al., 2016).

Under a high climate change scenario, by the 2050s, the abstraction demand is projected to outweigh the available water resources across the whole of Wales (Counsell et. al., 2015). In many areas, all available water is needed for environmental flows, leaving none left over for human uses.

Drier summers and increased drought could also increase the wildfire risk in Wales. Using the McArthur Forest Fire Danger Index, increases of fire risk of 30-40% are projected for the Pembrokeshire Coast and Brecon Beacons, and 40-50% for Snowdonia by the 2080s compared to 1980s (Defra, 2012b).

Extreme events can also alter water quality. Heavy rains and flooding can alter water quality through soil erosion as well as the transfer of excess nutrients and other pollutants from terrestrial to aqueous ecosystems (Ormerod and Durance, 2009).

Land use and soils

Observed Changes

Land use and land management are the key drivers of change in soil status [see land use and soils chapter], however, climate is another key factor. To date, land management has had the greatest impact on soil health (ASC, 2016). It is estimated that climate change accounted for 9–22% of carbon loss in organic soils of semi-natural habitats throughout England and Wales from 1978–2003 (Barraclough et.al., 2015). While in organo-mineral/mineral soils in agricultural land, less than 5% of reduction in carbon concentration could be linked to climate change. Unfortunately, there is very limited monitoring of soils in the UK, and almost none in Wales. Climate change has driven an increase in the length of the growing season by 15-35 days since 1961-1990 (Kendon et al., 2015), which has resulted in increased plant productivity.

Projected Changes

The impact of drought on soils, and the ecosystem services that they provide, is likely to be significant. The majority of projections suggest reductions in soil moisture are likely across the UK with climate change (Brown et al., 2016). Climatic moisture (and soil moisture) has been found to be positively related to topsoil carbon (Alison et al., 2019), therefore drought conditions could reduce carbon storage in soils. Peatland formation needs cool and wet conditions. Given that a large proportion of peatlands are already degraded and emitting carbon, climate change could further exacerbate the loss of greenhouse gases from peatlands (ASC, 2016). On average, drier summers combined with wetter autumn and winter conditions are likely to increase soil erosion and carbon loss. [see land use and soils chapter and Mountains, Moorlandss and Heaths chapter]

These projected changes to soils are likely to constrain land use in certain areas. **Land quality could reduce, changing the areas that are the most productive** (Brown et al., 2016). The agricultural quality of some land in Wales is projected to decrease due to drought (Keay et al., 2014) and some will be lost due to sea level rise (Keay and Hannam 2020). [see land use and soils chapter]. However, there is still significant uncertainty over how soils will respond to climate change (Rollett and Williams, 2019), and it is inevitable that physiography and soil types will continue to dictate land use options in Wales, and limit the potential for new crops.

A longer growing season may increase the production of some crops and grass fodder (Morison and Matthews, 2016). However, increased winter rainfall will exacerbate waterlogging and poaching so that access for livestock or land management will likely be more restricted, particularly in winter [see land use and soils chapter].

Increased carbon dioxide concentrations in the atmosphere could increase the carbon sequestration rates by both crops and trees and increase forest productivity (ASC, 2016). However, it is important to recognise that this may be countered by projected reductions in water availability and drought in summer. Woodland management will need to be adapted to the potential threats of drought, increased pest and diseases, and wind damage. For example, more frequent green spruce

aphid attacks could reduce Sitka spruce (a key productive timber species) growth in Wales. A wider range of tree species and greater genetic diversity could provide a risk management strategy for new woodlands [see woodlands chapter].

6. Opportunities for Action

Mitigation

Nature recovery and habitat restoration will be crucial to climate change mitigation by both reducing emissions and increasing carbon sequestration from ecosystems. The UK Government target and UKCCC recommendation for a Welsh net zero emissions target for 2050 necessitates ecosystems playing a key role in their attainment (UKCCC, 2020a).The Welsh Government plans to increase the tree cover in both urban and non-urban areas, including expanding both productive conifer forests and biodiverse broadleaved woodland. The target is to increase woodland cover by at least 2000 hectares per year from 2020 to 2030 (Welsh Government, 2019a). All woodland restoration efforts must ensure that replanting uses species that are appropriate for the current and future climate. Restoring forests is less effective if delayed, therefore it is important for ecological restoration to be prompt (UKCCC, 2020b). It will be critical to ensure that new woodland is planted in the right place so that expanded woodlands are consistent with solutions to the nature emergency as well as capturing carbon.

Restoring peatlands and other soils is also key to maintaining carbon storage and reducing GHG emissions. Avoiding damage and erosion is important for retaining existing carbon stores in soils and vegetation. Peatland soils comprise the single largest terrestrial store of carbon in Wales with an estimated 66 Mt (megaton) across the Welsh peatland resource (Williamson et al., 2019). Careful restoration and management of organic soils, especially deep peat which occupies around 4% of Wales, are particularly critical to achieving net zero goals (UKCCC, 2020b). Improving the condition of upland peat can involve blocking artificial drains and re-establishing peat-forming vegetation. Although peatland restoration can take decades to achieve well developed peat-forming vegetation that may be able to sequester carbon with greatly reduced GHG emissions; reduced emissions through raising water tables and revegetation can be achieved within a few years (Vanguelova et al., 2012). [see mountains, moorlands and heath chapter]

Appropriate agricultural practices are also important to maintaining healthy ecosystems in the face of climate change. **Sustainable agriculture can maintain soil carbon stores, help regulate water quality** and contribute to other ecosystem functions (IPBES, 2019). Fertiliser use is also a major contributor to greenhouse gas emissions from agriculture, both in terms of the energy needed for its production and the nitous oxide emissions from soils arising from its application. Furthermore, fertiliser is also attributed to water pollution [see enclosed farmland chapter and freshwater chapter].

Reducing and better targeting fertilizer use will be important for climate change mitigation. Reducing ploughing can help maintain soil organic carbon and increase its ability to hold water and resist erosion (Brown et al., 2016). Hedgerow

management to enhance carbon storage through their restoration and planting has been identified as another valuable action (UKCCC, 2020b). The 61,670 km of hedgerows in Wales reported by Maskell et al. (2019) have been estimated to sequester an additional 3.1 Mt CO_2e above the baseline carbon stocks for field margins (Axe, 2020). Improving all hedges to favourable condition and increasing their width and height provides the potential to sequester a further 3.0 Mt CO_2e.

Apart from woodland creation, other land use changes proposed by the UK Committee on Climate Change include **developing bioenergy crops on around 56,000 ha of agricultural land by 2050** (UKCCC, 2020a). This could include production of short rotation coppice. There is also a potential role for agro-forestry systems [see land use and soils chapter].

Enhancing blue carbon through protecting and restoring marine and coastal ecosystems is another contributor to meeting mitigation goals. Blue carbon is the term for carbon stored in marine and coastal ecosystems, including salt marshes, seagrass beds and seaweed habitats (Senedd Research, 2019). It has been estimated that Welsh marine habitats sequester at least 26,100 tonnes of carbon each year. This amount could be increased by protecting and restoring habitats such as saltmarsh and seagrass as well as greater protection of the seabed (Armstrong et al., 2020). [see coastal margins chapter and marine chapter]

Adaptation

Restoring damaged ecosystems, such as woodlands, peatlands, rivers and wetlands, will contribute to adaptation and increase resilience of the natural environment. Restored habitats will help species movement across the landscape as a response to warming. In addition, increasing plant cover in suitable habitats can reduce soil erosion while measures must also be taken to maintain good soil structure. Restoring trees and hedgerows on farmland will have added adaptation benefits of providing shelter and shade for livestock.

On the coast, where saltmarsh is being lost due to sea level rise, it is being replaced through managed retreat projects as part of the National Habitat Creation Programme. Such habitat creation along the coast can act as a natural defence and buffer to the impacts of storms and sea level rise through flood protection and water storage.

Further adaptation measures will also be needed to protect biodiversity in a changing climate. There are a broad array of adaptation measures that are applicable across different ecosystems; habitat by habitat and species by species approaches have been set out in the Natural England Climate Change Adaptation Manual (Natural England and RSPB, 2019). These include increasing the size, condition and connectivity of protected areas, directly managing the rarest and most vulnerable species, and examining the potential for managed translocations of species to areas that become more climatically suitable for them (Brown et al., 2016). While active intervention options are more limited for marine species, there is potential for adaptation through the network of Marine Protected Areas.

There is increasing evidence of the effectiveness of adaptation measures. Some important data from Welsh macro-invertebrate studies (Vaughan and Gotelli, 2019), reveal how improved water quality acts as a means of offsetting potential adverse impacts due to water temperature increase. Such evidence illustrates how reducing other stressors can improve resilience to climate change. Active management was found to increase the resilience of black grouse populations in Wales to unfavourable weather conditions (Pearce-Higgins et al., 2019). Reducing habitat fragmentation and increasing connectivity was projected to help butterflies in the UK respond to climate change (Oliver et al., 2015).

Urban and rural green infrastructure can deliver adaptation benefits and is also associated with a number of ecosystem services, including improving air quality through trapping pollutants. Urban greenspaces, especially those with trees, can reduce local surface temperatures and provide cooling and shading for people and buildings. [see Urban chapter]. In rural areas, there are also clear adaptation benefits, for example, restored riparian woodlands act as shade to reduce warming in Welsh streams and potentially enhance resilience of food webs by increasing biomass (Thomas et.al., 2015). Green infrastructure can also provide food and habitat for pollinators and contribute to habitat connectivity and nature recovery.

Sustainable drainage systems (SuDS), which manage water flow to reduce flooding, can be an important climate change adaptation measure in urban areas. The Greener Grangetown project in Cardiff has involved retrofitting SuDS Well-designed SuDS can provide multiple benefits, including surface water flood mitigation, biodiversity enhancements and wider well-being and recreation benefits. [see Urban chapter].

A range of measures must be put in place to reduce the risk of river and flash floods. The National Strategy for Flood and Coastal Erosion Risk Management (Welsh Government, 2020) recognises that a more holistic approach is needed to manage all types of flooding, in order to encourage wider resilience and to improve awareness and delivery of sustainable flood management schemes that deliver wider well-being benefits.

Introducing natural flood risk management measures, such as river and flood plain restoration and leaky barriers either in isolation or in conjunction with more traditional engineered defences, can help to increase water storage and improve a river's ability to manage flood water. For example, flood alleviation schemes like the Swansea Vale Flood Storage Area are designed to create more space for water. Natural flood management interventions will be most effective in small catchments (Keenleyside and Old, 2019).

Interventions upstream of flood-prone areas, in headwaters, can also help reduce flood risk. This could include restoring upland peat through vegetation management, grip blocking or gully blocking (Keenleyside and Old, 2019). For example, in the Afon Merin catchment installation of woody in-stream structures designed to hold up the flows and provide conditions for flood plain restoration that deliver flood flow attenuation, delay in time to peak, and low flow protection in the summer months

Agricultural and run-off pathway management interventions could also alleviate localised flood risk. Although natural flood management options can reduce peak

flows, they cannot prevent all flooding, particularly large scale events as seen in Wales during February 2020. However, they can be a valuable contribution when combined with hard defences. More traditional engineered flood defence infrastructure will still be needed in the areas of highest flood risk. As climate change will lead to larger floods with increasing frequency, maintaining and updating existing defences to ensure they can cope with the changing levels of risk is also important.

Similar adaptation strategies can be put in place along the coast. Some measures, such as beach nourishment, work with the natural processes but reduce the risk of flooding and coastal erosion. In addition, constructing flood defence walls and embankments, such as in Newport to protect against tidal flooding, can protect against higher coastal floods. In other areas, such as Cwm Ivy, managed realignment, which allows the shoreline to move naturally, is more appropriate. Shoreline Management Plans (SMP2) will be crucial to decision-making to protect Wales' coastline [see Coastal Margins Chapter]

An increased drought-risk may at least be partially alleviated by irrigation and increased water storage (Brown et al., 2016). This will be particularly important for agricultural land. Soil, water and crop management will be central to farm-level adaptation (Brown et al., 2016). The drought plans of both NRW and the water companies operating in Wales provide a flexible framework for identifying and managing drought events, including regulating abstractions [see water efficiency chapter].

Behavioural change will also be an important adaptation in the water sector, particularly the response to increased risk of droughts. Ensuring water use efficiency will be key to managing the water demand during dry periods and drought conditions. Reducing use, encouraging re-use and rainwater harvesting can also be used to reduce the impacts of droughts. [see water efficiency chapter]. Behavioural change is also important for adapting to increased flooding, as recognising that flooding will occur and taking appropriate action will be necessary.

7. Synergies, Trade-offs and Challenges

Synergies

Many mitigation and adaptation policies will have synergies with one another, leading to multiple benefits. For instance, the benefits of tree planting beyond storing carbon are widely recognised, including alleviating flood risk, improving air quality, providing additional habitats and for recreation and well-being (UKCCC, 2020b). Similarly, flood plain and saltmarsh restoration provide additional habitats and can benefit a wide range of species. Protecting and restoring nature can contribute to both wider climate change mitigation and adaptation benefits, such as some flood risk reduction and reducing erosion risks.

Trade-offs

Responding to climate change is likely to lead to trade-offs, particularly between competing land uses. For instance, setting aside land for biodiversity protection, ecosystem restoration or bioenergy could take space away from agriculture [see Land Use Chapter] Tree planting on agricultural land may involve excluding grazing in the short to medium term as mature trees take decades to develop. While much of Wales is rural with low population density, there are limited areas of high value agricultural land and strong pressure for development on flood plains due to topography. Such challenges mean that competition for land will be an increasing issue in the future.

Climate change will also pose a significant challenge for the flood defence infrastructure on flood plains and along the coast. Flood protection infrastructure cannot continually be updated to protect against increasing flood levels. Natural flood risk management techniques will not be suitable everywhere and will not help reduce risk from larger flood events. Therefore, difficult decisions must be made over where investment is to be prioritsied.

At the coast, protecting coastal communities can increase erosion elsewhere along the coastline. Coastal defences to protect properties can also lead to the loss of coastal habitats through coastal squeeze [see coastal margins chapter]. In addition, building flood defences can also reduce public perceptions of the true risk of flooding (Street et al., 2016). In some areas, there is a conflict between protecting flood plains and coastal areas and the economic drive to keep places vibrant. Similar issues apply with river defences, where flooding problems can be displaced elsewhere [see urban chapter].

Bioenergy crops will be necessary to achieve a low carbon economy but this could lead to significant trade-offs (UKCCC, 2019; 2020b). Some bioenergy crops can have negative effects on biodiversity, food security, water security and local livelihoods (IPBES, 2019). Trade-offs could be minimised by making better use of existing agricultural and forestry waste for energy to reduce the need for planted energy crops. [see land use and solis chapter]

Peatland, and particularly a high proportion of lowland peat, has been drained and converted for agriculture thereby resulting in very high per hectare greenhouse gas emisssions. Rewetting many of these areas and creating alternative agricultural approaches and income will be challenging and there will need to be trade-offs (UKCCC, 2020b). Paludiculture (the production of crops on rewetted peat), is a potential solution that requires further development of techniques and the potential for their application in Wales (NRW, 2020). [see mountains, moorlands and heath chapter].

Challenges

There will also be **challenges with the delivery of adaptation and mitigation policies**. For instance, reduced meat and dairy consumption is an efficient way of reducing greenhouse gas emissions but implementing this could be a significant challenge as it requires lifestyle changes and can impact on the economies of rural

communities. Although there is a greater awareness of environmental issues, large-scale changes in behaviour are yet to be seen.

In addition, **damaged ecosystems can be difficult, time consuming, and potentially expensive to restore depending on the amount of damage**. Farmers may not have the necessary skills for woodland management on agricultural land (Keenleyside and Old, 2019). The additional costs of managing restored habitats in the longer term must also be considered. For instance, in urban areas, there may be insufficient resources to manage greenspace. As a result of these constraints, low-regrets options and those strategies that can be supported through existing programmes are often favoured. Limited financial resources can restrict adaptation and mitigation options and may require activities to be prioritised. Effective mitigation and adaptation are urgent to limit warming and protect ecosystems. Prioritising some targets over others could prevent holistic management and undermine resilience.

Despite the creation of new woodland being a Welsh Government priority, there has been limited progress towards these targets. Current rates of woodland creation are not sufficient to meet the longer-term targets. [see woodland chapter] As discussed above, carefully selecting suitable tree species is paramount to achieving climate change adaptation and mitigation targets through woodland creation.

In terms of providing incentives to reduce emissions from agriculture through both changing land use or improving efficiency, the new sustainable land management scheme for Wales will be a crucially important for reducing agricultural emissions which is a major challenge.

Uncertainty is one of the largest barriers to adaptation. Although it is clear that the climate is changing, precise information on the magnitude and timing of climate risks will never be available. Adaptive management decisions must be made in the face of uncertainty and strategies must be regularly monitored and assessed.

It is important to remember that climate change will interact with all other cross-cutting themes and that **there are complex interactions between the drivers of change to ecosystems** (IPBES, 2019). Coherence between policies is key to reducing trade-offs, avoiding maladaptation, and maximising synergies.The strategic policy framework in Wales as set out in the National Development Framework, Wales National Marine Plan and the Land Use Framework provides a mechanism to integrate land use planning, land management, marine and coastal planning and management. It also encourages movement towards a whole system-based approach to achieving net zero emissions and biodiversity goals.

8. Evidence Needs

In the context of SoNaRR, evidence needs are those that would contribute to a better understanding of climate change in order to assess the sustainable management of natural resources. Key questions that need to be considered include:

- Is Wales' network of habitats sufficiently connected to be resilient to climate change, through allowing species movement?
- What ecosystem tipping points might affect Wales?
- How resilient are coastal environments?
- How might changes to species distribution and abundance affect well-being?
- What are the direct effects of climate change on health?
- Where is there the greatest potential for increasing carbon storage and reducing emissions from land?
- What are the likely recovery times for ecosystems and species?
- What needs are there to relocate species at risk of local extinction?

A research priority identified within the CCRA2 (UKCCC, 2016) was new and emerging pests and diseases, and invasive non-native species affecting people, plants and animals

The CCRA3 will be reviewing evidence needs but this was not available to inform SoNaRR2020.

9. References

ADAS. 2010. The Impact of Climate Change on the Welsh Visitor Economy. ADAS, Wolverhampton.

Alison J, Thomas A, Evans CD, Keith AM, Robinson DA, Thomson A, Dickie I, Griffiths RI, Williams J, Newell-Price JP, Williams AG, Williams AP, Martineau AH, Gunn IDM, Emmett BA. 2019. Technical Annex 3: Soil Carbon Management. In Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP): Sustainable Farming Scheme Evidence Review. Report to Welsh Government (Contract C210/2016/2017). Centre for Ecology & Hydrology Project NEC06297.

Armstrong S, Hull S, Pearson Z, Wilson R, Kay S. 2020. Estimating the Carbon Sink Potential of the Welsh Marine Environment. Natural Resources Wales Evidence Report No 428. NRW, Cardiff, 74p. Available from: https://naturalresources.wales/evidence-and-data/research-and-reports/marine-reports/marine-and-coastal-evidence-reports/?lang=en [accessed February 2021]

ASC. 2016. UK Climate Change Risk Assessment 2017 Evidence Report – Summary for Wales. Adaptation Sub-Committee of the Committee on Climate Change, London. Available from: https://www.theccc.org.uk/uk-climate-change-risk-assessment-2017/ [accessed February 2021]

Axe M. 2020. Calculation of hedgerow sequestration potential in Wales. NRW Contract Science Report 511

Barraclough D, Smith P, Worrall F, Black HIJ, Bhogal A. 2015. Is there an impact of climate change on soil carbon contents in England and Wales? European Journal of Soil Science. 66: 451–462. DOI: 10.1111/ejss.12253

Brown I, Thompson D, Bardgett R, Berry P, Crute I, Morison J, Morecroft M, Pinnegar J, Reeder T, Topp K. 2016. UK Climate Change Risk Assessment Evidence Report: Chapter 3, Natural Environment and Natural Assets. Report prepared for the Adaptation Sub-Committee of the Committee on Climate Change, London.

Burgess MD, Smith KW, Evans KL, Leech D, Pearce-Higgins JW, Branston CJ, Briggs K, Clark JR, du Feu CR, Lewthwaite K, Nager RG, Sheldon BC, Smith JA, Whytock RC, Willis SG, Phillimore AB. 2018. Tritrophic phenological match–mismatch in space and time. Nat Ecol Evol 2, 970–975 (2018). Abstract available from: https://doi.org/10.1038/s41559-018-0543-1 [accessed February 2021]

Chadwick EA, Slater FM, Ormerod SJ. 2006. Inter- and intraspecific differences in climatically mediated phenological change in coexisting *Triturus* species. Global Change Biology, **12**, 1069-1078. Available from: https://doi.org/10.1111/j.1365-2486.2006.01156.x [accessed February 2021]

Climate Action Tracker. 2020. Climate Action Tracker [online]. Available from: https://climateactiontracker.org/ [accessed February 2021]

Counsell C, Hall E, Ledbetter R. 2015. CCRA2: Updated projections of water availability for the UK. A research preport by HR Wallingford for the Climate Change Risk Assessment 2. Available from: https://www.hrwallingford.com/projects/projecting-future-water-availability-uk-second-ccra [accessed March 2021]

Defra. 2012a. UK Climane Change Risk Assessment: Government Report. London: The Stationery Office. Available from: https://www.gov.uk/government/publications/uk-climate-change-risk-assessment-government-report [accessed March 2021]

Defra. 2012b. UK Climate Change Risk Assessment 2012 Evidence Report. Defra Project Code GA0204. Available from: Defra, UK - Science Search [accessed February 2021]

Durance I. Ormerod SJ .2007. Climate change effects on upland stream macroinvertebrates over a 25-year period. Global Change Biology, **13**, 942–957. Available from: https://onlinelibrary.wiley.com/doi/full/10.1111/j.1365-2486.2007.01340.x [accessed February 2021]

Evans C, Rawlins B, Grebby S, Scholefield P, Jones P. 2015. Glastir Monitoring & Evaluation Programme. Mapping the extent and condition of Welsh peat. Welsh Government (Contract reference: C147/2010/11). NERC/Centre for Ecology & Hydrology (CEH Project: NEC04780). Available from: https://gmep.wales/resources [accessed February 2021]

Hajat S, Vardoulakis S, Heaviside C, Eggen B. 2014. Climate change effects on human health: projections of temperature-related mortality for the UK during the 2020s, 2050s and 2080s. Journal of Epidemiology and Community Health, 68(7), 641-648.

HM Government. 2020. The Ten Point Plan for a Green Industrial Revolution. Available from: https://www.gov.uk/government/publications/the-ten-point-plan-for-a-green-industrial-revolution [accessed February 2021]

Hoegh-Guldberg O, Jacob D, Taylor M, Bindi M, Brown S, Camilloni I, Diedhiou A, Djalante R, Ebi KL, Engelbrecht F, Guiot J, Hijioka Y, Mehrotra S, Payne A, Seneviratne SI, Thomas A ,Warren R, Zhou G. 2018. Impacts of 1.5ºC Global Warming on Natural and Human Systems. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty [Masson-Delmotte V, Zhai P, Pörtner H-O, Roberts D, Skea J, Shukla PR, Pirani A, Moufouma-Okia W, Péan C, Pidcock R, Connors S, Matthews JBR, Chen Y, Zhou X, Gomis MI, Lonnoy E, Maycock T, Tignor M, Waterfield T (editors)]. In Press. Available from: https://www.ipcc.ch/report/sr15/chapter-3-impacts-of-1-5oc-global-warming-on-natural-and-human-systems/ [accessed February 2021]

IPBES. 2019: Summary for policymakers of the global assessment report on biodiversity and ecosystem services of the Intergovernmental Science-Policy

Platform on Biodiversity and Ecosystem Services. Díaz S, Settele J, Brondízio ES, Ngo HT, Guèze M, Agard J, Arneth A, Balvanera P, Brauman KA, Butchart SHM, Chan KMA, Garibaldi LA, Ichii K, Liu J, Subramanian SM, Midgley GF, Miloslavich P, Molnár Z, Obura D, Pfaff A, Polasky S, Purvis A, Razzaque J, Reyers B, Roy Chowdhury R, Shin YJ, Visseren-Hamakers IJ, Willis KJ, Zayas CN (editors.). IPBES secretariat, Bonn, Germany. 56 pages. Available from: https://doi.org/10.5281/zenodo.3553579 [accessed February 2021]

IPCC. 2014. Summary for Policymakers. In: Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Edenhofer O, Pichs-Madruga T, Sokona Y, Farahani E, Kadner S, Seyboth K, Adler A, Baum I, Brunner S, Eickemeyer P, Kriemann B, Savolainen J, Schlömer S, von Stechow C, Zwickel T and Minx JC (editors.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. Available from: https://www.ipcc.ch/report/ar5/wg3/ [accessed March 2021].

IPCC. 2018: Intergovernmental Panel on Climate Change. Summary for Policymakers. In: Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty. [Masson-Delmotte V, Zhai P, Pörtner H-O, Roberts D, Skea J, Shukla PR, Pirani A, Moufouma-Okia W, Péan C, Pidcock R, Connors S, Matthews JBR, Chen Y, Zhou X, Gomis MI, Lonnoy E, Maycock T, Tignor M, Waterfield T (editors)]. In Press. Available from: https://www.ipcc.ch/sr15/chapter/spm/ [Accessed February 2021]

Keay CA, Jones RJA, Procter C, Chapman V, Barrie I. 2014. The impact of climate change on the capability of soils for agriculture as defined by the Agricultural Land Classification. Report to Defra.ADAS/University of Cranfield

Keay CA. 2020. Sea Level Rise & Agricultural Land Loss under UKCP18. Soil Policy Evidence Programme. Welsh Government Report. Available from: https://gov.wales/loss-agricultural-land-under-sea-level-rise-scenarios [accessed February 2021]

Keay CA, Hannam JA. 2020. The effect of Climate Change on Agricultural Land Classification 12379 (ALC) in Wales. Capability, Suitability and Climate Programme, Welsh Government Report.

Keenleyside CB, Old GH 2019. Technical Annex 9: Flood mitigation. In Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP): Sustainable Farming Scheme Evidence Review. Report to Welsh Government (Contract C210/2016/2017). Centre for Ecology & Hydrology Project NEC06297

Kendon M, McCarthy M, Jevrejeva S. 2015. State of the UK Climate 2014. UK Met Office, Exeter UK

Kendon M, McCarthy M, Jevrejeva S, Matthews A, Legg,T. State of the UK climate 2018. *Int J Climatol.* 2019; 39 (Suppl. 1): 1– 55. Available from: https://doi.org/10.1002/joc.6213 [accessed February 2021]

Kovats RS, Osborn D. 2016. UK Climate Change Risk Assessment Evidence Report: Chapter 5, People and the Built Environment. Contributing authors: Humphrey K, Thompson D, Johns D, Ayres J, Bates P, Baylis M, Bell S, Church A, Curtis S, Davies M, Depledge M, Houston D, Vardoulakis S, Reynard N, Watson J, Mavrogianni A, Shrubsole C, Taylor J, Whitman G. Report prepared for the Adaptation Sub-Committee of the Committee on Climate Change, London.

MCCIP. 2020. Marine Climate Change Impacts Report Card 2020. Stoker B, Turrell WR, Robinson KA, Howes EL, Buckley P, Maltby K, Matear L.(editorss.) MCCIP Summary Report. Marine Climate Change Impacts Partnership. Available from: https://doi.org/10.14465/2020.arc00.000-000 [accessed February 2021]

Maskell LC, Alison J, Smart SM. 2019. ERAMMP Year 1 Report 20: GMEP Outstanding Analysis Part 1 - Re-analysis of data for SoNaRR. Report to Welsh Government (Contract C210/2016/2017). Centre for Ecology & Hydrology Project NEC06297.

Met Office. 2018. Met Office Hadley Centre. UKCP18 Global Projections. Available at: https://ukclimateprojections-ui.metoffice.gov.uk/ui/home [accessed February 2021]

Mieszkowska N. 2019. MarClim Annual Welsh Intertidal Climate Monitoring Survey 2018. Natural Resources Wales Evidence Report No. 345 pp 23 + x, Natural Resources Wales, Bangor. Available from: https://cdn.cyfoethnaturiol.cymru/evidence-and-data/research-and-reports/marine-reports/marine-and-coastal-evidence-reports/?lang=en [accessed February 2021]

Morecroft MD, Speakman L. 2015. Biodiversity Climate Change Impacts Summary Report. Living With Environmental Change. ISBN 978-0-9928679-6-6. Available from: https://nerc.ukri.org/research/partnerships/ride/lwec/report-cards [accessed February 2021]/

Morison JIL and Matthews RB, (editors.). 2016. Agriculture and Forestry Climate Change Impacts Summary Report, Living With Environmental Change. ISBN 978-0-9934074-0-6

Murphy JM, Harris GR, Sexton DMH, Kendon EJ, Bett PE, Clark RT, Eagle KE, Fosser G, Fung F, Lowe JA, McDonald RE, McInnes RN, McSweeney CF, Mitchell JBF, Rostron JW, Thorntonm HE, Tucker S, Yamazaki K. 2018. UKCP18 Land

NAEI. 2020. National Atmospheric Emissions Inventory Greenhouse Gas Inventories for England, Scotland, Wales & Northern Ireland: 1990-2018. Thistlethwaite G, Smith H, Brown P, MacCarthy J, Pang Y, Passant N, Richmond B, Wakeling D, Walker C, Hampshire K, King K, May K, Garland L, Zhang H, Jones L, Thomson A, Buys G, Clilverd H, Malcolm H, ZwagermanT, Henshall P, Matthews R, Cardenas L, Gilhespy S, Misselbrook T. Available from: https://naei.beis.gov.uk/reports/reports?report_id=1000 [Accessed February 2021]

Natural England and RSPB. 2019. Climate Change Adaptation Manual - Evidence to support nature conservation in a changing climate, 2nd Edition. Natural England, York, UK. Available at:

http://publications.naturalengland.org.uk/publication/5679197848862720 [accessed February 2021]

NRW. 2016. Natural Resources Wales. The State of Natural Resources Report: Assessment of the sustainable management of Natural Resources. Available from: https://naturalresources.wales/evidence-and-data/research-and-reports/the-state-of-natural-resources-report-assessment-of-the-sustainable-management-of-natural-resources/?lang=en [Accessed February 2021]

NRW. 2019. Flood and coastal erosion risk in Wales. Cardiff: NRW. Available from: https://naturalresources.wales/evidence-and-data/research-and-reports/reports-evidence-and-data-on-flooding/flood-and-coastal-erosion-risk-in-wales/?lang=en [Accessed January 2021]

NRW. 2020. National Peatland Action Programme, 2020-2025. Natural Resources Wales, Cardiff. Available at: https://cdn.naturalresources.wales/about-us/strategies-and-plans/national-peatland-action-programme/?lang=en [accessed February 2021]

Oliver, T., Marshall, H., Morecroft, M. et al. Interacting effects of climate change and habitat fragmentation on drought-sensitive butterflies. Nature Clim Change, 5, 941–945 (2015).

ONS. 2019. Office of National Statistice. Excess winter mortality in England and Tales:2018 to 2019 (provisional) and 2017 to 2018 (final). Available online at: https://www.ons.gov.uk/peoplepopulationandcommunity/birthsdeathsandmarriages/deaths/bulletins/excesswintermortalityinenglandandwales/2018to2019provisionaland2017to2018final [accessed February 2021]

Ormerod SJ. and Durance I. 2009. Restoration and recovery from acidification in upland Welsh streams over 25 years. Journal of Applied Ecology, **46** , 164–174. Available from: https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/j.1365-2664.2008.01587.x [accessed February 2021]

Palmer M, Howard T, Tinker J, Lowe J, Bricheno L, Calvert D, Edwards T, Gregory J, Harris G, Krijnen J, Pickering M, Roberts C, Wolf J. 2018. UKCP18 Marine Report. Met Office Hadley Centre. Available from: https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/marine-projections [accessed February 2021]

Pearce-Higgins JW, Lindley PJ, Johnstone IG, Thorpe IG, Douglas DJT, Grant MC. 2019. Site-based adaptation reduces the negative effects of weather upon a southern range margin Welsh black grouse *Tetrao tetrix* population that is vulnerable to climate change. Climatic Change 153, 253–265. Abstract available at: https://doi.org/10.1007/s10584-019-02372-2 [accessed February 2021]

Polsky L, von Keyserlingk MAG. 2017. Invited review: Effects of heat stress on dairy cattle welfare. Journal of dairy science, 100(11), pp.8645-8657. Available from: https://www.sciencedirect.com/science/article/pii/S0022030217308494 [accessed February 2021]

Rollett A, Williams J. 2019. Assessment of Welsh Soil Issues in Context. Soil Policy Evidence Programme 2018-19/01. Welsh Government. Report code:SPEP2018-19/01. Available from: Assessment of soil issues in context | GOV.WALES [accessed February 2021]

SEI and GHD. 2015. Stockholm Environment Institute and GHD. Ecological and Carbon Footprints of Wales Update to 2011. Available from: https://gov.wales/ecological-and-carbon-footprint-report [accessed February 2021]

Senedd Research. 2019. Blue Carbon Research Briefing. National Assembly for Wales. Available from: https://research.senedd.wales/research-articles/blue-carbon-and-its-role-in-combating-climate-change/ [accessed February 2021]

SMP2. Shoreline management Plans 2:

Severn Estuary Coastal Group. 2017. Severn Estuary Shoreline Management Plan 2. Available at: https://severnestuarycoastalgroup.org.uk/shoreline-management-plan/smp2-action-plan/ [accessed February 2021]

South Wales Coast. South Wales Coasts Shoreline Managelment Plan.

North West England and North Wales Coastal Group. 2016. North West Shoreline Managelment Plan. Available at: https://www.mycoastline.org.uk/shoreline-management-plans/ [accessed February 2021]

West of Wales Coastal Group. 2012.. West of Wales Shoreline Management Plan 2. Available at: https://www.gagc.cymru/page/smp2/smp2 [accessed February 2021]

Steinbauer MJ, Grytnes JA, Jurasinski G. et al. 2018. Accelerated increase in plant species richness on mountain summits is linked to warming. Nature 556, 231–234 Abstract available from: https://doi.org/10.1038/s41586-018-0005-6 [accessed February 2021]

Street R, Di Mauro M, Humphrey K, Johns D, Boyd E, Crawford-Brown D, Evans J, Kitchen J, Hunt A, Knox K, Low R, McCal, R, Watkiss P, Wilby R. 2016. UK Climate Change Risk Assessment Evidence Report: Chapter 8, Cross-cutting Issues. Report prepared for the Adaptation Sub-Committee of the Committee on Climate Change, London.

Thomas SM, Griffiths SW, Ormerod SJ. 2015. Beyond cool: adapting upland streams for climate change using riparian woodlands. Global Change Biology, 22, 310-324. Abstract available at: https://doi.org/10.1111/gcb.13103 [accessed February 2021]

Turner AJ, Bowmaker V. 2016. NRW Evidence Report No 166. Environmental Change Network Yr Wyddfa/Snowdon site Summary of measurements and trends over the period 1995-2015. Natural Resources Wales, Bangor. Available from: https://cdn.naturalresources.wales/evidence-and-data/research-and-reports/state-of-the-environment-reports/publications-and-research-about-state-of-the-natural-environment/?lang=en [accessed February 2021]

UKCCC. 2016. UK Climate Change Risk Assessment 2017 Synthesis Report. Committee on Climate Change, London. Available from: Synthesis report - Climate Change Committee (theccc.org.uk) [accessed February 2021]

UKCCC. 2019. UK Committee on Climate Change. Net Zero The UK's contribution to stopping global warming. Available from: https://www.theccc.org.uk/publication/net-zero-the-uks-contribution-to-stopping-global-warming/ [accessed February 2021]

UKCCC. 2020a. Committee on Climate Change. Advice Report: The path to a Net Zero Wales Available from: https://www.theccc.org.uk/publication/the-path-to-net-zero-and-progress-reducing-emissions-in-wales/ [accessed February 2021]

UKCCC. 2020b. Committee on Climate Change. Land Use: policies for a Net Zero UK. Available from: https://www.theccc.org.uk/publication/land-use-policies-for-a-net-zero-uk/ [accessed February 2021]

UKGov. 2020. UK sets ambitious new climate target ahead of UN Summit. UK Government Press release. Available from: https://www.gov.uk/government/publications/uk-climate-change-risk-assessment-government-report [accessed March 2021]

UNEP. 2019. United Nations Environment Programme. Emissions Gap Report 2019. UNEP. Nairobi. Available from https://www.unep.org/resources/emissions-gap-report-2019 [accessed February 2021]

United Nations. 2015. United Nations Framework Convention on Climate Change. Adoption of the Paris Agreement, 21st Conference of the Parties, Paris: United Nations. Available from: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement [accessed February 2021]

Vanguelova E, Broadmeadow S, Anderson R, Yamulki S, Randle T, Nisbet T, Morison J. 2012. A Strategic Assessment of the Afforested Peat Resource in Wales. Report by Forest Research staff for Forestry Commission Wales Project, with Reference No 480.CY.00075 (T), October 2012.

Vaughan IP and Gotelli NJ. 2019. Water quality improvements offset the climatic debt for stream macroinvertebrates over twenty years. Nature Communications, 10, 1956. Available at: https://doi.org/10.1038/s41467-019-09736-3 [Accessed 15 February 2021]

Verberk WCEP, Durance I, Vaughan IP, Ormerod SJ. 2016. Field and laboratory studies reveal interacting effects of stream oxygenation and warming on aquatic ectotherms. Global Change Biology, **22**, 1769–1778. Available from: https://onlinelibrary.wiley.com/doi/10.1111/gcb.13240 [accessed February 2021]

Watts G and Anderson M. (editors) .2016. Water climate change impacts report card 2016 edition. Living With Environmental Change. ISBN 978-0-9934074-1-3. Available from: NERC - RIDE Forum - Climate change impacts report cards (ukri.org) [accessed February 2021]

Watts MA, Amann M, Arnell N, Ayeb-Karlsson S, Beagley J, Belesova K et al. 2020. The 2020 report of the Lancet Countdown on health and climate change; responding to converging crises. The Lancet. Available online at: https://doi.org/10.1016/S0140-6736(20)32290-X. [accessed February 2021]

Welsh Government. 2015. Well-being of Future Generations Act [online]. Available from: https://futuregenerations.wales/about-us/future-generations-act/ [accessed February 2021]

Welsh Government. 2016. The Environment Act (Wales) 2016 [online]. Available from: http://www.legislation.gov.uk/anaw/2016/3/contents [accessed February 2021]

Welsh Government. 2017. Natural Resources Policy. Available from: https://gov.wales/natural-resources-policy [accessed February 2021]

Welsh Government. 2019. Cabinet Statement Written statement: Welsh Government declares Climate Emergency. Available at: https://gov.wales/written-statement-welsh-government-declares-climate-emergency [accessed February 2021]

Welsh Government. 2019a. Prosperity for All: A Low Carbon Wales. Welsh Government. Cardiff. Available from: https://gov.wales/prosperity-all-low-carbon-wales [accessed February 2021]

Welsh Government. 2019b. Prosperity for All: A Climate Conscious Wales. A climate change adaptation plan for Wales. Welsh Government. Cardiff. Available from: https://gov.wales/prosperity-all-climate-conscious-wales [accesses February 2021]

Welsh Government. 2020. The National Strategy for Flood and Coastal Erosion Risk Management in Wales. Available at: https://gov.wales/national-strategy-flood-and-coastal-erosion-risk-management-wales [accessed February 2021]

Williamson J, Fitch A, Evans C. 2019. Developing core evidence resources to support the sustainable management of peatland ecosystems in Wales. Report to NRW. Natural Resources Wales.