The Second State of Natural Resources Report (SoNaRR2020)

Assessment of the achievement of sustainable management of natural resources: Woodlands

Natural Resources Wales

Final Report

About Natural Resources Wales

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- 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.

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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

These headline messages have been informed by the evidence referenced throughout the Woodlands chapter. They are a summary and should be read in conjunction with the remainder of the chapter to understand the context and evidence that supports them.

Action is needed to improve the resilience of existing woodlands to drivers of change and to secure benefits for both current and future generations (Sustainable Management of Natural Resources (SMNR) Aims 1 and 2). These drivers include climate change, pests and diseases, air pollution, lack of appropriate management and land-use change. Woodland, particularly ancient woodland, supports more threatened and vulnerable species than any other habitat (Welsh Government, 2018a) but most of Wales's woodlands, both native and non-native, are in intermediate ecological condition (Forest Research, 2020). Ecological condition needs to be enhanced to improve the resilience of woodland ecosystems, for example, through further diversification (of composition and structure) especially in plantation woodlands, action to increase biodiversity and bringing more woodlands into planned management (Planned management can take many forms, and in accordance with the UK Forestry Standard (UKFS) could include areas identified for 'minimum intervention' through to clearfell and complex continuous cover systems). In particular, action to support adaptation to climate change and pests and diseases is vital and needs to accelerate to maintain and improve the ecological functions of woodlands. Current stocks of natural resources need to be safeguarded, for example, by compensating for permanent woodland loss associated with approved development, and better connected through new woodland creation to reverse the fragmentation of native woodlands. Improving the resilience of woodlands will maintain and enhance their ability to provide ecosystem goods and services by making them more adaptable to change.

Timber, as a sustainable and natural resource, makes a valuable contribution to the Welsh economy and there is potential for it to contribute more (SMNR Aim 4). Timber supports employment in small and large-scale business and community enterprises, rural livelihoods, green growth and a regenerative economy. As well as being a renewable, sustainable material for a range of products and construction applications, use of timber locks up carbon (if long lifetime products), displaces carbon emissions associated with other types of materials, has the potential to reduce carbon emissions associate with transport if locally grown sources are used. Future predicted changes in the availability of softwood and hardwood timber may affect the forestry sector and its potential contribution to the Welsh economy, including the reliance on imports to meet domestic needs. More woodland needs to be brought into planned management and new woodland created that is capable of producing utilisable timber. Productive conifer woodlands should be part of the mix of new woodland creation needed in Wales, which is compatible with action to address the climate emergency. Supply chain and technological developments alongside market opportunities need to be encouraged and supported to add value to the existing resource and increase investment and confidence in the sector.

Trees and woodlands and have a vital role to play in tackling Wales's declared nature and climate emergencies (SMNR Aims 1-4). They support decarbonisation by sequestering carbon, resource efficiency through the use of timber, and help society to adapt to a changing climate, for example, by providing shade for people, livestock and wildlife, as well as and flood risk and drought mitigation. New woodland creation, depending on its location, nature and size, may generate local and immediate benefits, such as space for recreation near to where people live, or longer term and wider benefits, for example, an upstream woodland improving downstream water quality over time. As well as climate change mitigation and adaption, new woodland creation will also help tackle the nature emergency, improving extent, connectivity and ecosystem resilience which in turn will help secure well-being benefits for future generations.

2. Introduction

There are 309,000 hectares (ha) of woodlands in Wales (Forest Research, 2019a). Woodland is defined as land where the ecological condition is, or will be, strongly influenced by the tree canopy. In terms of land cover statistics (in the UK), woodland is currently defined as land with trees where the mature trees would cover more than 20% by area, are more than 0.5 ha in size and a minimum of 20 m wide (Forestry Research, 2019b). Large tracts are generally called forests, smaller units are described in a variety of terms such as woodlands, woods, copses and shelterbelts, but there is no minimum size for a woodland. Woodland types in Wales vary from ancient to recent, semi-natural to plantations (conifer, broadleaf and mixed).

In addition, there are 92,700 ha of tree cover outside of woodland in urban and rural locations (Forest Research, 2017). This includes tree cover along linear features like hedgerows, riverbanks and roadsides, and in orchards, parks, wood pastures and urban areas (for more information on trees outside woodlands see Enclosed Farmland and Urban chapters).

Woodlands deliver a range of ecosystem services which are important for well-being. Depending on woodland type, management and location, ecosystem services may include biodiversity, fibre provision, climate regulation and hazard regulation (for example, flood risk or air pollution mitigation), as well as opportunities for recreation, education and learning. Even woodlands without management objectives can still deliver benefits, for example, climate regulation, but they could potentially deliver more with planned management such as improved ecological resilience, carbon storage, increased biodiversity and public access.

All woodlands have the potential to provide habitat for a wide range of flora and fauna but some woodland types, such as ancient semi-natural woodlands, are more biodiverse. Wales's woodlands include significantly important semi-natural woodland habitat types and species, as detailed in SoNaRR2016 (NRW, 2016a).

Based on the evidence discussed in this chapter, we have assessed the overall resilience of the woodland ecosystem as medium but this masks significant variation in the assessment of individual attributes of resilience (see Section 4). This assessment indicates there are opportunities for improvements to support and enhance resilience.

There is clear policy and evidence in place that allows for the creation of new woodland. Currently the level of new woodland creation does not match the policy aspiration despite significant demand for available incentives. A total of 1,300 ha of new woodland was created in Wales between 2016-2019 (Forest Research, 2019a), facilitated through grant-funding.

Many factors, at all scales, effect change in woodland ecosystems. The main factors are: climate change; air pollution, pests, browsing and grazing, diseases and invasive non-native species (INNS), lack of management, and land-use practice linked to economic and political drivers.

Climate change will present both risks and opportunities for woodland ecosystems. Significant and proactive changes, for example, increasing species and structural diversity and developing more resilient habitat networks are needed to ensure adaptation happens without loss of ecosystem services provision.

Declining tree health, due to climate change and compromised biosecurity arising from global trade, is also a significant risk to future ecosystem service provision and well-being.

Changes in softwood and hardwood timber availability will affect the forestry sector and the potential contribution that timber can make to resource efficiency as part of a regenerative economy unless more woodland is brought into sustainable commercial management and more new woodland is created that can produce utilisable timber.

Trees' ability to sequester and store carbon means that woodlands have a vital role to play in tackling Wales's declared climate emergency. Accelerated rates of appropriate woodland creation will deliver knock-on benefits for biodiversity, ecosystem resilience and other ecosystem services important for well-being.

Optimising the services from woodland is challenging, both because of the timescales involved in their development and the changes that may result when interventions are made in their management. For this reason, action is required now to further safeguard and enhance the natural resources associated with woodland ecosystems and ensure the ongoing flow of ecosystem services and well-being benefits.

3. State and Trends (Aim 1)

Summary assessment of state and trends

Available evidence suggests that, on balance, the stocks (extent and condition) of natural resources associated with woodland ecosystems are generally stable, but it is not possible to say with confidence whether they are being safeguarded due to current and likely future drivers of change. However, it can be said with confidence that there is scope to do more to enhance these stocks, for example, by significantly increasing the rate of new woodland creation, encouraging appropriate woodland management activities (including for sustainable timber production), increasing the number of Plantations on Ancient Woodland Sites (PAWS) in active restoration, increasing tree species diversity, removing INNS, and addressing the other drivers of

biodiversity decline. These actions would positively affect both the extent and condition of woodland ecosystems, improving the stock of natural resources.

The following tables (Table 1 to Table 8) give a brief description of the past trends and future prospects. These are assessed to be:

- Improving trends or developments dominate shown in green
- Trends or developments show a mixed picture shown in amber
- Deteriorating trends or developments dominate shown in red

Further information is provided to put this in context.

Table 1 Key message – Past trends and future prospects for Climate change as a Driver of Change

Time Period	Rating	Description
Past trends (10 years)	Mixed picture	Observed changes (risks and opportunities) have been recorded in woodlands.
Future prospects (next 30 years)	Deteriorating	The impacts on woodlands are projected to be greater than those experienced to date. As trees take many decades to mature, woodland managers must anticipate much further into the future. The management actions needed to adapt to climate change are known but are currently lacking and need to accelerate significantly.

Table 2 Key message – Past trends and future prospects for pests and diseases as a Driver of Change

Time Period	Rating	Description
Past trends (10 years)	Deteriorating	*Phytophthora ramorum* has caused the widespread death of larch, and Chalara Ash Dieback has taken hold.
Future prospects (next 30 years)	Deteriorating	More pests and diseases are becoming established and impacts of existing pests and diseases will increase. The situation is likely to be further exacerbated by future climatic changes as well as global trade.

Table 3 Key message – Past trends and future prospects for appropriate management as a Driver of Change

Time Period	Rating	Description
Past trends (10 years)	Mixed picture	Evidence suggests that lack of woodland management has impacted on woodland condition, for example, biodiversity trends in woodland butterflies and dormouse.
Future prospects (next 30 years)	Mixed picture	Based on past monitoring evidence of woodlands in grant schemes, improvements in management may well be highly dependent on any future support mechanisms.

Table 4 Key message – past trends and future prospects for land use change as a Driver of Change

Time Period	Rating	Description
Past trends (10 years)	Mixed picture	Woodland loss will have occurred due to approved development, illegal activity, grazing and browsing by animals and government policy, but there is incomplete evidence to quantify the amount (Forest Research, 2016). Permanent woodland loss has been offset to a very limited degree by new woodland creation.
Future prospects (next 30 years)	Mixed picture	Decarbonisation priorities may drive forward increased rates of woodland creation, but real and perceived barriers need to be addressed to unlock the potential that exists.

Robustness for Table 1 to Table 4: Evidence and data availability are variable across the different drivers of change. For example, availability is good for some pests and diseases but not all. Much data and evidence on climate change impacts is modelled.

Table 5 Key message – Past trends and future prospects for sustainable management.

Time Period	Rating	Description
Past trends (20 years)	Improving	Certification of the entire Welsh Government Woodland Estate (WGWE) has been maintained for the last 20 years. The total certified area of privately-owned woodland in Wales has increased from 14% in 2001 to almost 20% in 2019 (Forest Research, 2019a). This is a positive trend. In addition, managed woodland in receipt of grant payments or felling licences will be managed in accordance with the UKFS. Improvements in woodland management in the private sector have been heavily dependent on grant aid.
Future prospects (next 30 years)	Mixed picture	The UKFS is in place and expected to continue because of its value. The challenge is to bring more woodlands into planned management (in accordance with the UKFS), to improve resilience and the flow of ecosystem services. Based on past progress, grant funding is likely to be key to achieving significant improvements in woodland management unless novel methods can be adopted.

Robustness for Table 5: There is a high degree of confidence in data on the area of certified woodland in Wales, as this woodland is independently audited by a third party. Data on other woodlands in Wales in sustainable management is less clear but is linked to regulatory compliance (felling licences) and the allocation of grant funding.

Table 6 Key message – Past trends and future prospects of extent of stocks of natural resources.

Time Period	Rating	Description
Past trends (10 years)	Mixed picture	Woodland extent in Wales has increased from approximately 303,000 ha in 2010 to approximately 309,000 ha in 2019. This is a positive trend, although some of this reported increase is due to changes to National Forest Inventory (NFI) mapping.
Future prospects	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.

Table 7 Key message – Past trends and future prospects of condition of stocks of natural resources

Time Period	Rating	Description
Past trends (10 years)	Mixed picture	Article 17 reporting (JNCC, 2019) indicates that important woodland habitat condition is stable (but not in good condition) after a long-term trend of reduction in habitat quality, however woodland-associated biodiversity is still declining. More generally woodland ecological condition is intermediate but pressures such as pests and diseases, air pollution, INNS and herbivores remain.
Future prospects	Mixed picture	There is potential for improvement in condition with the majority of woodlands in intermediate ecological condition. A reduction of pressures through appropriate management and continued improvements in diversification of species and structural diversity along with an increase in woodland cover have the potential to contribute to improvements in condition. The impact of climate change, notably through increasing risks from pests and diseases and populations of herbivores, and the likelihood that nitrogen level exceedance will remain are expected to put pressure on woodland ecosystems.

Table 8 Key message – Past trends and future prospects of timber stocks of stocks of natural resources.

Time Period	Rating	Description
Past trends (10 years)	Improving	Softwood removals in Wales (combined public and private) over the last 10 years have fluctuated from a low of 1,038,000 green tonnes in 2009 to a peak of 1,541,000 green tonnes in 2017 with an average of 1,308,600 green tonnes over the ten-year period (Forest Research, 2019d).
Future prospects	Mixed picture	The current forecast highlights a drop in softwood timber availability over the next 30 years but is hoped that this can be compensated for by smoothing out production levels, bringing more woodland into management, and creating more new woodland that can produce utilisable timber. On the plus side, forecast data shows an increase in the availability of hardwood timber, although concerns remain over the quantity and quality of products (as a potential substitute for softwood) that could eventually be derived from this increasing resource.

Note on Robustness for Table 6 to Table 8: Historic trend data are good quality but limited to designated sites monitoring and small surveys. The newly available baseline provided by National Forest Inventory (NFI) is statistically robust and will be repeated providing trend data into the future. Further evidence on changes in condition of ancient woodlands is desirable. Timber stock data are forecasted and have a medium level of confidence assigned.

Extent

The extent of woodlands in Wales is shown in Figure 1. Of the total of 309,312 ha, 117,000 ha comprises the Welsh Government Woodland Estate (WGWE) and 192,000 ha is privately owned (Forest Research, 2019a). Of this total, 94,940 ha comprises ancient woodlands, split across the public and privately-owned estate (FCW, 2011; NRW, 2016a). In addition, there are 92,700 ha of tree cover outside of woodlands in rural and urban locations, of which 49,200 ha are made up of small woodlands (76% of which are rural), 33,400 ha comprise groups of trees and 10,100 ha comprise lone trees (Forest Research, 2017) (See Enclosed Farmland and Urban chapters for more information on trees outside woodlands).

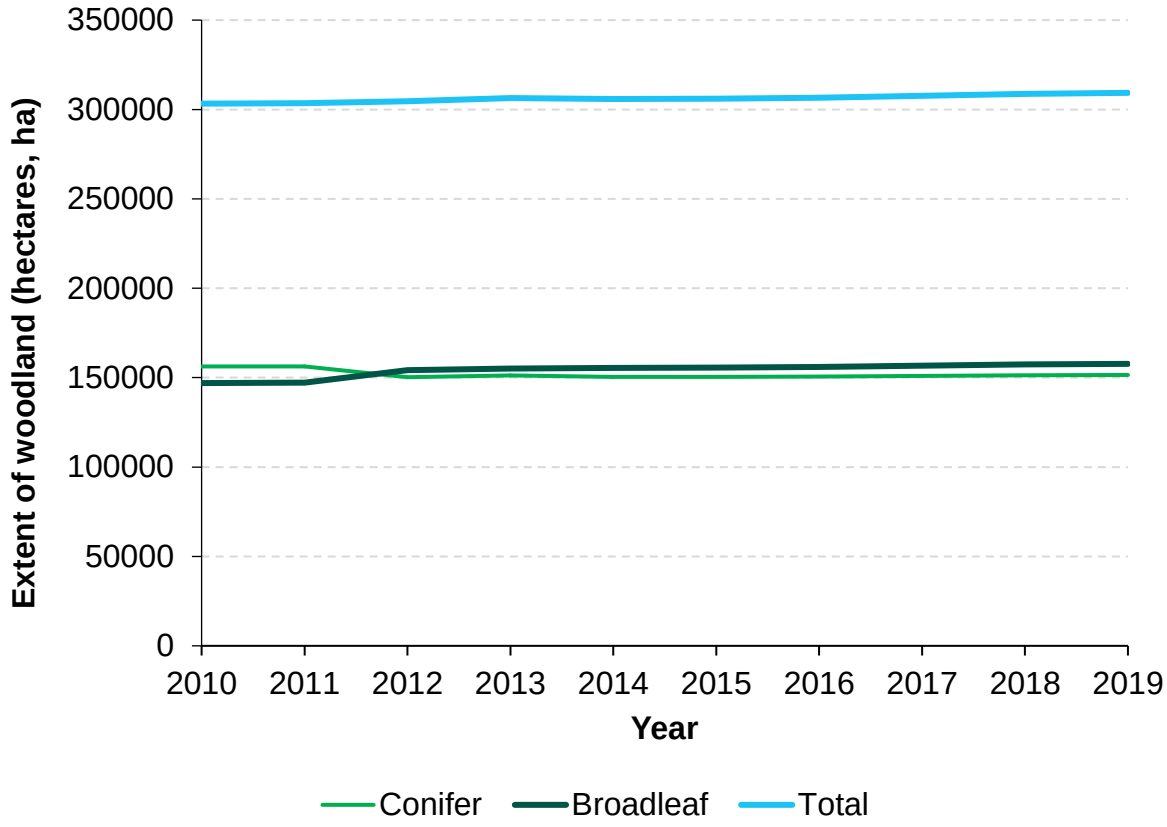

Figure 1 Change in woodland extent, by conifer and broadleaf, 2010-19 (Forest Research, 2019a).

Between 2016 and 2019, there was 1,300 ha of new woodland creation in Wales (Forest Research, 2019a) facilitated through grant-funding. This falls well short of Welsh Government's ambition which is to achieve 2,000 ha of new woodland creation per annum, rising to 4,000 ha per annum as rapidly as possible (Welsh Government, 2019a). Rates of new woodland creation remain insufficient to meet decarbonisation priorities. Current rates of new woodland creation remain highly dependent on public funding, but this could change in the future if the right incentives and mechanism exist. As a result of natural processes (natural colonization by trees) which takes place when grazing pressures are reduced, woodland cover may be increasing but there is currently no reliable evidence to verify this.

In the same period, 2016-2019, there has been some permanent woodland loss associated with renewable energy provision, open habitat restoration and approved development but there is incomplete evidence to allow the amount to be quantified (Forest Research, 2016). The Planning Policy Wales 10 (Welsh Government, 2018b) includes a statement that ancient woodland and ancient, veteran and heritage trees should be afforded protection. There is a programme of land acquisition and compensatory planting linked to renewable energy delivery on the WGWE.

Management (including stocks of timber)

The estimated area of woodland in Wales managed to the UKFS is 145,000 ha (Welsh Government, 2019a), as this is the known extent of woodland certified through the UK Woodland Assurance Standard (UKWAS). However, this figure is an underestimate as many more woodlands in Wales will be managed to the UKFS as evidenced by the granting of felling licences and the award of Welsh Government grant funding which requires adherence to the UKFS. This figure reveals an apparent downward trend since SoNaRR2016 (NRW, 2016a) which is primarily due to the cessation of Welsh Government's Glastir Woodland Management scheme in 2016. However, the overall trend from 2001 to 2019 is positive: certification of the entire WGWE has been maintained for the last 20 years and the total certified area of privately-owned woodland in Wales has increased from 14% to almost 20% (Forest Research, 2019a).

Woodlands in planned management will be making the greatest contribution to ecosystem service provision. Those not in planned management will still be delivering some ecosystem services such as climate regulation and habitats for species, but not as many as they perhaps could, and their condition may decline over time further reducing ecosystem service provision. An evidence review of the issues around the management of undermanaged woodland is provided in Kerr (2020).

Timber stocks are a significant natural resource associated with woodlands. As reported in SoNaRR2016 (NRW, 2016a), current forecasts of timber availability (Forestry Commission, 2014a; Forestry Commission, 2014b) predict a drop in softwood timber availability over the next 30 years which is a potential concern for the sector and more widely for Wales as it risks the continued flow of ecosystem services and well-being benefits from woodlands. The reasons for this are manifold but it is hoped that the drop can be compensated for by smoothing out production levels, bringing more woodland into planned management, and creating more new woodland that can produce utilisable timber.

An increase in the management of farm woodlands might help. Data (Welsh Government, 2019a) shows that in 2015, harvesting only occurred in around 31% of farm woodland so this is an under-utilised part of the total resource although it may not be a suitable substitute for commercial softwood production. On the plus side, forecast outputs predict increases in the availability of hardwood timber which presents market development opportunities though concerns remain over the quantity and quality of products that could eventually be derived from this increasing resource. A change in buyer preferences and product specification would be needed, alongside supply chain developments, to promote more widespread use of hardwoods particularly whilst the availability of softwood remains high.

Woodland condition

Woodland condition is dependent on a range of biological and physical attributes, which are affected by management past and present.

NFI data (Forest Research, 2020) provides information on the ecological condition of woodlands in Wales based on assessment of 15 attributes of condition including tree and shrub diversity, structural measures and levels of grazing, pests and diseases, invasive species, dead wood and veteran trees. These are benchmarked against ancient semi-natural woodland in good condition as these areas are taken to have the "*highest biodiversity value and are particularly important for many rarer and specialist woodland associated species*" (Forest Research, 2020). Whilst this condition assessment is designed to monitor ecological condition it includes attributes such as herbivore damage and tree health which are relevant to ecosystem services such as timber provision. It also includes attributes relevant to ecosystem resilience such as tree regeneration, age distribution and vertical structure. These all inform the assessment of the condition of the woodland stocks discussed previously.

Most woodland stands are in intermediate ecological condition but less than 5% are in favourable condition (Forest Research, 2020), see Table 9.

Table 9 Ecological condition classification of woodlands in Wales (Forest Research, 2020).

Woodland Stand type	Unfavourable (hectares)	Intermediate (hectares)	Favourable (hectares)
Native	200 (0.1%)	135100 (91.0%)	13200 (8.9%)
Near-native	100 (1.5%)	6700 (97.0%)	100 (1.5%)
Non-native	2300 (1.5%)	153400 (97.9%)	1000 (0.6%)
Totals	2600 (0.8%)	295200 (94.6%)	14300 (4.6%)

Note: The methodology and definition associated with this classification can be found on the Forest Research website for the National forest Inventory.

Habitats Directive reporting (JNCC, 2019) shows that the area and distribution of woodland habitats is stable, but the large majority are not in good condition although the short-term trend is generally stable.

Herbivore pressure, squirrel damage and deer browsing are present in a third of native and near native woodlands stands (Forest Research, 2020), although the survey recognised that this may be under-recorded noting that herbivore damage is only recorded where it's been observed: lack of observation does not necessarily indicate an absence. Grazing can be beneficial to woodlands, but the type and level of grazing is important to improve condition. Deer grazing is recorded as a pressure on Annex 1 woodland habitats(natural habitat types of (European) community

interest whose conservation requires the designation of Special Areas of Conservation (SAC)) (JNCC, 2019) along with unfavourable tree regeneration in many oak woodlands. Deer are cited as a pressure on woodland biodiversity in the State of Nature report (Hayhow *et al*., 2019).

All woodlands score poorly on old growth characteristics, the majority of stands of all types lack veteran trees and deadwood; 99% of woodlands in Wales contain no veteran trees within 20 ha and 75% of stands contain less than 20m^3/ha of dead wood (Forest Research, 2020).

The Glastir Monitoring Evaluation Programme (GMEP) (Emmett and GMEP team, 2017) reported *"An improvement in ancient woodland indicator plants species in large broadleaved woodlands over the last 10 years"* suggesting improved management (based on the number of ancient woodland indicators per 4 m^2 random plots located in all areas mapped as broadleaved woodland Broad and priority (sec.8) habitats). Further analysis of GMEP data (Alison *et al.*, 2020) through the Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP) reported that across all pollinator groups, deciduous and coniferous woodland supported consistently high abundances, add that woodlands generally rank higher than other ecosystems for abundance of pollinators. Woodlands support high abundances of a wide variety of insect pollinators in Wales. However, the State of Nature report 2019 (Hayhow *et al.*, 2019) shows a 50% reduction in woodland butterflies in the UK since 1990. Defra (2020) report that "*The long-term decline of woodland butterflies is thought to be due to a lack of woodland management and loss of open spaces in woods"*; the ecological condition of woodlands in Wales survey (Forest Research, 2020) reports that 84% of native woodlands are assessed as unfavourable for open space.

The woodland bird indicator (BTO, 2021) has reduced by 25% between 1970 and 2017. Generalist woodland species, (that also breed in gardens or farm woodland) have increased overall by 14%, whilst woodland specialists have shown declines of more than 80%. This demonstrates the complexities of woodland ecosystems and whilst some species benefit from the current state of Welsh woodlands others may not.

Welsh dormouse populations have declined by 79% between 1993 and 2014 (McDonald, 2017). Goodwin (2018) found that the abundance of hazel dormouse populations was higher at sites with active woodland management, greater landscape connectivity and a higher diversity of woodland plant species and that numbers were lower at sites with warmer and more variable winter temperatures. GMEP data analysis (Alison *et al.,* 2020) found that dormouse indicator species (food plants such as hazel and honeysuckle) were generally rare.

The majority of native woodlands are smaller and more isolated with less semi-natural habitat in the surrounding 100 km^2 than non-native stands; larger forests are ecologically well connected to other woodland or habitats in the landscape. (Forest Research, 2020).

Knowledge of the condition of ancient woodlands across Wales is limited. A study for The Woodland Trust (Marsh, 2019) of available data sources on ancient woodland condition may inform future assessments of woodland condition. A survey on the

WGWE in 2016 (NRW, 2016b) found that since 2012 deadwood had increased in all stands, native seedlings and saplings had increased in worked areas but there was no change to ground flora, invasive species or the proportion of broadleaved canopy. This indicates that interventions have positive trends overall, but condition improvements take time. The progress of work to restore PAWS to a more natural state has been slow.

Wales has an exceptionally diverse bryophyte flora with 850 species of moss, liverwort and hornwort (Bosanquet and Dines, 2011). Atlantic woodlands (natural or semi-natural woodlands found in western Britain and Ireland where the climate is mild and wet due to the influence of the Gulf Stream (Plantlife Cymru, 2013)) have the most outstanding bryophyte flora from an international perspective. Woodland specialist ground flora and epiphytic flora are adversely affected by pollution and changes in nutrient status. Kirby *et al.* (2005) (No more recent publications have been identified that specifically deal with woodlands in Wales) found signs of nutrient enrichment in ground flora of woodlands that were correlated with models of diffuse pollution and adjacent land management.

Pollution, especially Nitrogen, impacts on woodlands is highlighted by designated site monitoring (NRW, 2015; JNCC, 2019). Assessment of the proportion of ancient woodland sites exposed to critical levels of ammonia (NRW, 2020a) found that 61% of Ancient Semi-natural Woodland in Wales is modelled as experiencing ammonia concentrations above the Critical Level for lichen and bryophyte-rich ecosystems (see Table 10). Above this level, these communities will be unable to survive; both are crucial for woodland ecosystem function especially water interception/cycling, carbon capture, nutrient cycling and ‘cultural’ services. Nitrogen is an essential plant nutrient, but excessive nitrogen compounds affect the composition and functioning of both terrestrial and aquatic ecosystems (Bosanquet, 2019). Mitchell *et al.* (2005) reported that Atlantic Oakwoods are especially vulnerable to nitrogen deposition because of their high diversity and biomass of lichens and bryophytes. This may exacerbate changes to composition resulting from climate change.

An evidence review of woodland biodiversity in Wales is provided in Beauchamp *et al.* (2020a).

Table 10 Area (hectares, ha) of each category of Ancient Woodland (from Ancient Woodland Inventory (NRW, 2011)) in Wales exposed to four bands of ammonia concentrations (the proportion, %, within each band across each category is shown in brackets).

Category of Ancient Woodland	**Below Critical Level for Lichens and Bryophytes (0 to 1 µg/m^3 NH$_3$)**	**Above Critical Level for Lichens and Bryophytes (1 to 3 µg/m^3 NH3)**	**Above Critical Level for Vascular Plants (3 to 5 µg/m^3 NH3)**	**Significantly above Critical Level for Vascular Plants (5 to 15 µg/m^3 NH3)**	**Total (hectares))**
Ancient Semi Natural Woodland (hectares)	16077.1 (38.89%)	25105.8 (60.73%)	150.0 (0.36%)	3.9 (0.01%)	41336.8 (100.00%)
Ancient Woodland Site of Unknown Category (hectares)	2480.5 (46.05%)	2904.7 (53.92%)	1.7 (0.03%)	0 (0.00%)	5386.9 (100.00%)
Plantation on Ancient Woodland Site (hectares)	11247.9 (44.06%)	14246.0 (55.80%)	36.6 (0.14%)	0.3 (0.00%)	25530.8 (100.00%)
Restored Ancient Woodland Site (hectares)	6261.3 (28.87%)	15333.2 (70.71%)	84.6 (0.39%)	6.8 (0.03%)	21685.9 (100.00%)
Grand Total (hectares)	36066.8 (38.39%)	57589.7 (61.30%)	272.9 (0.29%)	11.0 (0.01%)	93940.4 (100.00%)

Drivers of change

Many factors, at all scales, affect change in the extent and condition (stocks) and management of woodland ecosystems. These drivers of change include climate change, air pollution, pests and diseases, INNS and land-use practice linked to socio-economic and political drivers. Background discussion about many of these drivers is available in SoNaRR2016 (NRW, 2016a) and is addressed in the UK NEA (2011). An evidence review of drivers of change affecting woodlands, the impacts and risks as well as resilience and adaptation measures is provided in Beauchamp *et al.* (2020b).

The impact of future climatic changes on woodlands is projected to be greater than those experienced to date. In SoNaRR2016 (NRW, 2016a) we summarised the observed and predicted changes and these are all still relevant (Nicoll, 2016; Ray *et al.*, 2016; Wainhouse *et al.*, 2016; UK CCC, 2017). The main climate change impacts are:

- Increased risk from pests and diseases;
- Changes in tree species suitability based on tree growth and woodland productivity;
- Changes in the range, distribution, composition, condition and even survival of native woodland types;
- Increased risk from extreme weather and wildfires events;
- Impacts on woodland flora and fauna;
- Changes in carbon sequestration rates; and
- Changes in land availability and suitability.

These impacts will affect the underlying functioning and resilience of woodland ecosystems and the ecosystem services and well-being benefits associated with them. As trees take many decades to mature, woodland managers must plan much further into the future than other land-managers in planning for climate change. Recent research (Environment Systems, 2020) suggests changes in the availability of land suitable for planting of sessile oak and Sitka spruce. Environment Systems (2020) states that planting schemes should take a longer-term view in order to consider the large geographic shift in land suitability (from lowland to upland areas) which is predicted to occur between 2050 and 2080, as these trends could affect the viability of woodlands planted between now and 2050. Adaptation strategies are discussed in Natural Resources Wales (NRW) (2017) including the potential of natural regeneration to provide genetic adaptation to climate change.

Tree health is declining, at a species and woodland level and the situation is worsening (Welsh Government, 2019a). This can be attributed to pests and diseases and variations in the seasonal amount and pattern of rainfall and temperature. The situation is likely to be further exacerbated by future climatic changes as well as global trade. Background information on a range of pests and diseases is included in SoNaRR2016 (NRW, 2016a), and surveillance work is ongoing via initiatives such as Tree Alert. Here we focus on the most significant changes since 2016.

As of 31st March 2020, stands of larch covering approximately 12,921 ha in Wales have been found to be infected with *Phytophthora ramorum* (NRW, 2020b). This is an increase of over 4,000 ha since SoNaRR2016 (NRW, 2016a) largely due to spread through mid-Wales. Whilst felling to manage the spread of *Phytophthora ramorum* has taken its toll on the visual, landscape, biodiversity and amenity aspects of significant areas of woodlands in Wales, it has facilitated faster-paced restructuring and tree species diversification some areas which will improve resilience to future threats.

Chalara Ash Dieback (Hymenoscyphus fraxineus) is now evident throughout virtually the whole of Wales (Welsh Government, 2019a), a worsening of the situation since SoNaRR2016 (NRW, 2016a). It is expected that a significant proportion of ash trees in Wales will be affected by the disease in the coming years, some of which will subsequently die and some of which may require removal for public safety reasons. Ash is a widespread species, within and outside woodlands, which makes a substantial contribution to the landscape character of Wales (Maskell, 2013) and is very significant for biodiversity in terms of the habitats it contributes to and species it supports (Broome *et al.*, 2017; Stocks *et al.*, 2019).

The significance of oak processionary moth (OPM) *Thaumetopoea processionea* has increased since SoNaRR2016 (NRW, 2016a). In addition to defoliating oak trees, OPM also poses a hazard to human and animal health. During 2019 there was a significant increase in interceptions of oak trees imported from Europe with OPM present: NRW and Animal and Plant Health Agency (APHA) issued Statutory Notices on 3 sites in Wales where OPM was confirmed and the pest was destroyed at each (Welsh Government, 2019a). A list of established threats, and examples of emergent threats to the UK's Protected Zone Status, are as reported in SoNaRR2016 (NRW, 2016a).

Land use and land-use management change is a significant driver affecting woodlands in Wales. It is relevant to the extent and condition of existing woodlands, as well as affecting opportunities for new woodland creation. Contributing factors include:

- Approved building or infrastructure development;
- Illegal activity such as unlicensed tree felling;
- Habitat fragmentation;
- Lack of management or inappropriate management including grazing and browsing by domestic and wild animals;
- Removal or changes in grazing patterns which can be linked to more natural regeneration of trees;
- Competing land uses, including renewable energy provision particularly on the public forest estate;
- Government policies (for example, forestry, renewable energy, decarbonisation, nature recovery, agricultural);
- The availability, nature, and scope of grant-funding for woodland management / restoration / creation;
- Future changes in government policies and grant funding as a result of leaving the European Union; and

- Land-use values (£/ha) as well as the perspectives and beliefs of individual land managers which influence their management decisions.

Some of these factors were discussed in SoNaRR2016 (NRW, 2016a), for example, habitat fragmentation, grazing and browsing by domestic and wild animals (more detail on some of these is provided in the Land Use and Soils chapter).

4. Assessment of Resilience (Aim 2)

Table 11 Ecosystem Resilience Assessment for woodlands.

Practical habitat unit	Diversity	Extent	Condition	Connectivity
Native woodland	**Medium-High** Overall, some of Wales's most diverse habitats. More than half of native stands are favourable for tree and shrub species diversity (64%) and structural diversity (55%).	**Medium** 51% of native stands (76,000 ha) are in woodlands greater than 20ha and score favourably for size.	**Medium** 91% of native stands are in intermediate ecological condition and 9% of native woodlands are in favourable ecological condition.	**Medium** Connectivity with other habitats is good but native woodland is a much fragmented resource. The majority have a favourable proportion of semi-natural habitat nearby (100 km^2) but 25% are less than 5 ha in size.
Non-Native woodland	**Low to medium** Despite extensive improvements, 45% of stands remain even-aged and forests are dominated by a few species (approx. 60% of non-native trees are Sitka spruce (Forest Research, 2019a).	**High** 89% (138,000 ha) (89%) of non-native stands score favourably for size as they are part of large forests.	**Medium** 98% of non-native stands are in intermediate ecological condition. A lack of veteran trees and deadwood is a key factor.	**High** Good by virtue of large size of non-native blocks across Wales. Internal ecological connectivity within forest blocks is good due to networks of rides, roadside verges, riparian zones and permanent canopy cover.

Notes:
1. The ecological condition data assesses attributes at woodland stand level. A stand is a distinct area of woodland (from either planting or

natural regeneration), generally composed of a uniform group of trees in terms of species composition and spatial distribution, and age and size class distribution (NFI).
2. Woodlands are often comprised of stands of native, non-native or mixed species.
3. All quoted figures are Forest Research (2020) unless otherwise indicated.
4. For trees outside woodlands, please refer to content in the enclosed farmland and urban chapters

Overall, we have assessed ecosystem resilience as medium but this masks significant variation in the assessment of individual attributes. Diversity of tree and shrub species is high for native woodland but poor for non-native: the removal of large areas of diseased larch due to *Phytophthora ramorum* illustrates the potential consequences of poor diversity in non-native stands. Condition has been more reliably assessed as medium due to the publication of additional comprehensive ecological condition data (Forest Research, 2020). These data are particularly significant for non-native stands showing that they are not all uniform monocultures and the majority are in intermediate ecological condition. UK reporting under the Habitats directive (Article 17) (JNCC, 2019) indicates that the majority of Wales's SAC woodlands are not in good condition. Less than 6% of these annex 1 woodland habitat was reported as being in good condition, based on survey data of 10.3% of the SAC woodland habitat.

The main challenges in delivering SMNR for woodlands in Wales are reversing the continuing decline in biodiversity and building and improving resilience to expected and unforeseen drivers of change, including pests and diseases, air pollution and climate change, so that the future flow of ecosystem services is safeguarded and enhanced. As trees take many decades to mature, woodland owners and managers need to plan much further into the future than other land-managers.

5. Healthy Places for People (Aim 3)

Woodlands are not unique in providing healthy places for people, or in helping protect people from environmental risks, but they are one of the most significant ecosystems in terms of the nature and range of regulating and cultural services they provide which contribute to well-being. An evidence review of regulating and cultural ecosystems services associated with woodlands is contained in Beauchamp *et al.* (2020c) and Matthews (2020). An evidence review of the valuation of ecosystem services is provided in Saraev *et al.* (2020).

There is an important spatial dimension to the supply of, and demand for, regulating and cultural ecosystem services. For example, the contribution of woodlands to flood risk mitigation is strongly dependent on their location, as is the use of woodlands by people for recreation.

One of the most important regulating ecosystems services for well-being is climate change mitigation. There is widespread acceptance that woodlands (creation and management) can contribute significantly to land-based carbon sequestration or the retention of land-based carbon stocks. However, occasionally, there is conflicting evidence as to what types of activity are most effective. Woodlands in Wales may contribute directly as reservoirs and sinks of carbon, and indirectly as a sustainable source of wood-based products and bioenergy. Matthews (2020) noted that if the goal of climate change mitigation is to be achieved, ideally, as a minimum requirement, the overall carbon balance (direct and indirect carbon flows) must be at least zero and ideally a net sink. Therefore, ensuring that forest management sustains or enhances the direct woodland carbon sink is not a sufficient test for guaranteeing that the carbon impacts of forest management are consistent with the goal of climate change mitigation.

As well as their importance for carbon, woodlands offer protection from and mitigation of the effects of climate change, for example, by slowing the flow of storm run-off, increasing water filtration or providing cooling and shade. Woodland cover can be an important component of nature-based solutions to manage risk by reducing compaction and increasing infiltration and evaporation. A comprehensive review of the effectiveness of natural processes in reducing flood risk (Environment Agency, 2017) concluded that it can help to mitigate against flood risk and is most effective for smaller magnitude floods across small to medium catchment scales. In SoNaRR2016 (NRW, 2016a), NRW identified opportunity spaces where tree planting could contribute to reducing flood risk. Case studies (Coed Cymru, 2013; Nisbet *et al.*, 2015; Turley *et al.*, 2018) also exist which feature hedgerow and tree planting, and the use of 'leaky' woody dams and timber bunds to reduce flood risk.

In terms of the economic significance of trees in reducing flood risk, a study (Broadmeadow *et al.*, 2018) estimated the economic value of the flood regulation service provided by the UK woodland estate. It focused on upstream catchments draining to communities at risk of downstream flooding. The study estimated a value of approximately £6.5 billion per year (£2,600 per ha) based upon a replacement cost approach, although it was acknowledged that these numbers are heavily caveated by a range of limitations of the approach and it is thought likely that they are an underestimate. In relation to drought, climate change predictions (Met Office, 2018) suggest the very low dry weather river baseflows experienced in Wales could reduce by 50% by 2050. Actions to reduce storm run-off through woodland planting could see increased infiltration into soils and increased soil retention of rain. This slowing effect will delay run-off so that base flows will be maintained for a longer period thus helping to mitigate against drought.

Trees are important for freshwater ecosystems. Trees and woody material provide cover and shade and river habitat structure, and influence water quality and biodiversity. For example, evidence suggests that riparian trees can help reduce local stream temperatures on hot summer days, which benefits salmon and trout populations under stress (Lenane, 2012), and this is likely to become more significant in the future due to climate change. In relation to water quality, a review of evidence (Silos, 2017) found that the creation of woodland buffers reduced nitrate concentrations (associated with agricultural diffuse pollution) in surface run-off by over 70% on average in oceanic climates such as the UK, with the strength of the effect being strongly related to the width of the buffer. Whilst the UKFS and supporting forestry and water guidelines now promote good practice, legacy issues associated with past management decisions such as planting up to riparian zones are still being resolved.

Woodlands also help to regulate air quality by removing pollution from the atmosphere, and are particularly efficient at removing particulate matter. The extent to which woodlands can provide this ecosystem service is affected by a number of factors, the influence of which varies over time, which include tree species, pollutant concentrations, interactions with other pollutants and woodland cover within a landscape setting. The location of woodland is particularly important as, for example, the location where changes in pollutant concentrations are experienced may not be the same as where the pollution removal happens; woodland can benefit locations downwind. Taking into account the location of pollution sources and wind direction is

also crucial to understanding the benefit provided by woodland. Whilst recent studies (Engledew *et al.*, 2019) have valued the air pollution removal regulating service from Welsh woodlands through avoided health cost modelling, this may come at a cost in terms of the impact on the woodland itself, particularly regarding ammonia and nitrogen removal which can compromise ecosystem function. The role of trees in air pollution removal in an urban setting is discussed in the Urban chapter.

In terms of cultural ecosystem services, woodlands are known to support mental and physical well-being, education and learning, community cohesion, a connection to nature and the landscape, recreation, tourism and employment. Whilst there are some negative impacts on well-being associated with woodlands, such as fly-tipping, antisocial behaviour and timber haulage, these are small compared to the many positives. A recent evaluation of the Active Forests programme confirms the importance of many of these positive factors (O'Brien and Forster, 2017) and a recent review of evidence (O'Brien *et al.*, 2019) both highlight the importance of contact with forests for mental well-being.

The most recent Public Opinion of Forestry Survey (Forest Research, 2019c) reported that 97% of people named at least one benefit of woodlands in Wales, the most frequently cited one being that 'they provide places for wildlife to live'. In contrast, 47% of people named at least one disadvantage of woodlands in Wales, the most frequently cited one being that woodlands were 'used for fly-tipping'. The results also showed that 77% of adults surveyed in Wales had visited woodland for recreation in the last 12 months, the most popular activity being walking (89%). The most commonly stated reasons for not visiting woodlands were 'other personal mobility issues' or 'too busy/not enough time'. The Space for People report (Woodland Trust, 2017) states that people in Wales have better access to woodlands (2ha+ within 500m and 20ha+ within 4km) than the UK average.

In relation to landscape character, and the symbolic, cultural and spiritual significance of trees and woodlands which will contribute to well-being and quality of life, LANDMAP data have been published for the first time in the Woodlands for Wales Indicators report (Welsh Government, 2019a). The data highlight that trees and woodland are important components of 67% of the landscapes of Wales (with many of these being evaluated as 'outstanding' and 'high'), and that woodlands make a very positive contribution to the landscape character of Wales as sites of heritage and cultural importance.

Trees outside woodlands, including ancient and veteran trees, are also important in providing healthy places for people, protected from environmental risks. The nature and flow of well-being benefits from trees outside woodlands are similar to those from woodlands, but typically more localised, or linear in nature. A recent study (Woodland Trust, 2017) summarises the many benefits of trees outside woodlands and attempts to value them. More information is provided in the Enclosed Farmland and Urban chapters.

Looking ahead, woodlands must continue to play an important role in the provision of regulating and cultural ecosystem services, and there is scope to further enhance the contribution they make to provide healthy places for people, protected from environmental risks. This will include promoting the role of woodlands as nature-based solutions and their role in climate change mitigation and adaptation.

Natural capital accounting (NCA) studies (Saraev *et al.*, 2017; Engledew *et al.*, 2019; ONS, 2020) have estimated the value of various ecosystem services provided by woodlands in Wales (UK). An evidence review of NCA studies was completed by Saraev *et al.* (2020). Interestingly, an important finding from NCA studies is that non-market values of many forest ecosystem services (for example, carbon sequestration, recreation, air pollution absorption) are significantly larger (by a magnitude) than that for marketable goods like timber (Beauchamp *et al.*, 2020d).

6. Regenerative Economy (Aim 4)

Standing timber, as a natural resource, has huge potential to contribute towards a regenerative economy. As well as being a renewable, sustainable material for a range of products and construction applications, use of timber locks up carbon (if long lifetime products), displaces carbon emissions associated with other types of materials, has the potential to reduce carbon emissions associate with transport if locally grown sources are used, and can give a boost to local communities in terms of employment and enterprise. An evidence review of the contribution of the forestry sector to the Welsh economy, including human capital, is provided in Saraev *et al.* (2020).

Welsh Government's consultation 'Beyond Recycling'on a strategy to make the circular economy in Wales a reality (Welsh Government, 2019b) proposes a key action around prioritising the purchase of wood, remanufactured and recycled content, and for the Welsh public sector to prioritise reused and remanufactured content in the products it buys. These actions are part of a wider package of integrated measures that are needed to support the contribution that timber can make to a resource efficient economy.

As a productive resource, recent data (Welsh Government, 2019a) indicates that the forestry sector contributes a total Gross Value Added (GVA) of £664 million per annum to the Welsh economy, up from the £499.3 million per annum reported in SoNaRR2016. Between 10,300 and 11,000 people worked in the forestry sector in Wales in 2017 (Welsh Government, 2019a), although this excludes the contribution of businesses that are supported wholly or partially by forestry, including, for example, woodland-based recreation businesses. NCA studies (Saraev *et al.*, 2017; Engledew *et al.*, 2019; ONS, 2020) have all estimated the value of timber extraction from Welsh (UK) forest resources. Engledew *et al.* (2019) valued the timber provisioning service from Welsh forests as £36 million in 2017.

The extent to which Welsh-grown timber contributes to resource efficiency within a regenerative economy in Wales will depend on:

- The amount of Welsh-grown timber that is processed and used in Wales at various economic scales.
- Adoption of the 'carbon hierarchy of use' associated with harvested wood products, for example, by ensuring that only non-viable saw logs are used as biomass for energy.
- Adoption of the 'waste hierarchy' in terms of how long harvested wood products retain value. The Publically Available Specification (PAS) 111 standard is significant as it provides a specification for recovering and

processing post-industrial and post-consumer waste wood into wood products.

- The relationship between exports, imports, domestic usage and the utilisation of wood fibre for various end uses, which is a function of global trade and market conditions.
- The willingness of Welsh businesses and consumers to pay for quality home-grown and processed timber, at potentially slightly higher cost, until economies of scale are achieved.
- Development of an integrated supply chain within Wales, for example, consideration of changes to existing capacity to accommodate non-mainstream species (including broadleaves) and additional suitable processing facilities for engineered wood products. This would help ensure the availability of high-quality wood thereby encouraging increased management of woodlands and higher value timber in the future.

Currently there are incomplete data to accurately quantify the contribution that Welsh-grown timber makes to a regenerative economy and the more efficient use of natural resources in Wales. This is a future evidence need which has been identified by Woodknowledge Wales (2020). Annual information is published about the UK production of timber from wood and the primary processing of harvested wood to give basic wood products with estimates for Wales where possible (Forestry Statistics, 2019).

The tree species that are grown and harvested in Wales will affect the range of suitable end-uses for the timber and is therefore relevant to supporting resource efficiency as part of a regenerative economy. The softwood processing sector in GB has largely been built around the use of Sitka spruce due to its availability, high quality, ease of processing and consistency in strength grading. However, studies have shown that the structural timber properties of noble fir, Norway spruce, western red cedar, western hemlock and Scots pine can all produce structural timber for use in construction of strength class C16 or above (Gil-Moreno *et al.*, 2016; MacLean, 2019). Currently, research by Woodknowledge Wales (WKW) suggests that only a small proportion of the current Welsh timber harvest (< 4%) is converted into construction grade product by the processing sector in Wales. WKW suggests this has often been linked to “the perceived poor quality of Welsh timber” but argue that that the majority of Welsh saw logs (and bars) are capable of yielding timber meeting grade C16 or higher which is the minimum viable grade for construction applications. In 2018, the Home-Grown Homes project was established to build supply-chain capacity and increase the use of high value timber products from Welsh timber.

Lower down the carbon hierarchy of use, but still of relevance, is the demand for woody biomass. Biomass use is well-established but not one without controversy, especially in relation to the use of whole trees. Biomass production can be both low carbon and sustainable, but governance is critical for this to be achieved (UK CCC, 2018). Managing biomass stocks must be as part of a system of sustainable land use where, as a minimum requirement, carbon stocks in plants and soils increase over time. If this doesn’t happen, there is the potential for worse outcomes for the climate than ongoing use of fossil fuels, as well as other negative impacts on SMNR. In Wales, timber residues, thinnings, small roundwood and low-grade logs mostly feed the biomass industry. There is currently little timber grown that is specifically targeted at biomass production. More widespread adoption of short-rotation forestry

(SRF) in Wales could be considered if appropriately managed in accordance with the UKFS, as it is a flexible production system that uses species and methods that promote sustainable biomass yield within a relatively short time-frame. A series of SRF trials in Wales are now well established and starting to yield interesting and informative results (Parratt, 2018).

Technological and supply chain developments, as well as maintaining confidence in the sector, are also important to sustain a regenerative economy and promote the more efficient use of natural resources. For example, the more widespread use of engineered wood products such as cross-laminated timber (CLT) and glued-laminated timber (glu-lam) would present opportunities for supply chain developments in Wales. Lignin, a complex compound found in woody plants, can also be used to manufacture bio-based plastics, and there is potential for market development. Lignin is typically sourced from paper pulping waste. The 2013 extension of the Coed y Brenin visitor centre on the WGWE (Brettstapel technique) and the Royal Welsh Showground Ty Unnos pavilion showcase the diverse range of innovative Welsh timber products (Woodland Trust, 2016).

Looking ahead, there is significant further potential for timber to support movement towards a regenerative economy with more efficient use of natural resources, and this is recognised by Woodknowledge Wales (2020). However, unless there is a radical change in market conditions, supply chain capacity, and the commercial viability of hardwood timber production, a major part of the focus must be on growing high-value conifer species. Productive conifer woodlands must therefore be part of the mix of new woodland creation needed in Wales, and this is entirely compatible with action to address the climate emergency. Whilst the forecasted availability of hardwood timber is increasing, market opportunities are currently limited. In the future, private businesses in the whole supply chain (from tree nurseries to final product), must have confidence in forestry in Wales to drive investment to support a regenerative economy and greater resource efficiency.

Reference should also be made to the Resource Efficiency chapters.

7. Synergies and Trade-offs

There are trade-offs and synergies associated with woodland management *per se*, as well as in relation to integrated land management, and these exist within and between different types of ecosystem services. Many are highly complex, particularly the trade-off between provisioning and regulating services, and occasionally also contentious, for example, in relation to biomass and the importance of different BECCS (Bioenergy Crops with Carbon Capture and Storage) scenarios.

A summary is provided in Table 12 based on Quine *et al.* (2011). It should be noted that there is currently little evidence to quantify these trade-offs and synergies, so this is a future evidence need. A recent integrated assessment (Emmett *et al.*, 2020) highlighted the importance of many cross-cutting themes which may impact on the delivery of benefits resulting from woodland creation and management, the trade-offs and synergies that exist, and the importance of temporal and spatial scales. Matthews (2020) examined in detail the complexity of the issues around the role of woodlands in climate change mitigation.

Table 12 Six examples of trade-offs and synergies in provision of ecosystem services and well-being benefits provided by woodlands (Quine et al., 2011).

Ecosystem Services	**Provisioning services**	**Regulating services**	**Cultural services**
Provisioning services	Not applicable	Synergy 1: Increased growth and production from existing woodlands and more new woodland creation can increase carbon storage.	Synergy 2: Thinning of woodland to improve the provision of timber and structural diversity can open access for visitors and improve habitats for wildlife. Opportunities may be provided for employment, volunteering and craft development.
Regulating services	Trade-off 1: Increased harvest reduces the carbon sink / store unless products have a long-life within a circular economy.	Not applicable	Synergy 3: Restoration of riparian woodland to aid flood regulation may enhance landscape and opportunities for recreation such as fishing.
Cultural services	Trade-off 2: Increased production may reduce the quality of the woodland environment for recreation (for example, increased traffic and machinery) and reduce the visual quality (for example, use of clearfells).	Trade-off 3: Most efficient carbon capture may be with novel crops / species that are not familiar or liked by some stakeholders.	Not applicable

A number of synergies and trade-offs are particularly significant in Wales given the policy and strategic framework that exists through Welsh Government's Natural Resources Policy (Welsh Government, 2017), Woodlands for Wales strategy (Welsh Government, 2019a) and A Low Carbon Wales (Welsh Government, 2019c), as well as the declared climate and nature emergencies.

New woodland creation is a key priority in Wales. It is known to be a way of increasing carbon storage and achieving some climate change mitigation during the expansion phase , subject to woodland management techniques that ensure the crop is healthy, fully stocked and reaches a stable mature state. Faster growing conifer species or the use of better-quality sites can fix carbon and produce timber of a utilisable size more quickly. As a result, felling may take place sooner and, provided that the carbon is then locked (for example, through use in construction timber) another rotation can be established to further sequester carbon. The situation is complex though, as there are multiple considerations to weigh up, as evaluated in Matthews (2020). Tree species choice, silvicultural management, yield class and end use, along with the underlying soil and climate type, will all influence the amount of carbon stored. Nevertheless, tree planting remains a priority for climate mitigation (Environment Systems, 2020).

Whilst there are many benefits and synergies associated with new woodland creation, there is also a key trade-off. More woodland means less land availability for other land uses such as agriculture, wind or solar energy provision, or other habitats. Further discussion about this trade-off, which includes the concept of ‘land sharing’ versus ‘land sparing’ is examined in more detail in the Land Use and Soils chapter.

It should be noted that synergies and trade-offs operate at multiple spatial and temporal scales, and there can be tension in relation to SMNR including between national and place-based priorities in accordance with Wales’ current legislative framework. Whilst the move to a more place-based approach, through Area Statements and local Well-being Plans, presents many opportunities, the approach must still ensure coherent delivery at a national level. Furthermore, there needs to be coordinated management of synergies and trade-offs across all land uses, not just for woodlands. Opportunity mapping of possible land-use changes is discussed in detail in the Land Use and Soils chapter.

8. Opportunities for action to achieve the sustainable management of natural resources

We have identified four Opportunities for Action to support SMNR associated with woodland ecosystems:

- Bringing more woodland into planned management;
- Improving and adapting the management of existing managed woodland;
- Compensatory planting for permanent woodland loss associated with renewable energy provision and approved development; and
- Increasing new woodland creation.

Combined and integrated action to address the four areas will help to:

- Safeguard and enhance stocks of natural resources;
- Improve resilience, including to future climate change and pests and diseases, as well as maintain and enhance woodland biodiversity; and

- Ensure that the benefits from woodlands are sustained and enhanced, contributing more to well-being by supporting a regenerative economy and the efficient use of resources and providing healthy places for people, protected from environmental risks.

These four Opportunities for Action are similar to those identified in SoNaRR2016 (NRW, 2016a), and compliment those identified and discussed in Beauchamp *et al.* (2020d), Beauchamp *et al.* (2020b) and Emmett *et al.* (2020).

Accelerated rates of new woodland creation would deliver wide-ranging benefits such as improved ecological resilience, carbon storage, increased biodiversity, timber supply, recreation and public access. Increased woodland establishment to UKFS standards needs to be integral to the pursuit of SMNR. A range of woodland types are needed; the size, character and location of these woodlands will depend on local, regional and national objectives. To achieve accelerated rates of new woodland creation, perhaps the most significant issue is the trade-off associated with the scale of land-use change needed to meet Welsh Government's woodland creation aspirations (see the Enclosed Farmland, Semi-Natural Grassland, Mountains, Moors and Heaths, and Land Use and Soils chapters). Engagement with all land managers, particularly in the agricultural sector, will be key in moving forward.

Additional opportunities to accelerate new woodland creation might include:

- The establishment of incentivised 'woodland enterprise zones', perhaps abutting existing areas of woodland, with a focus on the planting of productive conifer woodlands;
- The creation of 'space for trees' zones around towns and cities and woodland habitat networks, delivered through Unitary Development Plan (UDP) and Area Statements;
- More communication and engagement around the benefits of trees and woodlands, particularly with the agriculture sector to integrate woodland establishment and management into their farming business models;
- Improved mechanisms to match the national ambition around woodland creation with place-based identification of opportunity spaces, working closely with public service boards (PSBs), local landowners and communities;
- Collecting evidence to understand and quantify the ecosystem trade-offs and synergies for land use change; and
- Developing a framework for all land managers which provides incentives for ecosystems services from woodland creation and management and which will attract land managers to change their land use.

Improving and adapting the management of existing managed woodland, as well as bringing more woodland into planned management, are equally as important particularly given the predicted future impact of climate change and pests and diseases. Planned management can take many forms, and in accordance with the UKFS could include areas identified for 'minimum intervention' (only the basic inputs required to protect the woodland from external forces or to ensure succession of key habitats and species) through to clearfell and complex continuous cover systems. Decisions about the nature of planned management are linked to the desired outcomes being sought, at the appropriate scale. The delivery of ecosystem

services, and biodiversity, at a landscape or even national scale is likely to be best achieved by a heterogeneous set of woodlands that are subject to different forms of management. Optimising the services from woodlands is challenging because of the timescales involved in their development and change when interventions are made in their management. For this reason, woodland managers need to plan much further into the future than other land managers, and long-term objectives need to be clear. Ensuring there is continued interest in owning and managing woodlands will be important to sustain and enhance the benefits they bring.

Future opportunities might include:

- Targeted action to improve the condition of woodlands, for example, through management to achieve appropriate levels of grazing and improve species and structural diversity. This may require a long-term commitment to funding mechanisms for improved woodland management linked to payment for ecosystem services;
- Promotion and development of functional woodland habitat networks as part of wider resilient ecological networks, ensuring the potential risks to biosecurity are addressed. This would require spatially co-ordinated woodland restoration and creation, coupled with improvements of the condition of other intervening habitats to increase landscape permeability;
- Incentives to encourage greater and accelerated tree species diversification for climate change adaption beyond UKFS requirements;
- A requirement to source all planting stock from UK-grown sources;
- Targeted action to improve the condition of designated woodlands and achieve Favourable Conservation Status;
- Targeted, long-term action to encourage the restoration of PAWS through management by Low Impact Silvicultural Systems (LISS) to broadleaves;
- Targeted funding for woodland infrastructure to support the move to LISS and changes in the timing of management interventions;
- Targeted action to bring unmanaged woodland into planned management, including those on farms to support farm businesses;
- Development and promotion of area-based woodland management frameworks, with Area Statements providing evidence and connections to local place-based needs and opportunities and co-ordinating partnership working between public and private landowners;
- Adoption of a policy and legislative framework to ensure mandatory compensatory planting for any permanent woodland loss associated with renewable energy provision and approved development, as is done for common land under Section 16 of the Commons Act 2006; and
- Identifying ways to increase the contribution that timber makes to resource efficiency as part of sustaining a regenerative economy, for example, by looking at investing in new technologies, identifying market opportunities for hardwood timber, and increasing the management of farm woodlands; and
- Targeted action to increase confidence in the forestry sector in Wales, to support and encourage private investment in developing ways of adding value to the existing resource.

Co-ordinated action across multiple ownerships and at a range of scales, as part of a wider commitment to sustainable integrated land management is likely to be needed.

Research suggests that changing management practices relies on providing relevant information in a way which impacts owners' and managers' beliefs and responses to uncertainty (for example, about the efficacy of action, the costs involved, the perceived difficulty of doing things differently). For this reason, a tailored approach to engagement with different types of woodland and land managers is likely to be needed (Burton *et al.*, 2018). The need for a framework to support integrated land use decision-making is explored in the Land Use and Soils chapter.

Reference should also be made to the Land Use and Soils, Enclosed Farmland and Urban chapters for opportunities linked to woodlands (as part of integrated and sustainable land management) and trees outside woodlands, including in urban settings.

9. Evidence needs summary

Evidence related to woodlands is generally good and is improving all the time thanks to GB-wide monitoring programmes (for example, NFI), Wales-specific monitoring programmes (for example, GMEP and ERAMMP) and a comprehensive Science and Innovation Strategy for forestry in Great Britain which generates many research outputs that advance knowledge and understanding. A comprehensive review of evidence commissioned by Welsh Government via ERAMMP in 2020 is also an important point of reference.

Future evidence requirements to support delivery of SMNR in Wales can be grouped into the following overarching themes:

- The resilience of woodlands and the flow of ecosystems services and well-being benefits from them;
- The impact of pests and diseases on woodlands;
- The condition of woodlands in Wales;
- The extent of woodlands in Wales;
- The role of timber in supporting a regenerative economy;
- Ecosystem trade-offs and synergies relevant to woodland (and wider land use) to support SMNR; and
- The economic contribution of the wider woodland sector in Wales.

Under these overarching questions sit more specific evidence needs linked to action to bring more woodlands into planned management to improve resilience and adaptation to climate change and pests and diseases. Addressing these evidence requirements would support a more complete assessment of SMNR and help inform future policy decisions. The detailed evidence needs list can be found on the NRW website (see the SoNaRR2020 webpage for more details).
Addressing these evidence requirements would support a more complete assessment of SMNR and help inform future policy decisions.

10. References

Alison J, Maskell LM, Smart SM, Feeney C, Henrys PA, Botham M, Robinson DA, Emmett BA. 2020. Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP). ERAMMP Report 30: Analysis of National Monitoring Data in Wales for the State of Natural Resources Report 2020. Report to Welsh Government (Contract C210/2016/2017). UK Centre for Ecology & Hydrology Project 06297. Available from: https://erammp.wales/en/gmep-data-analysis [Accessed February 2021]

Beauchamp K, Alison J, Broome A, Burton V, Griffiths R, Keith AM, Maskell L, Siriwardena G, Smart S. 2020a. Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP). ERAMMP Report-33: National Forest in Wales – Evidence Review Annex-1: Biodiversity. Report to Welsh Government (Contract C210/2016/2017) (UK Centre for Ecology & Hydrology Project 06297). Available from: https://erammp.wales/en/r-year2 [Accessed February 2021]

Beauchamp K, Bathgate S, Burton V, Jenkins TAR, Morison J, Nicoll B, and Perks MP. 2020b. Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP). ERAMMP Report-35: National Forest in Wales - Evidence Review Annex-3: Future-proofing our Woodland. Report to Welsh Government (Contract C210/2016/2017) (UK Centre for Ecology & Hydrology Project 06297). Available from: https://erammp.wales/en/r-year2 [Accessed February 2021]

Beauchamp K, O'Brien L, Hall C, Dickie I, Swetnam R, Jenkins TAR, Doick KJ, Nisbet TR, Old G, Evans CD, Nicoll B, Jones L, Braban C, Robinson DA, Burton V, Tye A, Smith AR, Pagella T, Perks MP. 2020c. Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP). ERAMMP Report-37: National Forest in Wales - Evidence Review Annex-5: Ecosystem Services. Report to Welsh Government (Contract C210/2016/2017) (UK Centre for Ecology & Hydrology Project 06297). Available from: https://erammp.wales/en/r-year2 [Accessed February 2021]

Beauchamp K, Jenkins TAR, Alison J, Bathgate S, Bell C, Braban C, Broome A, Bursnell M, Burton V, Dickie I, Doick KJ, Evans CD, Fitch A, Griffiths R, Hall C, Healey JR, Jones L, Keith AM, Kerr G, Kuyer J, Maskell L, Matthews RW, Morison J, Nicoll B, Nisbet T, O'Brien L, Old G.H, Pagella T, Perks MP, Robinson DA, Saraev V, Smart SM, Smith AR, Siriwardena GM, Swetnam R, Thomas ARC, Tye A, Valatin G, Warren-Thomas EM, Wong J, Emmett BA. 2020d. Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP). ERAMMP Report-32: National Forest in Wales - Evidence Review. Report to Welsh Government (Contract C210/2016/2017) (UK Centre for Ecology & Hydrology Project 06297). Available from: https://erammp.wales/en/r-year2 [Accessed February 2021]

Bosanquet S, Dines T. 2011. A Bryophyte Red Data List for Wales. Plantlife, Salisbury.

Bosanquet SDS. 2019. Lichen surveys to investigate ammonia impacts. NRW Evidence Report No: 298, 126 pp, Natural Resources Wales, Bangor.

BTO. 2021. Bird Indicators [Online]. British Trust for Ornithology. Available from: https://www.bto.org/our-science/publications/developing-bird-indicators [Accessed February 2021]

Broadmeadow S, Thomas H, Nisbet T, Valatin G. 2018. Valuing flood regulation services of existing forest cover to inform natural capital accounts. Forest Research. Available from: https://www.forestresearch.gov.uk/research/valuing-flood-regulation-services-existing-forest-cover-inform-natural-capital-accounts/ [Accessed March 2021]

Broome A, Mitchell RJ. 2017. Ecological impacts of ash dieback and mitigation methods. FR Research Note.

Burton V, Metzger MJ, Brown C, Moseley D. 2018. Green Gold to Wild Woodlands; understanding stakeholder visions for woodland expansion in Scotland. Available from: https://www.forestresearch.gov.uk/research/understanding-stakeholder-visions-woodland-expansion-scotland/ [Accessed March 2021]

UK CCC. 2017. UK Climate Change Risk Assessment 2017: Evidence Report – Summary for Wales. UK Committee on Climate Change. Available from: https://www.theccc.org.uk/uk-climate-change-risk-assessment-2017/ [Accessed February 2021]

UK CCC. 2018. Biomass in Low Carbon Economy. Committee on Climate Change. Available from: https://www.theccc.org.uk/publication/biomass-in-a-low-carbon-economy/ [Accessed March 2021]

DEFRA. 2020. Butterflies in the United Kingdom: habitat specialists and species of the wider countryside, 1976 to 2019. Official statistics. Available from: https://www.gov.uk/government/statistics/butterflies-in-the-wider-countryside-uk#history [Accessed March 2021]

Emmett BE, GMEP team. 2017. Glastir Monitoring & Evaluation Programme. Final Report to Welsh Government - Executive Summary (Contract reference: C147/2010/11). NERC/Centre for Ecology & Hydrology (CEH Projects: NEC04780/NEC05371/NEC0578. Available from: https://gmep.wales/resources [Accessed March 2021]

Emmett BA, Beauchamp K, Jenkins TAR, Alison J, Bathgate S, Bell C, Braban C, Broome A, Bursnell M, Burton V, Dickie I, Doick KJ, Evans CD, Fitch A, Griffiths R, Hall C, Healey JR, Jones L, Keith AM, Kerr G, Kuyer J, Maskell L, Matthews RW, Morison J, Nicoll B, Nisbet TR, O'Brien L, Old GH, Pagella T, Perks MP, Robinson DA, Saraev V, Smart SM, Smith AR, Siriwardena GM, Swetnam R, Thomas ARC, Tye A, Valatin G, Warren-Thomas EM, Wong J. 2020. Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP). ERAMMP Report-39: National Forest in Wales - Evidence Review Annex-7: Integrated Assessment. Report to Welsh Government (Contract C210/2016/2017) (UK Centre for Ecology & Hydrology Project 06297). Available from: https://erammp.wales/en/r-year2 [Accessed March 2021]

Engledew M, Maclean K, Thomas T, Fitch A, Robinson DA, Jones L. 2019. ERAMMP Year 1 Report 24: Welsh National Natural Capital Accounts: Ecosystem service accounts for woodland, farmland and freshwater habitats. Report to Welsh Government (Contract C210/2016/2017)(CEH NEC06297). Available from: https://erammp.wales/en/r-year1 [Accessed March 2021]

Environment Agency. 2017. Working with natural processes. Available from: https://www.gov.uk/government/publications/working-with-natural-processes-to-reduce-flood-risk [Accessed March 2021]

Environment Systems. 2020. Tree Suitability Modelling – Planting Opportunities for Sessile Oak and Sitka Spruce and Wales in a Changing Climate. Final Report. Version number 3. Report commissioned by the Committee on Climate Change (CCC). Available from: https://www.envsys.co.uk/projects/tree-suitability-modelling/ [Accessed February 2021]

Forestry Commission. 2014a. Statistical Analysis Report: 50 year forecast of hardwood availability GB 2014. Available from: https://data.gov.uk/dataset/7749b439-e4e3-4deb-9472-f7d9e0b563bd/national-forest-inventory-50-year-forecast-of-hardwood-availability-gb-2014 [Accessed March 2021]

Forestry Commission. 2014b. Statistical Analysis Report: 50 year forecast of softwood availability GB 2014. Available from: https://data.gov.uk/dataset/5f2222ee-e2ad-46bd-ae2a-ede1b37f869c/national-forest-inventory-50-year-forecast-of-softwood-availability-gb-2014 [Accessed March 2021]

Forest Research. 2016. Preliminary estimates of the changes in canopy cover in British woodlands between 2006 and 2015. National Forest Inventory (NFI), Forestry Commission. Available from: https://www.forestresearch.gov.uk/tools-and-resources/national-forest-inventory/what-our-woodlands-and-tree-cover-outside-woodlands-are-like-today-8211-nfi-inventory-reports-and-woodland-map-reports/ [Accessed 09/02/2021]

Forest Research. 2017. NFI tree cover outside woodland in Great Britain. Statistical report. National Forest Inventory. Available from: https://www.gov.uk/government/statistics/national-forest-inventory-tree-cover-outside-woodland-in-gb [Accessed February 2021]

Forest Research. 2019a. Forestry Facts & Figures 2019. Available from: https://www.forestresearch.gov.uk/tools-and-resources/statistics/forestry-statistics/ [Accessed February 2021]

Forest Research. 2019b. About the NFI [Online]. National Forest Inventory. Available from: https://www.forestresearch.gov.uk/tools-and-resources/national-forest-inventory/about-the-nfi/ [Accessed February 2021]

Forest Research. 2019c. Public opinion of forestry 2019. Wales. Available from: https://www.forestresearch.gov.uk/tools-and-resources/statistics/statistics-by-topic/public-opinion-of-forestry/ [Accessed March 2021]

Forest Research. 2019d. Forestry Statistics - Chapter 2: UK Grown Wood. Available from: https://www.forestresearch.gov.uk/tools-and-resources/statistics/forestry-statistics/forestry-statistics-2019/uk-grown-timber/

Forest Research. 2020. NFI Woodland Ecological Condition. National Forest Inventory (NFI), Forestry Commission. Available from: https://www.forestresearch.gov.uk/tools-and-resources/national-forest-inventory/what-our-woodlands-and-tree-cover-outside-woodlands-are-like-today-8211-nfi-inventory-reports-and-woodland-map-reports/ [Accessed February 2021]

Gil-Moreno D, Ridley-Ellis D, McLean P. 2016. Timber properties of noble fir, Norway spruce, western red cedar and western hemlock grown in Great Britain. Research Note. Forest Research FCRN026. Available from: https://www.forestresearch.gov.uk/research/timber-properties-of-noble-fir-norway-spruce-western-red-cedar-and-western-hemlock-grown-in-great-britain/ [Accessed March 2021]

Goodwin ED, Suggitt AJ, Bennie J, Silk MJ, Duffy JP, Al-Fulaij N, Bailey S, Hodgson DJ, McDonald RA. 2018. Climate, landscape, habitat, and woodland management associations with hazel dormouse *Muscardinus avellanarius* population status. Mammal Review. 48 (3), 209-223.

Hayhow DB, Eaton MA, Stanbury AJ, Burns F, Kirby WB, Bailey N, Beckmann B, Bedford J, Boersch-Supan PH, Coomber F, Dennis EB, Dolman SJ, Dunn E, Hall J, Harrower C, Hatfield JH, Hawley J, Haysom K, Hughes J, Johns DG, Mathews F, McQuatters-Gollop A, Noble DG, Outhwaite CL, Pearce-Higgins JW, Pescott OL, Powney GD and Symes N. 2019. The State of Nature 2019. The State of Nature partnership.Available from: https://www.rspb.org.uk/our-work/state-of-nature-report/ [Accessed March 2021]

JNCC. 2019. Article 17 Habitats Directive Report 2019. Joint Nature Conservation Committee. Available from: https://jncc.gov.uk/our-work/article-17-habitats-directive-report-2019/ [Accessed March 2021]

Kerr G. 2020. Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP). ERAMMP Report-34: National Forest in Wales - Evidence Review Annex-2: Managing Undermanaged Woodland. Report to Welsh Government (Contract C210/2016/2017) (UK Centre for Ecology & Hydrology Project 06297).

Kirby KJ, Smart SM, Black HIJ, Bunce RGH, Corney PM, Smithers RJ. 2005. Long term ecological change in British woodland (1971-2001). English Nature Research Reports Number 653. Available from: http://publications.naturalengland.org.uk/publication/94019 [Accessed March 2021]

Lenane R. 2012. Keeping Rivers Cool - Getting ready for climate change by creating riparian shade. Environment Agency. Available from: https://www.ecrr.org/Publications/id/624 [Accessed March 2021]

MacLean P. 2019. Wood properties and uses of Scots pine in Britain. Forestry Commission Research Report. Available from:

https://www.forestresearch.gov.uk/research/wood-properties-and-uses-scots-pine-britain/ [Accessed March 2021]

Marsh R. 2019. Data on ancient woodland condition in Wales. A report for The Woodland Trust (unpublished – available from The Woodland Trust).

Maskell L, Henrys P, Norton L, Smart S, Wood C. 2013. Distribution of Ash trees (*Fraxinus excelsior*) in Countryside Survey data. Centre for Ecology and Hydrology (CEH). Available from: https://countrysidesurvey.org.uk/news-and-media/news/distribution-ash-trees-fraxinus-excelsior-across-gb-using-countryside-survey [Accessed March 2021]

Matthews R. 2020. Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP). ERAMMP Report-36: National Forest in Wales - Evidence Review. Annex-4: Climate Change Mitigation. Report to Welsh Government (Contract C210/2016/2017) (UK Centre for Ecology & Hydrology Project 06297). Available from: https://erammp.wales/en/r-forest-evidence [Accessed March 2021]

McDonald R. 2017. Trends in hazel dormouse populations in Wales. Unpublished letter to Natural Resources Wales. Available on request from NRW.

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

Mitchell RJ, Truscott AM, Leith ID, Cape JN, Van Dijk N, Tang YS, Fowler D, Sutton MA. 2005. A study of the epiphytic communities of Atlantic oak woods along an atmospheric nitrogen deposition gradient. Journal of Ecology 93, 482–492.

NRW. 2011. Ancient Woodland Inventory 2011. Natural Resources Wales. (Originally Forestry Commission Wales, FCW). Available from: https://naturalresources.wales/evidence-and-data/research-and-reports/ancient-woodland-inventory/?lang=en [Accessed February 2021]

NRW. 2015. Thematic Action Plan. Air Pollution: Nitrogen Deposition. LIFE Natura 2000 Programme for Wales. Natural Resources Wales. Available from: https://naturalresources.wales/about-us/our-projects/nature-projects/life-n2k-wales/life-n2k-thematic-action-plans/?lang=en [Accessed March 2021]

NRW. 2016a. The State of Natural Resources Report (SoNaRR): Assessment of the Sustainable Management of Natural Resources. Natural Resources Wales. Available from: https://naturalresources.wales/sonarr2016 [Accessed Feburary 2021]

NRW. 2016b. Ancient woodland baseline survey repeat sample. Natural Resources Wales. Unpublished.

NRW. 2017. Good Practice Guide 8. Forest Resilience Guide 3. Managing the genetic diversity of Welsh woodlands. Natural Resources Wales. Available from: https://naturalresources.wales/guidance-and-advice/environmental-topics/woodland-management/planning-for-the-future/genetic-diversity/?lang=en [Accessed March 2021]

NRW. 2020a. Assessment of critical levels of ammonia in ancient woodlands using modelled ammonia concentration data. Natural Resources Wales. Unpublished.

NRW. 2020b. Distribution of *Phytophthora ramorum.* Natural Resources Wales. Unpublished – available on request from NRW.

Nicoll B. 2016. Agriculture and Forestry Climate change report card technical paper No. 8 - Risks for woodlands, forest management and forestry production in the UK from climate change. LWEC. Available from: https://nerc.ukri.org/research/partnerships/ride/lwec/report-cards/ [Accessed March 2021]

Nisbet T, Roe P, Marrington S, Thomas H, Broadmeadow S, Valatin G. 2015. Project RMP5455: Slowing the Flow at Pickering. Final Report: Phase II. DEFRA. Available from: https://www.forestresearch.gov.uk/research/slowing-the-flow-at-pickering/slowing-the-flow-at-pickering-about-the-project/ [Accessed March 2021]

O'Brien L, Forster J. 2017. Fun and Fitness in the Forest: Monitoring and evaluation of the three- year Active Forest pilot programme. Report to Sport England and Forestry Commission England. Forest Research, Farnham. Available from: https://www.forestresearch.gov.uk/research/active-forest-programme-evaluation/active-forests-programme-reports-and-publications/ [Accessed March 2021]

O'Brien L, Ambrose-Oji B, Wheeler B. 2019. Mental health and wellbeing: The contribution of trees and forests to diverse populations in Britain. RFF - Numéro 23-4 - 2018 Spécial forêts et santé publique.

ONS. 2020. Statistical bulletin. Woodland natural capital accounts, UK: 2020. Office for National Statistics. Available from: https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/woodlandnaturalcapitalaccountsuk/2020 [Accessed March 2021]

Parratt MJ. 2018. Short Rotation Forestry in Wales Progress Report. Forest Research.

Plantlife Cymru. 2013. Lichens of Welsh Atlantic woodlands, Guide 2: The Parmelion lichens of birch, alder and oak. Available from: https://www.plantlife.org.uk/wales/our-work/plantlife-library/parmelion-lichens-welsh-atlantic-woodlands [Accessed March 2021]

Quine C, Cahalan C, Hester A, Humphrey J, Kirby K, Moffat A, Valatin G. 2011. The UK National Ecosystem Assessment (UK NEA) - Technical Report. Chapter 8: Woodlands. Cambridge: UNEP-WCMC. Available from: http://uknea.unep-wcmc.org/ [Accessed March 2021]

Ray D, Sing L, Nicoll B. 2016. Agriculture and Forestry Climate change report card technical paper No.9 - Forest Ecosystem Services & Climate Change. LWEC. Available from: https://nerc.ukri.org/research/partnerships/ride/lwec/report-cards/ [Accessed March 2021]

Saraev V, Beauchamp K, Bursnell M, Fitch A, Kuyer J, Thomas A, Dickie I, Jones L, Valatin G, Wong J. 2020. Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP). ERAMMP Report-38: National Forest in Wales - Evidence Review Annex-6: Economics and Natural Capital Accounting. Report to Welsh Government (Contract C210/2016/2017) (UK Centre for Ecology & Hydrology Project 06297). Available from: https://erammp.wales/en/r-forest-evidence [Accessed March 2021]

Saraev V, MacCallum S, Moseley D, Valatin G. 2017. Valuation of Welsh Forest Resources. Forest Research. Available from: https://www.forestresearch.gov.uk/research/valuation-of-welsh-forest-resources/ [Accessed February 2021]

Silos IP. 2017. Assessing the effectiveness of woodland creation for reducing agricultural diffuse pollution – developing value ranges to create look-up tables. Short-term Scientific Mission (STSM). Forest Research. Available from: https://www.forestresearch.gov.uk/research/pesforw/pesfor-w-short-term-scientific-missions/completed-stsms/ [Accessed February 2021]

Stocks JJ, Metheringham CL, Plumb WJ, Lee SJ, Kelly LJ, Nichols RA, Buggs RJA. 2019. Genomic basis of European ash tree resistance to ash dieback fungus. Nature, ecology and evolution, 3: 1686-1696. Available from: https://www.nature.com/articles/s41559-019-1036-6.epdf [Accessed March 2021]

Turley M, Southgate F. 2018. Sussex Flow Initiative Case Study: Natural Flood Management at Sussex Horse Rescue Trust. Woodland Trust. Available from: https://www.woodlandtrust.org.uk/publications/2018/07/natural-flood-management-washland-restoration/ [Accessed March 2021]

Turley M, Southgate F. 2018. Sussex Flow Initiative case study: Natural Flood Management at Kiln Wood, Blackboys. Woodland Trust. Available from: https://www.woodlandtrust.org.uk/publications/2018/07/natural-flood-management-leaky-dams/ [Accessed March 2021]

UK NEA. 2011. The UK National Ecosystem Assessment - Technical Report. Cambridge: UNEP-WCMC. Available from: http://uknea.unep-wcmc.org/Resources/tabid/82/Default.aspx [Accessed March 2021]

Wainhouse D, Daegan JG, Denman S, Green S, Webber JF. 2016. Agriculture and Forestry Climate change report card technical paper No.7 - Insect Pests and Pathogens of Trees. LWEC. Available from: https://nerc.ukri.org/research/partnerships/ride/lwec/report-cards/ [Accessed March 2021]

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

Welsh Government. 2018a. Woodlands for Wales strategy. Available from: https://gov.wales/woodlands-wales-strategy [Accessed March 2021]

Welsh Government. 2018b. Planning policy Wales. Edition 10. December 2018.

Welsh Government. 2019a. Woodlands for Wales Indicators 2017-2018. Available from: https://gov.wales/woodlands-wales-indicators-april-2017-march-2018 [Accessed March 2021]

Welsh Government. 2019b. Beyond Recycling – A strategy to make the circular economy a reality (consultation document) . Available from: https://gov.wales/circular-economy-strategy [Accessed March 2021]

Welsh Government. 2019c. Prosperity for all: A low carbon Wales. Available from: https://gov.wales/low-carbon-delivery-plan [Accessed March 2021]

Woodknowledge Wales. 2020. *A Route to Zero* report. Available on request from NRW or Woodknowledge Wales.

Woodland Trust, 2016. Adding value to timber from sustainably managed woods. Available from: https://www.woodlandtrust.org.uk/publications/2016/10/adding-value-to-timber-from-sustainable-woods/ [Accessed March 2021]

Woodland Trust. 2017. A Space for people - Targeting action for woodland access. Available from: https://www.woodlandtrust.org.uk/publications/2017/06/space-for-people-woodland-access/ [Accessed March 2021]

Woodland Trust. 2018. The benefits to people of trees outside woodland. Available from: https://www.woodlandtrust.org.uk/publications/2018/06/benefits-of-trees-outside-woods/ [Accessed March 2021]