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Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP)

National Forest in Wales Evidence Review

ERAMMP Report-32: National Forest in Wales - Evidence Review Report

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Abbreviations Used in this Annex

ASNW	Ancient Semi Natural Woodland
BAME	Black, Asian, and minority ethnic
BEIS	Department for Business, Energy & Industrial Strategy
BGS	British Geological Survey
BTO	British Trust for Ornithology
BVOC	Biogenic Volatile Organic Compound
CCF	Continuous Cover Forestry
eftec	Economics for the Environment Consultancy
ERAMMP	Environment and Rural Affairs Monitoring & Modelling Programme
EWP	Engineered Wood Products
GHG	Greenhouse Gas
INNS	Invasive Non-Native Species
NCA	Natural Capital Accounting
ONS	Office for National Statistics
PAWS	Plantations on Ancient Woodland Sites
PAYES	Payments for ecosystem services
PE	Particulate Emissions
PM*nn*	Particulate Matter; ‘nn’ is max. size in micrometres ($10m^{-6}$)
PPG	Payments for public goods
SFS	Sustainable Farm Scheme
UKCEH	UK Centre for Ecology & Hydrology
UKFS	UK Forestry Standard
VOC	Volatile Organic Compound
WG	Welsh Government
WGWE	Welsh Government Woodland Estate
WHO	World Health Organization

Abbreviations and some of the technical terms used in this report are expanded on in the programme glossaries: https://erammp.wales/en/glossary (English) and https://erammp.cymru/geirfa (Welsh)

Contents

FOREWORDS

Statement from the Welsh Government

The First Minister for Wales made a commitment to a National Forest in Wales in his 2018 manifesto for leader of the Welsh Labour Party. The Welsh Government has been developing an ambitious programme of work to take forward this vision, which was publicly announced by the First Minister on 12 March 2020, marking the start of a period of stakeholder engagement. Welsh Government officials would like to work with stakeholders to consider how a National Forest in Wales can maximise the economic, social and environmental benefits it produces.

The National Forest in Wales will provide many opportunities to Wales. Restoring existing woodlands and creating new woodlands will support Welsh Government's priorities to tackle climate change, halt the decline in biodiversity, build the resilience of our ecosystems and ensure the productive potential of Welsh woodlands. Wales will be known for its high quality National Forest which will increase our nation's access to and time spent in woodlands supporting their health and well-being and attracting visitors to Wales.

To achieve these ambitions, the Welsh Government requires robust and expert evidence to inform decisions made for the National Forest in Wales programme. The Welsh Government has commissioned the Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP) to produce phases of evidence to support and help overcome the key challenges for establishing a National Forest for Wales. For the first phase of the commission ERAMMP has produced an Evidence Review which informs and supports the business case for the National Forest for Wales programme. The evidence review will aid policy makers in delivering the greatest environmental, social and economic outcomes. Each chapter in the evidence review expresses an impact of woodland creation and restoration the National Forest in Wales aims to exploit or avoid.

The evidence review will help determine the most appropriate inputs Welsh Government can take to produce beneficial outputs and outcomes for Wales. It will inform the nature of the National Forest in Wales programme in areas including woodland restoration, creation, expansion and management.

Foreword from the ERAMMP Programme Lead

This evidence review was commissioned by the Welsh Government from ERAMMP in January 2020. The work was to involve a rapid review of the existing evidence base over a four month period, involving a number of experts across a range of organisations. We are very grateful for Forest Research for taking the lead for the work, and to many other experts who contributed to the writing and reviewing of the reviews. The Covid-19 pandemic resulted in all reviewing and discussion moving online for the critical final period which provided additional challenges. Our authors and reviewers completed the work to a high standard despite these very difficult working conditions. We hope the Welsh Government find the reviews a valuable source of information for their policy deliberations and the wider community are encouraged to continue in engage in the ongoing discussions this review is likely to stimulate.

Many thanks to all our authors and reviewers for all their hard work, and to our Welsh Government contract manager and commissioning team for their support through the process.

Prof. Bridget Emmett (UK Centre of Ecology & Hydrology)
ERAMMP Lead

1. Executive Summary

This review was commissioned by Welsh Government (WG) from the Environment and Rural Affairs Monitoring and Modelling Programme (ERAMMP) to provide key evidence of potential benefits and disbenefits of woodland creation, woodland expansion and managing undermanaged woodland, to provide an evidence base to inform the development of a National Forest for Wales.

During the commissioning process, WG emphasised that the evidence provided must reflect the collective views of the community by reviewing the literature in an objective way highlighting where evidence is contradictory or weak. Within the time available, evidence of causality of impacts, the likely timescales and magnitude of these impacts should be also be presented, for both positive and negative impacts of woodland expansion and management of undermanaged woodlands. This Evidence Pack should also build on the evidence put forward in the ERAMMP Sustainable Farm Scheme (SFS) (https://erammp.wales/en/resources) which included a range of assessments of the value of intervention measures which promoted trees within a landscape setting for a range of environmental, economic and social outcomes. The required rapid production of the review in four months meant an expert approach of key evidence was expected rather than a systematic review.

Key topics to cover were selected, in partnership with WG, focussing on issues that could fundamentally change decision-making going forward. The final agreed list was arranged under a series of high-level subject headings, and the individual reviews published as ERAMMP Reports 33 to 38 and include; Biodiversity; Managing Undermanaged Woodland; Future-proofing our Woodland; Climate Change Mitigation; Ecosystem Services, and Economics and Natural Capital Accounting. An Integrated Assessment was also commissioned to provide a synthesis of cross-cutting themes and dependencies between topics. These ERAMMP reports are all provided as Annexes to this report.

Document in this Series	**Ref**
National Forest in Wales - Evidence Review Report *(this document)*	ERAMMP Report-32
Annex 1: Biodiversity	ERAMMP Report-33
Annex 2: Managing Undermanaged Woodland	ERAMMP Report-34
Annex 3: Future-proofing our Woodland	ERAMMP Report-35
Annex 4: Climate Change Mitigation	ERAMMP Report-36
Annex 5: Ecosystem Services	ERAMMP Report-37
Annex 6: Economics and Natural Capital Accounting	ERAMMP Report-38
Annex 7: Integrated Assessment	ERAMMP Report-39

Experts in the community were approached to draft the reports that review the key evidence. As they developed, additional collaborators were invited to either contribute text or review them as required. These reports were then exposed to challenge and review by all report authors and a set of selected experts with a track record in the field. Initially this was intended to be in an intensive 2-day workshop. The 2020 Covid-19 pandemic resulted in the review process being curtailed to an online workshop.

In this report we focus on forests and woodlands rather than all green space, and the terms 'forest', 'woods' and 'woodland' are used synonymously and interchangeably, unless there is explicit information to the contrary within a particular section. There are no implied characteristics specific to any of these terms when used within this report or any of the individual reviews.

1.1. Key findings

Biodiversity: All aspects of woodland creation and expansion are likely to have some benefit for species and biodiversity associated with woodlands (Annex-1/ERAMMP Report-33: *Biodiversity*). However, there is significant variability in the magnitude of this outcome, depending on the woodland type, management implemented, and location of the action. Many species may take decades to populate new woodland habitat, while expansion of woodland into other habitats is likely to result in a loss of biodiversity associated with those habitats. However, the importance of this loss will depend on the quality of the respective habitats. To mitigate disbenefits, site-based evaluation is necessary. In some cases, expert value judgements may be required to establish which elements of biodiversity and ecosystem services to prioritise. This must sit in a landscape, regional and national context to ensure all habitats are conserved. However, decisions between which elements of biodiversity to promote are sensitive and value-laden and will inevitably involve a subjective choice between species assemblages. Unfortunately, there is currently a lack of studies exploring the socio-cultural aspects of woodland creation in Wales, and the UK more widely, that could support that decision-making.

Woodland specialist species are more likely to benefit from new woodland planted adjacent or connected to long-continuity woodland, particularly ancient woodland. However, the quality of the hedgerows and/or trees providing the connectivity is important and improving the quality and size of existing habitats is expected to be more beneficial. Connectivity may increase resilience to pests and pathogens but may also pose increased risk. Larger woodlands support woodland interior specialists whilst smaller woodlands support edge specialists. The relationship between size and species number is not linear, so increasing woodland size can be more important for small woodlands. Improving quality may be more important than increasing size for biodiversity, especially for larger woodlands. Specific groups and their management needs are separately reviewed within the report, covering plants, pollinators, soil microbiome, soil and saproxylic invertebrates, birds, and mammals. Targets for specific groups of species establishing in new woodland e.g. generalists or specialists, and the presence of self-sustaining populations are recommended over 'total species' or 'area of woodland' to measure success going forward.

Managing under-managed woodlands: The benefits of increasing the proportion of woodlands in Wales which are appropriately managed from the current 57% are explored in Annex-2/ERAMMP Report-34: *Managing Undermanaged Woodland*. Forest management can involve a wide range of actions, including, but not limited to intentionally leaving stands unmanaged; management of deer, livestock and squirrels; low impact silviculture continuous cover forestry; thinning; coppicing; and clear-felling. For older forests, allowing natural processes to dominate should be seen as a positive management decision. Some suggested a diversity of management approaches within large woodlands and between different small woodlands could increase whole system diversity. Risks to biodiversity from the recommencement of management are generally low but some highlighted the increased risk after about 100 years when gaps are likely to appear from natural processes and there is a risk of taking veteran trees out of the system.

Potential benefits of management include: increased revenue from responsible and sustainably produced timber and woodfuel; additional rural jobs (Annex-6/ERAMMP Report-38 *Economics and Natural Capital Accounting*); a reduced need for imports which also pose a biosecurity risk; increased resilience (Annex-2/ERAMMP Report-34: *Managing Undermanaged Woodland*) and potential benefits to cultural ecosystem services and landscape aesthetics (Annex-5/ERAMMP Report-37: *Ecosystem Services*). Some also highlighted the potential negative sides of some management actions, which detract from landscape aesthetics, amenity and well-being e.g. walking through a clear-fell site is not attractive to many.

A trade-off between production, and thus carbon capture, and biodiversity has been demonstrated in some large-scale continuous cover studies. It is recommended that a level of environmental standards is maintained in all woodlands (as for farmland), whilst prioritising sites beyond current designated sites for biodiversity, and sustainably intensifying production on sites of lower biodiversity potential. Consideration then also has to be given to other services that woodlands can provide e.g. recreation and air quality improvements (Annex-5/ERAMMP Report-37: *Ecosystem Services*).

Future proofing our woodlands: Impacts on our woodlands from climate change are already being seen. There has also been a near-exponential rise in the number of forest pests and pathogens linked to transfers through global trade. Interactions between these two pressures are likely to synergistically accelerate future risks (Annex-3/ERAMMP Report-35: *Future-Proofing our Woodland*). Correctly matching tree species and provenance to both site conditions and current and future climate conditions will support resilience to climate change and tree pests and diseases, as will appropriate forest management. Evidence suggests there is scope for further policy support, grants and incentives to support the forest sector to establish diverse and resilient woodlands and meet planting targets.

An adaptive approach at policy and operational scales, with monitoring and regular reviews of risk, evidence and strategy would support the sector to adapt. To establish diverse woodlands, advanced planning is needed to support nurseries and ensure plant availability; this delay needs to be accommodated within local planning and grant schemes which often constrain planting to short term scales. Pathways for the introduction and spread of tree pests and diseases must be understood, monitored and, ideally, shut down. Education, awareness raising, and increased monitoring are also essential as the next biological threat to Welsh forests is likely already here. Contingency plans play a critical role in resilience to forest pests and diseases and accelerating climate risks, such as wind and fire.

Climate change mitigation: Within the land-based sector, there is widespread acceptance that woodland creation (afforestation) and avoidance of woodland loss (prevention of deforestation) can contribute significantly to land-based carbon sequestration or the retention of land-based carbon stocks, where there are opportunities to undertake such activities. However, occasionally, there is conflicting evidence as to what types of activity are most effective. The assessment covers how woodlands in Wales may contribute directly as reservoirs and sinks of carbon, and indirectly as a sustainable source of wood-based products and bioenergy. The possible options for enhancing these contributions by Welsh woodlands are discussed and assessed.

Three ‘time horizons’ from present day (2020) to 2030, 2050 ad 2100 are considered. These time horizons are relevant for near-term policy goals and for longer-term objectives, such as achieving net zero emissions in the second half of this century, which is referred to in the Paris agreement. This reflects the important time lag in delivery of maximum carbon benefit due to practical constraints of planting large areas and the growth phase of the woodland. Critically, it should be noted that if the goal of climate change mitigation is to be achieved, ideally, as a minimum requirement, the *overall* carbon balance (i.e. direct and indirect carbon flows) must be at least zero and ideally a net sink. Hence, 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. It is also highlighted that there is a risk of impermanence of woodland carbon sequestration e.g. due to natural disturbances such as fire, due to changes in societal preferences, or due to some management actions.

Climate mitigation potential from a range of woodland creation and management options, as quantified using the Forest Research Carbine model, varied from an overall net emission (i.e. an overall carbon loss) up to a potential mitigation of 6 tCO_2-eq. ha^{-1} yr^{-1}. (Avoidance of woodland loss has significantly higher mitigation values, however, woodlands are already protected from clearance without permission, therefore this is not an intended policy direction). Net emissions result from forest management activities that increase production, including emissions from site preparation and harvesting. The results also indicate fast-growing productive woodlands (conifer or broadleaf) are not intrinsically more effective due to the ways woodland management (and their associated greenhouse gas (GHG) emission) is adapted. Avoiding tree harvesting is also no more effective than woodland creation or management actions nor is ‘rewilding’. The topic of bioenergy is a very active topic of current debate due to the complexities of the carbon inflows and outflows. It is emphasised in the review that in the right circumstances, and depending on the time horizon, all options can have potential benefits for climate change mitigation.

There are many caveats and assumption associated with the estimates provided and the full review should be referred to for these. Specifically, it is noted assumptions about the suitability of climatic conditions for specific tree species and associated growth rates are subject to high uncertainty. The contribution of soil carbon to carbon sequestration can be important on some soils with low carbon stocks, but for peat soils there is good evidence there will never be recovery of the initial level of soil carbon (and planting on peats is contrary to the Forestry Commission's Carbon Code and UK Forestry Standard) and for gleys there is trade-off between accumulation of soil carbon and the accumulation of carbon in woodland biomass as part of tree growth due to drainage to help establish the crop.

Finally, it was highlighted that as with any other single-objective management strategy for woodland creation, or for the management of new and existing woodland resources, management purely to achieve climate change mitigation through maximised carbon sequestration will inevitably necessitate trade-offs affecting the delivery of other ecosystem services (Annex-7/ERAMMP Report-39: *Integrated Assessment*).

Ecosystem services: Many other ecosystem services in addition to climate change mitigation from woodlands are reviewed, including removal of air pollution and a range of cultural services (Annex-5/ERAMMP Report-37: *Ecosystem Services*). It is well accepted that woodlands are five times more efficient at removing particulates from the air as other vegetation and twice as efficient for other pollutants. Many factors influence the rate of pollution removal, including tree species, pollutant concentration, interactions with other pollutants, and woodland cover within a landscape setting. Conifers are more efficient at removing pollution than deciduous trees as an annual average, because the surface area to volume ratio of needles translates to a higher leaf area index than deciduous trees and they hold leaf cover all year round. The location where changes in pollutant concentrations are experienced may not be the same as where the pollution removal happens, i.e. woodland can benefit locations downwind. Much of the health benefit in the UK is provided by vegetation outside of urban areas, however the precise distances over which a woodland is likely to have an influence on pollution concentrations is not known and it can be difficult to attribute uptake to individual patches of woodland. The location and direction of major pollution sources need to be considered, rather than solely prevailing wind direction, and the location of the benefitting population also needs to be taken into account. Some negative aspects are also highlighted, including the canyon effect of trees in streets effectively trapping traffic fumes, the production of precursors of ground-level ozone and other secondary pollutants, and pollen production which can impact on the health of hay-fever and asthma sufferers. Burning wood as fuel contributes to air pollution, with particular concern for the contribution of domestic wood stoves to particulate matter (PM2.5) emissions.

Cultural services capture the non-material benefits that people obtain from nature, and include physical and mental health, recreation, well-being from employment, opportunities for education, social capital, connection to nature, and spiritual or symbolic significance. There is good evidence about cultural ecosystem benefits from greenspace but less that is specific to forests and woodlands. Woodlands can provide many cultural benefits, as do many other semi-natural habitats, due to their provision of space for recreation, clean air, and opportunities for relaxation. This should be highlighted in any evaluation going forward i.e. is the benefit being described specific to woodland or green space and nature more generally?

There are many examples of how people gain education, knowledge of the natural environment, personal development benefits, and learn new skills from their engagement with trees, woods and forests. However others report having little or no experience of potential benefits, and others report negative experiences such as fear for safety or anti-social behaviour. As for cultural services which arise from all of nature, benefits are highly dependent on location and proximity to people, ownership, access, and habitat structure, with more benefits from woodlands which are light, open and rich in wildlife and support views of the wider landscape. In order to engage the widest range of the population it would be most beneficial to create a range of woodland types, both urban and rural, public and community woodlands, that promote engagement, either through top-down programmes or ground-up groups, as well as creating new woodland, and opening up existing woodlands for the wider population. Creating recreation facilities and opportunities for nature-based tourism can also engage a wider range of people.

With respect to landscape aesthetics, there is strong evidence the public value a range of structural components of woodland and favour plantings of a variety of species and perceived ‘naturalness’. There is also evidence for the high value of veteran and older trees in the landscape providing ‘visual’ coherence and a perception of continuity. Some negative aspects include the public dislike of clearcutting and management activities and perceived dark and gloomy commercial plantations. These perceptions may be considered alongside approaches to woodland management (Annex-2/ERAMMP Report-34: *Managing Undermanaged Woodland*). There is also no consensus as to whether trees are appropriate in the upland landscape particularly where pastoral farming has dominated for generations.

Woodlands can contribute towards an improvement in water quality due to both lower risks relative to agriculture but also as buffers between other land activities and water courses; providing this is well designed and managed. There remains an ongoing risk to water quality from conifer plantations on acid sensitive soils, due to ongoing air pollution and legacy effects of acidification, which need to be included in any site level assessment. Air pollution risks should be considered alongside air pollution reduction benefits outlined elsewhere in Annex-4/ERAMMP Report-36: *Climate Change Mitigation*.

With respect to flood mitigation, the strongest evidence is for decreasing flood peaks in small catchments (<10km^2), for small flood peaks (<10-year return period) and in catchments where woodland cover is >15-20%. Evidence for larger catchments and flood peaks is limited and is likely to be lower due to soil saturation and increasing flood volumes. Where woodland cover is < 15-20%, benefits may occur but are within measurement error.

Soil protection benefits are greatest from shrubby species and trees, reducing the risks of landslides and soil erosion. However, there are some management operations which can increase risks, including new planting and clearfelling. Windthrow and fires can increase risks, with a particular risk from pure stands of fast growing, tall conifers, due to their vulnerability to uprooting in storms. Poorly maintained infrastructure (drains, roads, etc.) can also contribute to risk. Future resilience to climate change will be enhanced through a mixture of low growing woody species such as native mixed woodland, that don't grow tall enough to be vulnerable to wind damage, maintained as continuous cover, which provide a matrix of different root forms and depths (see also Annex-3/ERAMMP Report-35: *Future-proofing our Woodland*).

Trees in an agricultural setting (agroforestry) can provide a range of additional benefits, including the reduction of ammonia and nitrogen emissions from housed and free-range animal production facilities, provision of new products including tree fodder to fill the spring gap, and effective shelter for stock. Barriers to implementation include increased cost relative to conventional woodland establishment, need for active management to ensure maintenance of productivity and other benefits, a skills gap, longevity of farm tenancies, intrinsic values of farmers, and potential loss of agricultural productive land.

Economic and Natural Capital Accounting: Profitability data for the forestry sector are only available for productive conifer plantations across the UK (Annex-6/ERAMMP Report-38: *Economics and Natural Capital Accounting*). Three year returns to investors between 2008-2017 were always above 11%. It is estimated hardwood production comprises < 2% of total wood production in Wales. Around 90% of the hardwood and 65% of the softwood raw material flowing into the Welsh industry is imported. An increase in the demand for Welsh wood and wood products is likely, due to the growing use of timber in construction, demand for domestic wood fuel, and increased interest in locally and nationally sourced material including in higher value markets such as construction, engineered wood products (EWP), veneers, furniture and hand-crafted wood products. Opportunities also exist for greater exploitation and investment in non-timber products such as fodder, food products and recreation use. The use of wood fuel has expanded and is now 57% of total renewable heat (see also Annex-5/ERAMMP Report-37: *Ecosystem Services* for discussion of air pollution from wood fuels). However, in some cases this had disrupted traditional timber industries and can negatively impact on carbon accounting (see Annex-4/ERAMMP Report-36: *Climate Change Mitigation* for discussion of carbon balances). Some potential concerns of increasing market products and wood fuel include: the need to minimise timber transport distance, the associated emissions and transport costs, and the potential impact on tourism and recreation.

Forests also provide a multitude of 'non-market' ecosystem services which are beneficial to humans (Annex-6/ERAMMP Report-38: *Economics and Natural Capital Accounting*). Natural Capital Accounting (NCA) methodologies attempt to value these services. The Office for National Statistics (ONS) NCA methodologies considered in Annex-6/ERAMMP Report-38 represent a good balance in terms of their practicality-complexity-precision, although scope remains to refine them further.

An important finding from Natural Capital Accounting exercises is that non-market values of many forest ecosystem services are significantly larger (by a magnitude) than that for marketable goods like timber. In the most recent assessment for the Welsh forest estate for the year 2014, conducted in 2019, the service of most value at £123m was recreation, followed by £113m for carbon sequestration, £44m for pollution removal and £30m for timber provision. When combined these gave a total annual value of £310m for the services which were valued. It should be noted, refinement of methodologies can change the overall value for individual services and the total value of the woodland estate. For example, in 2017, the woodland estate in Wales for the year 2015 was valued at £606m with the service of greatest value for air quality rather than for carbon sequestration and recreation as reported in the 2019 account. This was primarily due to a major revision of the approach relating to the valuation of air quality between the two studies. However, non-market goods remain greater than for marketable goods irrespective of these methodological adjustments. These values are always a partial account due to a lack of methods for many services, including biodiversity and should be considered alongside other sources of evidence

Integrated Assessment: The Integrated Assessment (Annex-7/ERAMMP Report-39: *Integrated Assessment* highlights the importance of many cross-cutting themes which may impact on the delivery of many potential benefits from woodlands. Key issues identified by experts as they carried out their reviews included:

- Trade-offs
- Timelags and a changing baseline
- Spatial and other contextual issues
- Skills economic and other barriers for uptake
- Resilience to climate change

A summary table was constructed to provide a visual overview of these issues to match a similar exercise approach undertaken for the ERAMMP Evidence Pack for the Sustainable Farm Scheme (ERAMMP Report-10a: *SFS Evidence Review - Integrated Analysis*)[1]. A total of 14 woodland creation and management opportunities were considered for 7 categories of benefits (split into 11 subcategories). A colour code is used for each opportunity and benefit assessment:

- Blue: woodland creation and management opportunities considered are most likely to realise benefits
- Amber: benefits may be realised, but evidence may be limited and/or there is a dependency which needs to be considered
- Pink: either expert judgement or evidence indicates little benefit is likely and/or there is an important potential trade-off to consider

In summary, the findings indicate no woodland creation or management opportunity was without some benefits. There is always a benefit to either woodland specialist species, timber production or other outcome. However, only 3 opportunities had no ‘Pink’ assessments indicating there may be important potential trade-offs for most opportunities which need to be considered before action is taken. Overall, of the 14 opportunities and 11 benefits considered; 32 outcomes were ‘Blue’; 86 were ‘Amber’ and 13 were ‘Pink’. The dominance of ‘Amber’ assessments highlights the critical issue of context dependency for many opportunities which need to be considered before action is taken. The challenge is therefore to provide a framework where decision-making can be supported within a local, regional and national context, ensuring there are sufficient cost-benefit outcomes to justify action, and that there is

[1] https://erammp.wales/en/resources#evidence-pack

due consideration of any trade-offs in the short and long term across different spatial scales and for different sectors of the community.

Next steps: It is recommended the next steps should include further review and integration of evidence and opinion across a wide range of stakeholders ensuring there is clear transparency of where evidence is weak; where interpretation of this evidence base differs; and where different value-judgements need to be taken into account.

2. Analysis and Interpretation of Key Evidence

In the following sections we first define some words and phrases used throughout the Report and Annexes and provide some underlying assumption and policy context. There is then a brief summary of the findings of the seven reviews (each being an Annex to this report).

2.1. Definitions

Forests, woods, and woodland. There is a frequently-held misconception that there are intrinsic and implied differences in character between areas described as 'forests', 'woods' or 'woodlands'. In Britain, the term 'forest' is sometimes erroneously used solely in relation to larger tree-covered areas, often assumed to be relatively newly-established and frequently dominated by close, quick-growing coniferous trees. Conversely, the terms 'woods' and 'woodland' are often believed to relate to smaller, more 'natural' areas populated with old, long-established, and mainly broadleaved trees. In reality there is no such distinction between these terms. Therefore, throughout this review we use the terms 'forest', 'woods' and 'woodland' synonymously and interchangeably. Unless there is explicit information to the contrary within a particular section, there are no implied characteristics specific to any of these terms when used within this report or any of the Annexes.

Woodland creation. Establishment of new woodlands on land under currently under other land uses. Woodland creation can be achieved through planting, natural processes, or a combination of these.

Woodland expansion. 'Woodland expansion' is used throughout this paper to encompass afforestation, reforestation, woodland creation, and forest landscape restoration, through natural or assisted measures. Afforestation and reforestation both involve the establishment of trees, in the former case where no trees existed before (for at least 50 years), while the latter refers to land that was recently forested but that has been converted to non-forested land.

Managed woodland. Areas of woodland actively managed for the delivery of one or more ecosystem services including: the production of timber, non-timber, or non-woody forest products; biodiversity; conservation; recreation; water catchment management *etc.*

Unmanaged woodland. Areas of woodland where there has historically been no active management taking place for the delivery of ecosystem services normally associated with managed woodland. There may be cases where the current management objective prescribes no active management, sometimes described as non-intervention management or long-term retention.

Undermanaged woodland. Managed woodland with the potential to deliver additional ecosystem services.

Urban forest. All the trees in the urban realm; in public and private spaces, along linear routes and waterways and in amenity areas. When considering urban greenspace in the context of natural capital accounts, urban forestry is described using a very specific definition of urban, focused on built up area and greenspace.

2.2. Assumptions

The authors of this report, and of the associated Annexes, assume that the establishment and management of all parts of a National Forest in Wales will follow ‘best practice’ and will adhere to, or exceed, the standards and requirements set out in the United Kingdom Forestry Standard (UKFS).

The UKFS is the reference standard for sustainable forest management in the UK. It outlines the context for forestry, sets out the approach of the UK governments to sustainable forest management, defines standards and requirements, and provides a basis for regulation and monitoring – including national and international reporting.

The UKFS approach is based on applying criteria agreed at international and European levels to forest management in the UK. There are a number of important EU directives and conventions that have been implemented through UK laws and that need to be taken into account when planning or practising forestry. The most relevant of these are the:

- Birds Directive 2009/147/EC
- Environmental Impact Assessment Directive 2014/52/EU
- Environmental Liability Directive 2004/35/EC
- European Landscape Convention
- Forest Reproductive Material Directive1999/105/EC
- Habitats Directive 92/43/EEC
- Water Framework Directive 2000/60/EC

However, because the history of forestry and the nature of the woodlands in the UK differ in fundamental ways from those of other European countries, a main purpose of the UKFS is to demonstrate that these agreements are applied in an appropriate way to the management of UK forests and woodlands.

The UKFS contains sections explicitly relating to the sustainable management of *Forests and*:

- *Biodiversity*
- *Climate Change*
- *Historic Environment*
- *Landscape*
- *People*
- *Soil*
- *Water*

For example, within the UKFS there is a specific presumption against the conversion [to woodland] of some priority habitats, such as deep peat or active raised bogs. This is for reasons of climate change in addition to biodiversity. The UKFS Guidelines on Forests and Biodiversity, the UKFS Guidelines on Forests and Climate Change, and the UKFS Guidelines on Forests and Soil all explicitly state: “*Avoid establishing new forests on soils with peat exceeding 50 cm in depth and on sites that would compromise the hydrology of adjacent bog or wetland habitats.*” With respect to restocking existing stands, the UKFS Guidelines on Forests and Climate Change further states: "*Consider the balance of benefits for carbon and other ecosystem services before making the decision to restock on soils with peat exceeding 50 cm in depth.*"

The requirements arising from other legislation, including the EU Water Framework Directive 2000/60/EC and supporting legislation across the UK, are embedded within the UKFS.

In terms of riparian management, UKFS guidance includes:

- *Aim for a mix of shaded and lightly shaded habitat within the riparian zone – around 50% canopy cover on average but guided by local circumstances and the requirements of priority species.*
- *Remove dense stands of conifers from riparian areas and from the edges of ponds and lakes, and control excessive conifer regeneration.*
- *Favour locally native tree and shrub species in the riparian zone and control the spread of invasive and non-native species.*
- *Design and manage riparian woodland along small watercourses (less than 5 m wide) to provide a source of leaf litter and woody debris; retain this within watercourses unless it poses a significant risk of damaging or blocking downstream structures.*
- *Provide and maintain defined buffer areas along watercourses and water bodies.*

2.3. Annex-1/ERAMMP Report-33: Biodiversity

Impacts of Woodland Creation & Management on Forest Biodiversity in Wales

All aspects of woodland creation and expansion are likely to have some benefit for species and biodiversity associated with woodlands (Annex-1/ERAMMP Report-33: *Biodiversity*). However, there is significant variability in the magnitude of this outcome depending on the woodland type, woodland age, management implemented, and location of the action. There is likely to be a trade-off against the biodiversity of the site to be afforested, as the expansion of woodland into other habitats is likely to result in loss of biodiversity associated with those habitats. The importance of this will depend on the quality of the habitat being lost. Furthermore, many species may take decades to populate new woodland habitat. To mitigate disbenefits, site-based evaluation is necessary. In some cases, expert value judgements may be required to establish which elements of biodiversity and ecosystem services to prioritise. This must sit in a landscape, regional and national context if all habitats are conserved. However, decisions between which elements of biodiversity to promote are sensitive and value-laden and will inevitably involve a subjective choice between species assemblages. Unfortunately, there is currently a lack of studies exploring the socio-cultural aspects of woodland creation in Wales, and the UK more widely, that could support that decision-making.

Environmental heterogeneity in general encourages biodiversity, with protection of older veteran trees within stands, and maintenance of deadwood and wetland habits within woodlands positively influencing biodiversity, as does maintaining diversity in woodland species, structure, and stand age.

Targets for specific groups of species establishing in new woodland e.g. generalists or specialists, and the presence of self-sustaining populations are recommended over 'total species' to measure success. Woodland specialist species are more likely to benefit where new woodland is created adjacent to or connected to long-continuity woodland, particularly ancient woodland. However, the quality of the hedgerows or trees providing the connectivity is important and improving the quality and size of existing habitats is expected to be more beneficial. Connectivity may increase resilience to pests and pathogens but may also pose increased risk. Non-native plantation forests can deliver some biodiversity benefits for woodland specialists where native woodland is scarce and if other habitat features and heterogeneity are retained, but high-density planting is associated with lower biodiversity when the canopy closes.

Specific groups and their management needs are separately reviewed within the report covering: plants, pollinators, soil microbiome; soil and saproxylic invertebrates; birds; and mammals. Below are some more general statements.

Woodland creation:

Good evidence is available for:

- The size of an individual woodland has an influence on the biodiversity it contains and its potential resilience. Small woodlands support woodland edge species but may not provide sufficient conditions for woodland interior specialists, due to light levels, humidity, and foraging area.
- There is a well-established species-area relationship. This relationship is more important for smaller woodlands, with increases in area having a greater effect than increasing the area of larger woodlands.
- The definition of a 'small' woodland also depends on the focal species being considered. Creating woodland that extends and buffer areas where there is already an ancient semi natural woodland component, where possible using site-native species, provides the highest biodiversity gains.
- Creating large woodland areas provides more internal woodland conditions which benefits woodland interior specialists and provides benefit through buffering from the effects of adjacent landuse. Larger woodlands also allow for heterogeneity e.g. open glades and incorporate other semi-natural habitats and a variety of topographic and water features, which has high biodiversity benefits and supports resilience.
- There may also be a point where more woodland habitat does not lead to greater numbers and diversity and increasing woodland size has diminishing return. This will be different across taxa and species
- The shape of the woodland is also important, with longer thinner forests supporting lower levels of biodiversity than more compact or circular. This is dependent of on the relative abundance of edge specialist versus woodland interior specialist species in the regional species pool.
- Maximising the area of woodland habitat available to species in the landscape by connecting fragmented woodlands, trees and hedgerows, allows species to migrate and supports ecological resilience. Reduction in woodland fragmentation is generally beneficial to woodland mammals but managing the increased dispersal of grey squirrel into red squirrel areas requires careful

management. However, there are concerns that pest and diseases could spread through green corridors, although, this depends on the dispersal mechanism of the organism.
- If woodland creation can only be of small areas of woodland, these should be focused in landscapes which are already relatively well wooded, although creation of woodland elsewhere, e.g. intensive agricultural landscapes, can have benefits e.g. for pollinators and birds.
- Woodland creation can have strong positive effects on biodiversity, although time lags can be both variable and long. Generalist species have less specific habitat requirements and are expected to respond first. Specialists may take longer to colonize an area e.g. woodland-associated birds and flora. Temporal lags in species response could mask the ability to observe progress towards conservation success. To take account of this, a shift away from measuring 'total species' as a measure of success, towards checking for more detailed milestones (e.g. arrival of generalists, successful breeding of generalists, arrival of specialists, self-sustaining populations of specialists) is recommended.
- Deciding where to locate new woodland will depend on several factors, not only where woodland may establish most successfully, but on the value of the underlying habitat (and its associated biodiversity) to be converted. There will need to be a consideration of trade-offs to facilitate 'net biodiversity gain'. Quantitative evidence of trade-offs may not be readily available and requires long-term, landscape scale monitoring or experiments.

Woodland management:

There is good evidence for the benefits of:

- Appropriate management can increase the biodiversity of new and existing woodland, in particular through generating open space, and increasing structural, species and genetic biodiversity; but the objectives must be clearly laid out as what will suit one species or group may not benefit another.
- Fencing to control levels of deer can support natural regeneration, where this is an aim, and enhance the shrub layer (understorey) of woodlands and as such have positive effects on a variety of woodland specialist species. Likewise, squirrel control can be essential for growing high-quality broadleaf woodlands which achieve the highest profits, however if this is not carried out on a large enough scale the costs can be prohibitive.
- Maintenance of woodland rides, open spaces and structural diversity is critical for pollinators, flora, and all taxa of woodland edge specialists and those that need open space for part of their lifecycle. Increasing woodland edges can have disbenefits for woodland interior specialists including some mammals, where the effects can be both beneficial and detrimental depending on their trophic level and whether they are open habitat or woodland species.
- The restoration of plantations on ancient woodland sites (PAWs) presents a fundamental opportunity to increase biodiversity. Many ecological features remain on PAWs sites and they can recover with restoration, even as the planation reaches maturity. The approach to restoration is important, with gradual opening of the canopy and change essential to conservation and preventing further damage and biodiversity loss.

- Forest management that mimics natural disturbances (close-to-nature and combined objective forestry) delivers greater biodiversity benefits through diversifying species and age classes of even-aged stands. Continuous Cover Forestry (CCF), where suitable, reduces many of the negatives associated with clear fell management, although increased management frequency can also have negative impacts to recreation and wildlife.
- The priority mammal species present in woodlands in Wales have variety of habitat requirements and woodlands at different stages of development, regeneration and scrub through to mature and post mature are required for their conservation. Edge effects can be both beneficial and detrimental to mammals depending on their trophic level and whether they are open habitat or woodland species.

Evidence is less strong for:

- Creating semi-natural woodland benefits many pollinator groups, but should be considered alongside other restorative solutions for pollinators (e.g. restoration of open semi-natural habitats). There is abundant observational evidence on the value of woodland for pollinators in intensive agricultural landscapes, including Wales-specific evidence. Maintenance of woodland rides, open spaces and structural diversity is critical for pollinators.
- There is no information on the rate of change on soil microbial and animal populations with either woodland creation or management within a welsh context.

With respect to the overall relationship between woodlands and biodiversity, good evidence is available for:

- The quality of woodland habitat may be even more important than size for biodiversity. Higher biodiversity value is associated with native and ancient semi-natural woodland often because of the longevity of such habitats and development of a complexity of structures and microhabitats often required by specialist woodland species, but conifer woodlands can contribute positively to biodiversity, especially diverse CCF where it offers heterogeneity and diversity of habitat features.

- Mature forests and veteran tree species support higher levels of biodiversity than younger stands. Support may be needed to preserve mature and ‘over-mature’ trees to allow them to reach veteran status. Ecological succession from mature trees near the end of their life to younger trees which also support the same habitat can be supported by management.

- Woodland when compared to other habitats supports a greater abundance of individual species rather than a greater richness of species.

2.4. Annex 2/ERAMMP Report-34: Managing Undermanaged Woodland

The current state of management of woodlands in Wales and challenges to bring more unmanaged woodland back into management are addressed in Annex-2/ERAMMP Report-34: *Managing Undermanaged Woodland*.

A minimum of 146,000 hectares (47%) of woodlands in Wales are managed according to the requirements of the UK Forestry Standard (UKFS); this figure includes the Welsh Government Woodland Estate (WGWE) and various private woodlands. There is uncertainty in the area of privately owned woodland managed according to UKFS that is not certified, therefore 47% is likely to be an underestimate. Some of the woodlands classified as unmanaged will be managed to variable extents but have no management plan filed and it should be noted that some woodlands are intentionally prescribed a non-intervention management plan for specific objectives and may be sustainable without the need for active management.

The area of woodland in Wales being managed to UKFS increased from 123,000 hectares in 2001 to 146,000 hectares in 2019. There is limited evidence to link this increase to specific factors but some authorities have indicated that they mainly attribute this to increased demand and prices for timber and woodfuel, which are currently [2020] at a 30-year high. The UK government had set a target for the area of woodland managed to UKFS to reach 67%, however some stakeholders argue that there is economic justification for the target to be higher (Royal Forestry Society 2019).

The Royal Forestry Society also estimated that the area of unmanaged woodland that could physically and economically be feasible to bring back into sustainable management is 53,000 hectares in Wales, which is about 40% of the current unmanaged forest area.

Critically, management involves a wide range of actions including, but not limited to, clear-fell, low impact silviculture, continuous cover forestry, and management of deer, livestock and squirrels. For older forests where natural processes are allowed to dominate this should also be seen as a positive management decision. For example, changes in the ground flora associated with shading are acceptable on some sites, as they are the consequence of the planned minimum intervention, and may only be temporary (in a woodland time-scale) until natural canopy gaps form. On other sites, thinning and ride management are planned in order to increase ground flora biodiversity. Another example where non-intervention or ‘abandoned with intent’ may be prioritised is within the humid bryophyte-rich Atlantic woodlands of western Britain. Others suggested that even in these cases, where natural processes are wanted and encouraged, some level of management intervention to removed unnatural pressures such as the presence of Rhodendron or high levels of deer grazing may be needed. Some suggested a diversity of management approaches within large woodlands and between different small woodlands could increase whole system diversity.

Risks to biodiversity from the recommencement of management are generally low but some highlighted the increased risk after about 100 years when gaps are likely to appear from natural processes and these is a risk of taking veteran trees out of the system. Site level assessments were seen as critical as overall diversity in itself may not be the goal in some situations but rather a small group of rare species which could actually be put at risk from an approach to achieving maximum diversity. Some also highlighted the negative sides of some management which detract from landscape aesthetics, amenity and well-being e.g. walking through a clear-fell site is not attractive to many.

The main benefits of bringing woodland back into management are reported by the review as:

Increased revenue from responsible and sustainably produced timber and woodfuel; and additional rural jobs (Annex-6/ERAMMP Report-38: *Economics and Natural Capital Accounting*); a reduced need for imports which also pose a significant biosecurity risk; increased resilience (Annex-2/ERAMMP Report-34: *Managing Undermanaged Woodland*) and potential benefits to cultural ecosystem services and landscape aesthetics, although this is not necessarily linked to management per se but the nature of the woodland it may bring about (Annex-5/ERAMMP Report-37: *Ecosystem Services*). It is highlighted that the main economic benefit may be the reduced risk from invasive non-native species, pests and disease resting from reduced imports of timber, although no specific data is available.

In terms of policy, bringing unmanaged woodland back into management provides an opportunity to deliver some rapid outcomes relative to woodland creation, which may take decades to deliver some benefits. Some in the community noted the need for a commitment for ongoing management from early in the cycle to ensure high quality woodland in the future for all newly created woodlands. The challenge is deciding what actions need to be taken to achieve objectives, and how to incentivise these. There was general agreement for a need to move away from targets and tracking of woodland area to capturing the flow of environmental, social and economic values derived from forests as a whole.

There are significant challenges to incentivise the improved management of woodland, as these need to be tailored to local social, biophysical and political conditions and developed in context. With respect to woodland size, the minimum size of woodland that is ‘economic’ is difficult to determine as there are so many factors involved but minimum areas of between 10-20ha have been proposed for conventional woodland operations. Co-operatives are traditional in continental Europe to overcome this issue but are not well tested in the UK, and it was agreed a disruptive approach was needed if the step change needed was to be achieved.

Issues which contribute to undermanaged woodland include:

- Some unmanaged woodland is on difficult terrain, and either cannot be safely extracted, would cause environmental damage, or is too costly to harvest, and whilst grants could overcome the latter, these access roads would further split up the landscape. These could instead be managed as carbon and biodiversity reserves letting deadwood accumulate and natural processes dominate. Landslide risks, from both management and lack of management, as well as soil erosion risks also need to be considered on steep slopes. (Annex-3/ERAMMP Report-35: *Future-proofing our woodland).*

- On exposed sites with a high wind risk, managing un- or undermanaged forest stands may lead to a detrimental increase in wind risk, and may be best left unmanaged; stands in exposed areas need to be actively thinned and managed from a young age to reduce risk. (Annex-3/ERAMMP Report-35: *Future-proofing our woodland).*
- Whilst financial return from forestry is currently higher than is has been for many years, the operating returns for broadleaved woodlands are modest compared to other land uses, and many stands are too small to manage economically for timber. Some suggested the best economic returns from small woodlands could be from cultural service rather than wood production although this is highly dependent on location and access issues.
- It is perceived that Government grants have become increasingly unattractive, restrictive and unfavourable to sustainable woodland management.
- Finally, a shortage of forestry contractors in the hardwood supply chain was reported, and there is a high proportion of sole traders who are undercapitalised, with limited capacity to respond to growing demand for harvesting and processing operations.
- 17% of woodland owners believed woods are better left unmanaged although more positively 37% are 'aspiring managers' who are looking for more guidance and support.

Overall there is a need to focus less on surveys of constraints and more on real-life interventions and their success or otherwise. A combination of incentives and advice with respect to farming, forestry, conservation and production and ecosystem service markets is likely to have greatest impact. There is a need to recognise the complexities of managing woodlands for a wide variety of different potential outcomes and ensuring management plans are context dependent.

2.5. Annex-3/ERAMMP Report-35: Future-proofing Our Woodland

Overall, there is good evidence that climate change is already having an impact on forests and woodlands in Wales, and that risks from wind damage and stress to trees from summer heatwaves, droughts and winter waterlogging are likely to increase. We have also seen a near-exponential increase in the number of forest pests and pathogens in the UK linked to transfers through global trade, and the interaction between these two pressures are likely to synergistically accelerate future risks.

Models of tree species suitability under climate change show a reduction in suitability for most species to 2050 and a further decline to 2080 due to constraints in water availability. The impacts of climate change are site and species specific, and earlier and greater impacts are likely in south Wales and on free-draining soils. Silver birch suitability declines from suitable to marginal under baseline conditions (1981-2000), becoming unsuitable in south Wales by 2080. Beech suitability declines dramatically from suitable and very suitable to unsuitable with scattered areas of 'marginal'. Sessile oak suitability decreases, but it remains very suitable in some areas to 2080.

For a small number of species, including commercial conifers Sitka spruce and Scots pine, modelled suitability and productivity are projected to increase to approximately 2060, especially at higher altitudes, although this is site specific and constrained on soils prone to drought or water logging and at higher elevations due to wind risk; this is therefore low certainty. Beyond this short-term increase, suitability and productivity also decrease. Sitka spruce suitability decreases from suitable and very suitable to suitable and marginal across most of Wales and unsuitable in south Wales by 2080 whereas Scots pine, which is more drought tolerant, remains widely suitable.

There is good evidence that newly planted and young trees are more vulnerable to stress and extreme events compared to established stands, including drought, scorch damage, late frosts, waterlogging and flooding, and have higher mortality rates than established stands that have deeper root systems. Correctly matching tree species and provenance to site conditions, and current and future climate conditions will support resilience to climate change and tree pests and diseases.

Undermanaged woodlands with lower biodiversity will be less resilient than well-managed woodland. Under-managed woodlands are at increased risk from drought, and higher risk from wildfires due to higher fuel-load from deadwood and limited access routes and firebreaks. Damage, such as from wind throw, can lead to subsequent pest or pathogen damage if not cleared, and infrequent access may mean pests or pathogens are undetected. Active management of new and existing stands and bringing undermanaged stands into appropriate active management will support resilience of the Welsh forest resource.

Forest management objective is crucial in determining resilience. Consideration of future-proofing our woodlands for the wider ecosystem services they deliver is reviewed in Annex-5/ERAMMP Report-37: *Ecosystem Services*. For native and Ancient Semi Natural Woodlands (ASNW), increasing woodland size (especially small woodland), connectivity, appropriate species selection, a diverse age-size structure, presence of open space, and controlling the level of grazing activity and Invasive Non-Native Species (INNS) can increase resilience. There is good evidence that hedgerows positively affect the richness and abundance of flora, invertebrates and birds but a lack of clear evidence of the positive benefits of hedgerows in increasing landscape connectivity for woodland-dependent taxa although there is good evidence of benefits of hedgerows for a different set of species (broadly, described as “edge specialists”). There are however concerns that increased connectivity of woodlands could affect the spread and effect of tree pests and diseases. For priority native woodland habitats, changes to tree species may not be an appropriate strategy as these ecosystems host many specialist taxa.

Sitka spruce occupies nearly 30% of the stocked forest area in Wales, which creates a potential vulnerability to pathogen or pest damage, such as to spruce bark beetles *Dendroctonus micans* and *Ips typographus*. Increasing the diversity of tree species in the forest landscape is considered a key strategy for reducing risk and supporting resilience to future change. However, Sitka spruce is the most valuable commercial species in the UK forestry industry and is in high demand, due to it being robust, fast growing and having well established markets. Evidence suggests there is scope for further policy support, grants and incentives to support the forest sector to establish diverse and resilient woodlands and meet planting targets.

Research is ongoing to explore alternative species for future climates, including minor species (already grown in the UK at small scales) and novel species (not widely grown in the UK), to understand their timber properties, growth, form, suitability. There is concern that an increase in non-native species could increase risks, especially to tree health. Expert judgement suggests strategic, gradual change, with the use of decision support tools at both operational and policy scales, and ongoing research into management, species and provenance choice, is preferred in order to prevent maladaptation.

Sufficient funding for landowners, appreciating that more diverse species and resilient management may require additional effort and cost, has been identified as a part of the solution to support adaptation, along with reducing bureaucracy, personal contact with advisors, and greater understanding of the cultural and emotional connection of landowners to their land. An adaptive approach at policy and operational scales, with monitoring and regular reviews of risk, evidence and strategy would support the sector to adapt. To establish diverse woodlands, advanced planning is needed to support nurseries and ensure plant availability; this delay needs to be accommodated within local planning and grant schemes which often constrain planting to short term scales.

Pathways for the introduction and spread of tree pests and diseases must be understood, monitored and, ideally, shut down. Education, awareness raising, and increased monitoring are also essential as the next biological threat to Welsh forests is likely already here. Contingency plans play a critical role in resilience to forest pests and diseases, as evidenced by the coordinated multi-agency responses and interceptions of the Asian longhorn beetle (established in Kent March 2012; eradicated in 2019), *Ips typographus* (intercepted in Kent, winter 2018), oak processionary moth (widely intercepted on recently imported trees outside of the existing control zone, summer 2019). Contingency plans for other climate risks such as wind and fire can also reduce climate impacts and support recovery.

2.6. Annex-4/ERAMMP Report-36: Climate Change Mitigation

Within the land-based sector, there is widespread acceptance that woodland creation (afforestation) and avoidance of woodland loss (prevention of deforestation) can contribute significantly to land-based carbon sequestration or the retention of land-based carbon stocks, where there are opportunities to undertake such activities. However, occasionally, there is conflicting evidence as to what types of activity are most effective. The report assesses how woodlands in Wales may contribute directly as reservoirs and sinks of carbon, and indirectly as a sustainable source of wood-based products and bioenergy. The possible options for enhancing these contributions by Welsh woodlands are discussed. Critically, it should be noted that if the goal of climate change mitigation is to be achieved, ideally, as a minimum requirement, the *overall* carbon balance (i.e. direct and indirect carbon flows) must be at least zero and ideally a net sink. Hence, 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. There is a risk of impermanence of woodland carbon sequestration e.g. due to natural disturbances such as fire or due to changes in societal preferences or due to some management actions. Whilst likely to be a small effect in British conditions, Woodlands also have reduced albedo, reflecting less sunlight, thus contributing to warming. Emissions of volatile organic compounds and increased evapotranspiration from woodlands may both have a cooling influence however their effect is hard to quantify.

Poorly defined use of definitions often lead to misunderstandings between stakeholders and some examples of these are worked through to help clarify the evidence base. These are:

1. “Managing trees on rotations that maintain fast growth will maximise woodland carbon sequestration” – this omits to take account of GHG emissions associated with shorter rotations. Carbon stocks in woodlands composed of species with different growth rates (Sitka spruce and oak) may be quite similar because of the ways in which woodland management (and the associated GHG emissions) is adapted to reflect the tree species and growth rates involved. Fast-growing productive forests have a part to play but they are not intrinsically more effective.

2. “Avoiding tree harvesting will maximise woodland carbon sequestration” – this omits the concept of carbon sequestration ‘saturation’ as woodlands attain an equilibrium carbon stock. Contrary evidence to this is generally limited to single trees rather than populations of trees for a given area. It may also result in a reduced flow of carbon into wood-products. Maintaining carbon stocks in current woodlands makes a contribution, but is not more effective than, other types of woodland creation or management actions.

3. “Allowing land to regenerate to a wilderness-woodland by natural succession is the best option for woodland creation to mitigate climate change” – evidence is limited on this and varies significantly from site to site depending on the initial conditions. The current evidence does not suggest there is any particular advantage of this approach relative to woodland creation and management, particularly when considering the timescales with which climate action is needed.

4. “Bioenergy produced from woodlands (wood fuel) is carbon-neutral” – the evidence suggests this is not always the case with potential impacts including a period of net emissions and the possibility of net reduction in carbon stocks. The subject is a topic of ongoing debate.

5. “Bioenergy produced from woodlands (wood fuel) releases more CO_2 emissions than burning coal” – this ignores consideration of all outflows from the system and the subject remains a topic for debate.

6. “Wood products (including wood fuel) are carbon-neutral as long as the carbon harvested from woodlands in harvesting does not exceed the woodland carbon sink”. – However if the existing net sink in woodlands is “eaten up” by efforts to produce more wood-based materials and energy and may contribute to a ‘carbon debt’. Again this is a topic of much analysis and debate and there is currently no consensus about the benefits for climate change mitigation (or otherwise) of materials and bioenergy produced from woodlands.

Modelling from past ERAMMP work has been used to estimate climate mitigation potential for a range of woodland creation and management options for three “time horizons”, from present day (2020) to 2030, 2050 and 2100. These time horizons are relevant for near-term policy goals and for longer-term goals, such as achieving net zero emissions in the second half of this century, which is referred to in the Paris agreement. This reflects the important time lag in delivery of maximum carbon benefit due to practical constraints of planting large areas and the growth phase of the woodland. The Forest Research CARBINE model was applied to produce a very large table of estimates of the impacts on woodland carbon sequestration and wider GHG emissions resulting from different options for woodland creation covering seven tree species, between two and four yield classes, and four woodland management options (Reserve; Continuous cover; Thin and Fell; and Short Rotation Forestry). Different climate, soil types and past land use were also included. These estimates could also be adapted to assess the impacts on a number of examples of management interventions in existing woodlands. The ERAMMP results were supplemented with estimates of long-term carbon stocks in woodlands, published as part of the UK Woodland Carbon Code Carbon Calculation Spreadsheet. Please refer to the full report for a full list of assumptions and results.

In summary, between 2020 to 2100, climate mitigation potential is quantified as follows:

- **Woodland creation** can mitigate about 6 tCO_2-eq. ha^{-1} yr^{-1}
- **Short rotation forestry plantations** (for raw biomass rather than timber production) can mitigate between 1 and 1.5 tCO_2-eq. ha^{-1} yr^{-1}
- The **avoidance of woodland loss** can mitigate between 55 and 120 tCO_2-eq. ha^{-1} yr^{-1}
- Adjustments to the **management of existing woodlands to conserve or enhance woodland carbon stocks and sequestration** can mitigate between about 0 and 2 tCO_2-eq. ha^{-1} yr^{-1}
- Adjustments to the **management of existing woodlands to increase wood production** – net emissions result due to the effects of increased harvesting
- **Adjustments to the species composition and growth rates of existing woodlands**, to enhance wood production whilst maintaining carbon stocks, give variable outcomes. The limited evidence available suggests 1 to 5.5 tCO_2-eq. ha^{-1} yr^{-1}
- The **extraction of branchwood and offcuts of stemwood** as a biomass feedstock is estimated to result in initial net GHG emissions switching to net mitigation of about 0.5 tCO_2-eq. ha^{-1} yr^{-1}.

There are many caveats linked to these results and the full report and appendix should be referred to. The results indicate the importance of the time horizon and the variable contribution of different stocks and flows depending on the woodland scenario. In the right circumstances, and depending on the time horizon, all options can have potential benefits for climate change mitigation. Conversely, no single option appears to offer a “silver bullet” solution above other options. Claims that are occasionally made for or against the case for a particular approach to woodland creation or woodland management are not supported by this assessment. All options are subject to a set of constraints to varying degrees.

Going forward, one possible strategic approach could be to manage woodlands according to one of three management approaches:

- Woodland carbon reserve management
- Substitution management
- Selective intervention carbon management.

Finally, it should be noted that as with any other single-objective management strategy for woodland creation, or for the management of new and existing woodland resources, purely to achieve climate change mitigation through maximised carbon sequestration may necessitate trade-offs affecting the delivery of other ecosystem services.

2.7. Annex-5/ERAMMP Report-37: Ecosystem Services

Key ecosystem services associated with forests and woodlands are considered in Annex-4/ERAMMP Report-36: *Climate Change Mitigation*. Ecosystem services can be defined as the benefits which flow from healthy ecosystems to society. Ecosystem services can be classified into broad categories of regulating and maintenance (e.g. climate mitigation, hazard reduction, biodiversity), provisioning (e.g. timber, fibre, fuel, non-timber forest products), and cultural (e.g. aesthetic, recreation, employment). The ability of trees, woodlands and forests to provide a wide range of ecosystem services is very much dependent on where they are located and how they are managed.

In addition, the climate change mitigation potential of forests is a regulating service and a key policy aim and is considered in Annex-4/ERAMMP Report-36: *Climate Change Mitigation*. The provisioning services of timber, woodfuel and non-timber products are considered in Annex-6/ERAMMP Report-38: *Economics and Natural Capital Accounting*, as is employment, which is classified as a cultural service. Components of biodiversity play significant roles in the support of ecosystem services, however as biodiversity has its own intrinsic value there is great value in considering it outside of the ecosystem service framework (see Annex-1/ERAMMP Report-33: *Biodiversity*). Here we focus on other ecosystem services.

2.7.1. Air Pollution

Air pollution is a major cause of respiratory illness, cardio-vascular complications, reduction in life expectancy and premature deaths worldwide. Air pollution in Wales is still at levels that have human health impacts, and which exceed WHO guidelines. Particulate matter is one of the principal air pollutants which impacts on human health. The greatest health impacts of particulate matter come from fine particles with a diameter less than 2.5 microns (PM2.5) since these are small enough to travel deep into the lungs. Ammonia in its aerosol form can be a substantial component of secondary PM2.5 and it is primarily generated in rural areas from agriculture sources, from where atmospheric transport carries it to urban areas.

Benefits: Vegetation, and woodland in particular, is efficient at removing particulate matter from the air. Trees are roughly five times as efficient at removing fine particulate matter (PM2.5) than other vegetation types such as crops, heathland or grassland, and around twice as efficient as other vegetation types such as ammonia, ozone and sulphur dioxide due to their higher leaf area index.

A number of factors influence the rate of pollution removal, including tree species, pollutant concentration, interactions with other pollutants, and woodland cover within a landscape setting. Conifers are more efficient at removing pollution than deciduous trees as an annual average, because the surface area to volume ratio of needles translate to a higher leaf area index than deciduous trees and they hold leaf cover all year round. The quantity of pollution removed by woodland depends on the amount of woodland in the landscape. At the level of an individual tree, lone trees or those on the edge of woodland are likely to remove more pollution because turbulence is greater around these tree canopies compared with a tree in the middle of a wood.

The location where changes in pollutant concentrations are experienced may not be the same as where the pollution removal happens, i.e. woodland can benefit locations downwind. Much of the health benefit in the UK is provided by vegetation outside of urban areas, however the precise distances over which a woodland is likely to have an influence on pollution concentrations is not known and it can be difficult to attribute uptake to individual patches of woodland. The location and direction of major pollution sources need to be considered rather than solely prevailing wind direction, the location of the benefitting population also needs to be taken into account.

Disbenefits: Trees planted in street canyons can lead to higher concentrations of pollutants at the level where pedestrians breathe in traffic fumes. This is because the tree canopy can reduce mixing of air layers at road level with the more turbulent air layers with higher wind speeds above the tree canopy.

Tree species emit biogenic volatile organic compounds (BVOCs), which play an important role in the formation of ground-level ozone (O3) and other secondary pollutants. Pollen production can be an air quality issue, and some species produce highly allergenic pollen with severe health effects for hay-fever and asthma sufferers. Species with high isoprene emission rates, which can contribute to the formation of ozone and particulates, include English oak, sessile oak, red oak, white willow, aspen and goat willow, while those with lower isoprene emissions include Austrian pine, larch, silver birch and maple.

Burning wood as a fuel contributes to air pollution, with particular concern for the contribution of domestic wood stoves to particulate matter (PM2.5) emissions. The WG policy proposals to limit PM2.5 emission include regulation of stoves, sales of wet firewood and bans on use of wood stoves in clean air zones.

2.7.2. Cultural services:

Cultural ecosystem services are one of three ecosystem service categories and capture the non-material benefits that people obtain from nature, and include physical and mental health, recreation, employment and contribution to the economy, opportunities for education, social capital, connection to nature, and spiritual or symbolic significance. There is good evidence about cultural ecosystem benefits from greenspace but less that is specific to trees, forests and woodlands. In Annex-5/ERAMMP Report-37: *Ecosystem Services* the evidence for how cultural ecosystem service benefit are realised from peoples' engagement with trees, woodlands and forests by forests and woodlands in Wales.

There is strong and widely accepted evidence for the following ecosystem services:

- Recreation: In Wales, in decreasing order these are: walking, dog-walking, picnicking, wildlife watching, sightseeing / visitor attractions, children's playground, running, off-road cycling / mountain biking, amongst others
- Physical health: There is good evidence that regular exercise improves physical health, and forests as for other semi-natural habitats support this by providing places for exercise and recreation. Creation of access, paths, trails, signs and infrastructure are important for delivering recreation and health benefits.
- Mental health and well-being: The mental health and well-being benefits afforded by engagement with nature as a whole including trees and woods are increasingly recognised and considered of great value to individuals, communities and society; but are diverse and difficult to measure. With respect to the forest and woodland environment, they offer opportunities for relaxation, sensory experience, mental stimulation and a sense of freedom.
- Employment: Forestry contributes to the local and national economy in Wales, as detailed in Annex-6/ERAMMP Report-38: *Economics and Natural Capital Accounting*, this is through revenue and employment directly from the production of timber, woodfuel, and non-forest products; site and forest management; as well as recreation activities and staff, car parks, cafes, retail, and associated tourism and hospitality.
- Education and skills: There are many examples of how people gain education, learn new skills and knowledge of the natural environment, and personal development benefits from their engagement with trees, woods and forests. Examples which promote this include; Cydcoed in Wales, the Community Forest Programme, Active Forests Programme and Westonbirt Community Project in England. An evaluation of Cydcoed found that knowledge and skills developed were being cascaded further through the community, hence not only benefiting those directly involved. They can also reduce antisocial behaviour.

The following cultural ecosystem services are less easily quantified but have good evidence and are significant for delivering the full range of benefits that nature, forests and woodlands can provide to the widest range of people.

- Connecting to nature: Connecting people to nature is an important cultural ecosystem service that can be realised by engagement with trees, woodlands and forests and can be beneficial in terms of building identity linked to nature. Nature connection can be through direct involvement in schools and community groups, planting and maintaining wooded sites or simply with the opportunity to be in the fresh air, somewhere perceived as pleasant, away from noise and air pollution, and a safe space away from traffic although this in itself is not unique to forests.
- Social cohesion, capital and identity: Cultural ecosystem benefits generate wider social benefits, for example through the development of social connections, social capital, community trust, partnerships and friendships. Evidence shows community woodland initiatives increase the level of trust in the community, help develop new and strengthen existing relationships and encourage engagement with the local community. This also applies to other

semi-natural habitats. Furthermore, in some situations, the forest or woodland can be the defining feature of their locality although this was not always positive with plantation forests in some case being perceived as for national financial profit and not for local community benefit or part of local identity.

In order to deliver the widest range of benefits there is good evidence that:

The type and management of the forest environment, as well as access, has a significant impact on ecosystem service provision, with additional benefits from mixed, broadleaf woodlands, mature, closer to nature forests which are light, open, and rich in wildlife and support views of the wider landscape. The design and management of rural and urban forests is important to enhance well-being.

It is not just important to create new woodlands or bring unmanaged woods into some kind of active management, but to seek to open up currently inaccessible woodlands in order to generate cultural ecosystem benefits for the population in Wales. It is emphasised that these benefits are highly dependent on location and proximity to people; but present a significant opportunity for rapid gains.

Proximity and access are primary influencers of woodland utilisation for recreation. Facilities such as car parks, trails, signage and infrastructure support visits, and on-site facilities that might increase visits also extend to retail and catering.

A significant proportion of the population of Wales visit woodlands regularly for walking, dog walking and picnics. These visits to local woodlands account for the majority of visits to forests and woodlands and deliver cultural ecosystem service benefits to many people. There is a need for increasing accessible woodland in areas with a low woodland cover.

As widely evidenced, many individuals have no interaction or access to the natural environment and may have either no experience of the benefits they can provide or even have negative associations with trees and woodlands, through fear for safety or experience of anti-social behaviour. Engagement, education and access are essential to address these barriers and deliver benefits to individuals, communities and society.

There is good evidence that forest ownership is important and expectations of benefits are higher for public forests than for private, particularly in locations where private owners can restrict access. Forests in public ownership may provide more facilities with the aim of being inclusive. Community woodlands present opportunities for ground level engagement and decision making. Urban forests create access for the largest numbers of visitors.

There is strong evidence that partnerships and projects that target and support specific groups and communities to access and engage with forests and woodlands generate cultural ecosystem benefits to the broadest range of communities and individuals which often includes more deprived communities, BAME groups and the disabled and groups that would not normally engage with woodland.

Community Woodland Groups are proactive in the creation, expansion and management of woodlands, provide trees in areas they are needed (Lee 2001) and create a sense of community ownership. Initiatives generally require some public or funding during inception and early years and lead to woodland areas near to local communities that are a free resource for socialising, exercise and thus experiencing physical and mental health benefits. Such initiatives and public funding enable the provision of support to encourage physical activities in woodlands, peri-urban and urban forests.

In order to engage the widest range of the population it would be most beneficial to create urban and rural public and community woodlands that promote engagement, either through top-down programmes or ground-up groups, as well as creating new woodland, and opening up existing woodlands for the wider population. Creating recreation facilities and opportunities for nature-based tourism can also engage a wider range of people.

2.7.3. Landscape aesthetics

Forestry and wooded components form a critical part of the natural infrastructure of rural landscapes. Trees affect the appearance of a view due to their size and vertical dominance. This happens at a range of perceptual scales from near to distant. Landscape aesthetics can be defined as "the enjoyment and pleasure felt through the observation of environmental scenery" and so is strongly visual in evaluation.

There is well accepted evidence of the positive contribution of trees to the appearance of most landscapes. However not all elements of forestry and forest operations are perceived as positive.

Benefits:

- Some of the strongest evidence with respect to landscape aesthetics is found in the consideration of species type, more broadly the preference for mixed/deciduous woodlands over conifers. The appearance of non-native conifers grown as a commercial timber crop has typified much forestry planting, particularly in upland areas of the UK such as Wales. The economic drivers for such planting do not match the preferences of the public, with mixed, deciduous woodlands being strongly favoured from an aesthetics viewpoint, as is seasonal colour. There is well accepted evidence that the public recognise and value a range of structural components of woodland and favour plantings of a variety of species.
- The public are sensitive to the perceived 'naturalness' of woodlands and forests in the landscape, strong opposition was given to forests planted in rows and one study indicated blocks of conifers were the most negatively rated landscape feature after road infrastructure. Some limited evidence suggests that complex shapes which provide heterogeneity in the landscape view are favoured, such as clumps of trees breaking up the homogenous shapes of agricultural fields, and dispersed trees in wood-pasture landscapes.
- There is well accepted evidence that older trees are more highly valued, providing a sense of continuity to welsh landscapes, with veteran trees often considered aesthetically pleasing due to their size, form or location in the landscape, and large trees lending "visual coherence" to the landscape.

Disbenefits:

- There is limited evidence detailing the public response to clear-felling in the UK, although advice is available to minimise landscape impact. Good evidence exists in Scandinavia concerning the dislike of the public for clear-felled areas and that cleared stands with mature 'retention' trees were significantly favoured over total clear cut (See also Annex-2/ERAMMP Report-34: *Managing Undermanaged Woodland*).
- Forest management activities restrict access to the public for recreation, closing or diverting trails, sometimes for extended periods.
- Dense stands of trees, in particular fast-growing conifer crops, and to a lesser extent other dense even aged woodland types, can represent a significant landscape challenges with respect to restricting preferred views.
- There is no consensus within communities as to whether trees are welcome in upland landscapes. Context and landscape siting remain key to acceptance. Different stakeholders may hold very different views of how an upland landscape "should look" particularly where pastoral farming has dominated for generations.
- Commercial conifer plantations in south Wales have been described as dark, unwelcoming places, where the trees provide secrecy for antisocial behaviour with the trees providing a screen of secrecy. Other words used to describe these plantations in the past are alien and gloomy, and although still considered to be a natural space, this is something that is beyond their own built and social environments

2.7.4. Urban forestry

The urban forest comprises all the trees in the urban realm – in public and private spaces, along linear routes and waterways and in amenity areas. Urban forests can be considered across four scale-based urban forest elements: single trees, lines of trees, tree clusters, and woodland. They contribute to green infrastructure and the wider urban ecosystem and contribute to the delivery of a wide range of ecosystem services. The FAO (1998) definition of forests effectively classifies urban areas across Wales as "forest", having a canopy cover > 10%; from towns and villages on Anglesey (12.1% average urban canopy cover) to those in Merthyr and Blaenau Gwent (both 22.5% average urban canopy cover). Whilst still an on-going initiative, the Canopy Cover Map for the UK reveals that urban tree canopy coverage ranges from 0.7% in Rest Bay, Bridgend to 45.1% in Killay South, Swansea. Urban trees therefore have the potential to make significant contribution to the National Forest Programme in Wales.

As an important single component of green infrastructure, trees can contribute to improved health and well-being, increased recreational opportunities, and an enriched and balanced environment that ultimately boosts a town's image and prosperity. Specifically, benefits that are strongly impacted by proximity to people will be enhanced in urban forests. These include many cultural services including physical and mental well-being, a source of recreation and a location for quiet enjoyment, a positive perception of 'place', air quality regulation and thus benefits to human health (see also Annex-5/ERAMMP Report-37: *Ecosystem Services*); as well as economic benefits such as increased property value (increases of 5-18%).

However, the potential issues of pollen production and the street canyon effect should also be noted, as should the beneficial role for woodland upwind of towns and cities to air quality, and the potential for prevailing winds introducing air pollutants, which are also important considerations. There are potential benefits of reducing heat and cooling costs to buildings and a reduction in noise pollution. Benefits unrelated to proximity to people include carbon sequestration, although urban forests are likely to make a relatively minor contribution to national targets due to the small urban area in Wales. Improvement in soil organic matter and structure, as with other areas of green infrastructure, may benefit surface water infiltration and help remove contaminants. Habitat for wildlife will also be present.

Negative issues include potential damage to infrastructure such as houses and water pipes due to tree and branch fall (especially during storms) and potential root disturbance of houses and infrastructure as indicated by insurance levels. There is also an increase in private and public maintenance costs due to fruit and leaf fall. There may also be risks of blocking light, heat and views, a creation of fear due to the potential for anti-social behaviour and crime and a link to animal excrement (e.g. aphid honeydew and bird droppings). There is also a potential for spread of pests and disease and invasive species (e.g. grey squirrels and Oak Processionary moth).

Overall, as the effects of climate change become better understood, it is becoming increasingly clear that one of the best ways in which we can make our communities more hospitable over the next few decades is to increase the number, size and species of trees.

2.7.5. Water quality

Woodland management activities, such as cultivation, drainage, road construction, fertiliser and pesticide use, and harvesting, all pose a risk of water pollution. Studies in Wales and elsewhere in the 1970s and 80s showed how these practices can seriously degrade water quality and disrupt water supplies. The primary issue is soil disturbance causing increased erosion and sediment delivery to watercourses, resulting in water turbidity and siltation. Other problems can arise from phosphate runoff after aerial fertiliser applications, nitrate leaching following clearfelling operations and accidental contamination due to the use of chemicals, fuel oils and lubricants.

A further concern was the link between enhanced capture of acidic pollutants by tree canopies relative to grassland and crops and the base cation removal from soil by conifer plantations on acid sensitive soils, which resulted in some streams and lakes losing their stock of fish and a loss of freshwater and associated species such as birds in Wales.

Concerns over these issues led to the development of the Forestry Commission's Forests and Water Guidelines, which were introduced in 1988 to provide advice to woodland managers, practitioners, planners and supervisors on how operations should be planned and managed to protect the water environment. These have now been incorporated into the UK Forestry Standard along with a set of legal and good forestry practice requirements. It is imperative that policy development surrounding the

National Forest in Wales takes full account of the guidelines in the UK Forestry Standard. Section 2.6 of Annex-4/ERAMMP Report-36: *Climate Change Mitigation* provides robust evidence for the impacts and benefits of woodland management, woodland design and location on water quality, which are summarised immediately below.

There is also high confidence in the water protection function of woodland cover, relative to some other land use types, providing this is well designed and managed. Poor woodland management can diminish or reverse this benefit and risk severe water pollution. It is well accepted that implementation of the UK Forestry Standard will help ensure that waters draining woodlands are of high quality and ecological condition. This includes the need for an ongoing assessment of the continuing risk of acidification on acid sensitive soils from conifer plantations despite declines in acidic deposition.

Agriculture is a major source of diffuse pollution in Wales, contributing to around a quarter of river water bodies failing to meet good ecological status. There is growing recognition that achieving water quality targets will require a significant element of land use change. Woodland creation and especially targeted planting is known to be a very effective measure for reducing diffuse pollution from agricultural activities. There is a substantial body of evidence that establishing wooded buffers can significantly reduce diffuse pollution inputs to watercourses along with improving most ecosystem functions, but more data are required to demonstrate that a network of riparian woodland can make a difference at the catchment scale.

2.7.6. Flood mitigation

Forests and woodlands have long been associated with an ability to reduce flood peak flows, but the subject is complex and multifaceted. The potential for tree cover to reduce rainfall-runoff is soundly based on scientific understanding of how trees affect several physical and biophysical processes.

Section 2.7 of Annex-4/ERAMMP Report-36: *Climate Change Mitigation* provides a broad base of evidence for the influence of trees in flood mitigation processes, focussing in on a number of identified key factors, namely catchment scale, flood size, woodland placement, timescale and longevity, effect modifiers, and risk. The main conclusions of this section are summarised immediately below.

It is well accepted (high confidence) that woodlands can affect flood runoff, based on sound process understanding and supporting data. There is strong observation-based evidence that woodland felling can increase, and new planting decrease, flood peaks in small catchments (<10 km^2). This applies to a range of flood peak sizes but the evidence is strongest for small flood peaks (<10 year return period) and very limited for large flood peaks (>100 year return period). The ability of woodland to reduce flood runoff declines with increasingly large flood events as a result of soil saturation and increasing flood volumes and depths, although canopy interception loss continues and can be significant.

The strong logic chain and model-based evidence provides medium confidence that these effects can extend to medium sized catchments (10-100 km^2), but much depends on the extent, nature and placement of woodland and management operations. Likewise, this implies that woodland effects could extend to large catchments (>100 km^2) but there is much less scope to affect flood peaks at this scale and the very limited evidence provides low confidence in woodland having a detectable effect.

In general, it is very difficult to detect changes to flood peaks when the extent of woodland planting or felling is <15-20% of any size of catchment. This does not mean that there is no effect, only that it cannot be detected against measurement errors.

2.7.7. Landslides

There is well accepted evidence that vegetation, including trees and shrubs, can effectively reduce erosion, landslides and rock-fall from vulnerable slopes through interception of rain, uptake of water and improved soil cohesion through root reinforcement. Significant evidence from around the world demonstrates that deforestation increases the risks of potentially fatal landslides, often triggered by low frequency, high magnitude events. The effects of climate change are anticipated to result in an increased risk of landslides, due to the increase in frequency of high intensity rainfall events that can trigger landslides and accelerate soil loss and the increase in extreme wind storms and wildfire which can exacerbate landslide risk. Evidence from the USA indicates that each 1% increase in annual rainfall can increase erosion rates by 1.7%.

Vegetation provides physical protection of the soil on vulnerable slopes by canopy interception of rainfall, root water uptake, and improved soil cohesion through root reinforcement. Greater protection is provided where there is full leaf cover and during spring and summer. Herbaceous species and grasses provide some protection, but this is increased greatly by the incorporation of shrubby species and trees with woody roots, which provide a stronger and deeper matrix in the soil, allowing the soil to be held together and anchored better to deeper layers and underlying rock.

Negative aspects of trees include where an increase in landslides and soil erosion may occur such as during planting until the development of reasonable vegetation cover and root systems. However, the implementation of management practices can lead to decreased landslide activity. Sustainable woodland management requires that a range of key ecosystem services, including soil protection, are maintained over time and are resilient to the changing climate. Logging activity is also implicated in increasing the density, frequency and magnitude of landslides. Trees being uprooted during storms lead to increased erosion, as well as the transport of woody debris downslope, blocking culverts and drains during storm events. There are therefore benefits of using relatively slow growing trees or shrubs that have low wind-throw risk on vulnerable slopes, whilst pure stands of fast growing, tall conifers are considerably more vulnerable to uprooting in storms. Forest fires denude slopes of vegetation leading to soil erosion and increased risk (Annex-3/ERAMMP Report-35: *Future-proofing our Woodland*).

Interactions between engineering, infrastructure placement and landslides within forests need to be considered. Many landslides are caused at interactions between engineering activities, largely roads. They classified landslides as being initiated up or down slope of a road with poor road drainage often being cited as a prime influence. In the creation of a new national forest, consideration would have to be given to geology, slope, regional annual precipitation, intensity of precipitation and likely type of landslide e.g. shallow or seated; and unstable ground must be avoided.

Selecting the right species to reduce landslide risk and that are also resilient to climate change in Wales will be essential. The most benefit is expected from a mixture of low growing woody species such as native mixed woodland, that don't grow tall enough to be vulnerable to wind damage, maintained as continuous cover, which provide a matrix of different root forms and depths. BGS have developed a National Landslides Database that records past, present and future landslides across Wales. This is added to via consultancy activity and the general public and will provide a valuable source of future evidence.

2.7.8. Agroforestry/Protective farm woodlands and shelterbelts

Protective farm woodlands and shelterbelts can be considered as types of woodland management in agricultural settings under the 'banner' of agroforestry. The two main agroforestry systems are *Silvo-pastoral,* where trees and/or shrubs are grown in grazed pasture in varied planting patterns, and *Silvo-arable* in which crops are grown between rows of trees at a spacing appropriate for the use of agricultural machinery.

There are many options for combining woody plants and crops/animals in different spatial arrangements. The most relevant options are *windbreaks* and *riparian buffer strips* which are both types of shelterbelts and *rows* of trees or shrubs which can be applied to both silvo-arable and silvo-pastoral systems; *single trees* or *tree cluster* arrangements under silvo-pastoral systems.

The inclusion of trees, woods and shelterbelts on-farm has a number of benefits including improved soil condition, soil conservation, reduced run-off, improved flood resilience (especially with riparian planting), livestock shelter; reduced ammonia and nitrogen emissions from housed and free-range animal production facilities, and habitat for wildlife. They can also contribute to the capture of particulates across the landscape benefitting human health, for which practical tools are now available for decision making.

The type of trees planted and their density and arrangement will depend on farmer's choice, farm location, soils and farmer objectives. For example, effective shelter provision has been shown to reduce lamb mortality rate by up to 50% in inclement weather and offers potential to improve livestock welfare in both summer and winter conditions. Future opportunities could include the use of tree fodder as an alternative source of nutrition and feed resource to fill the 'spring gap', and support adaptation to the impact of climate change on plant growth patterns. For example, willow and ash can have organic matter digestibility levels similar to hay and grass silage. All forms of agroforestry have potential to sequester carbon, although the benefits will vary depending on soil type, species, planting density and location (Annex-4/ERAMMP Report-36: *Climate Change Mitigation*). Evidence suggests that maximum benefits might be achieved on lowland areas, although potentially at a high agricultural opportunity cost.

The cost of establishment and subsequent management of silvo-pastoral agroforestry systems are generally higher than conventional woodlands and forests, which may impede agroforestry uptake. Whilst livestock & other herbivores must be excluded during establishment of any woodland, the unit costs are likely to be higher for small planted areas and particularly for individual trees that may require protection from livestock. In addition, the forest canopy requires active management to maintain the productivity of both the grass sward and the trees and to produce high quality timber. Such management requires a degree of arboricultural knowledge, which may not be readily available on the farm. Finally, the length of the proposed tree crop rotation may be longer than the longevity of the farm tenancies, which may pose additional logistical and ownership challenges.

A critical barrier to agroforestry adoption is the reticence for agricultural land managers to contemplate woodland as an active and contributory agent to farm development. The hills and uplands have often been a contested space and this sense of competition appears to remain a powerful discourse among many farmers, although formal evidence remains limited. For example, a study in Ireland found that decisions were often based on values and beliefs about the nature and purpose of farming, and that many agricultural land managers focus on the potential loss of productive land when areas are exclusively converted to woodland. This has led to reluctance to introduce a woodland element into agricultural land areas.

2.8. Annex-6/Report-38: Economics and Natural Capital Accounting

2.8.1. Economics

Published information on forestry sector profitability is available only for productive conifer plantations across the UK. Over the decade 2008-2017, returns to investors ranged from 7% and 33%, with the 3-year average always above 11%. Average returns for broadleaved woodlands and small forests may well be far lower, and there is ‘limited evidence’ on overall profitability. Hardwood production in Wales was on average less than 2% of total wood production. 57% of Welsh-grown roundwood was processed in Wales with the remainder processed in England. In addition, a large volume of wood is imported annually for processing in Wales. Accurate figures on volume are not available, but it is estimated around 90% of the hardwood and 65% of the softwood raw material flowing into the Welsh industry is imported. The Woodlands for Wales Strategy supports the increase of Welsh-grown wood processed in Wales and the development of local supply chains to increase the value of the forestry sector in Wales. Annex-6/ERAMMP Report-38: *Economics and Natural Capital Accounting* summarises information for the impact of forest type and management on provision of timber and non-timber products.

Welsh wood and wood products are in high demand, which is likely to increase in future due to the growing use of timber in construction, demand for domestic wood fuel, and increased interest in locally and nationally sourced material, including higher value markets, such as construction, engineered wood products (EWP), veneers, furniture and hand-crafted wood products. Opportunities exist for increasing access to small lots for standing sales to support local businesses, which can also make use of a wider variety of species and support the increase of diversity at re-stocking. Non-timber products such as fruits, nuts, mushrooms, and their derived products, such as alcoholic beverages, can provide additional income and supplement the diet of landowners, recreation users, animals and birds.

The industrial woodfuel market has grown 16-fold in under a decade, which has in some cases disrupted traditional timber processing industries by consuming high-quality virgin timber. This also has negative impacts on carbon accounting (See Annex-4/ERAMMP Report-36: *Climate Change Mitigation*). A high proportion of industrial wood fuel consumed in the UK is imported. Limited evidence is available for domestic woodfuel markets but they are known to have rapidly increased over the last 10-20 years and represented 57% of total renewable heat and 11.5% of all renewable energy fuel use in 2014. Woodfuel is burnt in approximately 16% of households. Firewood markets can be a driver for small woodland planting and the retention and management of undermanaged woodlands and hedgerows. This active management would provide significant opportunities to create local supply chains, bring revenue to Wales and supporting an increase in biodiversity if delivered sustainably. More work is needed to examine incentives for small scale plantings and management across the landscape for woodfuel.

Some potential concerns of increasing market products and wood fuel include the need to minimise timber transport distance and associated emissions, transport costs, and potential impact on tourism and recreation. Sustainability issues with respect to woodland size are also important (Annex-2/ERAMMP Report-34: *Managing Undermanaged Woodland*) as is the concept of future resilience (Annex-3/ERAMMP Report-35: *Future-proofing our Woodland*) and concerns about emissions of particulates from wood burning Section 3.5.1. The challenges of market demand driving production for the forestry sector are complex due to the long time periods involved, which creates additional uncertainty and undermines change for forest managers. Further social research into the barriers against management and species diversification, and potential solutions, is required.

2.8.2. Natural Capital Accounting

Forests provide a multitude of 'non-market' ecosystem services which are beneficial to humans. Natural capital accounting (NCA) methodologies attempt to value these services Annex-6/ERAMMP Report-38: *Economics and Natural Capital Accounting* values the forest ecosystem service values, which include timber production, carbon storage, air filtration, flood mitigation and recreation, with well accepted evidence. For other ecosystem services, NCA methodologies are still at the early stage (e.g. noise and temperature regulation) with only limited evidence in these cases, and there are other important benefits for which NCA approaches have yet to be developed (e.g. mental health). The validity of attempting valuation of biodiversity is challenged by many and is not discussed in the review. A few aspects remain controversial, such as Department for Business, Energy & Industrial Strategy (BEIS) carbon values in considering tree health risks and interpreting changes in natural capital values. For example, a decline in the service of air pollution removal in Wales in the last decade is due to an improvement in air quality, not a change in the amount of woodland. It should also be noted that Welsh Government Policy is for a Natural Resources rather than a Natural Capital approach and this review is intended as just one source of additional information which may be considered[2].

An important finding from Natural Capital Accounting exercises is that non-market values of many forest ecosystem services are significantly larger (by a magnitude) than that for marketable goods like timber. For example, per hectare values cited in Report 38 are higher for carbon sequestration, recreation, air pollution absorption and (in most cases of flood risk catchments) for flood risk attenuation. In the most recent assessment in 2019 for the Welsh forest estate as a whole for the year 2014 the service of most value at £123m was for recreation, followed by £113m for carbon sequestration, £44m for pollution removal and £30m for timber provision (total annual value of £310m for the services which were valued). (Note: These values are always a partial account due to lack of methods for many services including biodiversity.) It should also be noted that ongoing refinement of methods can impact on the value of the Wales Woodland Natural Capital Account. For example in 2017, the woodland estate in Wales for the year 2015 was valued at £606m with the service of greatest value for air quality whilst in 2019, for the year 2014 the value was put at £310m with carbon sequestration and recreation as the most valued services. This was primarily due to a major revision of the approach relating to the valuation of air quality, as described above. The overall message of non-market goods being larger than marketable goods however did not change.

Natural capital accounting methods and values can contribute to payments for ecosystem services (PAYES) and payments for public goods (PPG) and support delivery of policy targets.

2.9. Annex-7/Report-39: Integrated Assessment

The Integrated Assessment (Annex-7/ERAMMP Report-39: *Integrated Assessment*) highlights the importance of many cross-cutting themes which impacted on the delivery of many benefits from woodlands, and the need for site specific issues to be considered if trade-offs are not to occur without intention. Key issues identified by experts as they carried out their reviews included:

- Trade-offs – displacement of non-woodland biodiversity; value judgements relating to the value of different species assemblages; connectivity providing potential increased resilience but also potential risk to invasive species, pests and disease; woodland providing habitat for predatory species for adjacent habitats; the production of particulates from woodfuel; VOC and pollen emissions from trees.
- Timelags and a changing baseline – no change is not an option as we are in a fast moving world. Assessments of woodland value need to be clear as to what is the counterfactual (is the benefit specific to woodland or likely to be realized from nature / green space more generally? Are the potential timelags in benefits being realized clearly presented.

[2] The Natural Capital approach includes economic with environmental priorities to support decision making. The Natural Resource approach does not include the economic aspect and focuses more on sustainable management of natural resources.

- Spatial and other contextual issues – many benefits are linked to proximity; biodiversity benefits to woodlands being adjacent to existing mature woodlands; air quality benefits from appropriate positioning upwind of population centre; and processing and production plants being accessible to woodland prioritised for production. This also is true for potential risks e.g. to infrastructure from fire, windthrow and landslides. Woodland size also impacted on many of the benefits discussed, from biodiversity to timber production.
- Barriers to uptake (including skills, economic, and other) – disruptive approaches were highlighted as essential if real change was to occur. Managing expection and resources required was essential. Working with communities was also critical if actions were not to be seen as imposed for the economic gain of others.
- Resilience to climate change – risks and benefits were all potentially subject to change.

A summary table was constructed to provide a visual overview of these issues to match a similar approach undertaken for the ERAMMP Evidence Pack for the Sustainable Farm Scheme (ERAMMP Report-10a: *SFS Evidence Review - Integrated Analysis*)[3]. A total of 14 woodland creation and management opportunities were considered for 7 categories of benefits (split into 11 subcategories). A colour code is used for each opportunity and benefit assessment:

- Blue: woodland creation and management opportunities considered are most likely to realise benefits
- Amber: benefits may be realized but evidence may be limited and/or there is a dependency which needs to be considered
- Pink: either expert judgement or evidence indicates little benefit is likely and/or there is an important potential trade-off to consider

The findings indicate in summary no woodland creation or management opportunity was without some benefits. There is always some benefit to either woodland specialist species, timber production or other outcome. However, only 3 opportunities had no 'Pink' assessments indicating there may be important potential trade-offs for most opportunities which need to be considered before action is taken. Overall, of the 14 opportunities and 11 benefits considered; 32 outcomes were 'Blue'; 86 were 'Amber' and 13 were 'Pink'. The dominance of 'Amber' assessments highlights the critical issue of context dependency for many opportunities which need to be considered before action is taken. The challenge is therefore to provide a framework where decision-making can be supported within a local, regional and national context ensuring there is sufficient cost-benefit outcome to justify action; there is due consideration of any trade-offs in the short and long term, across different spatial scales and for different sectors of the community.

[3] https://erammp.wales/en/r-sfs-evidence-pack

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