

Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP)

National Forest in Wales Evidence Review Annex-5

ERAMMP Report-37 Annex-5: Ecosystem Services

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Abbreviations Used in this Annex

ABM	Agent Based Model
AQEG	Air Quality Expert Group
BAME	Black, Asian, and minority ethnic
BGS	British Geological Survey
BVOCs	Biogenic volatile organic compounds
CFD	Computational Fluid Dynamics
CICES	Common International Classification of Ecosystem Services
DOC	Dissolved Organic Carbon
eftec	Economics for the Environment Consultancy
ERAMMP	Environment and Rural Affairs Monitoring & Modelling Programme
ES	Ecosystem Service
GIS	Geographic Information Systems
GMEP	Glastir Monitoring and Evaluation Programme
IBM	Individual Based Model
IPCC	Intergovernmental Panel on Climate Change
LAI	Leaf Area Index
NCA	Natural Capital Accounts
NERC	Natural Environment Research Council
NFM	Natural Flood Management
NLM	Neutral Landscape Model
NRW	Natural Resources Wales
ONS	Office for National Statistics
OPM	Oak processionary moth
ORVal	Outdoor Recreation Valuation [modelling tool]
PFE	Public forest estate
PGE	Parasitic gastroenteritis
PM	Particulate matter
UKCEH	UK Centre for Ecology & Hydrology
UKFS	UK Forestry Standard
UKWAS	UK Woodland Assurance Standard
WHO	World Health Organization
WIAT	Woodlands In and Around Towns
WWNP	Working with Natural Processes

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)

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1. INTRODUCTION TO ANNEX-5

Ecosystem services can be defined as the benefits which flow from healthy ecosystems to society. The concept helps describe these benefits in a way that can influence policy and decision making. 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 (Sing, Ray, & Watts 2015).

A number of ecosystem service classification systems have been developed since the initial Millennium Ecosystem Assessment (2005). Although detail and subcategories vary between systems, broad categories of regulating and maintenance (e.g. of climate, water), provisioning (e.g. food, water, fibre, fuel), and cultural (e.g. spiritual, aesthetic, recreation, education) ecosystem services remain constant. The Common International Classification of Ecosystem Services (CICES) is widely and commonly used.

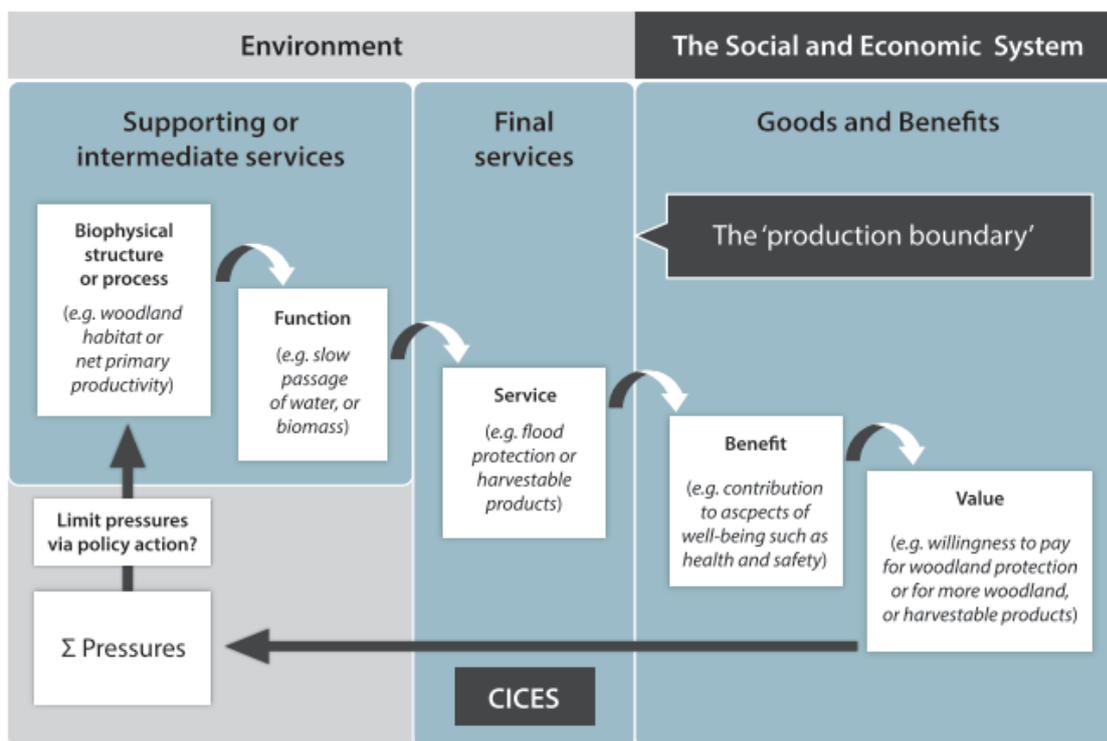


Figure 1-1 The cascade model. Credit Haines-Young & Potschin in Burkhard & Maes (2017).

Figure 1-1 illustrates the Cascade Model, representing a ‘pathway’ from ecological structures and processes at one end through to the well-being of people at the other (Burkhard & Maes 2017). This flow represents a ‘socio-ecological system’ and exploring how these socio-ecological systems work and how we can act to sustain them are core aims in the field of ecosystem services. As well as understanding ecology, aspects such as social practices, governance, technology, and the values people hold are of central importance.

The Ecosystem Approach, coined by the Convention on Biological Diversity as “a strategy for the integrated management of land, water, and living resources that promotes conservation and sustainable use in an equitable way” recognised that “humans, with their cultural diversity, are an integral component of ecosystems”

(Convention on Biological Diversity 2000). ‘Landscape Approaches’ aim to include people in ecological restoration and encourage true participation in environmental decisions (Sayer et al. 2013). The Welsh government integrates these concepts into its policies for Sustainable Management of Natural Resources, focusing on principles including evidence, collaboration and engagement, public participation, and building resilience. Landscape approaches are at their heart a negotiation process between different values and objectives. Integrated landscape thinking which aims to reduce conflicts necessitates understanding the synergies and trade-offs between different ecosystem services.

This annex considers some key ecosystem services associated with woodlands, including urban forestry in section 5. Many of the services provided by urban forests are considered in more detail elsewhere within this and other Annexes. Carbon sequestration and climate change mitigation potential of woodlands can be considered as regulating and maintenance ecosystem services and these are considered in Annex-3/ERAMMP Report-35: *Future-proofing our Woodland*. Biodiversity evidence is detailed in Annex-1/ERAMMP Report-33: *Biodiversity*. Table 1-1 outlines ecosystem services from trees, woodlands and forests in the UK, and highlights if and where each category is considered within this report.

Table 1-1 Ecosystem services discussed in this Annex

Ecosystem service	Description	Included in report?
Regulating and maintenance services		
Climate regulation	Carbon capture and storage (sequestration); protection from or moderation of the effects of extreme temperature, wind, ultra-violet light and precipitation, such as shelter for people or livestock, protection for fish through regulating water temperatures in streams.	Annex-4/ Report-36
Hazard regulation	Protection from or moderation of the effects of extreme temperature, wind, ultra-violet light and precipitation, such as shelter for people or livestock, protection for fish through regulating water temperatures in streams. Protection from soil erosion and slope failure (depending on forest management practices, see later section); rainfall interception moderates flooding by delaying and attenuating peak river flows.	This Annex
Detoxification and purification of soils, air and water	Trees are able to capture and absorb (scavenge) pollution, including diffuse pollution, from soils, water and the atmosphere, improving the quality of each. However, those pollutants may then be transferred into the water supply. Trees, woodlands and forests can therefore have both positive purifying and negative impacts on water quality that are species, site and management dependent. Belts of trees can act as noise buffers to reduce noise pollution (noise abatement), providing health benefits	This Annex
Disease and pest regulation	Woodlands with high biodiversity tend to exhibit increased age and tree species structure. These structural components have been shown to reduce the damaging effect of some pests and pathogens in woodlands. A meta-analysis comparison of single species and mixed forests (comprised of taxonomically more distant species) showed a significant reduction in plant material loss (herbivory) from mixed woodland compared to single species woodlands (Jactel and Brockerhoff 2007). It is thought that the reduction of host trees and niches in mixed woodlands causes the effect. In mixed woodlands, the risk of damage to any specific tree species is spread across more pathogens, and the potential for damage to the stand is reduced	Annex-3/ Report-35
Pollination	Trees, woodlands and forests provide habitat for pollinator species	Annex-1/ Report-33
Primary production	The fixation of carbon dioxide by photosynthesis produces organic matter, resulting in plant growth and oxygen production	

Soil formation	The breakdown of the underlying geology by roots and microbial fauna (mineral weathering) and the accumulation of organic matter from leaf litter within the soil layer	
Nutrient cycling	As with other forms of vegetation, trees, woodlands and forests enhance the cycling of nutrients between the leaf litter and the soil, as well as the interception of atmospheric compounds by the canopy, which provides essential nutrients to the soil, such as nitrogen required for primary production	
Water cycling	In addition to the provisioning service that forests provide society through the capture and supply of water, they have an important role in the wider hydrological cycle through moisture interception and transpiration.	
Biodiversity	Biodiversity and the associated genetic variation within locally adapted species and provenances can support flora and fauna that contributes to woodland dynamics, including providing habitats for pollinators and below-ground flora and fauna that maintain the decomposition processes underpinning soil formation and nutrient cycling.	Annex-1/ Report-33
Cultural services		
Health	The health benefits identified are: physical well-being, involving some form of physical activity, action or movement; mental restoration from spending time in woodlands; escape and freedom, allowing people to gain physical and mental distance from sources of anxiety or everyday life; and enjoyment and fun from recreational and leisure activities undertaken in woodlands and forests.	This Annex
Nature/landscape connections	These are the benefits people describe from sensory stimulation and feelings of connection to both the landscape and wildlife, including biodiversity and the well-being benefits from gathering NTFPs.	This Annex
Education and learning	The types of benefit range from formal learning through Forest Schools to personal development gained through volunteering and apprenticeships. Studies show the long-term educational importance of connecting children and young people with nature.	This Annex & Annex-6 Report-38
Economy	Woodlands and forests can contribute to local livelihoods through generating employment, both directly through timber production, forest-based recreation and other enterprises including NTFP gathering, and indirectly to local economies, for example businesses supporting the associated tourist industry.	This Annex & Annex-6 Report-38
Social development and connections	Activities undertaken within forests can strengthen existing social relationships, while organised activities within forest environments can create the opportunity for new relationships, including people's involvement with volunteer groups and community forests (social capital).	This Annex
Symbolic, cultural and spiritual significance	This includes use and non-use values, through cultural or historical associations, such as connections to historical or folk figures like Robin Hood and associations of evergreen foliage with Christmas	
Provisioning services		
Fibre and fuel products	Timber for construction, veneers and flooring; wood chip for board, pulp for paper; timber products for woodfuel, including stumps and roots, and harvesting residue.	Annex-6 Report-38
Non-timber forest products	Products such as food products derived from plants (tree fruit, berries, foliage, syrup and nuts as well as edible products from plants other than trees – like fungi), wild deer or livestock raised in woodland or forest settings in agro-forestry systems; beverages; craft, ornamental and gardening materials such as bark chips for play areas, poles, stakes and fencing; toys, medicinal products and chemicals derived from gums, resins, waxes, oils and fatty acids.	Annex-6 Report-38
Water supply	The provision of water through the interception of rain, mist and fog, which is then transferred to the soil and into a watercourse and groundwater. Woody debris creates dams in watercourses that increases storage and slows the water flow (contributing to flood hazard reduction, a regulating service).	This Annex
Genetic resources	Seed orchards of locally adapted provenances provide genetic resources for British growing conditions.	
Biodiversity	Forests that are managed to deliver particular types of diversity and species assemblages, for example through Biodiversity Action Plans and agri-environment schemes, providing habitats for rare, protected and priority species including red squirrels and rare butterfly or bird species	Annex-1/ Report-33

2. AIR QUALITY

2.1 Introduction

Air pollution is a major cause of death and contributes to the burden of non-communicable diseases globally (Lim et al. 2012). Air pollution in Wales is still at levels which have clear human health impacts, and which exceed WHO guidelines, i.e. PM_{2.5} concentrations < 10 µg m⁻³ and NO₂ < 40 µg m⁻³ as an annual mean.

The principal air pollutants with impacts on human health are particulate matter, ammonia, ozone, and oxides of nitrogen and sulphur (WHO 2006, 2013). Particulate matter (PM) includes particles of different size fractions, from a range of primary and secondary sources. The greatest health impacts of particulate matter come from fine particles with a diameter less than 2.5 microns (PM_{2.5}), since these are small enough to travel deep into the lungs. Ammonia is primarily generated in rural areas from agriculture sources, however it is transported to urban areas through atmospheric transport. In its aerosol form it can be a substantial component of secondary PM_{2.5}. Ozone (O₃) is a secondary pollutant formed by photochemical reactions with other pollutants. It is a powerful oxidant, causing damage to lung tissue and causes premature deaths. Nitrogen oxides (NO and NO₂) come primarily from combustion sources like power stations and vehicle exhausts and cause increased likelihood of respiratory problems. Sulphur dioxide (SO₂) is an irritant to mucous membranes and can exacerbate health conditions like asthma.

The main health impacts are respiratory illness, cardio-vascular complications, a loss of life expectancy and premature deaths. Air pollution is rarely the sole cause of death but exacerbates existing health conditions, with considerable cost to society (Cohen et al. 2005).

Vegetation in the UK has the potential to remove air pollution, and woodland is particularly efficient at removing particulate matter (PM). The extent to which woodland can provide this ecosystem service, and the factors which have an influence on the amount of service delivered are of particular interest to many policy makers. This is especially relevant in the context of decision making on where to plant woodland, and which species to plant.

Paradoxically, the burning of wood as fuel is a source of air pollution with particular concern for the contribution of domestic wood stoves to PM_{2.5} emissions (Air Quality Policy Team commission modelling in Clean Air Plan consultation document 2019). The Welsh Government policy proposals to limit PM_{2.5} emission include regulation of stoves, sales of wet firewood and bans on use of wood stoves in clean air zones. Production of fuelwood is a significant incentive for mobilisation of wood from unmanaged woodlands and for planting of small private woodlands (Wong et al. 2015). Many people who adopt wood burning do so because it is cheaper than alternatives, can be sourced locally, is considered a green / renewable source of heat, is aesthetically pleasing or they have few alternatives being off the gas grid (Wong & Walmsley 2013, POF 2019). Mixed policy messages which both promote and discourage wood burning is counterproductive and more evidence is needed of

the risks and benefits of wood burning and its links to public health and woodland management in rural Wales.

The following sections cover: mechanisms of pollution removal, factors which govern pollution removal, and discussion of associated myths around this service.

2.2 Mechanisms of pollution removal

Plants remove air pollutants from the atmosphere through two principal mechanisms (Nowak et al. 2006). There is direct deposition of particulate and gaseous pollutants onto leaf and stem surfaces. The second mechanism involves uptake of particles and gases through the stomata, which are the leaf openings that the plant uses for photosynthesis and respiration. In combination, these processes are termed dry deposition, which is distinct from wet deposition where particles and gases are washed out of the air during rainfall. Trees are roughly five times as efficient at removing fine particulate matter (PM_{2.5}) than other vegetation types such as crops, heathland or grassland (Jones et al. 2017). This efficiency is higher than for other pollutants like NH₃, O₃ and SO₂ where trees are only around twice as efficient as other vegetation types. The difference is due to their higher leaf area index (LAI) per unit area of ground surface, since direct deposition to leaf surfaces is greater for PM than it is for gaseous pollutants where stomatal uptake plays a greater role.

2.3 Factors governing efficiency of pollution removal by woodland

A number of factors moderate the rate of pollution removal. The influence of these factors varies over time, but broadly include:

- Tree species
- Pollutant concentration
- Interactions with other pollutants
- Woodland cover within a landscape setting
- Disbenefits related to air quality (BVOCs, pollen, street canyons)

Tree species alter the efficiency of pollution removal. At a general level, conifers are more efficient at removing pollution than deciduous trees as an annual average. This is partly because the surface area to volume ratio of needle-shaped leaves means they have a higher leaf area index than deciduous trees. The other main reason is that they hold leaf cover all year round, and so the leaf surfaces act as a deposition surface throughout the winter as well as the summer, in contrast to deciduous species. Within these broad classes, some tree species are more efficient at removing pollutants than others. In some cases this is because some species are taller or have larger tree canopies, for example oak compared with birch. Other factors such as leaf morphology play a role which governs leaf area index, and the nature of the leaf surface, with hairy leaves trapping more pollution than smooth leaves.

Pollution concentrations play a role. The realised deposition velocity increases with the concentration of pollution, because this governs the boundary resistance for pollutant uptake or deposition. In the UK Natural Capital Accounts (Jones et al.

2017), the quantity and therefore health benefit of the amount of pollution removed by vegetation decreases with time from 2007 through to 2015. This is primarily because the background pollutant concentrations have decreased over this period, while woodland cover has remained broadly the same.

Interactions with other pollutants also govern the rate at which pollutants deposit to surfaces. For example, deposition of ammonia is strongly dependent on concentrations of sulphur in the atmosphere. In regions of Wales with higher sulphur concentrations due to the presence of heavy industry, the rate of deposition of ammonia to plant surfaces is lower due to formation of ammonium sulphate aerosol.

Woodland cover within a landscape setting - The quantity of pollution removed by woodland clearly depends on the amount of woodland in the landscape, but a number of other factors are briefly discussed. 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 processes operating here are reviewed in AQEG (2018), but are broadly summarised as larger patches of woodland tend to divert airflow around them and the influence of individual trees within such woodland is less than for smaller groups of trees or single trees. However, the uncertainties in any calculation of this effect can probably only be captured for individual locations at fine scale using computational fluid dynamics (CFD) modelling approaches. At much larger scales, for example at country scale, there is a question about whether increasing tree cover in the landscape leads to a non-linear relationship for the amount of pollution removed. Modelling studies conducted by UKCEH (unpublished) suggest that even if the entire UK was covered in trees, the rate of removal is broadly linear.

Disbenefits:

Potential unintended consequences of forests, especially in the urban environment need to be considered; for instance due to increased release of pollen affecting individuals with allergies, the release of increased amounts of biogenic volatile organic compounds (BVOCs) (Owen et al. 2003), which play an important role in the formation of photochemical smog, leading to the formation of ground-level ozone (O₃; both an air pollutant and greenhouse gas) and other secondary pollutants (Fuentes et al. 2000) such as organic aerosol (Liu et al. 2019; Szogs et al. 2017). Species with high isoprene emission rates include oak, white willow, aspen, sessile oak, red oak and goat willow, while those with lower isoprene emissions include Austrian pine, larch, silver birch and maple (Donovan et al. 2005; Nowak 2002).

Trees may also introduce or enhance the potential for hosting disease vectors and affecting other ecosystem services (Coutts et al. 2015). Caterpillars of the Oak processionary moth (OPM), a Notifiable species, can have impacts on human health as their hairs cause rashes, sore throats and breathing difficulties and can be carried by the wind. The OPM is currently confined to greater London and seems to have arisen on imported trees.

The assessment of both co-benefits and unintended consequences is highly sensitive to the scale of the planned intervention. 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 (Reis & Eichhorn 2001). This requires microscale simulations and considerations of spatial design and placing of trees within an urban context. Larger-scale woodlands in peri-urban areas may affect clean, cool air flows into the urban centre and affect planning of new housing or transport infrastructure developments.

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. This is compounded by some planting guidelines for urban trees which recommend planting male rather than female trees to avoid excessive drop of fruit and seeds in urban areas.

In terms of the timescales, under climate change conditions, existing tree species may release more or different BVOCs due to water stress and increased temperatures, whereas alternative, more resilient and better adapted non-domestic species (Bush et al. 2018) may add more and different pollen loads contributing to allergic reactions currently not observed, and difficult to predict. Systematic reviews of the specific benefits, dis-benefits and their relationships, such as those conducted by Roy et al. (2012) are essential tools to avoid overall net-negative impacts of increasing urban and peri-urban tree cover.

2.4 Factors governing the health benefit for the receiving population

A number of factors govern the health benefit experienced by the population. Health benefits come about through a decrease in exposure, i.e. the concentrations of air pollutants that people are exposed to on a daily basis are lower. The majority of studies valuing air pollution removal follow Treasury Green Book guidance which uses damage costs based on the quantity of pollution emitted (£ per tonne pollutant emitted). Calculation of the benefit to receiving population using this approach is able to adjust for population density by applying three broad classes with different damage costs for urban, semi-urban and rural settings. This approach is designed for policy appraisal where it is not appropriate or necessary to run bespoke model assessments of impact. More complex assessments are able to model the changes in pollutant concentrations likely to result from policy implementation, and directly calculate changes in exposure and therefore health outcomes of the benefitting population. This more complex approach was taken to develop the UK Natural Capital Accounts for air pollution removal (Jones et al. 2017) and has been used in subsequent reporting by the Office for National Statistics (ONS) at UK level (ONS 2020), a UK urban assessment (Jones et al. 2017; Jones et al. 2019), for the Wales Natural Capital Accounts reporting (Engledew et al. 2019), and are reported in Annex-6/ERAMMP Report-38: *Economics and Natural Capital Accounting*. In this case, the policy intervention is enhanced woodland planting at national scale which increases the amount of pollution removed from the air, and a subsequent lowering of the pollutant concentrations to which the population of Wales are exposed. The

estimates of health benefit in the more complex approach used by Jones et al. (2017) for ONS calculated a population-weighted change in exposure to determine changes in Life Years Lost, respiratory hospital admissions, cardiovascular hospital admissions and mortality.

2.5 The importance of woodland location

The location of woodland is important because it integrates all the context-specific factors discussed above. Two aspects of location are worth discussing in more detail: that 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, and that the location and direction of major pollution sources also need to be considered, rather than assuming that the prevailing wind direction is the most relevant variable.

The analysis of Jones et al. (2017) shows the importance of woodland in the wider landscape. The annual health benefits from all UK vegetation amount to £1 billion per year for 2015 pollution levels, while the annual health benefits provided by urban vegetation alone amount to around £200,000. The urban extent used in that analysis covers most of the UK built up areas including small towns and villages, and therefore incorporated a substantial proportion of the UK population. This suggests that much of the health benefit in the UK is actually provided by vegetation outside of urban areas. The likely distance over which benefit is received has not been calculated and would require further analysis. The current assumption underlying the economic health assessment is that the majority of health benefit at local authority level can be attributed to pollution removal by the woodland within that local authority. However, while this assumption is likely to be broadly correct, it has not been rigorously tested and the precise distances over which a woodland is likely to have an influence on pollution concentrations is not known. This is a complex problem as a cumulative change in pollution concentration will build up over the trajectory of an air mass which can be difficult to attribute to individual patches of woodland.

Taking into account the location of pollution sources and wind direction is crucial to understanding the benefit provided by woodland. Model simulations conducted by UKCEH using artificial patches of woodland of different size within Wales show that simple assumptions about prevailing wind direction do not adequately predict the area of maximum benefit (Figure 2-1). The simulations were run with real meteorology on an hourly timestep for 2015 in a landscape with simulated woodland patches. The plumes of 'benefit' extend primarily to the north and west of the patches of woodland and show that in total across a full yearly period, the greatest benefit comes during the relatively short durations when winds come from the south east and have travelled over large pollution sources, rather than when winds are from the prevailing south westerly wind direction. The full analysis should also take into account the location of the benefitting population, which adds a further contextual factor to the full calculation of health benefit.

Therefore, in order to assess which woodland planting locations will provide the maximum benefit to the people of Wales, modelling studies should be conducted which take into account all the spatial factors described above.

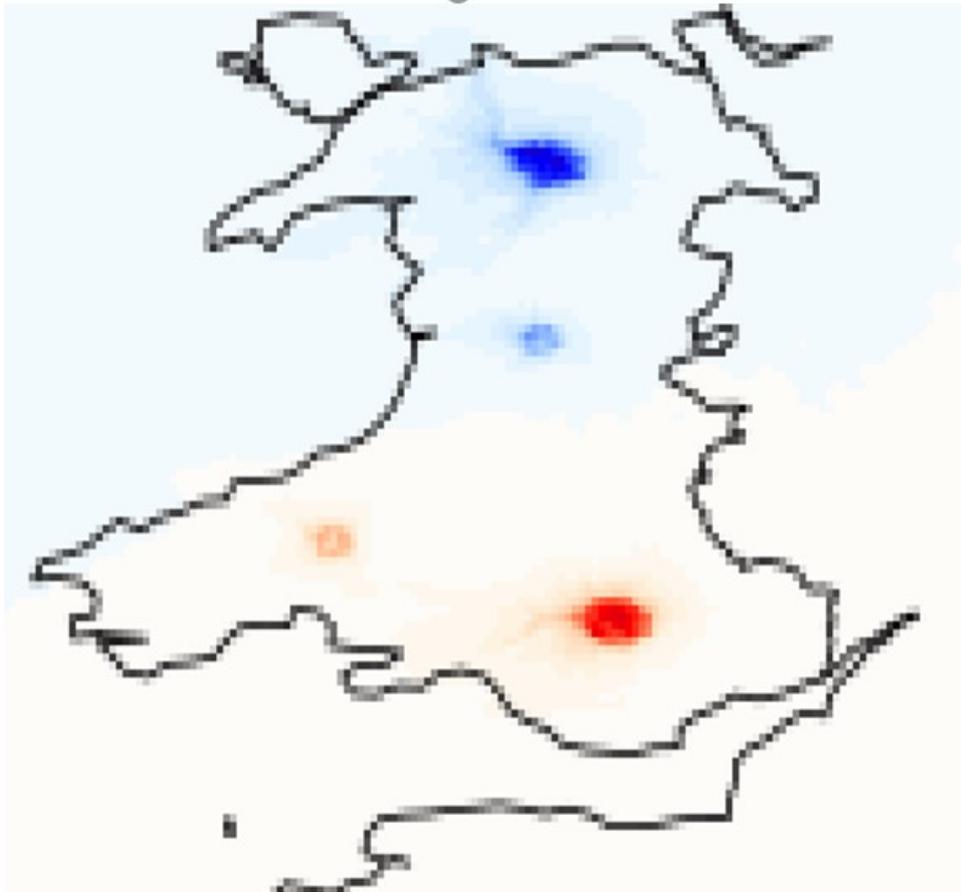


Figure 2-1 Simulations showing areas benefitting from reduced PM2.5 concentrations due to pollution removal by model-generated patches of woodland in Wales. Colours represent different scenario settings and are not important.

3. CULTURAL ECOSYSTEM SERVICES AND BENEFITS

3.1 Introduction

Cultural ecosystem services are one of three ecosystem service categories as described in 1.1. They are the non-material benefits that people obtain from nature, and include physical and mental health, recreation, 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 forest specific. In this review we consider the evidence for how cultural ecosystem service benefits are realised from peoples' engagement with trees, woodlands and forests in Wales.

3.2 Cultural Ecosystem Services

Cultural ecosystem services are informed by the interaction between the practices and activities which deliver cultural benefit (e.g. exercising, playing, relaxing) the place/location these activities take place in (e.g. parks, fields, woodlands), and the management and governance of that location (e.g. conservation, production, recreation; community or institute led). Each element influences cultural ecosystem service delivery, as demonstrated in the conceptual framework in Figure 3-1. This framework is adapted from the UK National Ecosystem Assessment Follow-On Project on cultural ecosystem services (Church et al. 2014; Fish et al. 2016), including the addition of Management and Planning approach. Research by O'Brien and Morris (2013) from 31 forest focused studies identified the key cultural ecosystem well-being benefits listed in Figure 3-1 (the gold coloured box at the bottom of Figure 3-1).

In this Annex we first consider the evidence for the delivery of these cultural ecosystem services benefits from forests and woodlands in this section (3.2), before exploring each of the framework components that influence the delivery of cultural ecosystem service benefits – management, place and activities in section 3.3. The intention is to provide consistency with other sections and enhance accessibility for policy decision making. An alternative approach proposed by authors is to present the information in the context of Place, Management and Activities, and this approach could be developed in a future iteration by WG.

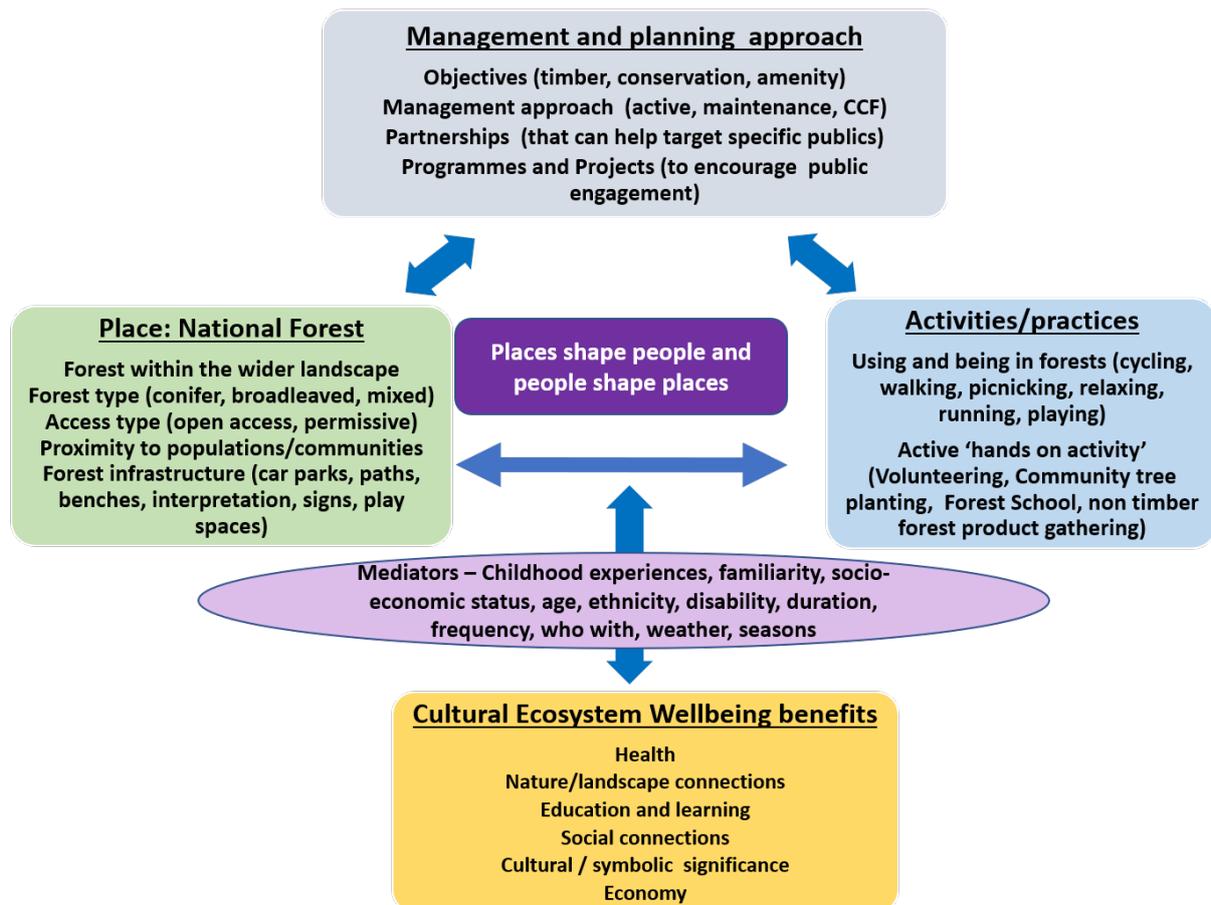


Figure 3-1 Conceptual framework concerning how 'management and planning' can influence the cultural ecosystem services of 'place' and 'practices' which in turn can contribute to cultural ecosystem wellbeing benefits. The light purple oval represents the socio-economic and experiential mediators which can impact on an individual's ability to benefit from ecosystem service delivery (adapted from Fish et al. 2016).

Cultural benefits include:

- Recreation: overlaps with physical and mental health and is the basis for many other benefits.
- Health: physical and mental health benefits from activity and time in nature; enjoyment of recreational activities; physical and mental distance from daily life.
- Nature/landscape connections: sensory stimulation from and connection to nature and landscapes; well-being benefits from gathering non-timber forest products
- Education and learning: from formal Forest Schools to personal development through volunteering.
- Economy: social benefits from the contribution to local livelihoods and economies. See Annex 6/Report 38: *Economics and Natural Capital Accounting*.
- Social development and connections: strengthening existing and establishing new social relationships through leisure or organised activities (social capital).
- Symbolic, cultural and spiritual significance: connections to historical or folk figures, associations of evergreen foliage with Christmas.

The classification of recreation as an ecosystem service or as the route to delivering ecosystem benefits is subject to different opinions, as nature provides opportunities for recreation, which in turn delivers many of the other listed benefits. In order to maintain consistency with key evidence and policy documentation a decision was made to consider recreation in its own section.

The following sections detail the evidence of how the different categories of cultural ecosystem benefit are realised from peoples' engagement with trees, woodlands and forests

3.2.1 Recreation

A wide range of recreational activities are undertaken in woodlands and forests in Wales. The most popular activities undertaken in woodlands in Wales are walking, dog-walking, picnicking, wildlife watching, sightseeing and visiting children's playground (Table 3-1). Whilst forests and woodlands can be enjoyed in the landscape (see Section 4 - Landscape Aesthetics), public access into the woodland is also essential for people to experience benefits from the cultural ecosystem services, visits to woodland or forest areas¹ and undertaking activity can be particularly important. Numerous data exist about visitation rates and activities to woodlands in Wales. Between 2000-2019, 62-79% of surveyed people visited forests and woodlands in Wales in the last year or few years (Table 3-2, Forest Research 2019).

<i>Table 3-1 Recreational activities undertaken in woodland in Wales in the last 12 months</i>	
Activity	Percentage of respondents who visited woodland in last 12 months and undertook activity (2019)
Walking	89%
Dog-walking	43%
Picnicking	32%
Wildlife watching	28%
Sightseeing / visitor attractions	27%
Children's playground	25%
Running	13%
Off-road cycling / mountain biking	12%
Other	25%

Source: Forest Research 2019

¹ Note however, that there are existence values which state that people can enjoy benefits from knowing that trees, woodlands and forests exist, without actually visiting those places. There are also benefits associated with virtual access to and from passing by trees and woods, for example on the way to work.

Table 3-2 Visits to forests and woodlands in Wales			
What was measured or asked	Data	Study date	Publication
Per cent of a surveyed sample in North Wales who had set out specially to visit a forest at least once during the year preceding an interview	70%	2000	Lee 2001
People surveyed in Wales who had visited woodland in the last few years or 12 months	62%	2003	Forest Research 2019
People surveyed in Wales who had visited woodland in the last few years or 12 months	79%	2007	Forest Research 2019
People surveyed in Wales who had visited woodland in the last few years or 12 months	72%	2014	Natural Resources Wales 2015
People in Wales who said that their most recent countryside visit was to a woodland or forest	15%	2016-17	Natural Resources Wales 2017
People surveyed in Wales who had visited woodland in the last few years or 12 months	77%	2019	Forest Research 2019

Grants for public access to private woodlands have the potential to support ecosystem service delivery by increasing the proportion of the population who have access to woods within walking, cycling or driving distance of their homes. 73% of respondents to the Public Opinion of Forestry in Wales stated they can reach a woodland without using a car or other transport (Forestry Commission 2019). Increasing woodland access would increase the percentage of the population with a small 2ha+ woodland within 500m of their home from 24% to 68% and with a large woodland of 20ha+ within 4km from 81% to 98% (Table 3-3, Woodland Trust 2017). Hence, it is not just important to create new woodlands or bring unmanaged woods into active management, but to seek to open up currently inaccessible woodlands in order to generate cultural ecosystem benefits for the population in Wales.

Table 3-3 Accessible and potentially accessible woods in Wales	
Accessible woods 2012	121,192ha
Accessible woods 2016	120,317ha
Population with access to a 2ha+ wood within 500m, 2016	23.6%
Population with access to a 20ha+ wood within 4km, 2016	80.6%
Additional population who would have access to a 2ha+ wood within 500m if existing woods were opened	44%
Additional population who would have access to a 20ha+ wood within 4km if existing woods were opened	17.5%

Source: Woodland Trust 2017

The ORVal tool (University of Exeter)² models patterns and value of recreational visits across England and Wales. It estimates that 158 million visits per year are made to the natural environment in Wales, and values the welfare from these (based on the Travel Cost Method) at £570m. ORVal estimates that over half of these visits 98 million (value: £321 million) are to sites or paths containing woodland habitat.

More cultural ecosystem benefits can be provided where facilities and forest destinations are diverse, and include, for example, a range of family-oriented leisure and educational opportunities, as well as areas for specific interests such as walking, mountain-biking, outdoor adventure, music festivals, crafts and performance arts (Carter et al. 2009). In addition, organised and supported activities can be important for those who face barriers to accessing woodlands (O'Brien et al. 2014). Other evidence suggests that wildlife watching is more important in woodlands than in other types of outdoor recreation destinations (Natural Resources Wales 2015).

Specific sites such as Coed y Brenin are valued for particular facilities, in this case, mountain biking. On-site facilities that might increase visits and hence cultural benefits also extend to retail and catering. This is illustrated with reference to Coed y Brenin where a 2014 study found that 57% of surveyed visitors used the café, restaurant or other catering, and 25% used the visitor centre or shop (Beaufort Research Ltd 2014). Whilst the benefits of forests with facilities may be higher, the proportion of forests with such facilities is fewer, therefore overall, forests without facilities but with access currently contribute more to recreation benefits overall.

While woodlands are a major recreational resource with considerable value, the key question for the business case for the national forest is the additional value that new woodland would provide. To illustrate this, data were taken from the ORVal tool, for theoretical new sites. The new sites were located near Swansea, one was on the edge of the City, the other 10 miles to the North. At each location two sites sizes were examined (10 ha and 100ha), and two potential habitat types (a woodland of 50% broadleaved and 50% conifer) and a mixed habitat (of 1/6th each of broadleaved/conifer, 1/3rd natural grassland and a 1/3rd moor/heath). The data from these sites is shown in Table 3-4. The number of 'new' visits is used, which is ORVal's estimate of the additional visits undertaken if the site was created. It does not include visits to these sites displace from other existing sites. The data should only be taken as a rough guide, as other local and cultural factors can determine recreational value. However, the data illustrate:

- Significantly higher values per ha for sites nearer the urban area.
- More values to larger sites, but diminishing marginal returns to scale, with larger sites have lower values per ha.
- More visitors, and slightly higher value per visit, to the site with mixed habitats. However, this result should be treated with caution as this location has significant existing accessible woodland areas – The Woodland Trust's (2017) data suggests that 84% of people in Abertawe have a 20ha accessible woodland within 4km of their house). This is likely to result in the additional value of new woodland being lower.

² Outdoor Recreation Valuation, Land, Environment, Economics and Policy (LEEP) Institute Business School, University of Exeter, <<https://www.leep.exeter.ac.uk/orval/>>.

Table 3-4 Benefits to the local community from woodlands (Wales).						
	Mixed habitats			Woodland		
Annual £ (2020)	Total value of new visits	Value per visit	New visit value/ ha	Total value of new visits	Value per visit	New visit value/ ha
Urban edge - 100 ha	249,198	3.50	2,492	158,816	2.93	1,588
Urban edge - 10 ha	126,839	3.77	12,684	46,421	2.68	4,642
10 miles - 100 ha	106,956	4.22	1,070	22,282	3.00	223
10 miles - 10 ha	59,815	4.42	5,982	9,349	3.42	935

Source: ORVal tool. Note that 84% of the population of Abertawe has 20ha+ of accessible woodland within 4km (Woodland Trust 2017)

3.2.2 Health

The physical and mental health benefits of engaging with trees and woodlands are now generally and widely acknowledged across studies and initiatives.

Physical Health

Programmes in woodland environments can lead people to take more regular exercise, improving physical health (Owen et al. 2008). Health-related activities are actively promoted and engaged (Morris 2006) with the impact of helping people to get healthier and in some cases lose weight (O'Brien 2019) by providing places for recreation (Forest Research 2019). Woodlands and forests are often identified by users as places where children can let off steam (O'Brien & Forster 2018) by providing a place for them to play (Owen et al. 2008). Community forests can be particularly good for creating health benefits where the emphasis is on providing opportunities and spaces for informal recreation, such as walking, cycling, riding or running (Land Use Consultants and SQW Ltd 2005). This can be achieved by developing suitable routes, paths and trails, and perhaps delivering guided walking tours (Land Use Consultants and SQW Ltd 2005). Programmes targeted at specific user groups with particular needs are also enabled by structured Community Forest programmes, such as those for adults with learning disabilities. The Community Forest programme in England was found to have achieved high levels of engagement and interest in woodland activities including practical woodland management tasks, making fires and cooking, sensory activities, and discovering nature amongst such groups (National Community Forest Partnership 2012). In terms of generating cultural ecosystem benefits such targeted initiatives can be highly successful.

Mental Health Benefits

The mental health and well-being benefits afforded by engagement with nature, including trees and woods are increasingly acknowledged and considered to be of great value to individuals, communities and society broadly. These benefits are

diverse and difficult to measure but visitors, when asked, frequently report significant positive mental well-being experiences. These include a sense of well-being through being in relaxing and stress free environments (Owen et al. 2008), experiencing peace and calm and feelings of stress reduction from difficult and sometimes chaotic lives (O'Brien 2018), finding escape and freedom, feelings of not being pressured (O'Brien 2019), becoming more relaxed in natural settings, experiencing feelings of peace and calm (National Community Forest Partnership 2012), and gaining a range of positive feelings through sensory experiences (O'Brien et al. 2014). Whilst there is good evidence of benefits, it can be difficult to separate out health benefits of woods, trees and forests from the health benefits of nature and greenspace broadly.

In the Woodlands In and Around Towns (WIAT) initiative a natural experiment evaluation study found no benefit from the woodland environment interventions at the community-level for mental health within 6 months of completion, compared with control communities that received no intervention. People in the intervention communities that visited the natural environment were less likely to be stressed and there was a moderate increase in physical activity levels for the intervention communities. (Ward Thomson et al. 2019).

3.2.3 Nature/landscape connections and aesthetics

Connecting people to nature, wildlife and the local environment is another important aspect of the cultural ecosystem benefits that can be realised by engagement with trees, woodlands and forests (House of Commons 2010). This may be particularly significant if new initiatives (like the National Forest in England) create opportunities for groups that would not normally engage with woodland (National Community Forest Partnership 2012). Nature connection can be through direct involvement, for example, schools and community groups planting and maintaining new wooded sites (House of Commons 2010). On the other hand nature connection may be realised simply through providing people with the opportunity to be in the fresh air (O'Brien & Forster 2018), to be somewhere perceived as pleasant that is away from noise and air pollution (Carter et al. 2009), and that is a safe space away from traffic (O'Brien & Forster 2018). This extends to a nature connection experience that fosters sensory experiences of seeing wildlife (O'Brien 2019), the realisation that they provide places for wildlife to live (Forest Research 2019) and increase biodiversity and local wildlife (Morris & Urry 2006; DC Research 2010). There is also a known connection between extent of well-being benefits and species richness (Luck, et al. 2011; Dallimer, et al. 2012; Flies et al. 2018). Design, planning and management, particularly of urban forests, should therefore emphasise biological complexity to enhance well-being (Fuller et al. 2007).

There is much evidence of the connection between initiatives to increase availability and accessibility of community woodlands and community forests, and an improvement in peoples' perception of the local environment and landscape. This includes perceptions of improvement in environmental quality (Ambrose Oji et al. 2014), making the local area a more attractive place to live, and creating better places for walking (Morris & Urry 2006). People perceive there to be cleaner air and cleaner places, including roadsides, hedges, and streets (Morris & Urry 2006).

Many people express a belief that trees make the landscape better (Forest Research 2019), thus new woodlands are found to improve the landscape (DC Research 2010). Recent work in Scotland to investigate views about woodland creation found that 82% of survey respondents feel that having more trees and woodlands would have a somewhat or extremely positive impact on the local area (Dunn et al. Forthcoming). When asked “what were their favourite things at Coed y Brenin”, many survey respondents referred to the scenery, views, beauty and naturalness (Beaufort et al. 2014). Overall, the aesthetics of the woodland environment are important to the cultural ecosystem benefits that can be experienced from woodlands and forests (O’Brien & Forster 2017; Henwood & Pidgeon 2001).

Nevertheless, not all woodlands and forests are viewed as a positive contribution to the landscape by all communities. In particular, 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 (Bishop et al. 2002). 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 (Bishop et al. 2002). Landscape aesthetics are considered in more depth in Section 4.

3.2.4 Education, learning and personal development

There are many examples of how people gain education, learning and personal development benefits from their engagement with trees, woods and forests, particularly through funded initiatives and large scale programmes that include Cydcoed in Wales, the Community Forest Programme in England, and Active Forests Programme and Westonbirt Community Project, also in England.

Learning, gaining new practical skills and knowledge of the woodland environment have all been realised from woodland and forest initiatives (O’Brien 2019; National Community Forest Partnership 2012). An evaluation of Cydcoed also found that knowledge and skills developed through the programme were being cascaded further through the community, hence not only benefiting those directly involved (Owen et al. 2008). Achieving the successful delivery of learning and education benefits from funded woodland programmes generally entails putting in place events and activities, often led by formal facilitators or trainers. This might include programmes of events for children over the summer holiday period, artistic and cultural events, the establishment of education officer posts within Forest Teams, and the production of education packs for disseminating educational materials (Land Use Consultants and SQW Ltd 2005). Programmes may successfully achieve education and learning benefits through project specific, hands-on learning within the forests themselves as well as more informal ‘outreach’ activities (Land Use Consultants and SQW Ltd 2005).

Personal development benefits are perhaps harder to define than education and learning and are more diverse. Nevertheless a number of studies have shown how engaging with trees and woods leads to greater self-confidence and self-worth (O’Brien 2018, 2019), provides a sense of achievement and challenge, provides mental stimulation (O’Brien & Forster 2017), and a sense of freedom (O’Brien & Forster 2018; O’Brien & Forster 2017). Participants may also gain more confidence in

natural settings (National Community Forest Partnership 2012). Additional evidence is found in a study conducted in north Wales. This asked people why wooded sites are important for people in Wales. One of the reasons was referred to as 'Family and personal memories', which aimed to capture the way in which seeing, visiting or thinking about a woodland can bring up memories from peoples' past and connect them to family and their personal history (Henwood & Pidgeon 2001).

3.2.5 Social connections

Cultural ecosystem benefits often focus on benefits for the individual (for example, improving their health, relaxing, trying a new activity, learning something new, enjoying the landscape), but it can be equally as important to generate wider social benefits, for example through the development of social connections, social capital, community trust, partnerships and friendships. Evidence shows community woodland initiatives can increase the level of trust in the community, help people develop stronger ties with others in their community (Owen et al. 2008) and encourage engagement with the local community (Holt & Rouquette 2017). The benefits of community groups also apply to other semi-natural habitats.

Partnerships can be created between public and private sector organisations that otherwise would not exist (Holt & Rouquette 2017), and landowners may be reconnected with local users (House of Commons 2010) such that there are positive changes in the relations between farmers and rural communities (Morris 2006). Bonds of friendship and companionship can develop during organised forest activities (Morris 2006) meaning that people get to know more people as a result of Community Forest programmes (Owen et al. 2008). In these cases what is important about such large scale funded woodland initiatives is the social support and encouragement people get from others, and simply the opportunities to have a chat, meet like-minded people, and have an enjoyable day (O'Brien 2019). This kind of social interaction is important, and may be with new people or with friends and family (O'Brien 2004; O'Brien 2019).

Overall, evidence has shown there are many opportunities afforded by woodlands for social connections with others and this is an important example of cultural ecosystem benefit arising from interactions with trees, woods and forests (O'Brien et al. 2014). More formally, organised forest programmes can provide people with an opportunity to volunteer and thus engage more with their community and environment (Owen et al. 2008). One result of increasing community engagement can be a reduction or cessation in anti-social behaviour in and around local woodlands (Owen et al. 2008).

3.2.6 Economics

Further cultural services generated by woodlands are the social benefits which surround the economic benefits of forestry, such as employment and livelihoods that are supported by the forestry sector, including management, processing, and utilisation of wood products, tourism and recreation (DC Research 2010). Employment furthers well-being in the broadest sense for individuals, households and communities, as it provides jobs and generates wealth. This section also includes people/communities' perceptions of the benefits of forests to tourism

(Edwards et al. 2009). Annex-6/ERAMMP Report-38: *Economics and Natural Capital Accounting* focuses on monetary value.

3.2.7 Cultural identity

Trees and forests hold cultural significance for people in local communities. In the south Wales Valleys it was found that a majority of local people placed great value on the role that the forests in their vicinity played in place identity, and some considered the forest to be the defining feature of their locality (Bishop et al. 2002). However, the identity of the forest was not considered wholly a positive feature for local valleys communities. Some people reported that the industrial nature and scale of the plantations generated the belief that the forest plantations are for national financial profit and not for local community benefit or part of local identity (Bishop et al. 2002).

In an evaluation of the National Forest in England it was found that local people had become more aware of what the National Forest could offer them and felt that it was “part of their culture” (House of Commons 2010). This leads to the creation of a sense of place (Holt & Rouquette 2017) and can help to increase the quality of life of those living in surrounding areas and local communities (House of Commons 2010; Owen et al. 2008).

3.3 Delivering Benefits: Management, Engagement, Place and Activities

As demonstrated in the conceptual framework in Figure 3-1, cultural ecosystem service delivery is informed by the interaction between the activities which deliver cultural benefits, the place/location these activities occur, and the management and governance of that location. These elements are considered in further detail here.

3.3.1 Place

The location, proximity and accessibility of any site and activity are important for the benefits they can deliver; this applies to all greenspaces and recreation facilities. We note that there is conflicting evidence around the terminology of place, and the cultural identity of fields, woodlands and forests.

The location and proximity are relevant to how many people can access woodlands, and how frequently, and this has implications for the cultural ecosystem benefits that can be generated from woodlands and forests. In Wales in 2019, 51% of woodland visits were to woodlands in the countryside, and 48% were to woodlands in and around towns (Forest Research 2019).

Urban trees and woodland areas enable many more people to benefit through their proximity to large populations. Strategies should ensure provision of urban forests, including street trees, very close to residences to promote the restorative benefits of trees for people (Williams et al. 2013). Peri-urban woodlands can contribute to self-reported health and well-being in multiple ways (O’Brien et al. 2014). Attempts have been made to link specific components of the urban forest to cultural ecosystem benefits (Figure 3-2). The full range of ecosystem services from urban forests are considered in Section 5 (p.31)

Ecosystem service		Urban forest components			
		Single tree	Line of trees	Tree cluster	Woodland
Cultural	Health	Rarely delivered	Sometimes delivered	Commonly delivered	Commonly delivered
	Nature and landscape connections	Rarely delivered	Sometimes delivered	Commonly delivered	Commonly delivered
	Social development and connections	Rarely delivered	Sometimes delivered	Commonly delivered	Commonly delivered
	Education and learning	Rarely delivered	Sometimes delivered	Commonly delivered	Commonly delivered
	Economy	Rarely delivered	Sometimes delivered	Commonly delivered	Commonly delivered
	Cultural significance	Rarely delivered	Sometimes delivered	Commonly delivered	Commonly delivered

Commonly delivered
 Sometimes delivered
 Rarely delivered

Figure 3-2 Relationship between cultural ecosystem services and urban forest components. Source: Davies, H., et al. 2017.

The Cydcoed project confirmed the importance of proximity to residential areas to realise cultural ecosystem benefits from community forestry projects close to populations (Owen et al. 2008). The State of Natural Resources Report for Wales (2016) suggests that given the range of interests and uses of the natural environment there is a role for both urban greenspaces/forests where most of the population live, and for more remote visitor facilities to provide a broad range of ecosystem services including cultural ecosystem wellbeing benefits.

3.3.2 Activities

There are different ways in which people can engage with forests (O'Brien & Morris 2013), including activities associated with viewing forests, using and being in forests for leisure and recreation, and more active hands on engagement such as through tree planting, other types of volunteering and gathering non-timber forest products, as well as Forest School (O'Brien & Murray 2007). It is from these activities that occur in nature that the cultural ecosystem services are derived. Recreation activities that take place within forests and woodlands include walking, picnicking, wildlife watching, playgrounds, running, cycling, concerts and crafts as considered in section 3.2.1 *Recreation*, in this Annex.

3.3.3 Management and Governance

The management of a location impacts the range of activities which can take place there, as well as the level of benefit delivered. The forest management objective, whether conservation, production, amenity or mixed, determines the forest type, silviculture, access and facilities, and therefore underpins visitor experience.

Forest type and management

The type and degree of management of trees and woodland areas can affect the cultural ecosystem benefits that are experienced by visitors and local residents. For some people, there is a need to have woodland areas that are left in a largely unmanaged, and hence perceived natural condition, where infrastructure is limited to some unmanicured footpaths (Carter et al. 2009). In line with this, many visitors to

woodland and forests express preferences for forest management that may be considered close-to-nature but not entirely unmanaged forest nature reserves (Edwards et al. 2010a). Correspondingly, where forest is managed for conservation any increase in those areas could cause a corresponding increase in the recreational value of forests (Schellhaas et al. 2010), particularly for those visitors who prefer an environment that feels closer to nature. Preferences for different degrees of forest management are captured in more detailed examination of peoples' preferences for silvicultural attributes that reflect the level of management intervention. These attributes can include things such as the extent of clear fell, brash left from thinning and harvesting, and openness of the canopy or vistas into and through the forest (Edwards et al. 2010b). Elsewhere people express a preference for what they perceive to be more natural woodlands that are not planted in straight lines (Lee 2001). Thus people want forests that look natural to them, that are colourful, that they consider to be beautiful and to look inviting, that blend into the landscape, and have a lot of variety (Lee 2001).

Importantly, people perceive a difference between forests and woods (Lee 2001). Forests are considered to be new and associated with close, quick-growing conifer trees, which are sometimes seen as boring to walk in (Lee 2001). Woods (as opposed to forests) are often described as 'natural', old and established, with mainly broadleaved trees (Lee 2001). In line with this people express a strong preference for broadleaved trees and the ideal forest is seen to consist of a mixture of trees (Lee 2001). In Great Britain, variation in tree size is important but not variation between stands (Edwards et al. 2010b).

Old-growth forest in a natural state, veteran trees, and mature commercial forest have been found to be significantly most restorative than an urban recreation forest or a young commercial forest (Simkin et al. 2020), hence they generate greater cultural ecosystem benefits, however urban forests are more accessible. Similarly, greater extent of tree canopy has been found to be associated with lower incidence of fair to poor general health (Astell Burt 2019).

Overall, evidence suggests that in order to generate cultural ecosystem benefits there is a need to maintain a diversity of woodlands and management priorities; diverse tree species, a degree of openness of the forest stand, and having mixed and deciduous native woodlands to visits are all important (Carter et al. 2009; O'Brien et al. 2014).

Access

The infrastructure in terms of footpaths, benches, play spaces, and signage can be critical in enabling access and defining user experience (Carter et al. 2009; O'Brien et al. 2014). As established in 3.2.1, it is not just important to create new woodlands or bring unmanaged woods into active management, but to seek to open up currently inaccessible woodlands in order to generate cultural ecosystem benefits for the population in Wales.

Ownership and facilities

There is good evidence to suggest that forest ownership and governance can be important, and expectations of benefits are higher for public forests than for private

forests, particularly in locations where private owners can prevent or restrict access (Carter et al. 2009). Forests in public ownership may provide more facilities and cater to more interests and sections of society with the aim of being inclusive. Likewise, privately owned forests where tourism and recreation are a primary management objective can provide equally high levels of benefits; although entry fees, parking and activity costs must be considered in reference to inclusivity. Community owned woodlands and opportunities to engage people with woodlands are considered in the next section.

3.3.4 Community Engagement

Referring to the conceptual framework in Figure 3-1, between the place-activity-management and the cultural ecosystem services that are delivered, there are a range of socio-economic, climatic, and experiential influences on the user’s ability to access, experience and value each ecosystem service. This is an essential component of delivering cultural ecosystem service benefits.

As summarised in Figure 3-3, many, but not all cultural ecosystem services that forests and woodlands can provide are recognised or valued by society. The greatest recognition is for landscape and recreational value, with scope to improve accessibility and community opportunity. The perceived value of forests has increased between 2011 and 2019.

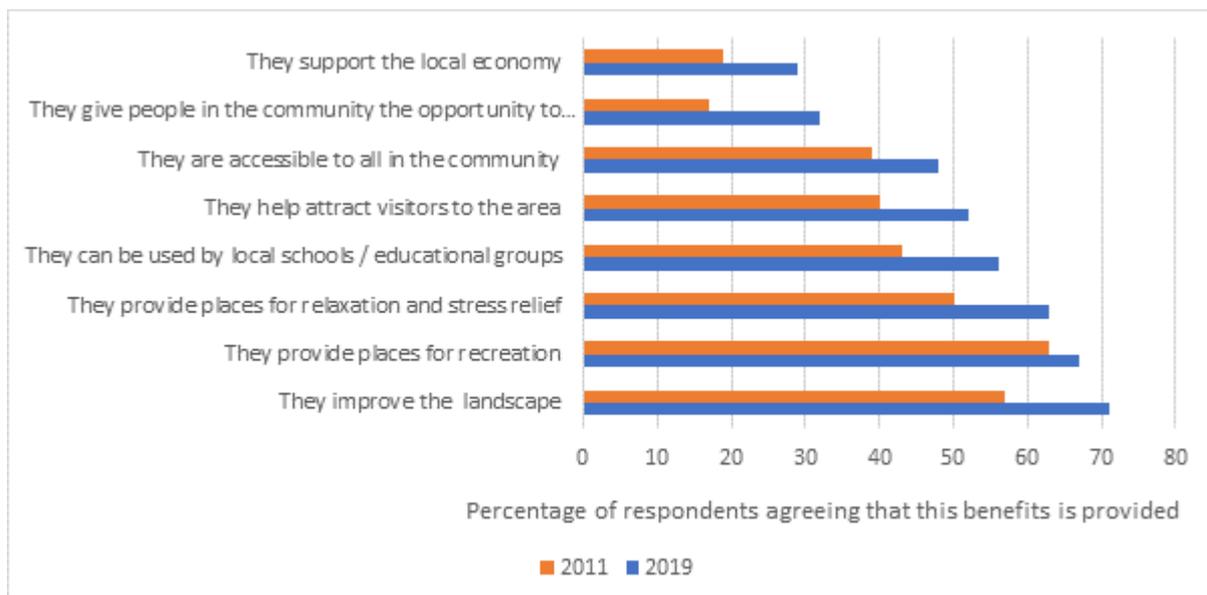


Figure 3-3 Percentage of Welsh survey respondents who agreed that cultural ecosystem benefits are provided to communities by woodlands for 2011 and 2019. Source: Adapted from: Public Opinion of Forestry in Wales (Forest Research 2019).

As evidenced in Table 3-1 and Table 3-2, a significant proportion of the population of Wales visit woodlands regularly for walking, dog walking and picnics, and these visits to local woodlands account for the majority of visits to forests and woodlands. However, many individuals have little or no interaction with the natural environment, have limited access to greenspace, trees and woodlands, and may have either no experience of the benefits they can provide, or in the worst case, individuals may have negative associations with greenspace or woodlands, through fear for safety or

experience of anti-social behaviour. Therefore, 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 wide range of people.

There is strong evidence that partnerships and projects that target and support specific groups and communities to access and engage with forests delivers a broad range of cultural ecosystem benefits (Molteno et al. 2012). These include larger organisations and projects, including National Forest in England, the Community Forests in England, Cydcoed in Wales, Active Forests Programme in England, WIAT (Woodlands In and Around Towns) in Scotland, and the Westonbirt Community Project in England. These organisations engage local communities in a range of activities associated with the forests including tree planting, organised events and sometimes in decision making concerning management or new woodland creation.

Smaller scale projects also engage communities with forests and are usually single site focused and include woodlands owned and managed by communities, charities, or local authorities. Community Woodland Groups are those that own a woodland or share in the management decisions concerning a woodland, and in Wales Llais y Goedwig was set up as a community woodland network to represent and support these groups. The Cydcoed programme in Wales ran from 2001-2008 and funded 163 Community Woodland Groups to undertake woodland projects and was a catalyst for Community Woodland Groups to form and access funding. In 2013 Lawrence and Ambrose-Oji (2014) suggested that there were 150 Community Woodland Groups in Wales. Community Woodland Groups are proactive in the creation, expansion and management of woodlands.

Organisations such as the Community Forests or National Forest engage communities in a more top down way, whereas Community Woodland Groups arise generally via a bottom up approach due to a community need. Both of these approaches often seek to engage communities with their local woodlands/forests and thereby help create a sense of place and community identity. Community Woodlands, the Community Forest and National Forest often aim to give people the opportunity to plant trees which is a good way to establish woodlands in areas where they were needed (Lee 2001) and to create a sense of ownership amongst those involved. Initiatives such as these generally require some public/philanthropic funding, at least during inception and the early years of development. What they enable is creation and/or management of woodland areas, often nearby to local communities, that are a free resource where people can socialise and exercise and thus experience physical and mental health benefits (Carter et al. 2009).

Such initiatives and the associated funding enable the provision of support programmes that help deliver strategies to encourage physical activities in local woodlands and peri-urban forests (Williams et al. 2013). Such initiatives also present opportunities for partnerships between public and third sector organisations in urban areas to promote wellbeing from urban forests (Williams et al. 2013).

These are some ways in which publicly funded large-scale initiatives provide a management structure that enables the provision of cultural ecosystem benefits to the widest possible diversity of communities. It should be noted that these conclusions can also apply to other areas of green space, however they are an important consideration for a new national forest.

3.4 Conclusion and Evidence for Cultural Ecosystem Service Benefits

Table 3-5 summarises the existing evidence reviewed above. The sources of evidence included here are diverse, and date from 2001 to 2020. The majority of examples are from studies from the UK, with an emphasis on Welsh findings where available. For some of the cultural ecosystem benefits, for example health, there are multiple examples of strong, and widely accepted evidence. For others, such as cultural significance, evidence is less conclusive, less widespread and in some cases conflicting.

Table 3-5 Existing evidence of the cultural ecosystem well-being benefits of woodlands and forests

Cultural Ecosystem Benefit	Well accepted evidence	Limited evidence	Conflicting evidence
Health (physical exercise and mental well-being)	Reasonably well accepted Large body of evidence gathered over two decades. Physical activity within woodlands provides major health benefits to the population of Wales. Physical health can be improved through the organisation of diverse activities and programmes aimed at particular sections of society. Large body of qualitative data highlights mental wellbeing benefits of nature and forests.	Can be difficult to separate out health benefits of woods, trees and forests from the health benefits of nature and greenspace broadly. More evidence focused specifically on trees, woods, forests would be beneficial, but also need to recognise that habitat variety may motivate visits and help realise health benefits.	Some conflicting evidence suggesting that even with increased accessible woodlands, communities' health and well-being may not improve if people do not visit them due to external factors.

<p>Nature /landscape connection and aesthetics</p>	<p>Reasonably well accepted.</p> <p>There is a reasonable body of evidence on the benefits from a connection to nature and wildlife (through woodlands).</p> <p>Large scale National Forest Programme and Community Forests Programme in England highlight that these initiatives can improve perceptions of local environmental quality.</p>	<p>There is some evidence of landscape aesthetics bringing benefits to people, although much is now quite old and generally rural-focused.</p> <p>More evidence would be beneficial.</p>	<p>Some conflicting evidence.</p> <p>It needs to be the right trees in the right place – forestry plantations can be viewed negatively.</p>
<p>Education and learning and personal development</p>	<p>Reasonably well accepted</p> <p>Reasonable body of evidence on how woodland initiatives and organised activities in forests can help people learn and develop new skills and confidence.</p>		
<p>Social connections</p>		<p>Limited evidence</p> <p>The body of evidence on the importance of social connections in forests is based on evaluations of initiatives such the National Forest in England.</p> <p>Evidence includes the benefits of social connections with family and friends, as well as partnerships and communities.</p>	

Cultural /symbolic significance		<p>Limited Evidence</p> <p>Much of the evidence on the cultural and symbolic significance of trees and woods is in books (not reviewed here).</p> <p>Limited evidence suggests that people can view trees and woods as a symbol of nature more broadly. Particularly in urban areas.</p>	Some conflicting
Economy		<p>Limited evidence</p> <p>Much of the value to the economy of forests is outlined in Annex 6</p> <p>There is currently limited evidence of perceptions of benefits to the economy, and how it adds more broadly to community well-being.</p>	

3.4.1 Notes on Methodologies and Methods

Across the literature reviewed here, and beyond, the broad and diverse range of cultural ecosystem benefits have been identified via a wide range of methodologies and methods including survey-based approaches, the use of validated scales, monetary valuation, physiological measurements, mapping and visualisation techniques including participatory Geographical Information Systems (GIS), participant observation, interviews, and focus groups (O'Brien et al. 2017). The recent Natural Capital Accounts (NCA) produced for the public forest estate (PFE) in England (Forestry Commission England 2018) illustrates some of the challenges of including cultural ecosystem benefits alongside other ecosystem service categories to capture the full value of trees and woodlands (see Annex-6/ERAMMP Report-38: *Economics and Natural Capital Accounting*) (Forestry Commission 2018). Many qualitative and quantitative methods outline a much broader range of benefits than are routinely capture through current monetary valuation studies. A review of methods for integrating cultural ecosystem services/benefits³ with other ecosystem benefits (O'Brien et al. 2017) identified that multi-criteria analysis, participatory GIS

³ Note that the terms services, values and benefits are also often used interchangeably in the literature on ecosystems (see O'Brien et al. 2017).

and deliberative methods are being used to take account of different services/benefits. For all of these methods there is a strong deliberative component that recognises ethical issues, less tangible values and benefits, and community values, as well as attachment to place. Non-monetary valuation methods are the approaches behind many of the findings reported in this Annex.

3.4.2 Concluding comments

This section illustrates that the cultural ecosystem benefits of trees, woodlands and forests are large, broad and diverse and depend on context such as governance approach, place, and the different activities through which people engage with forests.

Existing woodland

- I. Proactive community engagement and planning of programme and project interventions can be used to target those less likely to currently benefit from engaging with forests, which often includes more deprived communities, BAME groups and the disabled.
- II. Often people visit a range of forests and woodlands with some nearby and others further away, however, there is potential to reach more people through forests located near to large populations in urban and peri-urban areas that are easily accessible.
- III. Opening up currently inaccessible woodlands could increase the percentage of the population who have access to nearby woods to benefit from the cultural ecosystem services provided.
- IV. There is more evidence of benefits from proactive interventions and encouragement of access in public forests managed by public bodies or charities rather than for private forests.
- V. There is some evidence of the restorative benefits from mature woodland rather than newly created woodland. Extent of tree canopy can be important to health and well-being.
- VI. Many of the benefits of forests and woodlands are not easily monetised and not all are quantified. Much qualitative evidence illustrates the richness and complexity of engagement with forests and the benefits derived from this, and mixed method approaches are critical to understand these in greater detail.
- VII. There is a lot of evidence about the cultural ecosystem benefits from greenspace but overall much less that is forest specific.

New woodland

- VIII. The creation of forests such as the Community Forests and the National Forest in England show that engaging people in the creation and management of these forests can be beneficial in terms of building identity linked to the forest.
- IX. Creation should not be thought of solely in terms of tree planting. It relates also to the creation of place and identity and connects people to their environment.
- X. New woodland creation for specific activities has greatest benefit in terms of providing cultural benefits where they are currently under-provided

- XI. Additional benefits of new woodland depend on the context, particularly proximity to populations and other existing woodlands, where new woodland is valued less in areas which are already heavily wooded, and more highly valued in non-afforested areas or areas where woodlands are small or fragmented.

4. LANDSCAPE AESTHETICS

Landscape aesthetics - evidence of the public perception of the contribution trees make to the aesthetics of landscapes generally and evidence for Wales specifically.

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 and this happens at a range of perceptual scales from the near (eye-height) to the distant (the view of a woodland from kilometers away) (Swetnam et al. 2017). Aside from large water bodies such as reservoirs, no other component of a rural view has greater visual impact than a forest. There is well accepted evidence of the positive contribution of trees to the appearance of most landscapes (Arriaza et al. 2004; Gobster et al. 2007, Ode et al. 2009). In 2013, Lothian published a review of 227 landscape studies in which 78% referred to the positive benefits of trees in the landscape. Whilst a more recent survey in the UK by Urquhart et al. (2017) which sampled the views of 1000 people, reported 88% of respondents strongly agreed / agreed that woodlands were important for aesthetic reasons.

Landscape aesthetics can be defined as "the enjoyment and pleasure felt through the observation of environmental scenery" (Tribot et al. 2018: 3) and so is strongly visual in evaluation. The aesthetic qualities of woodland are determined by a number of key factors as follows:

1. Form / Shape
 - a. Density
 - a. Contiguity
 - b. Structural components
2. Species Type - conifers vs deciduous / mixed
 - a. Impact of type on colour / variety
3. Age
 - a. Successional stage
 - b. Maturity
4. Landscape setting / Position
 - a. Landscape Views through the woodland / viewpoints
 - b. Siting

From an aesthetic viewpoint, there are clear differences between the shape and form of commercial plantations when compared to native woodlands. There is some limited evidence that complex shapes which provide heterogeneity in the landscape view are favoured (Schirpke et al. 2013; Liu et al. 2018). The preferred arrangement of woodland in a landscape is strongly place-dependent with clumps often favoured in more agricultural settings where the woodland provides a distinct visual contrast to the homogenous shapes of agricultural fields. Häfner et al. 2018 conducted a visual preference survey of over 200 people in agricultural landscapes of Germany which demonstrated that clumps of trees in these mixed landscapes was favoured. In contrast the more dispersed nature of trees in wood-pasture landscapes (Welsh

Government 2018) and the Fridd of the upland fringes (RSPB 2014) create heterogeneous habitat mixes which are visually pleasing. Forestry plantations do afford recreational opportunities (see *Section 3.2 on cultural ecosystem services*), however, few walkers enjoy pathways through dark, enclosed conifer plantations where the view of the wider landscape is seriously foreshortened (Milligan & Bingley 2007; Carter et al. 2009)

There is well accepted evidence that the public recognise and value a range structural components of woodland (Binner et al. 2017; Faccioli & Bateman 2018). A variety of species planting is favoured (O'Brien et al. 2012). In a recent review of the preferences of different nationalities Ciesielski & Sterenczak (2018) showed that cultural differences persist with a mixed species structure favoured in a UK context (Edwards et al. 2012).

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. This debate is well founded in the UK forestry sector with the pioneering landscape work published by Sylvia Crowe in the 1960s (Crowe 1966). 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 both in the UK (Lee 2001; Carter et al. 2009; Tratalos et al. 2016; Mcvittie & Faccioli 2017; Nijnik & Mather 2008) and elsewhere in Europe (Otero-Pastor et al. 2007; Albildtrup et al. 2013; Almeida et al. 2018; Giergiczny et al. 2015). The species of tree is extremely important to the visual aspects of landscape. Evidently, conifer forests (larch accepted) are evergreens which are dark green in colour all year around. The seasonal colour shifts brought about by deciduous tree leaf burst, maturity and autumn senescence are exceptionally valued by people. Autumn leaf colour is visually spectacular in many locations and actively sought out by visitors and residents alike for its aesthetics and seasonal sense (Lee 2001). Seasonal colour changes are incorporated directly into the Visual / Sensory layer of LANDMAP (NRW 2016) with specific reference made to tree changes and contribute positively to the overall scenic value.

Woodlands offer temporal dynamism in a landscape view, both annually due to leaf changes, but also over decades as forests are felled and replanted. Even fast-growing conifer woodlands take decades to mature to height, whilst native woodland takes even longer. There is well accepted evidence that older trees are more highly valued both in a UK context (McVittie & Faccioli 2017) and a Scandinavian context (Nielsen et al. 2012; Edwards et al. 2012; Filyushkina et al. 2017). Wales, has some of the oldest trees in Europe (Rackham 2010) and the Welsh Government has placed emphasis on their preservation in its 2018 Strategy Update (Welsh Government 2018). Veteran trees are often aesthetically pleasing either due to their size and /or form or location in the landscape, with large trees lending "visual coherence" to the landscape (Herzog 1984). Selman & Swanwick (2010) discuss the concept of "time-depth" with respect to Welsh landscapes and the importance of continuity. Ancient woodland and trees contribute positively to what is considered beautiful and this is reflected in the Welsh Register of Historic Landscapes (CCW 2001)

In contrast to the centuries-long lifespan of veteran trees, conifer crops are designed to be rotationally felled over 50 – 70-year timeframes and this represents significant landscape challenges with respect to preferred views. There is limited evidence detailing the public response to clear-cutting in the UK, though advice on minimizing the landscape impact was provided by Crowe in her early publications for the Forestry Commission (1966, 1979). Good evidence exists in Scandinavia concerning the dislike of the public for clear cut areas (Gundersen & Frivold 2008). For example, Tonnes et al. (2004) demonstrated in a photographic preference study of felled areas in Finland (sample size = 373 people) that mature 'retention' trees were significantly favoured over total clear cut. Recent studies in the UK on such evaluations are lacking.

Another critical parameter for evaluation of forest aesthetics relates to the views through trees to landscape beyond. Ribe (1989) refers to this as “visual penetration”. Dense, young stands of trees which do not allow a light horizon to be seen are not favoured (Brush 1976; 1979). Much of the evidence for this does date from the 1970s and 1980s in the US with a lack of comparable studies on commercial forest planting in the UK.

The siting of a forest / woodland in a landscape plays a significant role on its perceived aesthetic value and was discussed at length by Lee (2001) in a commissioned report to the UK Forestry Commission. Recent research in Cumbria (UK) by Iverson (2019) presents conflicting evidence that new woodlands / forest are always welcomed 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 (Iverson 2019:241). The public are sensitive to the perceived 'naturalness' of woodlands and forests in the landscape as shown by Lee's survey in 2001 where strong opposition was given to forests planted in rows. This is often one of the defining visual characteristics of commercial conifer forests in Wales. In a photographic preference survey conducted for the Welsh Government through the GMEP project to which over 2200 people eventually responded (Swetnam et al. 2015) a clear preference for native woodland was expressed whilst blocks of conifers were the most negatively rated landscape feature after road infrastructure (Figure 4-1).

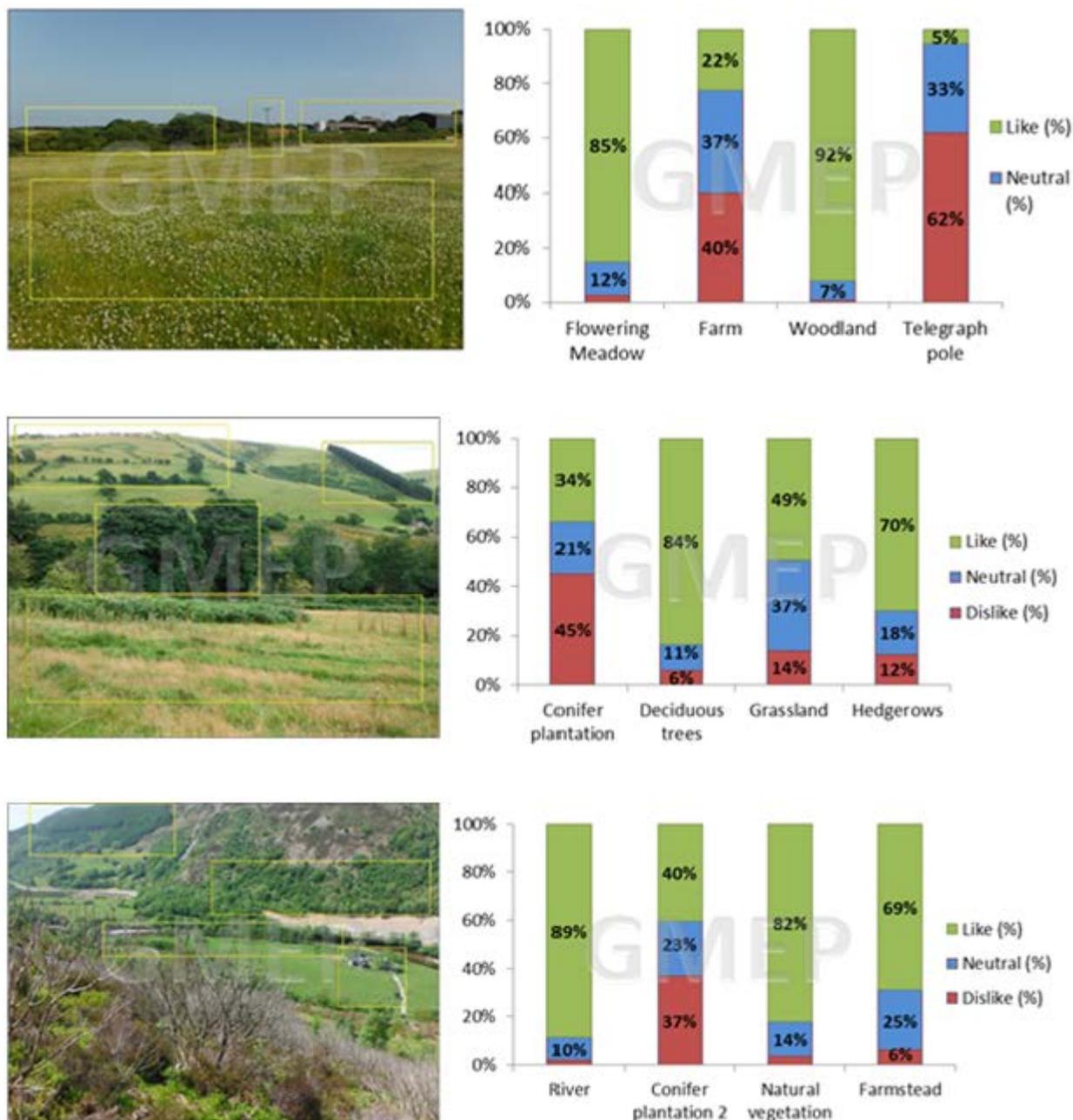


Figure 4-1 Results of photographic preference surveys from the GMEP photographic preference survey (Data shown for the first 1000 responses). Participants were shown the photographs on the left hand side, with the features highlighted in the yellow boxes and asked whether they liked the appearance of it or not. Note the contested results for the conifer plantations in these Welsh landscapes (Swetnam et al. 2015).

5. URBAN FORESTS

Trees are amongst the most versatile natural assets that planners, policy makers, businesses and communities can use to cost-effectively raise the quality of Welsh towns and cities (NRW 2016). They can help contribute delivery of nine of the seventeen UN Sustainable Development Goals.

Until relatively recently, very little has been known about Wales' urban tree resource - its extent, location and whether current provisions are adequate to effectively support the sustainable growth, health and well-being of Welsh urban communities (NRW 2016). However, since the Tree Cover in Wales' Towns and Cities assessments of 2006, 2009 and 2013 (NRW 2016), Forest Research has been commissioned to carry-out a number of i-Tree Eco [urban forest] surveys across Wales (in Bridgend, Cardiff, Newport, the Tawe catchment, Wrexham) the reports of which are available on-line (except for Newport, in preparation at the time of publication) (Forest Research 2020b).

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 (Figure 5-1). It contributes to green infrastructure and the wider urban ecosystem (Davies et al. 2017). 80% of the Welsh population live in towns and cities (NRW 2016). Wales' mean urban canopy cover was estimated at 16.8% for 2009. Wales' total urban area was measured at 84,336 hectares. Of this, 14,164 hectares were covered by trees (NRW 2016).

The Peri-urban forest includes tree resources outside of, but close to urban areas; it provides many benefits and services to urban societies. Key sources of evidence may refer specifically to the Urban forest whilst others to both the Urban and Peri-urban forest.

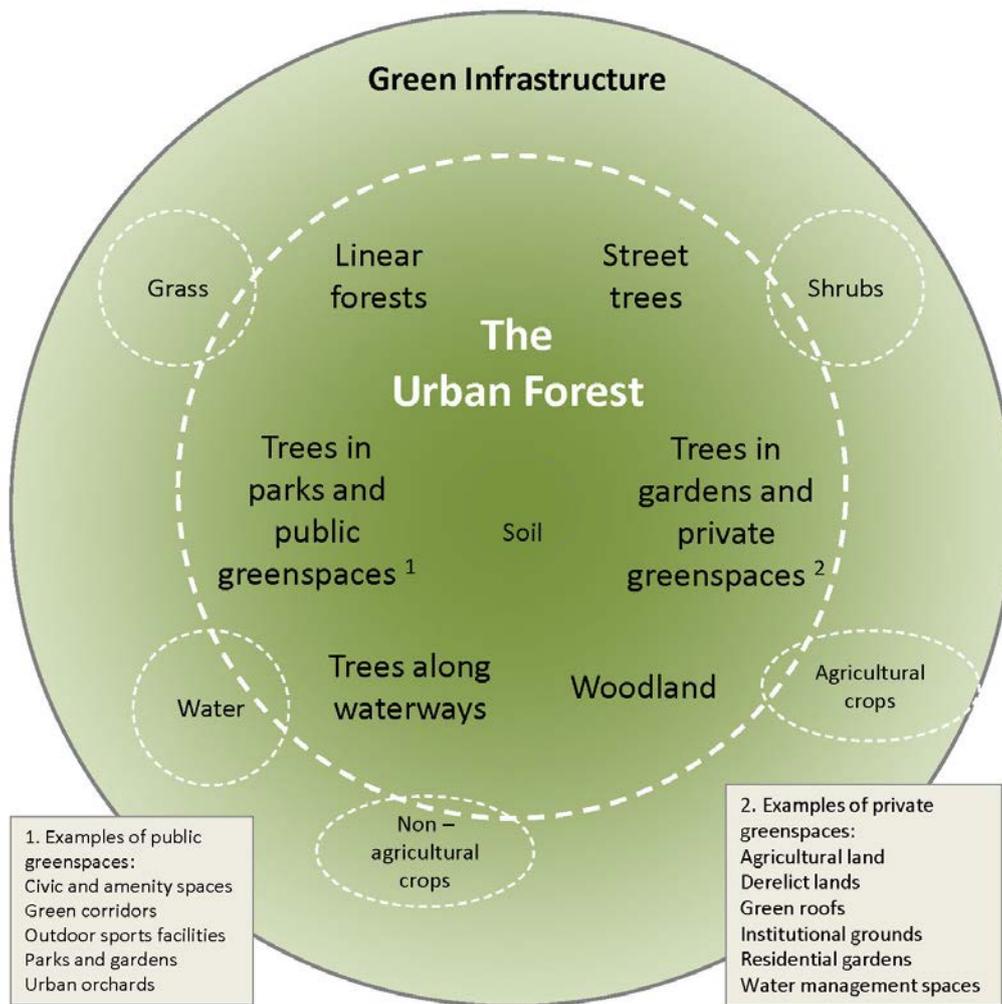


Figure 5-1 Components of the Urban Forest (Davies et al. 2017).

“Forest” is defined by the Food and Agriculture Organization of the United Nations as:

“Land with tree crown cover (or equivalent stocking level) of more than 10 percent and area of more than 0.5 hectares (ha). The trees should be able to reach a minimum height of 5 meters (m) at maturity in situ. May consist either of closed forest formations where trees of various storeys and undergrowth cover a high proportion of the ground; or open forest formations with a continuous vegetation cover in which tree crown cover exceeds 10 percent. Young natural stands and all plantations established for forestry purposes which have yet to reach a crown density of 10 percent or tree height of 5 m are included under forest, as are areas normally forming part of the forest area which are temporarily unstocked as a result of human intervention or natural causes but which are expected to revert to forest.” (FAO 1998)

This definition effectively classifies urban areas across Wales as “forest”, 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). Urban canopy cover values at electoral ward level are also beginning to emerge. Whilst on-going, the Canopy Cover Map for the UK reveals that coverage ranges from 0.7% in Rest Bay, Bridgend to 45.1% in Killay South, Swansea (Forest Research 2020a). Urban

trees therefore have the potential to make significant contribution to the National Forest Programme in Wales.

NRW (2016) highlights that it is now widely accepted that trees and woodlands in and around towns and cities have a vital role to play in promoting sustainable communities. A growing body of research has demonstrated that trees bring a wide range of benefits both to individual people and to society as a whole and has been addressed in recent literature e.g. by Hartley et al. (2020), Jones et al. (2019), Rahman et al. 2020) or Venkataramanan et al. (2019). Some of this evidence has already been presented in the sections above.

As the most 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 (NRW 2016). A summary of key benefits associated with good tree canopy coverage in urban areas is listed in NRW (2016); these include:

- Economic benefits
- Social benefits
- Environmental benefits

Amongst other economic benefits, trees

- Increase property values by 5-18% and this growth increases proportionately with the tree growth
- Within mature landscapes, tend to make development sites worth more
- Create a positive perception of 'place' for potential property buyers be it homeowners or commercial investors
- Contribute to retail areas performing better - people are more productive, with job satisfaction increased
- Improve the environmental performance of buildings by reducing heating and cooling costs, thereby cutting bills
- Provide a cost-effective and sustainable alternative to 'grey' infrastructure provision in tackling storm-water run-off
- Reduce, through shading, degradation of tarmac surfacing and frequency of replacement
- Reduce green space maintenance costs
- Add to tourism and recreational revenue
- Improve the health and well-being of local populations, so reducing healthcare costs
- Can enhance the prospect of securing planning permission if existing trees are protected and the new tree-planting design is imaginative
- Offer valuable by-products e.g. timber, firewood/woodchip, renewable fuel via coppicing, fruits (e.g. community orchards) and compost/leaf litter mulch.

In terms of social benefits, trees have been demonstrated to

- Create a sense of place and local identity

- Provide focal points and landmarks
- Benefit communities by increasing pride and social cohesion in the local area
- Have a positive impact on crime reduction
- Due to their stature, strength, and endurance, promote spiritual well-being, e.g. putting people in touch with nature and reducing depression and anxiety
- Provide a source of recreation, entertainment and quiet enjoyment, offering opportunities to unwind and de-stress, and provide families with a pleasant environment within which to spend quality time together
- Have a positive impact on people's physical and mental health e.g. less asthma and skin cancer and patient recovery times
- Encourage exercise that can counteract heart disease and Type 2 diabetes
- Offer a rich outdoor learning classroom for all, especially when part of a natural wooded environment

The Environmental benefits of trees includes that they:

- Remove carbon dioxide to create a carbon sink
- Transpire, reflect sunlight and provide shade, all combining to reduce the 'urban heat-island effect'
- Remove dust and other particulates from the air
- Reduce traffic noise by absorbing and deflecting sound
- Reduce wind speeds, thereby helping to reduce wind chills in winter
- Provide food and shelter for wildlife, thus helping to increase biodiversity
- Create new habitat links across towns and to the countryside, and strengthen existing wildlife corridors
- Create attractive greener landscapes, including by helping to hide eyesores
- Reduce the effects of flash flooding by slowing the rate at which rainfall reaches the ground
- Help to improve soil quality when planted on despoiled and degraded ground
- Create organic matter on the soil surface from their leaf litter and, with their roots increasing soil permeability, this results in:
 - Reduced surface water run-off from storms
 - Reduced rainwater soil erosion and sedimentation of streams
 - Increased ground water re-entry that is otherwise significantly reduced by paving
 - Lesser amounts of chemicals transported to streams
 - Reduced wind erosion of soil
- Are a key element of any urban climate change adaptation strategy. 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.

It has been estimated that urban trees delivered just over 30% of the total removal by trees of PM10 particulates from the air in Wales, a service from urban trees which contributed an estimated £116 million to the Welsh economy at 2015 prices (Saraev et al. 2017).

Davies et al. (2017) looks at a broad range of urban forest-based ecosystem services and disservices and, using a literature review, links their provision with four aspects of urban forests (physical scale, physical structure and context in terms of location and proximity to people and land use and ownership). A key objective of Davies et al. (2017) is to illustrate the specific role of trees in delivering benefit to society, as opposed to delivery being assigned to green infrastructure in general, or to a particular greenspace type.

Davies et al. (2017) consider four scale-based urban forest elements: single trees (such as might be identified in civic areas or domestic gardens), lines of trees (as would comprise an avenue along a street or in a residential area), tree clusters (such as experienced in communal greenspaces, on recreational ground, or at large road intersections) and woodland. The ecosystem services are grouped into provisioning, regulating and cultural, and in the main part of this report each service is considered in turn, with in most cases a table summarising the urban forest parameters that are reported in the literature to improve that service.

A summary table in Davies et al. (2017) brings together delivery indicators for urban forest ecosystem service provision; the report then considers ecosystem disservices in a similar way. Such information will be helpful for mapping and quantifying ecosystem service delivery over a given area and for determining how and where the urban forest can be bolstered in support of ecosystem service provision, including a reduction in ecosystem disservices. To this end, synergies and trade-offs in ecosystem service delivery are also considered. By revealing which component parts of the urban forest are frequently associated with the benefit, Davies et al. (2017) suggest that their report can help policymakers and urban forest practitioners in Britain make informed decisions on how to improve the long-term and sustainable delivery of ecosystem services for a more resilient society.

Regulating services considered:

- Carbon sequestration and storage
- Temperature regulation
- Stormwater regulation
- Air purification
- Noise mitigation

Cultural services considered:

- Health, including physical well-being, mental restoration, escape and freedom, and enjoyment and fun.
- Nature and landscape connections
- Social development and connections
- Education and learning
- Economy and cultural significance

Ecosystem disservices

- Fruit and leaf fall
- Animal excrement (e.g. aphid honeydew, and bird droppings)
- Blocking of light, heat or views
- Decrease in air quality (this is the most commonly reported disservice in the literature and includes the formation of tropospheric ozone (O₃) and particulate matter (e.g. PM₁₀ or PM_{2.5}), which contribute to respiratory illnesses, following the emission of biogenic volatile organic compounds (BVOCs) by certain trees.
- Allergenicity
- Spread of disease and pests
- Spread of invasive species
- Damage to infrastructure
- Creation of fear
- Tree and branch fall (especially during storms)

6. WATER QUALITY AND QUANTITY

Dr T. Nisbet, Forest Research & Dr C. Evans, UKCEH

6.1 Introduction

This section provides a summary of existing research and evidence relating to the impacts of woodland creation and management on water quality and quantity. We start with an assessment of the impact of woodland management and then consider the role of woodland design and location. This is followed by a review of the impacts of woodland creation. The contribution of woodlands to flood mitigation is addressed in Section 7.1.

Woodland cover is widely recognised around the world as the preferred land use for protecting water quality (FAO 2008; Eberhardt et al. 2019). This reflects a range of woodland attributes, including: the ability of woodland canopies to moderate rainfall inputs due to wet canopy evaporation; the well-structured nature of woodland soils resulting from sustained organic matter inputs, tree rooting and lack of soil disturbance, reducing erodibility and promoting slope stability; active uptake and tight canopy recycling of nutrients; and the generally very low level of chemical inputs to woodlands such as fertilisers or pesticides (Nisbet et al. 2011). Consequently, waters draining woodlands are typically of very high quality and ecological condition, requiring little or no treatment for water supply.

The main threat to the water protection function of woodlands is from woodland management practices, especially those associated with productive management for timber and other wood products. Others arise from planting the wrong tree in the wrong place, linked to interactions with air pollution, soils, water resources and the riparian environment. These threats are considered below, along with how woodland policy and management practices have evolved to minimise them and secure woodland water benefits.

6.2 Impacts of Woodland Management

Cultivation, drainage, road construction, fertiliser and pesticide use, and harvesting, all pose a risk of water pollution (Nisbet 2001). Studies in Wales and elsewhere in the 1970s and 80s showed how these practices can seriously degrade water quality and disrupt water supplies (Stretton 1984; Richards 1985). The primary issue is soil disturbance causing increased erosion and sediment delivery to watercourses, resulting in water turbidity and siltation (Nisbet 2001). 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.

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 (Forestry Commission 1988). There have since been four revisions, culminating in the

incorporation of the guidelines into the UK Forestry Standard (UKFS) in 2011 (and reviewed in 2017), along with a set of legal and good forestry practice requirements (Forestry Commission 2017).

Evidence from a range of studies, including several in Wales, has shown the guidelines to be fit for purpose, addressing the risks posed by individual management operations, including on highly sensitive sites (NRA 1990; Orr 1990; Marks and Leeks 1998; Neal and Reynolds 1998; Nisbet et al. 2002). All UK water regulators support the effectiveness of the guidelines, although recognise the need for continued training and testing to secure appropriate implementation. Occasional sediment pollution incidents have occurred and been traced to deficiencies in practice. This led to the introduction of supplementary guidance in 2019 in the form of a Forestry Commission Practice Guide (Forestry Commission 2019). The Guide is aimed at practitioners and explains what they need to do to comply with the UKFS requirements and guidelines, including highlighting the importance of good operational and contingency planning.

6.3 Impacts of Woodland Design and Location

There are a number of threats to the water protection function of woodlands that are linked to woodland design and location, namely greater acidification, nitrogen leaching, increased dissolved organic carbon/water colour, reduction in water resources and degraded hydromorphology. Each of these is considered below.

6.3.1 Acidification

The role of forestry in surface water acidification has been a major water quality issue in Wales, primarily associated with the planting of extensive conifer plantations within acid-sensitive upland areas in the 1950s and 1960s. This subject was reviewed by Nisbet and Evans (2014), which forms the basis of the following assessment.

Forestry is known to influence the degree of acidification, principally due to the ability of forest canopies to capture more acid sulphur and nitrogen pollutants from the atmosphere than other types of vegetation. Pollutant scavenging is thought to have peaked in the 1970s when emissions were greatest and planted forests reached canopy closure. This led to surface waters draining catchments dominated by forestry being more acidic, with higher concentrations of non-marine sulphate, nitrate, aluminium and/or hydrogen (lower pH) (Harriman and Morrison 1982; Stoner and Gee 1985).

The introduction of emission control policies in the 1980s achieved major improvements in air quality. This has led to marked chemical recovery and increasing evidence of biological recovery in acidified lakes and streams across all affected regions of the UK (Kernan et al. 2010). Recovery has continued to 2020, with many formerly acidified lakes and streams now returning to positive alkalinity values, although it is thought that most have not yet returned to their pre-acidification status. There is also uncertainty about how the recovery process will be affected by future nitrogen deposition and climate change.

Monitoring studies (e.g. the UK Upland Waters Monitoring Network (Kernan et al. 2010) and Welsh Acid Water Monitoring Network (Broadmeadow et al. 2019)) show

forest sites to be recovering in line with their moorland counterparts, with some evidence of convergence in chemistry. Despite this, some forest streams remain more impacted, including having elevated inorganic aluminium concentrations that exceed water quality standards for fish, indicating that the timescale for recovery may take longer (Evans et al. 2014). Modelling suggests that the improvements in air quality will reduce forestry's contribution to acidification to a small margin, such that action to remove existing forest cover or prevent new planting is unlikely to be required to achieve chemical recovery in many cases (Kernan et al. 2010; Helliwell et al. 2014). However, there is a risk that the most acid sensitive of surface waters will remain impacted by the reduced levels of acid deposition, requiring continued restrictions on new planting and forest restocking.

Appropriate controls and measures are in place, including catchment-based critical loads assessments and site impact assessments to protect the most acid sensitive waters from any potential forestry effect (FC 2014). A recent assessment of results from the Welsh Acid Waters Monitoring Network suggests that these measures are effective at protecting vulnerable waters and fisheries from forestry related acidification (Broadmeadow et al. 2019). Nevertheless, since biological recovery is slow, continued monitoring is essential to demonstrate that existing measures remain fit for purpose and inform the need for future revisions to guidance on good practice.

6.3.2 Nitrogen leaching

Nisbet and Evans (2014) also evaluated the impacts of forests and forest management on nitrate leaching. In general, nitrate concentrations can be up to 2-3 times higher in surface waters draining forested catchments compared to moorland, which is attributable to the pollutant scavenging processes described above, and the subsequent 'nitrogen saturation' of soils. This effect is greatest for mature conifer stands with low nitrogen demand (Stevens et al. 1997), whereas data from younger plantations (including recent data from replanted forests in the Plynlimon and Beddgelert paired catchment studies in Wales) generally show nitrate concentrations as low, or even lower, than their moorland counterparts. This may be partly due to lower rates of scavenging by smaller trees, but is likely also due to the high nutrient demand of the growing forest. Declining nitrogen deposition levels will likely reduce the impact of forests on nitrate leaching, although to date these reductions have been limited. Broadleaf trees have a higher nitrogen demand and tend to recycle nitrogen more efficiently within the rooting zone, reducing the risk of nitrogen saturation and nitrate leaching (e.g. Tipping et al. 2012).

In general, forest felling leads to a pulse of nitrate leaching, as nitrogen is mineralised from decomposing organic matter and not recaptured via plant uptake. This effect was clearly seen in felling studies at Plynlimon, with a duration of around 2-5 years (Neal et al. 2004), although a larger scale study across upland Wales by Neal and Reynolds (1988) found that the effect only occurred in 15-20% of cases, and was thought to depend on soil type. The extent of ground vegetation may also be important in providing short-term retention of available nitrogen within the forest ecosystem, similar to the role of winter cover crops in agricultural systems.

Finally, major ecological disturbance events such as pathogen attacks can cause large pulses of nitrate leaching as trees die and the retention capacity of the ecosystem is overwhelmed. This phenomenon has been observed at some of the UK's Forest Level II monitoring sites, and very large pulses of nitrate leaching (up to tenfold compared to the pre-event baseline) have been recorded following a major bark beetle attack in the Bohemian Forest, Czechia (Kopaček et al. 2018) and after a large forest fire in Sweden (Granath et al. in press).

With the possible exception of major disturbance events, the ecological impacts of elevated nitrate leaching from forests may be limited; compared to nitrate concentrations observed in agricultural runoff, those observed in surface waters draining forests are low, and unlikely to contribute significantly to downstream eutrophication. On the other hand, there is growing evidence that some upland surface waters are nitrogen-limited for parts or all year (Maberly et al. 2002; Mackay et al. 2020), suggesting some potential ecological impact here. Higher nitrate leaching may also contribute to the acidification issues discussed in the preceding section, although given the strong recovery of acidified UK surface waters now being observed, and the relatively minor contribution of nitrate to current acidification, this influence is likely to be small in most instances. Neal and Reynolds (1988) showed how the risk of nitrate leaching following clearfelling could be controlled by limiting the extent of the operation to <20% of a catchment within any three-year period. This measure has been adopted as a UKFS water guideline (FC 2017).

6.3.3 Dissolved organic carbon/water colour

Rising trends in Dissolved Organic Carbon (DOC) that imply increasing water colour levels have been widely reported across upland parts of the UK, wider Europe and in North America (Monteith et al. 2007). Levels are increasingly impacting on drinking water supplies by raising costs of water treatment. The increase in DOC is generally considered to be a response to declining acid deposition, as decreased acidity and ionic strength leads to a higher solubility of organic matter in the soil (Monteith et al. 2007; Evans et al. 2012). However, it is possible that a range of other factors including climate change and variation, nitrogen deposition, land-use and disturbance events, have either exacerbated or lessened the rate of DOC increase in some situations.

The role of land-use as a potential influence on DOC trends was recently reviewed as part of the NERC-Scottish Water FREEDOM project (Williamson et al. 2020). With regard to the role of plantation forestry, this review identified a number of studies in the UK and Ireland showing higher DOC concentrations in streams draining forestry than in those draining adjacent moorland (Drinan et al. 2013; Feeley et al. 2013; Gough et al. 2012), although other studies and reviews are equivocal (Chapman et al. 2017; Shah and Nisbet 2017).

The strongest evidence for a forestry impact on DOC levels in water is for sites on peat soils, with much weaker evidence of an effect on mineral or organo-mineral soils (Shah and Nisbet 2017). A targeted sampling programme of streams draining afforested versus unafforested blanket bog in Northern Scotland for the FREEDOM project supports the conclusion that peatland afforestation increases catchment DOC export, and further suggests that this is largely due to additional DOC being

generated from the forest litter layer, rather than a change in DOC production within the peat itself (A. Pickard et al. in prep.). This is consistent with a recent Swedish study suggesting that the expansion of forest cover, and resulting accumulation of surface organic matter, has contributed to increased DOC concentrations in lake waters over an 80-year period (Kritzberg 2017). On this basis it could be argued that, notwithstanding the potential impacts on drinking water treatment, higher DOC export from forested areas is a positive indicator of carbon accumulation in the soil.

Williamson et al. (2019) also considered the potential impacts of forest management activities on DOC losses to water, notably harvesting. Again, several studies have shown a positive impact, including Cummins and Farrell (2003), who found increases in ditch DOC of up to 50 mg l⁻¹ after felling in Ireland. Similar, although much smaller, increases have been observed within catchment streams elsewhere in Ireland (Drinan et al. 2013; Ryder et al. 2014), and in Scotland (Zheng et al. 2018; Shah and Nisbet 2019); Canada (O'Driscoll et al. 2006) and Sweden (Schelker et al. 2012). Schelker et al. (2012) noted that DOC fluxes increased more than concentrations due to a concurrent increase in discharge following clearfelling. On the other hand, a Finnish study concluded that forestry operations had a rather limited effect, contributing to <1% of DOC export to waters (Palviainen et al. 2016).

A recent study by Shah and Nisbet (2019) found that large-scale felling on peatlands had the greatest impact, whereas phased felling had little or no detectable effect on runoff DOC and other water quality parameters.

6.3.4 Water resources

Another potential threat concerns the ability of trees to use more water than other types of vegetation due to wet canopy evaporation and/or potentially higher transpiration rates sustained by deeper tree rooting (Nisbet 2005). While this can be beneficial for reducing flood flows (see Section 7.7), less water runoff or recharge can also reduce water resources. The subject is complex, widely researched and still attracts debate (Creed and Noordwijk 2018). Much depends on a wide range of site factors, especially geographical scale, climate, altitude, geology, soil type, forest type, tree species, tree age and the counterfactual land cover. In general: conifers reduce water yield more than broadleaves; differences between individual species tend to be small (although with a few exceptions); reductions are much less for very young and old trees; and the impact on catchment water yield is relatively small (difficult to measure) when less than 20% of a catchment is planted or cleared of forest (Nisbet 2005). The long-term forest hydrology study at Plynlimon in mid-Wales found that while large-scale conifer afforestation in the upper Severn initially reduced water yield by 10-15% compared to the adjacent moorland upper Wye, a programme of forest redesign and felling reduced the difference to a margin of 1-2% (Hudson et al. 1997). The UKFS manages the potential threat to water resources by requiring consultation with water regulators and companies where large scale planting is proposed within sensitive catchments, including consideration of the effects of climate change.

The wet climate of upland Wales means that water resources are less under pressure than in other parts of the UK and so less vulnerable to a forest effect. However, the impermeable geology means that seasonal low river flows become

an important issue during extended dry periods. The generally greater water use by trees could be expected to reduce low flows but much depends on the nature of local soils and geology. Research suggests that upland conifer forests on impermeable geology have a relatively small effect on these flows, with water use effects limited by the small size of sub-surface water stores and offset by impacts of cultivation and drainage enhancing low flows (Nisbet and Stonard 1995; Robinson et al. 2003).

Conceptually, woodland creation on poorly structured soils could increase low flows by improving soil infiltration, leading to a greater proportion of net rainfall draining to depth, rather than generating rapid runoff (Garcia-Chevesich et al. 2017). Similarly, the presence of riparian and floodplain woodland are known to slow the flow and enhance flood water storage, and the subsequent release of these waters could help to maintain dry season flows (Ngai et al. 2018). Observed data are lacking to quantify such effects but both could apply to parts of Wales.

6.3.5 Hydromorphology

The water protection function of forests is threatened by the legacy of planting conifer forest too close to watercourses. This resulted in excessive shade leading to poor channel morphology such as eroding banksides and shallow watercourses (Broadmeadow and Nisbet 2004). The UKFS addresses this issue by recommending bankside clearance of conifers within riparian buffer zones and promoting the establishment of an open canopy of native riparian woodland (FC 2017). Much progress has been made in removing riparian conifer trees across upland Wales but a lot more needs to be done to secure the establishment of a network of native riparian woodland to benefit the freshwater environment, including the provision of dappled shade to limit climate warming (Broadmeadow et al. 2010).

6.4 Benefits of Woodland Creation

The success of the UKFS in securing the water protection function of forests has promoted the potential benefits of woodland creation for tackling the much greater threat of diffuse pollution from agricultural land use (Nisbet et al. 2011). Agriculture is often associated with frequent soil disturbance, soil damage, increased erosion and high inputs of nutrients and chemicals. Despite recent improvements to farming practice, many agricultural activities typically generate significant losses of sediment, nitrate, phosphate, pesticides and/or Faecal Indicator Organisms to the water environment (Collins and Zhang 2016). These generate diffuse pollution and cause around a quarter of river water bodies in Wales to fail to achieve good ecological status (NRW 2013). This includes 21% of river water bodies not meeting good status due to phosphorus pollution, much of which is derived from diffuse agricultural sources (NRW 2016). Food security often prevents large-scale forest planting to tackle the issue but there is significant scope for targeted woodland planting or the use of agroforestry to make a difference (Stutter et al. 2012).

Targeted planting works because the sources of pollutants, the pathways by which they move to watercourses and the vulnerability of downstream water users are spatially variable (Stutter et al. 2020). For example, soils vary in their vulnerability to damage, ability to retain nutrients and chemicals, propensity to generate rapid

surface runoff, and degree of connectivity to watercourses. Once pollutants are mobilised in water or the air, they tend to move along preferred pathways such as surface channels, drainage lines and the prevailing wind direction. Water receptors such as groundwater boreholes draw water from distinct areas and depths of ground. Tree planting on, around, across or along these key pollutant sources, pathways and receptors can potentially be very effective at reducing pollutant delivery to watercourses and water supplies, thereby markedly improving water quality for a limited land take (Nisbet et al. 2011).

Planting across or along pollutant pathways in the form of buffer areas or strips offers a dual water quality benefit (Stutter et al. 2020). Firstly, the pollutant input associated with the previous agricultural activity on this sensitive area of ground will be removed. Secondly, there is a significant opportunity for the planted trees to act as a barrier to the movement of pollutants from upslope or upwind. Pollutants can be retained or removed by: runoff being encouraged to infiltrate into the better structured soil of the buffer; by filtration or surface deposition as surface runoff passes through the surface leaf litter layer or is held in surface depressions created by tree roots; by root uptake and incorporation in tree growth; or by interception and capture as the polluted airflow passes through the tree canopy. Riparian buffers have the added benefit of removing pollutant inputs and reducing damage to this very vulnerable and connected area of land, as well as providing scope for planted trees to remove pollutants carried downstream within the main watercourse during out-of-bank flows (Broadmeadow and Nisbet 2004). A recent review of the concept of 3-D buffers found wooded and engineered buffers to be the most effective at reducing diffuse pollution from adjacent land (Stutter et al. 2020).

It is difficult to predict the barrier effect of buffer areas since this is influenced by many design and management factors, as well as by the nature and type of pollutant and the scale of intervention. However, studies have shown that with good design and appropriate management, tree buffer areas can be highly effective at reducing pollutant delivery from upslope land, with efficiencies of up to 100% possible for certain pollutants (Stutter et al. 2020). There is strong logic that the benefits of woodland buffers should be scalable to reduce diffuse pollution at the catchment level but there is a lack of observed data quantifying the impact of riparian buffer networks.

A review of 65 studies found buffer width to be a dominant factor, with pollutant removal generally decreasing with declining buffer width (Perez-Silos 2017). There are a number of important factors that act to reduce the efficiency by which tree buffers can remove diffuse pollutants from upslope land. These include increasing volume of runoff, increasing pollutant load (especially if the quantity of pollutant draining from upslope land exceeds the capacity of the trees and soil to remove or process it), the presence of very young or old trees, poor tree condition or weak tree growth, wider tree spacing, and the presence of any bypass channels such as drains. Great care is therefore required in the design and management of buffer areas to cope with local pollutant loads and to achieve and maintain high levels of pollutant removal.

Opportunity mapping can help identify and prioritise water bodies and component areas of land for targeted tree planting and forest management measures to reduce

water pressures (Broadmeadow et al. 2012). It thus supports integrated catchment management and helps guide and underpin the development of payments for forest for water schemes. The approach is based on using Geographical Information Systems (GIS) and integrates a wide range of spatial datasets to determine the most effective locations for changes in land use and management to meet Water Framework Directive (WFD) targets and generate multiple benefits for society.

6.5 Summary for Water Quality

There is high confidence in the water protection function of a woodland cover, 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.

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 at the reach scale, 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.

7. FLOOD MITIGATION

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This section provides a summary of existing research and evidence relating to the benefits and risks of woodland creation and management for mitigating downstream flooding. As well as evidence of causality and the magnitude of impact, the review considers the role of key factors such as catchment scale, flood size, timescale and longevity of effectiveness, effect modifiers and risks. The main sources used for this summary were the following recent reviews:

- The 2018 *Working with Natural Processes (WWNP) – Evidence Directory* by the Environment Agency (Burgess-Gamble et al. 2018) and the related literature review *Working with Natural Processes to reduce flood and coastal erosion risk* (Ngai et al. 2017).
- The UKCEH systematic literature review addressing the question *do trees in UK- relevant river catchments influence fluvial flood peaks?* This was based on a search of peer-reviewed literature, identifying studies with similar climatic characteristics as UK catchments, but discounting those that did not specifically report the impact of decreasing or increasing tree cover on river floods (Stratford et al. 2017).
- Technical Annex 9: Flood mitigation. In Environment and Rural Affairs Monitoring & Modelling Programme (ERAMMP): Sustainable Farming Scheme Evidence Review. Report to Welsh Government (Contract C210/2016/2017). Centre for Ecology & Hydrology Project NEC06297.ERAMMP Report-9. (Keenleyside & Old 2019).

7.1 Impacts of woodland creation and management on downstream flooding

Forests and woodlands have long been associated with an ability to reduce flood flows (Anderson et al. 1976; McCulloch and Robinson 1993) but the subject is complex and multifaceted. The potential for a tree cover to reduce rainfall-runoff is soundly based on scientific understanding of how trees affect several physical and biophysical processes. The processes are reviewed in Ngai et al. (2017) and summarised as:

- i. The higher evapotranspiration rates of trees compared to shorter vegetation, especially the evaporation of water from wet canopies during and after rainfall, often referred to as interception loss. On an annual basis, canopy interception can reduce the amount of rainfall reaching the ground by 25-45% under conifer trees and by 10-25% for broadleaves (Nisbet 2005). Canopy interception is an important process in Wales due to the wet climate, with an average 29% loss recorded under conifer forest at Plynlimon (Marc and Robinson 2007). The percentage reduction is thought to be much less on storm days generating floods (e.g. a maximum of 7-8 mm for conifers predicted by modelling (Calder 2003)), but a recent assessment (pers com,

unpublished) of plot measurements from many studies suggests that interception can reduce storm rainfall by 10-30%, including for very large storms (300-400 mm rainfall). The higher evapotranspiration rates of trees also typically result in drier soils, potentially providing greater belowground flood water storage (several 10s mm) until soils become saturated.

- ii. The higher infiltration rates of woodland soils, especially compared to those under agriculture that are subject to surface sealing, compaction or poaching by livestock grazing and arable cropping (Bracken & Croke 2007). A tree cover protects soils from physical disturbance and together with leaf fall and tree rooting, helps build soil organic matter and creates good soil structure with 'macro-porosity' (Neary et al. 2009). Woodland soils are characterised by high infiltration rates usually of the order of 100s or even 1,000s mm/hr (Archer et al. 2013; Chandler et al. 2018), which are rarely exceeded by rainfall intensity and thus much less likely to generate infiltration-excess overland flow (Carroll et al. 2004). Soil infiltration rates were found to be 67 times higher within young native woodland shelterbelts compared to adjacent grazed pasture soils at Pont Bren (Marshall et al. 2014).
- iii. The slower rates of surface runoff under trees due to the physical barrier presented by tree butts, surface roots, deadwood and leaf litter. This hydraulic roughness is greatest for dense/multi-stemmed stands of trees, with values for willow coppice >5 times that of short grass (Chow 1957). The entry of deadwood into woodland watercourses also increases channel roughness, especially where it collects and forms leaky woody structures. The latter are very effective at slowing down and pushing flood waters out of bank onto the floodplain, enhancing flood water storage.
- iv. The lower erosion rates of well managed woodland soils (Collins & Walling 2007), reflecting the ability of a tree cover to protect soils, slopes and river banks from disturbance, as well as improve soil structure and increase soil strength through organic matter inputs, tree rooting, soil drying and reduced surface runoff (Benito et al. 2003). Sediment delivery to watercourses is increasingly viewed as an important factor in flood risk management (McIntyre & Thorne 2013). Downstream siltation reduces flood conveyance and increases the risk of local flooding, leading to demand for more dredging with consequent environmental problems.

The ability of the above processes to reduce peak flows is supported by small-scale (headwater) catchment studies, although the majority of these examine the impacts of woodland felling rather than new planting. Guillemette et al. (2005) reviewed 50 observation-based studies from across boreal and temperate regions of the world and found changes to peak flows (return periods ranging from 1.5 to 100 years but most between 1 and 10 years) to range from 0 to +170% in 49 of the 50 studies. A sizeable component of the variation in the results could be attributed to the percent of the catchment felled, with the greatest increases in peak flows associated with >70% felling. These findings contrast with those from the two main catchment felling studies in GB, including Plynlimon in Wales, where felling of 26-50% of three sub-catchments and 32% of the upper catchment of the River Severn had no detectable effect (Robinson & Dupeyrat 2005). The disparity in the results is considered to be due to the restricted scale and extended time period over which the felling was carried out in

the GB studies, with a maximum of 20% of a catchment felled in any one year and felling extending over a period of between 5-17 years. It is known that the effects of clearfelling decline over time due to the rapid regrowth of restocked crops (Iroume et al. 2010).

Due to the length of time it takes for woodlands to become established, only a small number of catchment studies have measured the impact of new planting on flood flows. This includes a study by Fahey & Jackson (1997) in New Zealand of the impact of 67% afforestation by Radiata pine on previous tussock grassland. After 10-12 years of tree growth, mean flood peaks had fallen by between 55% and 65% across the three peak size classes recorded, while quickflows had decreased by 45-55%. At Chiemsee in southern Germany, conifer planting on farmland was measured to reduce peak flows by around 100% by the time the trees reached 20 years age (Robinson et al. 2003). The only UK headwater catchment study is at Coalburn in the north of England, where 90% conifer afforestation in 1972 produced a 5-20% reduction in peak flows, declining with increasing peak size (Birkinshaw et al. 2014). A shift in flood frequency was also noted, with events of a return period of 20 years reducing to 13 years.

As both catchment size and flood peak increase, the evidence for a woodland impact on flood flows becomes weaker. This is due to a number of factors, particularly methodological issues, including: the difficulty of measuring changes to very infrequent events in normal project timescales; the smaller woodland footprint as catchment size increases; the increasing problem of controlling for impacts of wider land use change and management in larger catchments; and background shifts in flood frequency due to climate change. The systematic review by Stratford et al. (2017) found few observation-based studies that assessed impacts of woodland planting or felling on large flood peaks and those that did were inconclusive.

In view of the methodological difficulties, most studies examining the impact of woodlands on large floods and in large catchments have been model-based. Hydrological, hydraulic and combined models allow the effects of different land use change scenarios to be explored in detail and upscaled to large catchments. Models can be process-based but data needs become more challenging with increasing catchment scale. Another issue is that present models often focus on surface roughness or lump processes together, and frequently don't state parameter value ranges. These difficulties, combined with the lack of observation-based studies to validate results, introduces significant uncertainty.

Stratford et al. (2017) found no clear evidence in model-based studies of increasing woodland cover having a significant impact on large floods, with equal numbers of studies finding a decrease or no effect. However, a significant difficulty faced by reviewers was not being able to consider the contribution of effect modifiers, such as the extent of woodland planting or felling in the studied catchments. Another problem was the lack of consistent terminology and definitions between published studies in what constituted a small or large flood or catchment. For example, large floods were variably defined in reviewed studies as having return periods of between 5 and 200 years.

Two model-based studies were undertaken as part of the Pont Bren project in mid Wales. The first involved a physics-based model and predicted that complete

afforestation (with deciduous trees) of the 12 km² headwater catchment would reduce a large flood peak (140 mm of rainfall over two days, with an estimated return period of 180 years) by an average of 36% (with 95% confidence intervals of a 10% and 54% reduction) (McIntyre et al. 2012). This contrasted with the planting of woodland strips across 7% of the catchment, which was predicted to reduce the peak of a severe flood by 5%. A second runoff generating model used regionalised values of flow indices from national datasets and predicted that complete afforestation would reduce a flood peak with a 10 year return period by 12-15% (Bulygina et al. 2009). The latter results were considered less reliable than the former due to use of national scale generalisations, rather than local knowledge and data, as was the case with the first model.

7.2 Role of Key Factors

A number of key factors influence how woodlands can affect flood flows. These are summarised below from Ngai et al. (2017):

7.2.1 Catchment scale

There is high confidence based on strong process understanding and observational studies that woodland can reduce flood peaks in small catchments (<10 km²). There is medium confidence based on logic and modelling studies for this effect to extend to medium-sized catchments (10-100 km²) but low confidence in the scope for woodlands to reduce flood peaks in large catchments (>100 km²), based on the lack of observed data, generally small footprint of woodland cover and greater role of river channel processes downstream. In reality, due to the difficulty and practicality of achieving a sufficient scale of land use change, the scope for woodlands to reduce flood peaks decreases with increasing catchment size.

It is very difficult to detect changes to flood peaks when the extent of woodland planting or felling is <15-20% of a catchment (Bosch & Hewlett 1982; Cornish 1993; Stednick 1996). This is due to the limited size of the effect and difficulty of quantifying it against measurement errors.

7.2.2 Flood size

The effect of woodland on flood peak can be expected to decline with increasing peak size. This arises from the declining influence of woodland soil infiltration, belowground water storage and surface roughness benefits with increasing soil saturation and depth of flood water. The main exception appears to be woodland interception loss which is maintained with increasing storm/flood size (see above). There is high confidence that woodland can reduce small flood peaks (<10 year return period), medium confidence in reducing medium flood peaks (10 to 100 year return periods) and low confidence in reducing large flood peaks (>100 year return events).

7.2.3 Woodland placement

The placement of woodland within catchments impacts on its effectiveness for reducing flood flows. For example, targeting/concentrating woodland cover within

specific tributary catchments can have a positive or negative effect depending on the scope for tributary synchronisation or desynchronisation to moderate downstream flood peaks. Dixon et al. (2016) modelled the effect of floodplain woodland restoration in the New Forest and showed how flood peak desynchronisation may reduce downstream flood peaks by up to 19%. In general, the more rapid the tributary response and the closer the location to the community or asset at risk of flooding, the greater the scope for the woodland delaying function to negate or reverse any flood storage effect (Odoni & Lane 2010). However, the generally wide distribution of woodland cover and high spatial variability of rainfall patterns make synchronisation or desynchronisation effects highly uncertain.

The relative position of the woodland in a catchment is another important factor. Woodland placed across or along runoff pathways has the greatest potential to interact with and thereby retain or slow flood runoff. This includes cross-slope woodland, which can intercept upslope surface runoff and enhance soil infiltration and belowground storage. The long perimeter and edge effect of cross-slope woodland increases water use and soil water deficits (Nisbet 2005). Riparian and floodplain woodland are similarly well placed to maximise flood water retention, although primarily aboveground storage, as a result of high hydraulic roughness pushing flows out of bank and retarding passage across the floodplain. Many studies have modelled the effects of floodplain and riparian woodland plus associated large woody structures on flood peak size and timing and shown these to exert a small (1-8% reduction and 15-140 min delays) but potentially significant effect, depending on woodland extent and location (Ngai et al. 2017). Floodplain woodland is effective only if it is able fully interact with flood flows, which is likely to require the removal of any existing embankments or other barriers (Burgess-Gamble et al. 2018). Riparian and floodplain trees can also maintain high evaporation losses during summer periods, especially water-demanding species such as willow and poplar, enhancing belowground flood water storage (Brown 2013).

7.2.4 Timescale and Longevity

Woodland cover is a long-term and secure measure for reducing flood risk since woodland removal is subject to a Felling Licence and normally conditional on replanting. The different woodland processes that contribute to the flood benefit vary in timescale to become effective. The quickest to establish are improvements in soil infiltration, which can be delivered within a year (Marshall et al. 2014) due to the cessation of agricultural pressures on the soil, effects of soil cultivation and rapid root growth. Woodland water use and notably the canopy interception effect is much slower to develop, depending on site fertility, tree species and management system. The effect gradually develops and is largely established by the stage of canopy closure at around 15-20 years (Nisbet 2005). Surface roughness also evolves over time, initially dominated by the growth of ground vegetation and shrubs (5-10 years), followed by the establishment of trees (10+ years) and in the longer term (decades), by increasing inputs of deadwood. The timeframe for increasing surface roughness can be shortened by planting faster growing tree species, including short-rotation coppice, and by constructing features such as leaky woody structures within watercourses. Reductions in soil erosion and sediment delivery can occur quickly in

response to the cessation of agricultural activities, while river bank protection takes longer to develop depending on the growth rate of bankside trees.

7.3 Effect Modifiers

The effectiveness of woodland for reducing flood flows is influenced by many factors, which are summarised below, based on Ngai et al. (2017):

- i. Climate - affects woodland water use and therefore the magnitude of the soil water deficit and thus potential for belowground water storage and scope to reduce summer floods. The wet and windy climate of upland Wales will limit the soil water storage benefit but increase the contribution of wet canopy evaporation, which could become more important with climate change.
- ii. Soils - soil type and depth influence the soil water storage capacity and availability of water to sustain woodland water use during dry periods, and thereby the size of the woodland effect. Soil type also determines soil vulnerability to damage and thus the relative size and significance of the soil infiltration benefit.
- iii. Geology - exerts a strong control over runoff pathways and the ability of woodland to affect these. The more porous the geology, the less scope for woodland processes to affect surface runoff, particularly by enhanced infiltration and hydraulic roughness. The predominantly impermeable nature of the geology of Wales will support these woodland benefits.
- iv. Type of land use being replaced - the lower the water use, the more damaged the soil and the lower the hydraulic roughness of the baseline land use, the greater the net benefit of woodland creation for reducing flood runoff.
- v. Woodland extent - In general, the larger the extent of woodland cover, the greater the expected impact on flood peaks. This simply reflects the footprint of the woodland at the catchment scale and thus the relative contribution of the different woodland processes.
- vi. Woodland type - strongly affects woodland water use, which is greatest for conifers (interception losses typically twice that for broadleaves). This results in higher and more sustained soil moisture deficits under conifer, with a greater capacity to reduce flood runoff. Water use differences between tree species appear to be relatively small, except for certain species such as willow and poplar in wet locations.
- vii. Woodland design – influences woodland water use and particularly hydraulic roughness. Water use is generally greatest for closed canopy woodland, with open canopy, low density woodland expected to intercept less water and have wetter soils. Hydraulic roughness increases sharply as tree spacing reduces from 2.5 m to 1.0 m, although this is partly offset by the accompanying reduction in the amount of ground vegetation and shrub layer due to shading. Tree diameter, number of stems per tree, alignment of trees, the amount of deadwood on the ground and the size of tree butts and related microtopography, also influence hydraulic roughness. Woodland age can have a significant influence on water use, with transpiration rates greatest for actively growing young stands and diminishing with old age (Vertessy et al. 2001). Tree age and species can also affect soil infiltration rates (Archer et al. 2015).

- viii. Woodland management practices - cultivation and drainage, road construction and felling/harvesting operations can all increase the volume and/or speed of surface runoff and thereby reduce or temporarily remove woodland benefits. Much depends on the nature/standard and scale of practice, with the poorer and more extensive the operation, the larger the impact. Old style deep ploughing and drainage can speed up surface runoff, reducing time to peak and increasing peak height, although the effect declines with increasing peak size and can be difficult to detect for flows greater than the mean annual flood (Archer & Newson 2002). Developments in good practice such as the use of shallower forms of linear cultivation, gentler drain gradients and discharging cultivation channels and drains to buffer areas are expected to reduce the impact on peak flows, although there is a lack of both measured and modelled data to quantify this. Runoff from woodland track and road surfaces and associated road drains can also increase peak flows (Jones 2000), while good practice measures such as disconnecting road drainage from natural watercourses helps to mitigate the effect.
- ix. Clearfelling has potentially the biggest impact of all forestry practices by removing tree cover, reducing water use and re-wetting soils, while soil compaction and rutting associated with poorly managed timber harvesting can greatly reduce soil infiltration and increase overland flow and sediment delivery to watercourses (Birkinshaw et al. 2011). These effects can be partly offset by harvesting residues/brush, which can exert a significant interception loss, increase surface roughness and help protect soil from ground damage (Nisbet 2001). The main way of controlling the impact of clearfelling is to restrict the scale of the activity at the catchment level. Since woodland regrowth is generally rapid, the water use effect can be largely restored within a ten to fifteen-year period, depending on the speed of replanting. The tendency in some parts of GB to leave up to a five-year fallow period to control weevil damage will extend the recovery period. Limiting the scale of clearfelling to <20% of the catchment in any 10 to 15 year period will minimise the impact and make it unlikely to be detectable (Stednick 1996).

7.4 Risks

The main risks to woodland flood benefits are those relating to woodland survival and growth, such as extensive pest and disease outbreaks, windblow and fire. The latter probably poses the greatest threat since it has the potential to seriously affect all woodland processes, including reversing soil benefits by the burning of soil organic matter and increasing soil hydrophobicity. These impacts will be greatest in the short-term and largely moderated in the medium-term by woodland regrowth and potentially, by woodland redesign.

The risk of poor management practices increasing flood runoff is low providing the UK Forestry Standard and underpinning requirements and guidelines are implemented. The independent UK Woodland Assurance Standard (UKWAS) provides a check on good practice.

A number of specific risks are associated with riparian and floodplain woodland that can contribute to increased flooding. This includes their ability to reduce channel conveyance and back-up floodwaters, block downstream structures by the washout

of woody debris, and increase flood peaks by synchronising sub-catchment flows. These risks can be controlled through care over woodland placement and management. A related issue is the stability of large woody structures within watercourses and maintenance needs to maintain their effectiveness. This topic, along with liabilities, is covered by recent guidance (ADEPT 2019).

The higher water use of woodland, especially conifer, can pose issues for water resources, particularly for large-scale woodland within drought prone areas (see Section 6.3.4). This is unlikely to be a problem across much of upland Wales.

Lastly, climate change may limit woodland flood benefits by increasing peak flows and affecting woodland survival and growth. Kay et al. (2019) predicted that Natural Flood Management (NFM) measures in general are much less likely to be able to offset the impacts of climate change for later time periods and for higher emission scenarios, depending on catchment type and location.

7.5 Summary for flood mitigation

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 km²). 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 km²), but much depends on the extent, nature and placement of woodland and management operations.

Logic implies that woodland effects could extend to large catchments (>100 km²) 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.

8. LANDSLIDES

The potential for woodland creation to reduce risk & mitigate increasing risk.

8.1 Impacts of woodland creation & management on landslides & soil erosion

There is considerable evidence that trees and shrubs can effectively reduce erosion, landslides and rock-fall from vulnerable slopes (Norris et al. 2008; FAO 2011). Additionally, significant evidence exists from around the world demonstrating that deforestation increases the risks of potentially fatal landslides, often triggered by low frequency, high magnitude events (Glade 2003). Effects of climate change are anticipated to result in an increased frequency of high intensity rainfall events that can trigger landslides and accelerate soil loss (IPCC 2014). Evidence from the USA indicates that each 1% increase in annual rainfall can increase erosion rates by 1.7% (Pruski and Nearing 2002).

Landslides, rocks, debris flows and eroded soil can potentially impact infrastructure (e.g. rail lines, electricity, gas pipelines, housing) and also inhabited areas including housing (Norris et al. 2008). These events threaten the safety, economic viability and well-being of communities. In a UK context, the role of landslides and forestry has been identified by Foster et al. (2012), who developed a hazard assessment methodology to assess the potential risks to infrastructure. This work aimed to identify and characterise the hazards, pathways and elements at risk. It was used by the National Forest Estate in Scotland to assess options for unstable slopes with one option being the silviculture where trees could stabilise slopes (Humphreys et al. 2015). In addition, landslide damage may remove the soil resource, block rivers and increase river sedimentation. 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 (See UKFS, Forestry Commission 2017).

With respect to the forest life cycle there are key points in the cycle where an increase in landslides and soil erosion may occur. The planting of forests and harvesting (deforestation) will change the hydrological cycle of the land. Vegetation on vulnerable slopes provides physical protection of the soil by canopy interception of rainfall (evaporation and attenuation), root water uptake reduces soil water pore pressure through storage of water and transpiration) and improved soil cohesion through root reinforcement (Meijer, et al. 2016; 2019; Cohen and Schwarz 2017; Douglas et al. 2011). The improvements these mechanisms provide to slope stability vary depending on the type and density of the vegetation (Danjon et al. 2007, Stokes et al. 2008). The protection provided will also vary through the year, with deciduous species providing greater canopy interception when in leaf than when leafless in winter months, and with all species taking up the most soil water during spring and summer months. Herbaceous species and grasses do provide some protection to the soil, but this is increased greatly by the incorporation of shrubby species and trees with woody roots. The roots of woody species provide a much stronger, and commonly deeper, matrix in the soil, allowing the soil to be held together and

anchored better to deeper layers and underlying rock than would be the case with herbaceous vegetation alone.

An increase in the risk of landslides may be expected during planting until the development of reasonable vegetation cover and root systems have developed. However, the implementation of management practices can lead to decreased landslide activity. Dhakal and Sidle (2003) suggest that maintaining a vigorous understory vegetation, partial cutting, increasing rotation length, provision of leave areas are effective in minimizing this landslide potential. A common concern is for trees being uprooted during storms leading to increased erosion (Nicoll et al. 2005) as well as the transport of woody debris downslope, blocking culverts and drains during storm events (Rayner and Nicoll 2012). There are therefore benefits of using relatively slow growing trees or shrubs that have low wind-throw risk on vulnerable slopes (Norris et al. 2008, Rayner and Nicoll 2012). Pure stands of fast growing, tall conifers are considerably more vulnerable to uprooting in storms (Gardiner et al. 2013) and are therefore less appropriate for soil protection (Rayner and Nicoll 2012). In addition, clear-fell-replant regimes add to the vulnerability of slopes as they leave the site without adequate cover or root reinforcement for several years between rotations.

Logging has been implicated in increasing the density, frequency and magnitude of landslides. Jakob (2000) reported a nine-fold increase in the number of landslides in logged terrain compared to undisturbed forest in British Columbia, Canada. Failures in logged terrain were found to occur on shallower slopes than those of unlogged terrain as fewer slopes > 40° had been logged. Concave and straight slopes were found to be more susceptible to landslide initiation.

Interactions between engineering, infrastructure placement and landslides within forests need to be considered. Jakob (2000) suggested that many landslides were caused as 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. Forest roads need to be well maintained with adequate culverts to avoid wash-outs that can lead to debris flows.

Geology type and depth of soil are large determinants on the type of landslide produced. Geological lithology was implicated in landslide occurrence as reported by Jakob (2000), but often the influence is not clear because other confounding factors may impact geology including slope, and planting strategy.

8.2 The context and risks situation specific to Wales

Landslide occurrence is normally associated with three triggering mechanisms including (i) water, (ii) seismic activity and (iii) volcanic activity. In the case of Wales (ii) and (iii) are unlikely but landslides, associated with high precipitation amounts and high intensity events are likely, and in places there is vulnerability because of the history of coal and slate mining leaving unstable ground such as waste tips. This has historical resonance (e.g. Aberfan) and also recent occurrence in 2020 (<https://www.bbc.co.uk/news/uk-wales-51635124>).

In the creation of a new national forest, consideration would have to be given to geology, slope, annual precipitation, likely intensity of precipitation and the likely type

of landslide that may occur (e.g. shallow or deep-seated). Consideration must also be given to whether the new forests would be planted on unstable ground such as slag heaps (e.g. Aberfan). Climate change and an increase in high magnitude events will be a key consideration, particularly the increase in magnitude and intensity of rain events.

A further climate change related event which would need consideration is the recorded increase in forest fires that could help denude slopes of vegetation leading to higher soil pore water pressures, hydrophobic soil surface and soil erosion. Jollands et al. (2011) undertook a review of wildfires in Wales during the period 2000 and 2008 and identified over 55000 occurrences. The impacts of wildfires on landslides has been demonstrated in Italy by Carabella et al. (2019) who identified five parameters including slope, post-wildfire vegetation cover, lithological features bedrock fracturing and geomorphological factors as being key to initiating landslides.

Nicoll (2016) assessed the risks of woodland and forestry production to climate change in the UK. One item was in the selection of the right type of tree with the best rooting system for location. Extending knowledge to assess the right tree to prevent landslides as well as to survive climate extremes in the context of Wales may need to be considered.

With respect to soil erosion and forestry, Wales is fortunate to have had a significant study undertaken over a reasonable period of time at Plynlimon. Increased suspended sediment was found after timber harvesting with the estimated increased annual suspended sediment being ~39 % or 9 t km⁻² yr⁻¹ (Leeks and Marks 1997). Stott et al. (2001) discussed how changes in the hydrology of the Plynlimon catchment after timber harvesting caused a significant increase in main channel bank erosion rates during a two-year period (1995-96), with bank erosion producing 80% of total catchment sediment yield. Increases in total annual stream flow were found after logging, but importantly it appeared that felling meant that low flows were augmented. In addition, felling did not increase storm peak flows suggesting that felling guidelines were effective and that the forest had a limited impact of flooding (Robinson & Dupeyrat (2005). Changes in water temperature, potentially effecting aquatic ecosystems were also found after logging (Stott and Marks 2000).

8.3 Expert opinion on the confidence and acceptance of the evidence.

Considerable resource has been expended by the British Geological Survey (BGS) on developing a National Landslides Database that records past, present and future landslides across Wales. This is added to via consultancy activity and the general public. A report by Conway et al. (1980) is currently the most up to date reference for Welsh landslides, but no specific exercise has been carried out on landslides within Welsh forests. The effects of forestry practice on landslides and soil erosion across the world appear to be fairly consistent, in an extensive peer review literature. For example, in New Zealand where long-term erosion rates have been examined (based on lake sedimentation rates), the effect of historical land-use change across catchments, erosion rates from grazing land were found to be 5 to 6 times higher than they had previously been under scrub, and 8 to 17 times higher than they were

under native high forest (Page and Trustrum 1997). This is supported by recent meta-analysis, where forestry had erosion rates between $\sim 0.001-0.01 \text{ mm yr}^{-1}$, compared to arable systems with $\sim 0.1-100 \text{ mm yr}^{-1}$ (Pruski and Nearing 2002)

However, at the landscape scale, the benefits of woody vegetation and trees on steep slopes has been shown to greatly outweigh the disadvantages. Low mixed woodland maintained as continuous cover, such as can be achieved using native species, may be most appropriate on vulnerable slopes in Wales. Most benefit is expected from establishing and maintaining a mixture of woody species that don't grow tall enough to be vulnerable to wind damage, but that provide a matrix of different root forms and depths (Norris et al. 2008).

9. PROTECTIVE FARM WOODLANDS AND SHELTERBELTS

9.1 Agroforestry

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* – a farm system in which trees and/or shrubs are grown in grazed pasture and where planting patterns can be more varied; and
- *Silvo-arable* – a farm system in which crops are grown between rows of trees and/or shrubs at a spacing appropriate for the use of agricultural machinery.

Within the two main agroforestry systems, 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* made of trees or shrubs, both of which are a type of shelterbelt and can be applied to both silvo-arable and silvo-pastoral systems;
- *rows* of trees or shrubs that are also applicable to both systems;
- *single trees* or *tree cluster* arrangements, best applied only to silvo-pastoral systems. The type of trees planted, the density and arrangement will depend on farmer’s choice, farm location, soils and farmer objectives.

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 and reduced ammonia and nitrogen emissions from housed and free-range animal production facilities.

Woodlands in agricultural landscapes diversify wildlife habitats and can increase woodland habitat connectivity, which enhances biodiversity resilience in the face of climate change (Perks et al. 2019). New agroforestry woodlands require protection from stock browsing during the establishment phase.

9.2 Windbreaks and shelterbelts

Windbreaks and shelterbelts have been used to modify microclimate in agricultural landscapes for centuries because of the provision of physical protection from a thermally stressful environment as generated by wind, sun and precipitation (Brandle et al. 2004; He et al. 2017). Particularly pertinent to Welsh agriculture is the potential for shelter to improve livestock welfare and production efficiency by maintaining thermoneutrality and minimising metabolic energy requirements. Lamb mortality in the UK ranges from 10 to 25% (Mellor and Stafford 2004) and has been reported anecdotally as being as high as 30–40% on individual farms, indeed exposure-related mortality has been shown as a major contributor to neonatal deaths in outdoor-lambing systems (Dwyer 2008; Gascoigne et al. 2017). In addition to the economic costs of neonatal mortality, exposure is recognised as an important welfare issue for livestock (Mellor and Stafford 2004; Dwyer 2008).

The impact of wind speed and evaporation on homeothermic livestock can be additive leading to rapid loss of heat through radiation and conduction (Pollard 2006).

Indeed, lamb mortality rates can exceed 70% in wet conditions where wind speed exceeds 5 ms^{-1} (Obst and Ellis 1977). Cold-exposure impacts upon lambs' cognitive functions and their ability to stand and suckle at birth, resulting in poor lamb vigour and death due to hypothermia and starvation (Dwyer 2008). 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 (Donnelly 1984; Pent et al. 2020a; Pent et al. 2020b Pritchard et al. 2020). Shelterbelts modify microclimate by a combination of slowing the speed of wind that travels through the shelterbelt and increasing air pressure on the windward side whilst decreasing air pressure on the leeward side to create a sheltered zone. The shelter zone is predominantly on the leeward side and encompasses a distance approximately 14 times the height (H) of the shelter. Some shelter (about 2 H) is also provided on the windward side (Gregory 1995). Location, height, and wind porosity are stated as the most important factors to consider when parameterising models of shelter to estimate wind speed reduction (Gregory 1995). Opportunities exist to identify tree species-specific traits that maximise the provision of shelter, and other ecosystem services, to spatially optimise the location of shelter within the agricultural landscape to maximise livestock welfare and production gains.

9.3 Tree fodder as a feed supplement

Tree fodder can also provide an alternative source of nutrition and feed resource, which may become more important as a result of the impact of climate change on plant growth patterns. There is also potential for preserved tree fodder to fill the 'spring gap' when the productivity of new season grass is low (Luske et al. 2018). An evidence-base for nutritional values of temperate tree species is being collated in an online database of nutritional values that can be used to inform species selection (Luske et al. 2017). Traditionally, many species of deciduous trees have been used for fodder, in particular wych elm (*Ulmus glabra*), ash (*Fraxinus excelsior*), silver birch (*Betula pendula*), and goat willow (*Salix caprea*), and research has shown that willow and ash can have organic matter digestibility levels similar to hay and grass silage (Musonda et al. 2009; Pitta et al. 2007). One of the limitations of using tree fodder as a feed is that nutritive value and digestibility peaks in spring and decreases through to autumn (McWilliam et al. 2005).

9.4 Integrated parasite and disease control

Since the 1960s, intensive sheep production has relied on the prophylactic use of broad-spectrum anthelmintic drugs. However, over the last 10 years anthelmintic-resistant worms have become an increasing problem and a significant challenge to control. Alternative parasite control strategies are needed to more effectively control parasitic gastroenteritis (PGE) and reduce the reliance on anthelmintics. Studies investigating the impact of anti-parasitic secondary compounds (e.g. condensed tannins) in pasture sward species (e.g. chicory (*Chichorium intybus*) and birdsfoot trefoil (*Lotus corniculatus*)) have been shown to reduce the presence of parasite faecal eggs and increase livestock live weight gain when compared to a control group fed on a traditional sward mixture of rye grass (*Lolium perenne*) and white clover (*Trifolium repens*). Many species of native deciduous trees contain high levels

of condensed and hydrolysable tannins (e.g. oak (*Quercus* spp.) beech (*Fagus* spp.)) that offer potential use as anthelmintics (Manolaraki et al. 2010; French 2018).

9.5 Ammonia Pollution Capture

Bealey et al. (2016) modelled tree canopy capture of ammonia pollution and evidenced a maximum of 27% of the emitted ammonia was captured for the animal housing source, for the slurry lagoon the maximum was 19%, while the livestock under trees attained a maximum of 60% recapture. They noted that “*Using agroforestry systems of differing tree structures near 'hot spots' of ammonia in the landscape could provide an effective abatement option for the livestock industry that complements existing source reduction measures*”. This research was developed into a free-to-use practical tool to support decision makers maximize the benefits of planting tree shelterbelts for ammonia recapture.⁴

9.6 Carbon Capture and Storage

All forms of agroforestry have potential to sequester carbon, although the benefits will vary depending on soil type, species, planting density and location. Evidence suggests that maximum benefits might be achieved on lowland areas, although potentially at a high agricultural opportunity cost (Perks et al. 2019)

There are multiple ecosystem service benefits from agro-forestry systems: They can improve a farm’s resilience to a changing climate by providing shelter to animals and crops, reducing feed costs, reducing risk of flooding, improving animal welfare, potentially reducing crop pests by housing beneficiary predators, reducing soil erosion and moisture extremes, and diversifying farm income.

9.7 Practical Barriers to Implementation

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 (Slee et al. 2012; Smith et al. 2016). While 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 (Hislop & Claridge 2000). 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 (Slee 2014). The hills and uplands have often been a contested space and this sense of competition appears to remain a powerful discourse among many

⁴ <https://www.farmtreestoair.ceh.ac.uk>

farmers although formal evidence remains limited. For example, a study in Ireland from 1996 to 2006 found that decisions were often based on (intrinsic) 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 (Duesburg et al. 2013).

10. SYNTHESIS OF ECOSYSTEM SERVICES EVIDENCE

10.1 Co-benefits and trade-offs

Lee and Lautenbach (2016) reviewed a large number of studies in order to quantify relationships between ecosystem services in terms of trade-offs, synergies, or 'no-effect'. Synergistic relationships dominated between different regulating services and between different cultural services, whereas the relationship between regulating and provisioning services was trade-off dominated (Lee and Lautenbach 2016). Work has also aimed to identify multifunctional 'bundles' of services, with higher diversity found in forested areas and mosaic landscapes (Mouchet et al. 2017).

A recent review and analysis by Sing et al (2018) identified the effect of forest management type and intensity on the provision of priority ecosystem services by forests in the UK, as well as the synergies and trade-offs amongst services.

The Integrated Assessment in Annex-7/ERAMMP Report-39 considers the evidence presented throughout ERAMMP Report 32 and all seven Annexes and summarises trade-offs, co-benefits and cross-cutting themes.

10.2 Tools & Models for decision support

Governance around ecosystem services

The applicability of ecosystem services (ES) as indicators meant that many earlier approaches were purely biophysical and focused on development of spatial mapping tools (Haines-Young and Potschin 2009). Ecosystem service maps are acknowledged to be important tools to bring ecosystem services into practical application, by communicating complex spatial information, raising awareness and informing landscape planning (Burkhard and Maes 2017). Regulating and maintenance services have been most commonly mapped, followed by cultural and provisioning services, with logical and empirical approaches being applied most (Englund, Berndes and Cederberg 2017). However, the proliferation of mapping approaches together with rapid development of computer based mapping programmes has led to an almost inflationary generation of ES maps, some of which have been of inferior quality (Burkhard and Maes 2017).

Research has acknowledged challenges and aims to look for areas where further investigation could address these. In particular, issues have been identified regarding the discipline-bound nature of different sectors, and a need for further evidence for the processes and feedbacks within socio-ecological systems (Carpenter et al. 2009). Challenges have also been acknowledged in terms of integrating the ES concept into actual land use planning, management, and decision making (Groot, Fisher and Christie 2010).

Recent approaches have reflected on the use of ES maps as tools, and whether they are actually used in decision making. Root-Bernstein and Jaksic (2017) provided a critical reflection on the use of the ES framework by ecologists, arguing that too much effort has been focused on providing decision-makers with the wrong kind of data. Recent literature suggests that, despite a number of projects and toolkits aimed at

integrating ecosystem services into decision-making, assessments rarely play an instrumental role in influencing decisions (Ainscough et al. 2019). The concept does have an important role as a 'boundary object', by raising awareness and incorporating multiple different types of values into ecosystem assessments (Ainscough et al. 2019). With this boundary object role in mind, there is increasingly a need for a shift in focus, with research efforts aiming to understand the governance around ES rather than producing further detailed technical mapping.

Modelling approaches

Models have played a major role in land system science, as they allow structured analysis of complex interactions within the land system (Rounsevell et al. 2012). They are used to describe, explore and predict changes in land use and other human systems (Brown, Brown and Rounsevell 2016). By doing so, they provide experimental settings that would otherwise be unavailable, and so can help to understand system dynamics, sensitivities, and uncertainties (Brown, Brown and Rounsevell 2016).

Synes et al. (2016) have reviewed approaches in landscape ecological modelling to date. Approaches mainly fall into two categories: 1) pattern-based (or top-down) vs. 2) process-based (or bottom-up) (Synes et al. 2016; Brown, Brown and Rounsevell 2016). Pattern based applications include Neutral Landscape Models (NLMs), which represent pattern, with no representation of processes that created them or that might influence them in the future. They have encompassed research exploring habitat fragmentation, functional connectivity, and species distribution, as well as statistical models which derive the scenario-based climate projections developed by the Intergovernmental Panel on Climate Change (IPCC) (Synes et al. 2016). Predictive pattern based models focus on supply and predict land use patterns based on spatial data representing land suitability and on external assumptions about demand (Rounsevell et al. 2012). There are a variety of more integrated approaches, such as land allocation models, which use demand or price information from economic models to update land-use patterns in detailed environmental models (Rounsevell et al. 2012). Process based approaches are increasingly used, aiming to better represent the behaviours and dynamics that drive landscape patterns. In ecology, these have included population-based approaches and Individual Based Models (IBMs). At the landscape scale, Agent-Based Models (ABM) explore alternative accounts of human decision-making under socio-economic or environmental pressures (Synes et al. 2016).

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