Agriculture and Forestry Climate change report card technical paper

9. Forest Ecosystem Services & Climate Change

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Summary

Characterising, assessing and valuing ecosystem services from forests and woodlands may be used to examine if forests are sufficiently resilient to meet both the future demands from society, and projected changes in climate. The effects of climate change on the provision of ecosystem services are expected to vary spatially and temporally. Impacts are likely to be most severe in the south and south-east of the UK because of: extreme seasonal shifts in rainfall, especially more extreme wet winter weather and more extreme warm dry summer weather; increasing biotic threats due partly to the proximity to mainland Europe and volume of trade to/from ports in the south. The main impacts of climate change on ecosystem services from trees, woodlands and forests in the UK will be:

- Recent increases in tree growth have occurred in Europe, and this is thought partly to be a result of a warmer climate and higher atmospheric CO_2 concentrations compared to 50 years ago (*Likelihood: very likely / Confidence: high*).

- The continued ability of trees, woodlands and forests to provide specific ecosystem services determined by management objectives is very much dependent on where they are located, how they are managed into the future, their species and genetic diversity, and the interaction with changes in site condition caused by climate change *(Likelihood: likely / Confidence: high)*.

- Impacts on species will vary due to differences in site types. Tree species which are more centrally situated in the core region of their site niche will be less affected by changes in the climate - species at the edge of their niche will be impacted more severely (*Likelihood: very likely / Confidence: high*).

- Damage to drought sensitive species will occur in the medium term in the south of the UK, leading to reductions in growth (*Likelihood: very likely / Confidence: High*), reduced timber quality (Likelihood: likely / Confidence: medium), and a reduced rate of carbon sequestration (*Likelihood: very likely / Confidence: high*).

- In the medium term (next 35 years) tree growth/yield in the lowlands is likely to decrease by approximately 40% for oak, and decrease by approximately 20% for spruce and pine. In the uplands, over the same period the growth of oak is predicted to increase by 20% and spruce and pine to decrease by 20% and 10% respectively,

(Petr et al., 2014b) on average across Britain (*Likelihood: very likely / Confidence: high*). However, towards the end of the century more frequent extreme events may cause greater reductions in growth/yield (*Likelihood: likely / Confidence: medium*).

- More frequent and more extreme storm events, leading to flooding and water quality issues (Likelihood: very likely/ Confidence: high). There is unlikely to be sufficient woodland creation to reduce the risk of flooding in large catchments where the proportion of forest and woodland is small (*Likelihood: likely / Confidence: medium). I*n smaller catchments, where the proportion of forest or woodland is high, natural flood management is expected to be more successful in attenuating flood hydrographs of medium/high magnitude, but not very high magnitude (*Likelihood: likely / Confidence: medium)*.

- Climate change will lead to more mild winters and warm spring temperatures, advancing the date of flushing of many tree species (*Likelihood: very likely / Confidence: High*). This will increase the risk of frost damage in broadleaved and some coniferous trees (*Likelihood: very likely / Confidence: high*), and may reduce natural regeneration success *(Likelihood: likely / Confidence: high).*

- Biodiversity in semi-natural and managed woodlands, and associated ecosystem services, are expected to reduce due to climate change *(Likelihood: likely / Confidence: medium)*. Prioritised adaptation action to form ‘bigger, better, more joined up’ woodland habitat will be required to counteract this trend *(Likelihood: very likely / Confidence: high).*

- Under climate change, deer and squirrel numbers will increase through milder winters *(Likelihood: very likely / Confidence: high)* leading to reduced natural regeneration success, more bark stripping, and reduced timber quality in sycamore, beech and oak woodlands *(Likelihood: likely / Confidence: high).*

- In a warmer and drier climate, the public attitude to forests and woodlands as places for recreation and relaxation will strengthen *(Likelihood: very likely / Confidence: very high).*

- People will increasingly value green space with trees as being an important part of urban infrastructure which helps maintain lower ambient peak summer temperatures *(Likelihood: very likely / Confidence: high*), and improves the quality of air in towns and cities *(Likelihood: very likely / Confidence: high).*

- Climate change projections will continue to drive forest and land use policy objectives for woodland expansion *(Likelihood: likely / Confidence: high)*. Native and ancient woodland will be managed with thinning interventions to stimulate a sequence of tree cohorts regenerated from seed which may be better adapted to changing site and climate conditions *(Likelihood: likely / Confidence: medium)*

1. Introduction: Ecosystem services frameworks

Ecosystem services are the benefits provided by ecosystems that contribute to making human life possible (Mace et al., 2011). The ecosystem services framework (also referred to as the "ecosystem services approach") assesses the linkages between ecosystem structures and processes and human well-being through the identification and valuation of goods and services. Final ecosystem services are those which directly contribute to the goods and services that are valued by people, while intermediate ecosystem services and ecosystem processes underpin the final ecosystem services.

All ecosystems are characterised by biotic (living organisms) and abiotic (climate, soil, rocks etc.) components. This stock of living and non-living assets forms the natural capital from which ecosystem services flow. As the quantity and quality (health) of an ecosystem changes, so does the natural capital, and this will affect the provision of ecosystem goods and services (Figure 1).

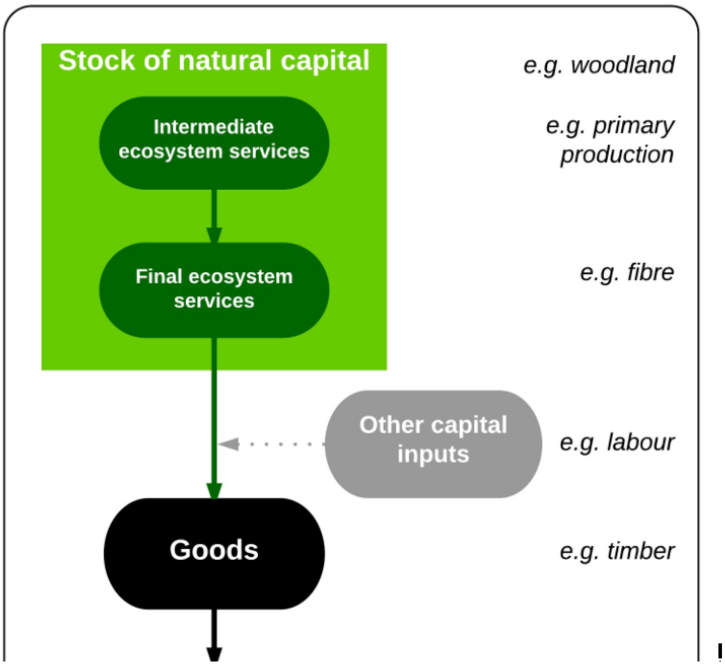

Figure 1 Relationships between natural capital stocks, the flow of ecosystem services and human well-being values, from Sing et al. (2015), with examples of forest ecosystem services.

Characterising ecosystem services

The Millennium Ecosystem Assessment (2005) made a global assessment of the understanding of the consequences of human-made ecosystem change for people's well-being. It found that humans have modified ecosystems more in the last 50 years than in any comparable period in history. More than 60% (15 out of 24) of the ecosystem services assessed were either degraded or used unsustainably as a result of increased natural resource exploitation, and the intensification of land use to meet the growing demand for essential goods such as food, water, fibre and fuel.

The UK National Ecosystem Assessment (UK NEA), conducted between 2009 and 2011, assessed the main broad habitat types in the UK and their current state, the benefits these ecosystems provide for people in terms of goods and services and consequent well-being (UK NEA Assessment, 2011). Table 1 shows the list of ecosystem services identified as being provided by woodland. The UK NEA concluded that the value of nature, and the ecosystem goods and services provided, were not fully taken into account in decision making. The UK NEA Follow-On project (2014) produced a range of new tools and information for decision makers to address this problem.

Table 1 Detailed list of ecosystem services provided by trees woods and forests (Sing et al., 2015).

Provisioning services: The direct use products derived from forest ecosystems	
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.
Non-timber forest products (NTFPs)	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.
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).
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.
Regulating services: The regulatory functions that forest ecosystems provide which benefit people and the environment	
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.
Hazard regulation	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.
Detoxification and purification of soils, air and water (including noise)	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.
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.
Pollination	Trees, woodlands and forests provide habitat for pollinator species.
Cultural services: the non-tangible well-being benefits which people gain from ecosystems. A study by Forest Research on the cultural services of British woodlands identified the following types (O'Brien and Morris, 2014)	
Health	The research identified four types of health benefits: 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.
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.
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.
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.
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).
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.
Supporting services: The ecosystem processes that support and underpin provisioning, regulating and cultural services, from which people indirectly benefit	
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.

2. Changes in ecosystem service focus in British forestry and woodland management

Forest policy and management has undergone a succession of changes since the start of the 20th century as different goods and services were delivered in response to changes in forest policy. This notably resulted in an increase in the forest cover (the natural capital stock) from 4.7% in 1910 to 13.0% by 2014 (Forestry Commission, 2015) and the establishment of a UK wood processing industry. Policy makers are now concerned with issues of sustainability and multifunctional land use, through safeguarding and protecting the natural environment. This includes meeting biodiversity conservation targets, through adherence to the European Habitats Directive, the European Water Framework Directive, and the Convention on Biological Diversity (CBD) Aichi 2020 targets, as well as mitigating climate change and maintaining timber production. This considerable challenge is interlinked with issues of environmental change and climate change. Forestry in Britain is dependent on financial incentives, and so the challenge of meeting policy targets can be linked to woodland grants as part of the sustainable forest management delivering multiple benefits from woodlands and forests. The concept of sustainable forest management is synonymous with the provision of multiple ecosystem services (Quine et al., 2013a). Indeed, the UK National Ecosystem Assessment (UK NEA Assessment, 2011) showed the maintenance or increase in many important ecosystem services in woodlands compared to other habitats. Below we have summarised (and refined) some key findings from the UKNEA woodland section (Chapter 8):

Timber production is an important provisioning service from woodlands:

- domestic production increased from an estimated 4% in the 1940s to 20% of UK consumption of timber, pulp and panel products today
- 8.5 million green tonnes of softwood was produced in the UK in 2009, approximately 60% of annual growth increment
- production is predicted to rise to 11–12 million tonnes in the 2020s

- 0.4 million tonnes of hardwood were produced from broadleaves in 2009, about 20% of annual growth increment

Woodlands are highly valued for cultural services and non-timber products:

- approximately 250–300 million day visits to woodlands per year
- woodland includes nearly 5,000 Scheduled Ancient Monuments, plus many areas managed for geological study
- the landscape value of woodland estimated at £185 million (at 2010 prices)
- recreational visits were valued at £484 million (at 2010 prices).
- non-timber products from woodlands contribute £640 million per annum to the UK economy (e.g. game shooting).

Carbon sequestration is one of the most important regulating services provided by woodlands:

- the total carbon (C) stock in UK forests (including soils) is around 800 megatonnes (Mt) of carbon (2,900 Mt of carbon dioxide (CO_2) equivalent), and a further 80 Mt C has been estimated in timber and wood products
- the strength of the UK forest carbon sink increased from 1990 to 2004, but has started to decline due to reduced rates of planting in the last 20 years
- at peak growth, coniferous forest can sequester around 24 tonnes of CO_2/ha/yr, with a net long-term average of around 14 t CO_2/ha/yr
- rates of around 15 t CO_2/ha/yr have been measured in oak forest at peak growth, with a net long-term average likely to be around 7 t CO_2/ha/yr
- the social value of net carbon sequestration by UK woodlands is currently at least double the market value of wood production per hectare
- the total value of net carbon sequestration by UK woodlands planted after 1921 increased more than six-fold over the period between 1945 and 2004
- carbon sequestration currently has the highest annual social value of the woodland ecosystem services considered.

Biodiversity values provided by woodlands and forests:

- about a quarter of all UK Biodiversity Action Plan priority species are associated with trees and different types of woodland

- the condition of woodland SSSIs and the seven priority native woodland habitats is improving
- a survey of visitors by the Forestry Commission in 2009 showed that over 80% of respondents recognised the provision of wildlife habitat as one of the major benefits of forests
- the non-use of marginal benefits of forest types have been calculated as £0.35, £0.84, £1.13 per household per year, respectively for Sitka spruce forest, lowland broadleaved woodland, and ancient semi-natural woodland
- red squirrel habitat protection has been valued by the Northumberland Wildlife Trust at £2.94 per member per year
- forest habitat restoration for increasing capercaillie habitat was valued at £28 per household per year in Aberdeen
- charitable bodies such as the Woodland Trust and RSPB receive substantial legacies for the maintenance of woodland owned by these organisations (e.g. £12 million to the Woodland Trust in 2009)
- it is extremely difficult to value forest and woodland biodiversity as a whole, and the value of legacies and membership fees to the Woodland Trust, Scottish Forestry Trust, and Wildlife Trusts featuring woodland conservation (rather than specific and rare species conservation) gives an indication.

Other regulating aspects of woodlands and forests:

- the UK Forestry Standard and the supporting series of Forest Guidelines describe the standards of operational and tactical forest management which if maintained, enable forests and woodlands to provide important regulating roles
- forests and woodland can improve water quality compared to run off from agricultural land, improving infiltration and filtering water through a deeper layer of soil
- forests and woodlands can reduce flood risk from short to medium return period peak flows through attenuating the flood peak hydrograph by increased temporary storage of rainfall
- flood plain woodland and the incorporation of natural flood defences can reduce downstream flooding and damage to people and property

- forests and woodlands and urban trees reduce atmospheric pollutant concentrations through absorption on leaf and bark surfaces – it has been calculated that this saves the NHS up to £0.9 million per year
- Trees and shrubs are effective reducers of noise pollution – a 30m belt of trees can reduce noise by 7 dB.

3. Impacts of climate change on ecosystem services

Climate range shifts and abiotic stress

There have been numerous studies demonstrating the likely effects on tree species of a shift in the climate space using climate envelope models (Elith and Leathwick, 2009; Ogawa-Onishi et al., 2010; Gray and Hamann, 2013; Hanewinkel et al., 2014; Nakao et al., 2014), including the UK, (Berry et al., 2002; Pearson and Dawson, 2003; Broadmeadow et al., 2005; Xenakis et al., 2011; Petr et al., 2014b). Such models use climate variables to make spatial predictions of species suitability using minimum and maximum boundaries for species occurrences. Criticisms of the method focus on the lack of analysis of landscape features and habitat quality. Despite this criticism, climate envelope modelling is considered useful in providing low resolution, imprecise projections of the possible shifts in tree species suitability (Pearson and Dawson, 2003). There is also compelling evidence of how observed changes in the climate have exposed native and exotic stands of trees at the edge of their range, or on vulnerable sites, to decline. These include abiotic and biotic impacts e.g. Scots pine at the southern edge of its range in the southern Alps (Herrero et al., 2013); semi-arid and Mediterranean forest decline due to drought (Carnicer et al., 2011); acute oak decline in southern England, possibly related to stress from climate change, and Scots pine decline from *Dothistroma* needle blight in the UK, likely due to increased spring and summer humidity and rainfall (Woods et al., 2005).

Impacts on productivity and carbon sequestration

Since 1998 the forestry sector has been a net carbon sink, in 2015 removing 10 $MtCO_2$ from the atmosphere (Committee on Climate Change, 2014). The Committee on Climate Change has suggested that with continued land use change to forestry, the sector is very likely to remain a carbon sink beyond 2050. Milder winters will extend the growing season with greater productivity in the uplands and north and western Britain at least until about 2050 (Petr et al., 2014b). In the lowlands changes in seasonal rainfall, coupled with more frequent extreme events from climate change, is likely to reduce the potential carbon sink, through reductions in stand productivity from more frequent droughts, wind damage, and the effects of pests, pathogens and invasive species (Ray et al., 2010).

Impacts on food, fibre and fuel security

Globally, any reductions in forest productivity resulting from the changing climate will impact the forest provisioning service of fibre and cellulose production for goods including timber, fuel and paper (Reyer et al., 2014). In addition to increasing natural abiotic (including drought, waterlogging, fire, extreme high or low temperatures) and biotic (pests and pathogens) disturbance, it has been suggested (Hanewinkel et al., 2012) that in Europe by 2100 there will be a serious economic impact through loss in monetary value of forest land (range of economic loss 14-50%). This will be due to a decline in economically valuable species in the absence of adaptive capacity and measures to maintain resilient productive forests. If the analysis by Hanewinkel et al. (2012) is correct, there would be a downturn in the forest industry sector in Europe caused by a reduction in long term investment from the financial sector investment portfolios. Consequent reductions in the extent and intensity of forest management would ensue. Such a scenario could result in forest clearance, forest damage and a deterioration of quality and volume of timber, with potential reductions in amounts of carbon sequestered by European forests.

In the UK, Defra responded[1] to the Natural Capital Committee's third report agreeing with the need to strengthen natural capital, and aiming to provide a healthy natural economy. Recommendations included the planting of 11 million trees in England to help build resilience in natural capital to minimise the impacts of environmental change. Confor and the Woodland Trust have stated a new ambition in woodland expansion in England. They are lobbying for a 7,000 ha per year target until 2020, and 10,000 ha per year beyond for woodland expansion, using a wide range of woodland types and species.

To date, the ability of the forestry sector to adapt, and the extent to which it can do so, is uncertain. Although much research has been undertaken to encourage an increased diversity of forest species and forest management systems, there are big uncertainties (Lindner, et al., 2014), particularly associated with pests and pathogen impacts (Jactel, et al., 2012; Telford et al., 2015; Tubby and Webber, 2010). This may be unsettling for forestry investment, with a very uncertain climate future and incomplete knowledge of the impacts on productive forest stands. To date the private forestry sector in the UK has continued to rely on Sitka spruce. The species is robust on a range of challenging site types, but it is very susceptible to the effects of drought (Petr et al., 2014b). Nevertheless the industry probably consider stands may be harvested before the maximum mean annual increment on a shorter rotation, in the event of climatic or biotic impacts. The inherent risks and uncertainties of a Sitka spruce business model under climate change has been partly offset by an expanding renewable wood fuel market which has reduced the difference in value between biomass and sawlog quality timber.

Impacts on flood risk and soil protection

Climate projections indicate that more frequent, and more extreme, storm events will lead to increased flooding and water quality issues. Woodland creation and management in riparian zones is now being used to slow peak flood flows with the aim of protecting downstream property and infrastructure (Nisbet et al., 2011).

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[1] The government's response to the NCC third state of natural capital report (https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/462472/ncc-natural-capital-gov-response-2015.pdf)

Woodlands have long been associated with an ability to attenuate peak flows in streams and rivers (McCulloch and Robinson, 1993), but the evidence suggests this occurs only for smaller flood events in small catchments (Robinson et al., 2003; O'Connell et al., 2004). Nisbet and Thomas (2006) outlined three mechanisms by which trees can alleviate flooding: greater water use and interception storage, greater infiltration rates in woodland soils (compared to agriculture and urban areas), and the greater hydraulic roughness of floodplain and riparian woodland. The higher water use of conifer forests, and particularly the higher interception loss, provides some scope for flood reduction, but the effect reduces with increasing storm intensity (Nisbet et al., 2011).

It will always be necessary to mix flood protection solutions across different land use types, and mix natural defences with engineered defences. Woodlands can help mitigate small floods locally in small catchments. In the UK, woodland cover is not usually extensive enough to have a major mitigating effect on the risk of flooding in large catchments. Where the proportion of land use and land use change to woodland is higher, and where the woodland is targeted in areas to increase the hydraulic roughness of the floodplain (Thomas and Nisbet, 2006), then trees can support flood risk mitigation. Modelling studies of small rivers in Somerset and North Yorkshire (Thomas and Nisbet, 2006, Nisbet and Thomas, 2008) have shown how targeted floodplain woodland creation can reduce the peak flows of 1 in 100 year events through temporary storage of water in the woodland and by de-synchronising the peak flow contributions from adjacent tributaries.

Compared to intensive agriculture and pasture, agro-forestry systems promote improved regulation of soil water and infiltration (Pramova et al., 2012) thereby moderating some of the detrimental impacts of extreme events (Stokes and Kerr, 2009). Wood-pasture systems and well placed shelter belts in upland catchments have been shown to be highly effective in reducing overland flow, by improving soil structure and infiltration (Marshall et al., 2009) thus helping to attenuate peak flows and downstream flooding, as well as soil erosion, following intense rainfall events. Nisbet et al. (2011) reviewed modelling work that predicted a reduction in peak flows by between 13 and 48% by planting shelterbelts across the lower parts of sloping pasture (Jackson et al., 2008), figures supported by field observations.

Impacts on biodiversity

Compared to many European countries Britain has a lower percentage cover of woodland (13% for GB compared to 38% for EU28; (Forestry Commission, 2015)). In addition, and partly due to the low woodland percentage, woodland habitat in Britain is highly fragmented (Watts et al., 2010) as a consequence of a long period of human activity (Bailey et al., 2002). Fragmentation and its impact on patch connectivity is a particular problem for many woodland species faced with a shift in climate space, and particularly where the landscape matrix forms barriers to connectivity. Recent work (Lawton, 2010; Humphrey et al., 2014) has provided evidence that in addition to local actions in maintaining high quality habitat, there is a need for landscape-scale action to improve connectivity through maintaining corridors for vertebrates, and ecological continuity for vascular plants and invertebrates. A combination of actions to provide 'bigger, better, more joined up' habitat (Lawton 2010) will help improve woodland biodiversity resilience in a changing future climate. However, there is inevitably a lag between today's actions and the provision of future high quality woodland habitat (50-100 years depending on woodland type). There are some management actions which could improve biodiversity in the short term, such as increasing woodland structure. Action is urgently needed to implement measures that will maintain woodland biodiversity conservation in the face of rapid climate change over the next 50 years. So it is important to prioritise adaptation action, and this has been suggested in the form of a decision framework (Oliver et al., 2012) designed to focus action to increase the adaptive capacity of species based on their current distribution and future projected climate space.

There are big uncertainties in the future magnitude of climate change, the rate of change through coming decades, and the uncertainty of arrival into the UK of invasive species, and pests and pathogens as a consequence of global trade. This uncertainty coupled with a current inertia for land use change measures which could increase the adaptive capacity and resilience of woodland habitat to drought (Choat et al., 2012), means that biodiversity impacts are very likely to be severe and regionally patchy. Evidence is provided by examples of regional vegetation die-off of

Pinyon pine-juniper woodland in the south-west USA (Breshears et al., 2011), and reductions in primary productivity in the 2003 European heat wave (Ciais et al., 2005) which show how climatic threshold tipping-points can change woodland and forest biodiversity. In both these examples, direct abiotic drought and high temperature damage or stress to trees led to biotic damage which in turn caused losses to woodland biodiversity and to a range of other ecosystem goods and services (less carbon sequestration, loss of fuel, increased soil erosion, less microclimate regulation, reduced recreation quality).

Ancient native and semi-natural woodlands are often unmanaged, and have little opportunity to regenerate other than by filling gaps left by fallen trees. It has been argued (Cavers and Cottrell, 2015) that management should be implemented to harness evolutionary processes by allowing woodlands to respond to abiotic threats through natural selection. This might be too slow to keep pace with the projected rate of climate change. Even so an increase in the number and frequency of interventions (such as thinning or small patch felling) in ancient semi-natural woodlands would introduce greater vigour and dynamism into these important woodland ecosystems and encourage natural regeneration of component tree species.

Amongst others, Sparks and Gill (2002) showed how climate change has had an effect on the timing of seasonal events such as the first leafing of important tree species including oak, sycamore, and hornbeam. Earlier flushing in the spring predisposes some plants to a greater risk of frost damage (assuming the risk of late frosts does not change with the mean temperature). Mild winters and increased spring seasonal temperatures also advances the arrival time of many migratory species, for example butterflies such as the orange tip, ringlet and brimstone, and birds such as chiffchaff and blackcap, as well as the breeding time of resident birds, e.g. chaffinch. There is evidence that other taxa respond to climate change, e.g. the timing of amphibian breeding (such as the common frog) is related to temperature. Climate change is expected to result in increased populations and geographic ranges of species of deer and squirrels, because of warmer winter temperatures and an assumed reduction in the frequency of cold winters. This will have an impact on the shrub and field layer, and tree regeneration capacity of woodlands and forests.

These examples highlight the need to embrace multi-disciplinary ecosystem management and be aware of tipping-points. This has been recognised (Mace et al., 2012) as a means to manage habitats in a way which supports biodiversity, increases ecosystem service resilience, and lessens the impacts of climate change. The examples illustrate the likely effects of climate change operating over regional scales; in particular how the increased frequency of extreme weather may affect areas of Britain, with potentially severe impacts likely beyond 2050, causing woodland ecosystem disturbance and loss of biodiversity and goods and services.

Impacts on recreation, aesthetic value and human health

Forestry Statistics provide estimates of visits to UK forests and woodlands in 2013-2014 as: 417 million in England; 90 million in Scotland; 68 million in Wales; 0.4 million to Northern Ireland Forest Service woodlands (Forestry Commission, 2015). These numbers have risen steadily over the last 20 years from 303 million visits in 1994 to approximately 575 million visits in 2013/14. The popularity of forest visits has been encouraged by the Forestry Commission and Natural Resources Wales, through increased infrastructure, e.g. camping, cycling, mountain biking, Go-Ape, bird watching (e.g. ospreys), picnic areas, car parking etc. While climate change is perhaps not a recognised direct reason for increased numbers of visits, a number of warmer and drier summers in recent years are likely to have contributed to people choosing to visit forests. Forests are thus considered as an important resource for increasing visitor numbers in a warmer climate (Snowdon, 2009).

Although it is a subjective and personal choice, the visual aesthetics of woods and forests in the landscape do appear to stimulate human enjoyment of the countryside. People enjoy big trees and some species diversity, with open spaces to allow views of the landscape (Edwards et al., 2012). Single-aged stands of monoculture spruce forest are not so well received as mixed woodlands managed using low impact silvicultural management systems. Climate change adaptation should encourage planting a greater range of species, including mixed species stands. Woodland expansion grant aid is likely to encourage such changes. In Scotland, the ambitious Climate Change (Scotland) Act 2009 has stimulated a Land Use Strategy (2016-

2012) which, amongst other changes, will encourage a ‘community led’ woodland expansion in Scotland. Therefore, it is very likely that climate change, or the projections of future climate change will alter the appearance of Scotland’s landscapes through woodland expansion shaped by the aspirations of local communities.

Climate change is very likely to have severe consequences on human health. For example, the European heat wave of 2003 produced very high maximum temperatures, 20-30% higher than the seasonal average. The all time maximum temperature recorded in England was exceeded on 10th August with 38.5^{0}C, and the maximum for Scotland (32.9^{o}C) was recorded the day before. The 2003 heat wave caused an estimated 2,000 casualties in the UK, and over 35,000 across Europe[2]. Extreme heat waves have been predicted to become more common under projected future climates.

Urban heat islands form in towns and cities, in which temperatures are elevated by several degrees above rural areas (Doick et al., 2014) as a result of the reduction in latent heat transfer from urban engineered surfaces compared to vegetated surfaces. There is substantial evidence to show the heat reduction benefit which urban greenspace, and urban trees and woodland parks in particular, provides (Doick et al. , 2014; Gill et al. 2007; Handley and Gill, 2009; Klemm et al., 2015). Increasing urban woodland and green space is considered to be a very effective adaptation strategy for climate change, and will provide an important regulating service in urban areas (Lindley et al., 2006).

Given this evidence, it is imperative for city planners to introduce and maintain urban green infrastructure which is resilient to climate change. It is likely therefore that green space will be maintained and improved in cities under climate change. The health and relaxation benefits, and the benefits of reduced temperatures are extremely valuable to society, and will become more and more critical in cities.

[2] Encyclopaedia Brittanica - http://www.britannica.com/event/European-heat-wave-of-2003

Forests and woodland, including urban woodlands and green space, also provide health benefits including reduced stress levels (Park et al., 2011; Ward Thompson et al., 2012). Research has demonstrated the synergy between the psychological benefits of physical activity and the restorative effects of the natural environment compared to physical activity elsewhere (Mitchell, 2012). As well as benefits to mental health from mental relaxation and exercise in forests (Lee et al., 2011) and green space (Barton and Pretty, 2010), there is also recent evidence of a human health benefit from the exposure to weak concentrations of volatile organic chemicals and other compounds released by trees that stimulate the body and its immune system (Moore, 2015). However, for these benefits to be resilient to climate impacts such as extreme weather, (e.g. drought coupled with higher temperatures), the environmental limits to key plant physiological process such as photosynthesis, xylem cavitation (Choat et al., 2012), and water use efficiency need to be specifically assessed for selected species of tree. Species which exhibit greater plasticity and genetic diversity to drought should be favoured, particularly in urban woodland, and as street trees in cities.

<u>Impacts on economics, profitability and employment</u>

Forests and woodlands make a contribution to the UK economy, estimated at 2.5% in 2005 through direct and indirect operations (£26 billion gross value added) according to the State of the UK's Forests, Woods and Trees report (Atkinson and Townsend, 2011). The numbers employed in primary forestry operations and processing has remained fairly steady from 2009 to 2013 at approximately 26,000 (Forestry Commission, 2015).

It is very likely that climate change will affect the wood processing industry, since one of the main climate adaptations is to plant and grow tree species better suited to the changing site conditions, which in turn may require the industry to invest in new machinery in the medium to longer term (40-100 years). In addition, from 2030 to 2050 a dip in the production forecast on the Public Forest Estate (PFE) in England and National Forest Estate (NFE) in Scotland will occur, followed by successive peaks and dips towards the end of the century. This is a feature of the current age class distribution of the PFE/NFE, and may cause problems in meeting agreed targets to maintain the UK forestry sector processing industry. Changing species from Sitka spruce to a mix of conifers should make the industry more resilient, particularly with regard to the possibility of spruce pests and pathogens. Such a change, over the course of the coming century, will tend to reduce production slightly, as other conifers tend not to be as productive as Sitka spruce. Although Sitka spruce will be much less productive in areas experiencing a warmer and drier summer climate, in the west of the UK (and particularly west Scotland) it, and a mix of other conifers, may continue to be productive, depending on site type.

Scottish Government's aspiration of at least 25% forest cover by mid-century, driven by the need to sequester more carbon and meet Climate Change (Scotland) 2009 targets will help to maintain the UK wood processing industry. Such an expansion in forests is likely to safeguard the wood processing industry in Scotland. However, in England and Wales, climate projections suggest more warm and dry summers and mild and wet winters. This is likely to cause more extreme seasonal changes in site conditions, leading to climatic and drought stress followed by increased winter waterlogging. More extreme seasonal fluctuations in site conditions will predispose many species to biotic impacts such as *Phytophthera* spp., species decline, root disease, and beetle attack, and it is likely more pests and pathogens will enter the UK from global trade and take advantage of abiotically stressed woodland stands.

4. Discussion

<u>Supply, demand and synergy</u>

The supply of ecosystem services may be considered at a range of spatial and temporal scales. Forest planning and management decisions which are implemented today, at the local or regional level, will have some immediate benefits and also some benefits that may not be realised for decades, but will eventually contribute regionally, nationally and internationally, as well as locally.

For example, providing access to woodlands for recreation provides immediate health benefits to local people, while the carbon sequestered in the same trees benefits society at large and contributes to national and international targets over longer timescales to mitigate the emissions of greenhouse gases from the burning of fossil fuels. There is a temporal dimension to the supply and consumption of ecosystem services with a lag in the receipt of benefits; for example, the slow accumulation of peat or soil formation processes will only truly benefit future generations. The human demand for ecosystem services also varies spatially and temporally, and over time there has been a considerable shift in the services which society has demanded (Sing et al., 2015).

Demand for ecosystem services from woodlands and forests is very likely to increase (Atkinson & Townsend, 2011) with competing pressures for land use, and partly driven by the uncertainties and pressures of climate change. Quine et al. (2011) predict an increase in the proportion of gross annual increment harvested, particularly for broadleaved woodlands, following a rise in the use of commercial and domestic wood-fuel in response to increasing gas and electricity prices. Each of the countries of the UK has expressed a commitment to woodland expansion, which is based on a need to sequester carbon, maintain wood production, improve woodland biodiversity, improve opportunities for for woodland recreation, improve water storage and reduce flood risk, and to reduce water pollution on agricultural land. Woodland expansion is a key policy objective in Scotland to help meet Climate Change (Scotland) Act 2009 sequestration targets to reduce Scotland's greenhouse gas emissions by 42% by 2020 and by 80% by 2050. In England, woodland expansion targets are more modest, aiming to reach 12% woodland cover by 2060, while in Wales the Welsh Government has committed to increasing the woodland cover from 14% in 2016 to 20% by 2030, and the Northern Ireland Forestry Strategy aims to double the area of woodland from the current 8% to 16% by 2060.

The ability of trees, woodlands and forests to provide ecosystem services is dependent on both the type of management and the location of wooded patches in the landscape, since different forest management systems and woodland types lead to differing outcomes (Ray et al., 2015, Sing et al., 2015). For example, the climate change mitigation benefits resulting from carbon sequestered in the trees and soil is dependent on silvicultural operations such as site preparation, species choice and harvesting methods (Morison et al., 2012). Ecosystem service bundles are described in the research literature (Raudsepp-Hearne et al., 2010) as a collection of services that are regularly provided together through the interaction of a forest management system on a forest type. For example, irregular patch-size stands of short rotation silviculture in conifer forests leads to regular biomass harvests and an emphasis on the form of biodiversity associated with the stand initiation phase of the forest growth cycle. In this case there is a trade-off with reduced recreational value of the stands and a lack of later successional stage biodiversity, due to the absence of older trees and low species and structural diversity. Compare this to stands of mixed broadleaved trees managed using a shelterwood system where the tree species and structural diversity is greater, leading to a greater range of biodiversity and recreational values. Water demands by these forests vary seasonally but will be more stable through time compared to clearfell–restock rotation systems. Water quality is also likely to be more stable through time compared to the regular disturbance of clear fell systems. The smaller scale but more frequent disturbance from regularly thinned woodlands will create more worksites in the forest, and this perhaps conflicts with recreation, biodiversity and sometimes water quality. However, again there is a trade-off with lower biomass production (and carbon sequestration), and the operational costs of harvesting, when compared to even-aged conifer plantations (Morison et al., 2012).

In the UK management of each of the devolved public forest estates is starting to respond to the threat of climate change by diversifying stands when the opportunity occurs, to reduce the risk of widespread biotic damage from pests and pathogens, and abiotic damage from extreme weather (Ray et al., 2010), including forest fire (Forestry Commission, 2014). Measures have also been developed to help practitioners in the private sector through knowledge exchange awareness raising events. Use of on-line research tools are encouraged to better match species and forest management systems to current and projected future conditions , e.g. SRDP Forestry Grant Scheme[1] and Ecological Site Classification[2].

Landscape scale issues

At the landscape scale, the broad habitat land cover of conifer, broadleaved and mixed woodlands are located alongside freshwater, cropland (arable and pasture),

1 https://www.ruralpayments.org/publicsite/futures/topics/all-schemes/forestry-grant-scheme/woodland-creation/

2 https://www.eforestry.gov.uk/forestdss/

green space, grassland, moorland and other habitats. When making decisions at the landscape scale, changes in land use and forest management to adapt to projected future climates will have some level of impact on ecosystem services provision. These impacts can be quantified by comparing the value or the amount of goods and services. Climate change will cause a variable effect across landscape components since, for example, woodlands have a much longer rotation length than agricultural crops. The integrated assessment of climate impacts at the landscape scale is thus an important investigation which must be undertaken to fully understand ecosystem service provision, including: food production, water storage, carbon sequestration, and biodiversity of the wider landscape.

Future challenges

The UK NEA (UK NEA, 2011) found that the management of ecosystem services will in future need to be resilient and adaptive to climate futures, societal demands, environmental issues and land use changes. This is quite challenging due to the inherent uncertainty of climate and socio-economic futures. Forest management can be supported to achieve this aim (Quine et al., 2011) through an improved understanding of the drivers and pressures of change, their impacts on ecosystem supply and demand, and the response options that are available to managers and decision makers (Bouriaud et al., 2015). The possible impacts of these drivers, and pressures for change, can be tested with scenario analysis of the potential impact of alternative management approaches on ecosystem services (Ray et al., 2015), using a range of climate change projections and socio-economic futures. It seems likely that the valuation of services will become more prominent and may underpin new funding streams which pay for trees, woodlands and forests in the right place to contribute to required ecosystem services (Quine et al., 2013). This raises a further challenge in planning ecosystem service provision under climate and socio-economic change, namely decision makers must ensure easily valued goods and services from forests (such as timber and carbon) do not overly influence management system priorities at the expense of delivery of other ecosystem services (particularly those without markets). In adapting forests to climate change we must consider a longer-term sustainable view rather than just short-term adaptive management approaches for quick wins (Sing et al., 2015).

Payments for ecosystem services have been widely discussed as a means of enhancing management practices and encouraging land use with multiple benefits. In the UK forestry sector, there are very few examples other than through the country woodland grant schemes (where premiums have targeted particular types or location of woodlands to benefit services such as biodiversity (Quine and Watts, 2009), recreation, and public access), and the early development of a voluntary carbon market (underpinned by the 'Woodland Carbon Code' [3]). However, new mechanisms are being considered and developed (e.g. Brown et al., 2015) ; for example, multiple funding sources have supported schemes such as 'Slowing the Flow at Pickering' (Nisbet et al., 2015), where encouragement of woodland planting reduces the need for costly conventional flood defences. . The new COST Action (CA15206) Payments for Ecosystem Services – Forests for Water will research incentive mechanisms across Europe that could standardize approaches to promote land use change to deliver water quality targets, perhaps as additional benefits that add value to carbon policy schemes.

Tree health is currently a major topic of concern, partly related to climate change, and partly a result of global trade providing the pathways for pests and pathogens to move globally. Visitors to UK forests need to be vigilant: practising biosecurity measures, and alerting forest managers to unusual symptoms of pests and pathogens, and this area of work has improved with the availability of online monitoring (e.g. Observatree4). Suppliers and purchasers of plants (whether business or private individuals) need to be similarly vigilant over biosecurity and non-risky choices of sources of supply. The Tree Health and Biosecurity Initiative5 is investigating a range of new tree pests and pathogens that may affect ecosystem function, biodiversity and ecosystem services provision.

5. Conclusions

[3] Woodland Carbon Code http://www.forestry.gov.uk/forestry/infd-863ff

[4] Observatree http://www.observatree.org.uk/tree-health/reporting/

[5] THAPBI https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/206957/pb13921-thpb-progress-report.pdf

The adoption of the ecosystem services approach in forestry can provide consistent assessment and valuation of the human benefits of trees, woodlands and forests through a period of rapid climate change. This is important for several reasons:

1. Forestry has long been undervalued, the industry has been expected to produce good quality home grown timber on some of the poorest site types in the UK. A proportion will become unsuitable for growing Sitka spruce and other species productively as the climate changes. Sitka spruce is a robust high yielding species, tolerant of poor and wet sites, but intolerant of drought: a serious risk from climate change. The inherent risks and uncertainties of a Sitka spruce business model under climate change has been partly offset by an expanding renewable wood fuel market that has reduced the difference in value between biomass and sawlog quality timber.

2. Forest and woodland expansion is a country policy objective in England, Scotland and Wales to mitigate greenhouse gas emissions. Modelled ecosystem service assessments from woodlands and forests under climate change can help target where and when to make land use changes based on the relative benefits provided.

3. There can be considerable conflict in changing land use, with farmers opposed to woodland expansion on better quality farmland, and some sporting estates and non-government organisations opposed to woodland expansion on moorland and heathland. Such tensions must be carefully evaluated under climate change, and the ecosystem services framework is able to provide the consistent mechanism to assess the relative human benefits of woodland, pasture, arable land, moorland, wetland, freshwater and urban development in relation to climate projections.

4. In using the ecosystem services framework, a more quantitative approach to land use issues in a changing climate is expected to emerge, along with a more transparent rationale for stakeholder involvement in planning decisions at local, regional and national levels.

5. Woodland expansion in the past century helped establish the UK wood processing sector, and changing forest policy in response to multiple pressures has helped form the current area of multipurpose forests and woodlands which

can deliver a range of ecosystem goods and services. Climate change policies have stimulated a new era of woodland expansion to sequester carbon and to provide urban greenspace. Implementation of these policies is likely to: further develop a more sustainable economy based on renewables; provide new opportunities to mitigate flood risk; help reduce soil erosion from pasture and other agricultural land; improve water and air quality, help to cool urban areas; in the longer term help maintain and enhance biodiversity and provide greater opportunities for recreation and improved health and wellbeing.

6. Forest planning must better assess potential future impacts under uncertainty in order to support forest policies and help deliver desired outcomes under climate change,. Doing so, should help improve the resilience of trees, woodlands and forest to the threats of climate change. Missing the opportunity for careful forest adaptation planning within the bigger framework of appropriate land use is very likely to threaten the delivery of ecosystem goods and services as forest species and stands become affected by drought, waterlogging, and pests and pathogens associated with climate change.

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