Feasibility Study for the Valuation of Forest Biodiversity

Final Report

Forestry Commission

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Disclaimer

Executive summary

This report considers how the value of biodiversity can be accounted for in economic analyses that support forest management and policy decisions. It reviews the role of biodiversity values in forestry policy and management decisions and provides recommendations for addressing evidence gaps.

Introduction

Biodiversity provides the fundamental underpinning for ecosystem functioning - such as biomass production, litter decomposition, pest control, and pollination – along with the resulting ecosystem services that provide benefits to society, such as timber, climate regulation, recreation and wildlife conservation. The type and quality of benefits are determined by a combination of factors including management actions, climate, soil type and nutrients, and biodiversity in terms of the types of plants and animals, their abundance, and the interactions between them within an ecosystem. Biodiversity also plays a crucial role in ensuring the resilience of ecosystems to 'shocks' and pressures, both in the short term (e.g. disease and invasive species) and over longer timescales (e.g. climate change). In summary, ecosystem service benefits and their sustained provision over time are critically dependent on biodiversity.

Defining biodiversity

Biodiversity is multi-dimensional and can be classified in many ways, meaning there is no single measure or indicator of biodiversity that captures all of its dimensions and attributes. It is most commonly defined as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part, this includes diversity within species, between species and ecosystems" (CBD, Article 2). A key distinction is often drawn for the 'level' at which biodiversity is considered:

- Genetic diversity - the variety of genes within a particular species;
- Species diversity - the variety of species within a habitat or area; and
- Ecosystem diversity - the variety of ecosystems within a given area, including the communities of organisms within it.

Overall, 'greater' biodiversity is generally positively associated with ecosystem functioning (i.e. better outcomes) but the relative importance of species diversity compared to aspects such as functional roles and diversity (e.g. position in the food chain) varies for different ecological functions.

Economic assessments of the value of biodiversity are often partial. This is because economic valuation focuses on the value of 'final' goods and services. The contribution of biodiversity is largely implicit and embedded in valuations, which typically focus on the present flows of benefits to individuals and society overall. The dependency on biodiversity for sustaining economic values *over time* – i.e. current and future values - is often not recognised. As a result, because different types of forest management outcome can depend on different aspects of biodiversity, the potential trade-offs between management alternatives may not be apparent.

Economic value of biodiversity

Figure S.1 illustrates the links between biodiversity, ecological functions and processes, and the different ways in which biodiversity contributes to wellbeing. Overall, the economic value of biodiversity is the combination of its direct and indirect contributions to individual and social welfare, both now *and* in sustaining these benefits into the future:

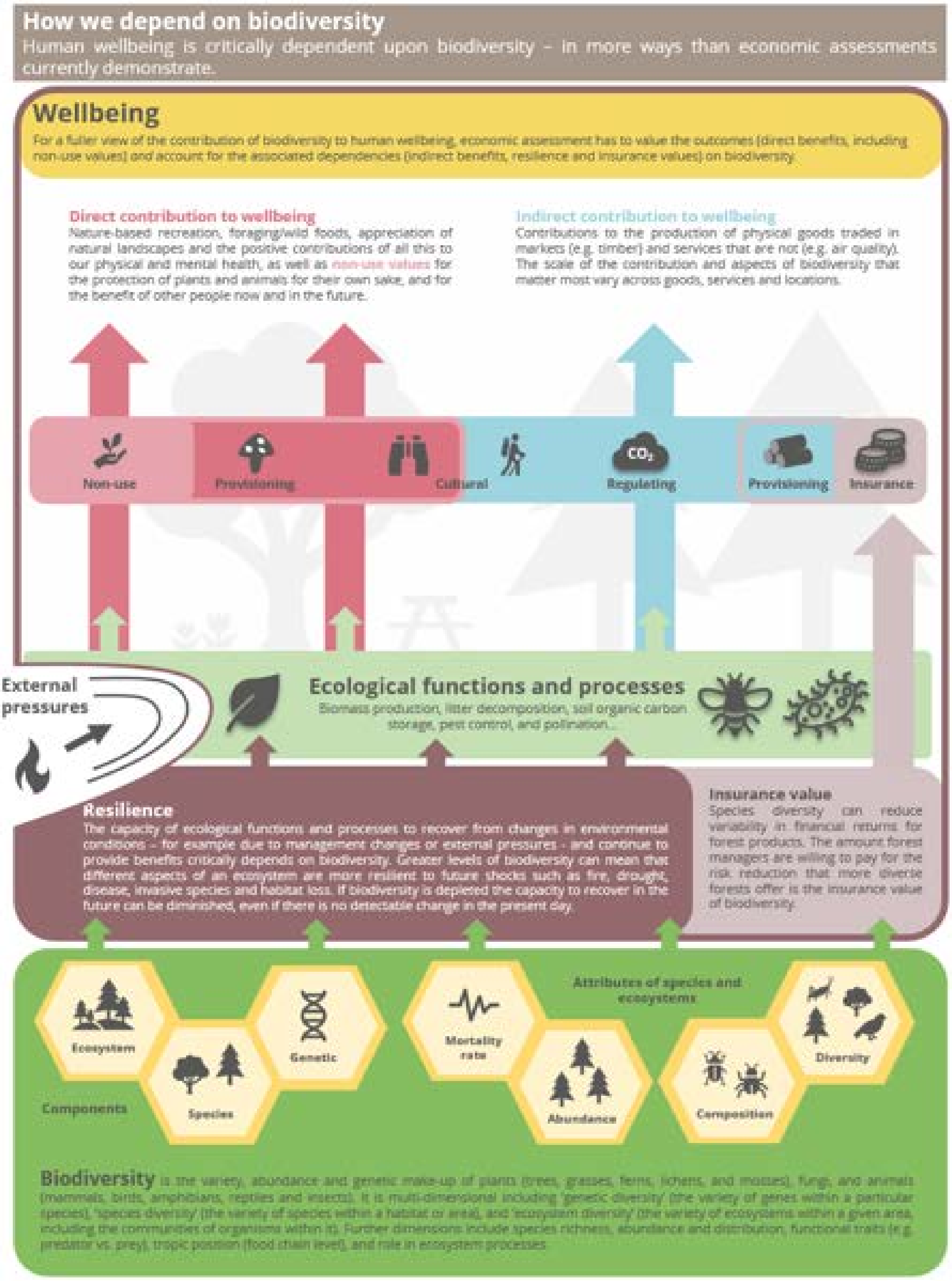
- Direct value or contribution: an aspect of biodiversity is the final good or service that individuals benefit from, such as nature-based recreation, or wild species conservation; and

- Indirect value or contribution: an aspect of biodiversity contributes to the production of a good or service that individuals benefit from, such as timber, carbon sequestration, local air quality, flood risk protection.

The **direct value** covers a variety of values; for example, greater bird species diversity in a woodland can increase the enjoyment of forest visitors (a non-consumptive use value). If wild food (plants and fungi) abundance and diversity increases in woodlands, this may generate additional benefit for foragers (a consumptive use value). Individuals may also derive benefit from greater species diversity or abundance because of non-use value motivations – a pure existence value, or because they gain from knowing that others benefit, now or in the future (altruistic and bequest motives).

The **indirect value** relates to the instances where aspects of biodiversity generate value because they are inputs to the production of final goods and services that people value. These benefits are measured by assessing how changes in the 'level' of the biodiversity input changes the value of the final good or service. Higher diversity can result in higher outputs of some ecosystem services but lower outputs of others. For example, more diverse woodlands may have lower levels of commercial timber growth and lower carbon sequestration levels, but higher recreational value. The relative value of each of the final goods and services (timber, carbon sequestration, air quality regulation, etc.) will partly determine whether the overall indirect value is increasing or decreasing in some measure of biodiversity.

Figure S.1: The economic value of biodiversity



Closely linked to the indirect value is the **insurance value** associated with biodiversity. Forest managers face uncertain future income given that weather, disease, fire and flood risks cannot be reliably anticipated in management decisions and future output prices are also uncertain. If higher levels of biodiversity mean lower variability in future returns (i.e. less risk of large falls in output), then investing in biodiversity is analogous to buying insurance. The amount forest managers are willing to pay for greater diversity is in effect an insurance premium, or the insurance value of biodiversity. This value is additive to the indirect value associated with forest outputs, since it measures the benefit of reducing risk (i.e. future uncertainties) rather than the value of other final goods and services.

The **resilience value** of biodiversity is the value of maintaining specific ecosystem service outputs over time despite risk factors like variability in environmental conditions, disturbance due to external pressures, and management uncertainty. Insurance value is one dimension of this that is specifically concerned with the risk of income losses in the context of environmental variabilty. The concept of resilience value is, though, broader in the sense that biodiversity is an asset and the 'stock' of it can enable higher resilience in a system. Assuming that resilience increases with a measure such as species richness, then if biodiversity is depleted, the stock of resilience falls. Even if there is no detectable change in outputs in the present day, the forest moves closer to a threshold or tipping point, beyond which it will move into a different level of functioning and usually lower level of benefits. Simplistically, the 'amount' of resilience is measured by the difference between the level of biodiversity (for the aspect of interest) and the threshold, whilst the value of resilience is measured by the difference in flow of benefits over time between the alternative states of the world – before and after the threshold is breached.

Finally, some decisions over forest management may result in irreversible impacts on biodiversity. For example, there is no practical sense in which loss of ancient woodland could be reversed. These losses need to be treated differently in economic analyses, since they imply foregoing future benefits and information. Deciding to protect the forest today yields an option value which represents the value of preserving it so that it might be available for use in the future. Such **option values** should be included in forest management decisions when irreversible losses are involved.

Using biodiversity values in different decision-making contexts

Decisions about forest management are usually concerned with comparative assessment settings: comparing 'business as usual' to alternative options or scenarios that stem from particular management or policy objectives (Table S.1).

Table S.1: Forest management and biodiversity value evidence needs

Decision / policy context*		Economic analysis – application	Biodiversity dependency and value(s)
Woodland creation	Conversion of open habitats to forest habitat	Benefits assessment (CBA): changes in the value of ecosystem services provided through alternative management options	Indirect: composition (habitats, communities) and functional roles that underpin ecosystem service provision Direct: species diversity (e.g. wildlife-based recreation)
Operational management	Species selection (e.g. monoculture vs. diversified) and age structure, harvesting system (clear felling vs. continuous cover)	Benefits assessment (CBA): trade-offs between value of production output (e.g. standing sales) and enhanced/ deteriorated provision of other ecosystem services	Indirect: structure and functional diversity Direct: species diversity (e.g. wildlife-based recreation)
Plant health, invasive species, pests & pathogens	Active management actions that increase resilience of forests (e.g. species diversification)	Benefits assessment (CBA): comparing opportunity cost of management actions to potential loss of productive output and provision of other ecosystem services	Indirect: stock of resilience Direct: nature conservation (e.g. non-use value)
Biodiversity targets	Management actions that deliver against national targets for conservation and enhancement of biodiversity	Benefits assessment (CBA): comparing opportunity cost of management actions (e.g. habitat restoration) to biodiversity conservation benefits	Indirect: structure and functional diversity Direct: nature conservation (e.g. non-use value)

Note: *This summary focuses on benefits assessment uses of biodiversity values. The main report also considers ecosystem accounting uses of biodiversity values. Whilst ecosystem accounting has a different emphasis for the measurement of value compared to benefits assessment, the concepts concerning the direct and indirect contributions of biodiversity still apply.

Economic analysis is ordinarily conducted within a cost-benefit analysis (CBA) framing with the purpose to identify a preferred management option or prioritise a set of interventions, such as management actions. Costs and benefits are projected over the lifetime of the intervention (i.e. current and future values). Impacts on biodiversity may feature either as a cost or a benefit depending on the context, or both (e.g. loss of habitat, active management enhancing specific biodiversity features). Resource costs include the inputs required to implement the management options (e.g. capital expenditure, equipment, labour). Benefits include a mix of market (e.g. timber sales) and non-market (e.g. informal recreation) outcomes.

As Table S.1 highlights, both direct and indirect contributions of biodiversity to current and future economic value are relevant to the benefits assessments. Different methods may be used to quantify and monetise these values. The main report (Section 4) sets these out, including a 'reference card' for the principal valuation methods across different final goods/services, the components of 'total economic value' (i.e. use and non-use values), and the direct and indirect contributions of biodiversity.

Summary

Typically, economic analysis is concerned with assessing trade-offs between the provision of (final) ecosystem services and the associated market and non-market goods/services, rather than the underlying trade-offs related to species richness, abundance and functional traits of biodiversity that underlie these outcomes. Trade-offs at the fundamental level of biodiversity and ecological functioning are instead implicit within economic analyses. Yet, alternative management options may imply systematically different structures and compositions of biodiversity within an ecosystem and hence differing capacities to sustain the provision of certain types of service in the future and changing environmental conditions.

Economic analyses that weigh-up the trade-offs between final goods and services cannot be assumed to automatically reflect the longer-term consequences of changes in biodiversity, such as changes in the capacity of ecosystems to produce certain outcomes under future environmental conditions. This means that in order for economic analyses to provide a fuller view of the contribution of biodiversity, the objective for economic valuation has to be to value the outcome *and* account for the associated dependencies on biodiversity.

Improving the way economic analysis accounts for the value of biodiversity requires refining the objective of economic valuation. This is not a fundamental change in approach but rather a need to provide a more comprehensive assessment of the final outcomes and their dependencies on biodiversity. A mix of monetary, quantitative and qualitative evidence is required to assess the direct and indirect contributions of biodiversity to ecosystem service provision over time. It is also important to qualify the boundaries of economic values in terms of the extent to which the status and condition of the biodiveristy attributes of interest are covered.

Research recommendations

New tools and guidance are needed for economic valuation and analysis to take better account of the dependence of ecosystem service provision on biodiversity. However, before these can be developed more work is needed to consolidate existing evidence and address gaps. The following high-level recommendations are intended to set a direction of travel for improving the evidence base and demonstrating more of the ways in which biodiversity contributes to welfare.

1. ***Undertake new research to estimate non-use values for forest biodiversity***. The current default values are around 20-years old. These values are an important aspect of the direct value contribution, but presently they cover a fairly narrow aspect of biodiversity in terms of tree species mix. A new research study provides an opportunity to produce new values for alternative management and nature conservation outcomes, and to address issues concerning aggregation of values (e.g. distance decay in non-use values) and transferability across decision-contexts.

2. ***Consolidate understanding and evidence of biodiversity dependencies***. Research is needed to develop biodiversity dependency 'logic chains' (see main report) for a range of final goods/services. These can be used as demonstration cases for practical benefits assessments. This is a multi-disciplinary research task that should trace through the biodiversity – ecosystem function – ecosystem service – economic value links. Initial scoping will be required to determine the level at which meaningful generalisations can be made, but the aim is to develop the framing for the qualitative narrative and - where possible – quantitative evidence that supports the understanding of the contribution of biodiversity in terms of indirect (particularly) and direct values.

3. ***Develop case study evidence on insurance values and resilience values for forests***. In cases where the biodiversity value is embedded within the value of final goods and services, qualitative assessments are a minimum requirement for providing an improved account of the indirect contribution of biodiversity. Insurance values and resilience values, however, are ordinarily not accounted for in these outcomes. The first step is to improve understanding of these concepts and their materiality to decision-making; for example, in assessing climate change adaptation measures for forestry. A case study approach would be ideal, applying the empirical approaches demonstrated in the literature (see Annex 1) to estimate insurance and resilience values. Overall, this requires an analysis that, for an aspect of biodiversity such as species mix, shows how the flow of values from a forest varies over time under different future conditions (i.e. varying levels of water availability, or disease/pests that impact production). The purpose would not be to produce generalisable results but instead highlight the potential relevance and importance of these values to decision-making.

Contents

Abbreviations & Acronyms

BAP	Biodiversity Action Plan
BAU	‘Business as usual’
CBA	Cost-benefit analysis
CBD	Convention on Biological Diversity
CCF	Continuous cover forestry
CICES	Common International Classification of Ecosystem Services
CV	Contingent valuation
DCE	Dichotomous choice experiments
ES	Environmental Stewardship
FE	Forestry England (formerly Forest Enterprise England)
FEGS	Final environmental goods and services
FSC	Forest Stewardship Council
IEGS	Intermediate environmental goods and services
MA	Millennium Ecosystem Assessment
NFI	National Forest Inventory
SEEA-EEA	System of Environmental-Economic Accounting – Experimental Ecosystem Accounting
SNA	System of National Accounting
TEV	Total economic valuation
UKFS	UK Forestry Standard
WTA	Willingness to accept compensation
WTP	Willingness to Pay

1. Introduction

This report has been prepared for the Forestry Commission to assess the feasibility of valuing forest biodiversity. The purpose is to consider how the value of biodiversity can be accounted for in economic analyses that support forest management and policy decisions.

1.1 Background

There is a diverse range of woodland and forests in the UK[1], including upland woods, Caledonian pinewoods, native lowland woodland, wet woodland, wood pasture and parkland, ancient trees, plantations, and ancient woodland (Woodland Trust, 2018). These represent some of the richest habitats in terms of the variety of plants and fungi they support (e.g. trees, grasses, ferns, lichens, and mosses) as well as mammals, birds, amphibians, reptiles and insects. Along with the nature conservation value, forest habitats also provide a range of socio-economic and cultural benefits that support local economies and communities through activities such as timber production, wild foods (foraging) and recreation. Added to these are 'unseen' benefits that include carbon sequestration and contributing to natural flood control processes in river catchments.

The range of benefits that the natural environment provides for people, either directly or indirectly, are typically conceptualised in terms of 'ecosystem services' (e.g. Daily, 1997; MA, 2005). Conventional categorisations distinguish between provisioning services (products obtained from ecosystems, such as timber), regulating services (benefits from the regulation of natural processes, including climate and water/flood regulation), and cultural services (the non-material benefits people obtain from ecosystems through recreation, aesthetic enjoyment, etc.).

Biodiversity provides the fundamental underpinning for ecosystem functioning, and consequently the provision of ecosystem services and the benefits to society. In combination with land management actions and factors such as climate, soil type and nutrients, biodiversity - in terms of the types of plants and animals, their abundance, and the interactions between them within an ecosystem – determines the types and quality of ecosystem services and, crucially, how resilient their provision is to external 'shocks' and pressures, both in the shorter term (e.g. disease and invasive species) and over longer timescales (e.g. climate change). Put another way, ecosystem service benefits and their sustained provision over time are critically dependent on biodiversity.

Forest management decisions are primarily concerned with trade-offs between the multitude of different ecosystem services outcomes that could be delivered and the associated costs of delivery. The overarching priority for forestry in the devolved administrations across the UK is to balance rural development, economic regeneration, recreation and access, and environmental conservation objectives (Defra, 2013; Scottish Government, 2018; Welsh Government, 2018). Inherent in all forest management decisions is the

[1] The terms and 'woodland' and 'forest' are often used interchangeably. UK Forestry Statistics defines woodland as land under stands of trees with a canopy cover of at least 20% (or having the potential to achieve this), including integral open space, and including felled areas that are awaiting restocking (Forestry Commission, 2011). Forest, on the other hand, typically describes extensive wooded areas, but in an historical context has also been applied to areas that are not wooded (e.g. heath, grassland and wetland) that support deer and other game, particularly in the case of Royal Forests (the earliest of which date from the 11th century).

dependency on biodiversity. The trade-offs between different potential outcomes (timber, recreation, conservation) are also translated to the level of biodiversity and its dimensions. For example, changing management practices from clear felling to continuous cover forest for harvesting of timber, or converting open habitat to woodland implies significantly different compositions of species and the interactions between them. Given the long-time horizons for forest management decisions (40 – 60 years based on tree growth) there can be substantial implications for the functioning of underlying ecological processes (e.g. biomass production, pollination, nutrient cycling, water retention), their resilience to environmental change, and the provision of other types of ecosystem service.

Moreover, the changes due to management decisions may or may not be reversible. For instance, ancient woodlands and the genetic diversity they contain cannot be replaced. Their loss might entail the loss of species that have future value that has not been recognised yet (e.g. pharmaceutical products). There may also be ecological communities and networks present in ancient woodlands that take centuries to establish; these also cannot be replaced in meaningful timescales from a management perspective.

Gaps in knowledge and evidence concerning forest biodiversity mean that decision-making is based on partial scientific information. This includes the multifunctional role biodiversity plays and the dependency of ecological functions and ecosystem services upon it; how different aspects of biodiversity can be measured; and the relative importance of physical (abiotic) processes and factors alongside biodiversity in ecosystem service provision.

In addition, the economic evidence concerning ecosystem service outcomes, which helps to measure and balance trade-offs between costs and benefits in management decisions is also incomplete (Binner et al., 2017). Indeed, it is widely recognised that even within the conceptual framework of the ecosystem service approach, the economic value of biodiversity is, for the most part, implicitly assumed and/or 'hidden' (Bolt et al. 2016). Where valuations are available, the coverage is partial and does not capture the full spectrum of benefits that can potentially be valued in monetary terms. Rather the focus tends to be concentrated on very specific aspects of biodiversity such as charismatic species, which do not necessarily reflect well the critical dependencies of ecosystem service provision on biodiversity.

1.2 Objectives

The overall aim of this study is to assess the feasibility of valuing forest biodiversity and to provide a range of practical assessment options for economic valuation. The specific objectives of this study are to:

- Review the basis for valuing forest biodiversity for informing forestry policy and management decisions, including determining which aspects of the role of biodiversity it is appropriate to value;
- Examine the range of economic values associated with forest biodiversity and assess which valuation methods are appropriate to capture these values; and
- Develop options for valuing the different aspects of forest biodiversity and recommend practical and worthwhile ways to address evidence gaps.

The study is primarily focused on forest-level management, concerning decisions such as woodland creation, operational management (e.g. continuous cover forestry), tree and plant health strategies (disease and invasive species control), and nature conservation objectives (e.g. biodiversity targets). There is, though, relevance for broader decision-contexts, including demonstrating 'value for money' of forest management, as well as the developing 'public money for public goods' agenda within the context of agri-environment policy. Furthermore, whilst the focus is on forestry, the principles that are examined in relation to valuing biodiversity generally apply to wider land and water environment management issues and policies.

For the most part, the study is framed from an economic analysis perspective and measuring the value of biodiversity in terms of the contribution to individual and social wellbeing. This is consistent with the principles set out in The Green Book (HM Treasury, 2018), which guides the appraisal approach for public sector policies, programmes and projects. Economic analysis (such as cost-benefit analysis, CBA) – supported by economic valuation methods – seeks to provide an explicit account of the trade-offs between policy and project outcomes, which informs impact assessments and business cases.

Requirements for ecosystem accounting are also considered, including continuing efforts to test and develop the System of Environmental-Economic Accounting – Experimental Ecosystem Accounting (SEEA EEA) (UN et al. 2014; 2017). There are ongoing discussions and work on the extent to which the role of biodiversity and associated values at different levels of biological organisation are captured in ecosystem accounts (e.g. King et al., 2019). In the main, valuing biodiversity's role in ecosystem service provision for ecosystem accounting is more concerned with measuring the productive capacity of the natural environment in line with national accounts, rather than the overall contribution to social wellbeing. Nevertheless, there are still parallels in terms of explicitly identifying the dependency of multiple ecosystem service benefits on different aspects of biodiversity and the resilience and adaptability that the natural 'system' can sustain.

Overall, the purpose of this report is to summarise key insights from literature in order to inform a practical assessment of options for valuing forest biodiversity that would address key gaps in the evidence base. The intention is not to provide a formal literature review nor summarise and compile 'biodiversity valuations' from existing studies. Previous Forestry Commission studies including '*Valuing the social and environmental contribution of woodlands and trees in England, Scotland and Wales*' (Binner et al., 2017) have reviewed the current state of knowledge regarding economic valuation of the socio-economic benefits of trees and woodlands.

1.3 Report structure

The remainder of this report is structured as follows:

- Section 2: provides an overview of the value of biodiversity from an economic analysis perspective. It addresses three questions: what is forest biodiversity, what is the economic value of forest biodiversity, and what are the uses of forest biodiversity values?

- Section 3: reviews some of the key challenges and associated opportunities that are encountered in practical assessments that seek to link biodiversity to economic values and understand how changes in biodiversity result in changes in economic values.

- Section 4: sets out suggestions for a practical approach, identifying how different aspects of biodiversity values can be assessed across different ecosystem services using different valuation methods.
- Section 5: concludes with a summary of the main points with respect to valuing the contribution of biodiversity to individual and social wellbeing. High-level recommendations for further research and guidance to support the practical approach are also provided.

In addition, three supporting annexes accompany the main the report content:

- Annex 1: summarises the main results from empirical studies that have assessed insurance values and the resilience values associated with biodiversity.
- Annex 2: presents examples of logic chains concerning the value of biodiversity.
- Annex 3: summarises different methods and approaches available for estimating the economic value of biodiversity.

2. Overview of the value of biodiversity

This section considers three interlinked questions: what is forest biodiversity; what is the economic value of forest biodiversity; and what are the uses of forest biodiversity values?

2.1 What is forest biodiversity?

Defining and measuring biodiversity

The most commonly cited definition of biodiversity is provided by the Convention on Biological Diversity (CBD.). It defines biodiversity as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems *and the ecological complexes of which they are part, this includes diversity within species, between species and ecosystems*" (CBD, Article 2). Defined in this manner biodiversity is a multi-dimensional construct and can be classified in many ways, meaning there is no single measure or indicator of biodiversity that captures all its dimensions and attributes (MA, 2005).

A principal distinction is often drawn for the 'level' at which biodiversity is considered, ranging from 'genetic diversity' (the variety of genes within a particular species), to 'species diversity' (the variety of species within a habitat or area), to 'ecosystem diversity' (the variety of ecosystems within a given area, including the communities of organisms within it). Beyond this, there are different dimensions such as species richness, abundance and distribution, functional traits (e.g. predator vs. prey), tropic position (food chain level), and role in ecosystem processes (Harrison et al., 2014).

Any one measure, such as species richness - a count of the number of species within an ecological community - will likely be a limited proxy for the other dimensions of biodiversity. This limitation extends to index-based measures which may provide a composite measure for a single dimension (e.g. woodland and farmland bird indices[2] – species abundance) or at most two dimensions (e.g. Shannon index – species richness and abundance). Hence much care needs to be taken when interpreting measures of biodiversity and understanding what information they convey about the status and condition of ecosystems. **Box 2.1** illustrates how biodiversity is currently characterised in relation to the management of forests in the UK, based on the UK Forestry Standard (UKFS, 2017).

[2] Bird population indices in general may provide a reasonable indication of the state of wildlife given the range of habitats the monitored species occupy, and the range of environmental pressures faced. They also feature long-term datasets in the UK starting from 1970. However, this is only a partial view of the condition of ecosystems and their capacity to supply a range of ecosystem services.

Box 2.1: Characterising biodiversity within forest and woodland ecosystems

A starting point for characterising forest biodiversity is the UK Forestry Standard (UKFS, 2017). It sets out the approach for sustainable forest management including requirements with respect to biodiversity and outlines a range of factors that are important for the management of forest biodiversity.

Factor	Biodiversity level	Importance for biodiversity
Priority habitats and priority species	Species	Priority habitats have the potential to provide for the richest and most varied components of biological diversity. Priority species are those that are rare and at risk of extinction, threatened, or have special requirements.
Native woodlands	Species	Native woodlands, and especially ancient woodlands, are the priority habitats of greatest relevance to forestry. They have a very high biodiversity value or potential and support a large proportion of priority species.
Ecological connectivity	Ecosystem/ landscape	Ecological connectivity facilitates the movement of species by providing linkages between habitats.
Ecological processes	Ecosystem	Natural ecological processes can deliver diversity of structure and other habitat features that benefit many species.
Tree and shrub species selection	Species	Diversity of tree and shrub species is generally beneficial for biodiversity; genetic diversity within species is an important component of biodiversity and underpins sustainable forest management.
Forest and stand structure	Species	Structural diversity in forests creates a wide range of habitats.
Veteran trees and deadwood	Species	Old trees and deadwood are particularly significant for woodland biodiversity.
Open, scrub and edge habitats	Ecosystem	Open-ground and edge habitats associated with woodland provide important resources and habitats for biodiversity
Riparian zones	Ecosystem	Riparian ecosystems are rich in wildlife habitats and provide linear habitat linkages.
Habitat creation and restoration	Ecosystem	Significant gains for biodiversity arise from restoring degraded habitats and the targeted creation of new habitats
Invasive species	Species	Species that are invasive, and particularly non-native and invasive, can diminish biodiversity and need effective control.
Grazing and browsing		Managing domestic stock and other herbivores effectively is necessary to protect and enhance biodiversity.

Source: UKFS (2017).

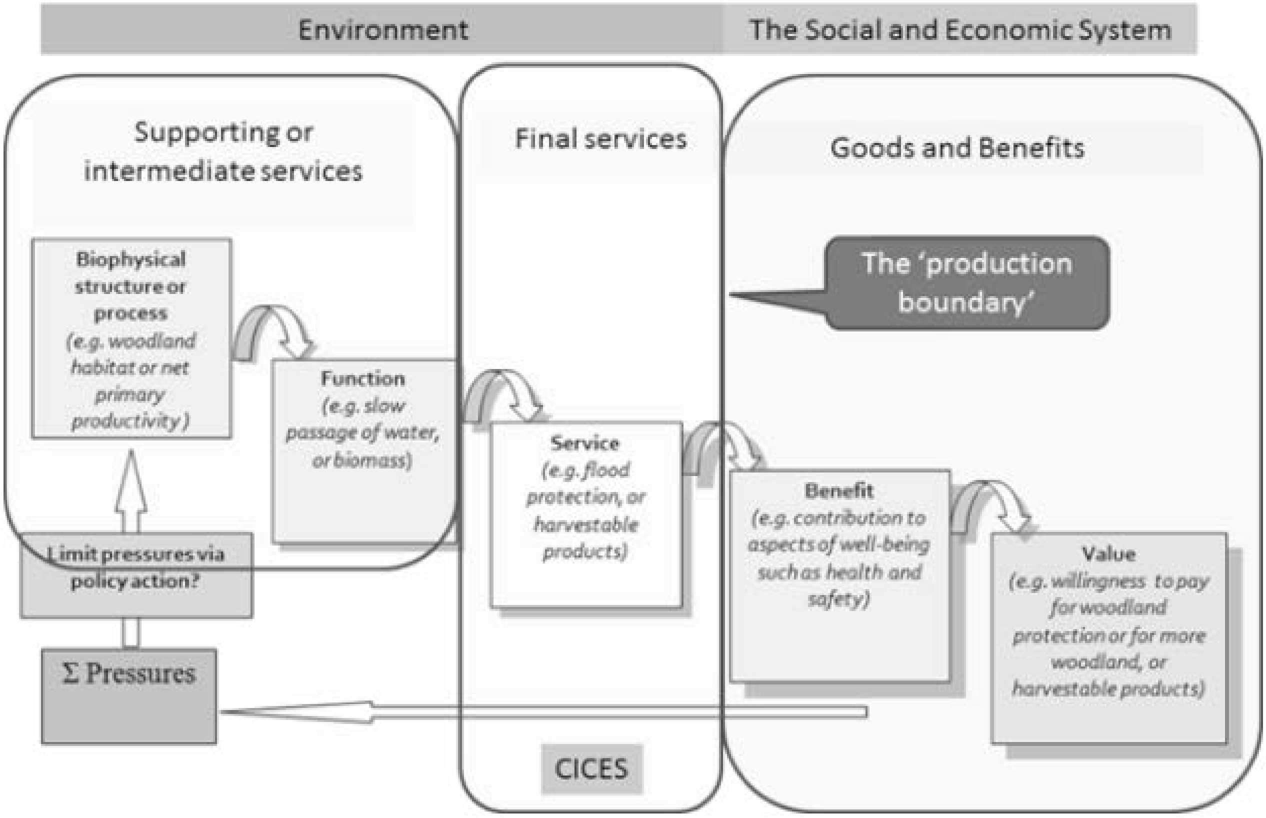
Various assessments use metrics and indicators associated with these characteristics to monitor and assess the integrity of biodiversity and ecosystem functions and services it supports. For example, various woodland natural capital and ecosystem accounts that have been developed (e.g. Forest Enterprise England, 2018; ONS, 2017; eftec, 2015). A primary source of data is the National Forest Inventory (NFI) which is designed to provide information about the size, distribution, composition and condition of forests and woodlands and track changes taking place over time (Forest Research, *n.d.*). In particular, the NFI includes detailed spatially explicit data on species type and forest structure (e.g. size and age class).

Defra/ONS experimental spatially disaggregated ecosystem accounts for England, Scotland and Wales (see eftec, 2015) include the following characteristics to represent the 'stock' of biodiversity within forests: volume of deadwood (dead and dying trees play a key role in the functioning and productivity of forest ecosystems); invasive species (non-native species that become invasive are considered to be main direct drivers of biodiversity loss); number of native species (tree species influence the overall composition of biodiversity); and vertical structure (the dimension from ground to canopy includes layers of foliage, gradients of microclimate and a diversity of plants and animals that respond to that vertical structure). Note that this combination of characteristics differs from SEEA-EEA guidance, which suggests accounting for the abundance and distribution of species; however, this would only capture a single aspect of biological diversity within woodland habitats.

Role of biodiversity in ecological processes and functioning

Biodiversity is fundamental to the ecosystem functioning and processes that underpin ecosystem service provision (**Figure 2.1**). This includes processes such as biomass production, litter decomposition, soil organic carbon storage, pest control, and pollination. In some ecosystem service classifications, these underpinning processes are classified as 'supporting services' or 'intermediate services' (e.g. MA, 2005)[3]. A key concept in this regard is 'ecosystem multifunctionality' which recognises the potential of ecosystems to simultaneously provide multiple functions and benefits to society.

Figure 2.1: Common International Classification of Ecosystem Services (CICES) 'cascade' model



Source: Potschin and Haines-Young (2016).

The CICES cascade model characterises the relationships between individual and overall social welfare and the provision of 'final' ecosystem services and the associated goods and benefits they provide. The provision of these services is underpinned by ecosystem functions, processes and structures that generate them (intermediate and supporting services). This includes processes such as net primary production, biomass production, litter decomposition, soil organic carbon storage, pest control, and pollination.

A distinction can be drawn between the developing understanding of the drivers of *ecosystem functioning* in terms of the collective biological, physical and geochemical processes that occur in an ecosystem, and *ecosystem service* multifunctionality (Manning et al., 2018). The latter concept concerns the potential for landscapes to be managed to deliver multiple ecosystem services and socio-economic benefits in accordance with land use management objectives and policies.

[3] Mace et al. (2012) emphasise that biodiversity is important at all levels in ecosystem services provision, underpinning ecosystem processes (supporting services), providing intermediate (e.g. pollination) and final services, and representing a source of economic value itself (e.g. individuals' preferences for wildlife conservation). Here the term 'ecosystem functioning and processes' is used to describe the supporting services and intermediate services levels to allow for a clearer distinction of final ecosystem services that generate economic goods and benefits.

Typically, economic analysis is concerned with assessing trade-offs between the provision of ecosystem services at the landscape scale, rather than the underlying trade-offs related to species richness, abundance and functional traits of biodiversity that underlie these outcomes. Trade-offs at the fundamental level of biodiversity and ecological functioning are instead implicit within economic analysis. Given the scope of economic analyses, gaps in knowledge and evidence, the full range of consequences of different management options on ecological functions may not be adequately reflected in economic values. For example, alternative management options may imply systematically different structures and compositions of biodiversity within an ecosystem and hence differing capacities to sustain the provision of certain types of service in the future and changing environmental conditions. It cannot be assumed, however, that economic analyses would automatically account for these future effects even though any change in the flow of benefits over time should be measured.

Overall, greater levels of biodiversity are generally positively associated with ecosystem functioning, but the relative importance of species diversity, functional diversity (functional traits), and functional composition varies for different ecological functions. Added to this, abiotic factors (e.g. climate, geology, water availability) can be stronger drivers of ecosystem functioning than differing biodiversity attributes (van der Plas, 2019). The trade-offs between these determining factors are not only of importance to ecosystem functioning and service provision under current environmental conditions and management regimes, but also future circumstances. Indeed, a fundamental property that biodiversity ensures in ecosystem functioning is resilience.

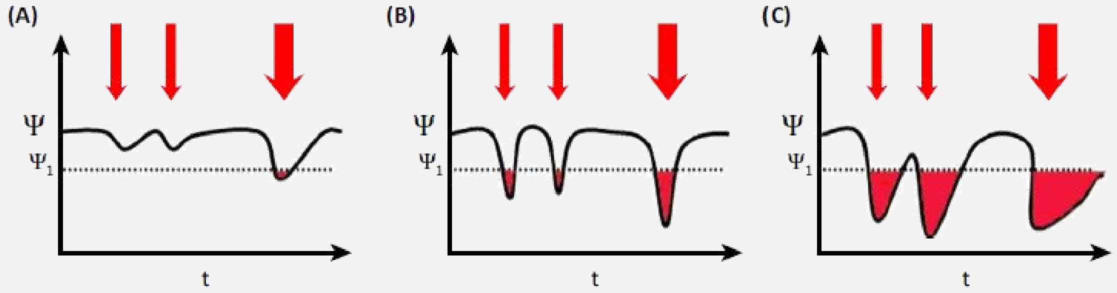
From an ecological perspective resilience is the degree to which an ecosystem function can resist or recover from changes in environmental conditions[4] in terms of maintaining the function above some threshold level (e.g. such as a 'safe minimum standard') (see **Box 2.2**). This highlights a key point that whilst ecosystem resilience may be regarded in general terms, it fundamentally relates to the capacity of specific function to withstand a specific event (i.e. the resilience "of what, to what?"). The potential causes of changes in environmental conditions are various (climate, land conversion, pollution, fire, invasive species, etc.) and the effects, which alter the structure or relationships between biotic and abiotic attributes of an ecosystem, can be rapid (e.g. disease), long term (e.g. loss of habitat) or transitory (e.g. drought).

The stability of an ecosystem function over time and its resilience is dependent on various species, community and ecosystem level factors and the interconnections between them (Oliver et al., 2015). One such characteristic is 'functional redundancy', which is the tendency for different species to perform similar functions but exhibit different response traits to environmental changes and therefore act as substitutes for each other's contribution to ecosystem processes. This, essentially, represents nature's insurance since an ecological function is dependent on a 'portfolio' of species, rather than a single species. Accordingly, there is a direct association with the insurance value associated with biodiversity in terms of ecosystem service provision (see Section 2.2).

[4] Changes in environmental conditions are disturbances or perturbations that alter the structure or functions within an ecosystem. The UKFS (2017) defines resilience as "*The ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change*" (p. 223).

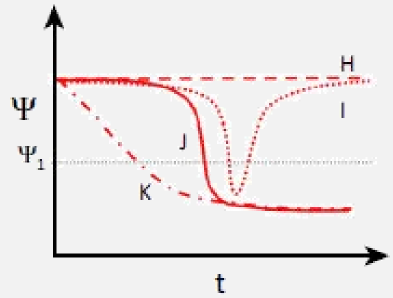
Box 2.2: Resilience and ecosystem functioning (Oliver et al. 2015)

Oliver et al. (2015) depict different potential levels of resilience that an ecosystem function (Ψ) may have to environmental perturbations (red arrows):



Panel (A) shows a system with high resistance but slow recovery; panel (B) shows a system with low resistance but rapid recovery; panel (C) shows a system with both low resistance and slow recovery. Lack of resilience (vulnerability) could be quantified as the length of time that ecosystem functions are provided below some minimum threshold set by resource managers (this threshold shown with the symbol Ψ_1) or the total deficit of ecosystem function (i.e., the total red-shaded area). Note that, in the short term, mean function is similar in all systems but in the longer term mean function is lower and the extent of functional deficit is higher in the least resilient system (C).

The panel below shows four qualitatively different outcomes for ecosystem functioning over time, relative to Ψ_1 that indicates a minimum threshold set by resource managers:



H represents a system that is fully resistant to an environmental change; *I* limited resistance but full recovery; *J* limited or low resistance and *K* no recovery of function.

Source: Oliver et al. (2015)

2.2 What is the economic value of forest biodiversity?

Biodiversity generates economic value when it contributes to human wellbeing. More specifically, it has economic value when it contributes to 'welfare' or 'utility'[5], and when changes in some aspect of biodiversity cause a change in welfare[6]. Such contributions can take two basic forms:

- **Direct contribution**: some aspect of biodiversity is the (final) good/service that an individual benefits from, such as wild species conservation; or
- **Indirect contribution**: some aspect of biodiversity contributes to the production of a (final) good/service that an individual benefits from, such as timber.

The 'overall' value of biodiversity can therefore be assessed as the sum of the direct and indirect contributions to individual and social welfare. **Figure 2.2** provides a high-level summary of how the direct and indirect contributions correspond to the different component of total economic value (TEV)[7]. For individuals and households, TEV represents the ways that all goods and services – whether they are 'priced' and provided through markets, or unpriced and non-market and/or public goods – generate utility. For society overall, TEV represents the aggregated sum of individual values, ordinarily across the beneficiary population and discounted across an appropriate time horizon. For ecosystems or natural assets, TEV reflects all of the ways the ecosystem functions, ecosystem services and goods can impact individual and overall social welfare.

Figure 2.2: Contribution of biodiversity to economic welfare

	Direct contribution to welfare	Indirect contribution to welfare		
Use value	***Direct changes in households' utility***	***Relationships between ecosystem service provision and the production of final goods and services***		*Resilience value(s) – dependency on biodiversity for sustained ecological functions and process that underpin all contributions to welfare*
Consumptive use	Provisioning services: e.g. wild food	Provisioning services: e.g. timber and other forest products	*Insurance value(s): reduced variation in future income*	
Non-consumptive use	Cultural services: e.g. wildlife-based recreation, aesthetics and amenity, physical and mental health	Regulating services: e.g. carbon storage and sequestration, air quality regulation, flood regulation		
Option value	Future consumptive and non-consumptive use values	Future consumptive and non-consumptive use values		
Non-use value	***Direct changes in households' utility***			
Altruism, bequest and existence value motivations	Biodiversity conservation (e.g. threatened or priority species)			

Notes: selected examples of final goods and services.

[5] Utility or welfare is the (net) benefit an individual derives from the consumption of a good or service (use value) or knowledge that it exists and/or that others derive from its consumption, now or in the future (non-use value).
[6]. For more detail on what follows, see Hanley and Perrings (2019).
[7] See eftec (2011; 2015) for non-technical summaries of the underlying concepts for economic valuation related to forestry and biodiversity, respectively.

The main distinction in the TEV typology is between use value and non-use value. Use value arises from consumptive or non-consumptive interactions with a resource now or in the future – the latter referred to as option value. Non-use value is associated with individual's altruistic preferences for others living now (altruism), for future generations (bequest value) and for aspects of the natural world in their own right (existence value). As the summary in **Table 2.1** shows, most empirical studies concerning biodiversity focus on direct contribution to welfare in terms of non-use values. A more detailed review of forest-related valuation studies is included in Binner et al. (2017).

Direct contribution to welfare

Individuals may derive utility directly from some aspect of biodiversity. This is relatively straightforward to conceptualise if biodiversity is characterised in terms of habitats, or particularly, charismatic species. For example, if there is a fall in the population of red kites in Scotland, some people will feel worse off. If a native pine forest is destroyed by fire, some people will feel worse off. If these affected individuals are willing to give up some of their income or consumption of other goods and service in return for avoiding such negative impacts, they would be said to be willing to pay to prevent reduction in the population of red kites, or reduce the risk of fire in the native pine forest. The most an individual is willing to give up represents their maximum willingness to pay (WTP) to prevent a decline in biodiversity or to secure an improvement. Alternatively, individuals may be willing to accept compensation to tolerate a decline or to forgo an improvement. The minimum such amount represents their minimum willingness to accept compensation (WTA).

Note that WTP and WTA are measure of economic value that are defined in relation to some *change* in a measure of biodiversity. Welfare measures such as WTP and WTA only have meaning when defined over a specific underlying quality or quantity change. Note also that the direct value of (a change in) biodiversity may not be positive; if individuals prefer lower populations of a species (e.g. mosquitos), then they would be willing to pay for a reduction in their abundance.

Direct use values of forest biodiversity can be non-consumptive. For example, higher bird species diversity in a woodland increases the utility of forest visitors. Direct use values can also be consumptive, for example if wild food abundance and diversity increases in woodlands (i.e. plants and fungi), this may generate additional benefit for foragers. Individuals can also enjoy direct benefits from an increase in biodiversity through their in-situ use of a resource. For instance, bird watchers visiting a nature reserve will derive a use benefit from higher species diversity. But those who do not visit the reserve may still derive benefit from higher species diversity or greater species abundance for a variety of (non-use value) motivations – a pure existence value, or because they gain utility from knowing that others benefit, now or in the future (altruistic and bequest motives).

Table 2.1: Selected example of forest biodiversity empirical studies

Author(s)	Valuation scenario	Biodiversity attributes	Contribution to welfare	TEV	Valuation Method
Areal and Macleod (2014)	Valuation of tree species susceptible to Phytophthora ramorum, (sudden oak death) (North Yorkshire).	Diversity of tree species.	Direct and indirect	Non-use and use	Stated preference: contingent valuation
Boatman and Willis (2010)	Aesthetic value and biodiversity provided by woodland, enclosed farmland; semi-natural grassland as a result of the Environmental Stewardship (ES) Scheme (England).	Species richness, diversity of species	Direct	Non-use	Stated preference: contingent valuation
Christie et al. (2011)	Value of ecosystem services provided by BAP habitats: wild food, non-food related provisioning services, climate regulation, water regulation, sense of place, charismatic species, non-charismatic species (UK).	Species richness, diversity of species	Direct and indirect	Non-use and use	Stated preference: choice experiment
Christie et al. (2006)	Agri-environmental and habitat re-creation policy on farmland in England.	Species protection, habitat restoration and ecosystem service preservation	Direct and indirect	Non-use and use	Stated preference: choice experiment and contingent valuation
Christie et al (2004)	Agri-environmental and habitat re-creation scheme in Cambridgeshire and Northumberland.	Species protection, habitat restoration and ecosystem service preservation	Direct and indirect	Non-use and use	Stated preference: choice experiment and contingent valuation

Author(s)	Valuation scenario	Biodiversity attributes	Contribution to welfare	TEV	Valuation Method
Czajkowski et al. (2009)	Valuing changes in forest biodiversity (UK).	Familiar species of wildlife (rare and common), unfamiliar species of wildlife (rare and common), quality of habitat, ecosystem processes, ecosystem resilience, habitat for endangered and protected plant and animal species, forest stand structure, landscape diversity, amount of dead wood.	Direct and indirect	Non-use and use	Stated preference: choice experiment
Garrod and Willis (1997)	WTP for marginal increases in biodiversity from restructuring remote commercial conifer plantations (UK).	Species richness, diversity of species	Direct	Non-use	Stated preference: contingent ranking
GHK Consulting (2011)	Bundle of services provided by coastal margins; mountains, moorlands and heaths; woodland; semi-natural grasslands; freshwaters; enclosed farmland. (England and Wales).	Species richness, diversity of species	Direct and indirect	Non-use and use	Stated preference: choice experiment
Hanley et al. (2002)	WTP for marginal increases in biodiversity from restructuring remote commercial conifer plantations (UK).	Species richness, diversity of species	Direct	Non-use	Stated preference: contingent valuation
MacPherson et al. (2017)	Assess the role of crop species and genetic diversity in reducing risks to commercial outputs for forests (UK).	Diversity of tree species.	Indirect	Consumptive use value	Production function approach
Sheremet et al (2017)	Willingness to pay for forest disease control (UK).	Composition and abundance of tree species.	Direct and indirect	Non-use and use	Stated preference: choice experiment

Indirect contribution to welfare

Biodiversity also generates value as an input to the production of something (a good or service) from which people derive utility. Economists usually conceptualise the link between biodiversity as one input and a desired good or service as an output as a production function[8]. Biodiversity will be one input of many into such production functions, and its value is captured in the marginal or partial effect of a change in biodiversity on the change in some desired economic good or service, holding other inputs constant. This could be regarded as 'the marginal revenue product' of biodiversity and, in effect, a measure of a producers' (maximum) marginal WTP for the aspect of biodiversity as a production input[9]. How changes in some aspect of biodiversity result in changes in a good or service is dependent on the (mathematical) form of the production function. Added to this, is also the form of household's utility functions which ultimately transform this change in a good or service into a change in individual welfare[10].

Both relationships can be empirically estimated, although the evidence base with respect to explicit measures of biodiversity tends to be limited. As noted above (Section 2.1), evidence from ecology suggests that in some contexts, more biodiverse forests are causally associated with ecosystem functioning and higher levels of ecosystem service provision. But whether economic value is increasing or decreasing in some aspect of diversity via ecosystem functioning and a production function relationship is context specific. For example, more diverse woodlands may have lower levels of commercial timber growth and lower carbon sequestration levels. Higher diversity can thus be linked with higher outputs of some ecosystem services but lower outputs of others, so that the relative (economic) value of each of these outputs (carbon sequestration, timber, wildlife-based recreation) will partly determine whether overall indirect forest economic value is increasing or decreasing in some measure of biodiversity.

Insurance value

Closely linked to the indirect contribution of biodiversity to welfare via the production function relationship is the notion of an insurance value associated with biodiversity. In particular, ecosystem service outputs over time are partly 'stochastic'. In economic analysis terms, this means there is a random element in the production function that is not predictable; i.e. there will be fluctuations in output that cannot be reliably anticipated in management decision due to factors such as natural hazards (e.g. weather, disease, fire,

[8] Note that the treatment in this report differs slightly from Binner et al. (2017) even though ultimately the same conclusions with respect to valuing the contribution of biodiversity to economic welfare are reached. Binner et al. break the production function process into two parts: (i) an 'environmental production function' that describes the underlying processes in an ecosystem that leads to the provision of final ecosystem services; and (ii) an 'economic production function' that describes how environmental inputs are combined with other forms of capital to produce final goods and services that confer welfare. The terminology 'intermediate environmental goods and services' (IEGS) is used to represent environmentally produced goods and services that act as inputs to some other environmental process and 'final environmental goods and services' (FEGS) to represent environmentally produced goods and services that enter household or firm production functions. Here, instead, the distinction is made between direct contributions to welfare which accord to benefits that are derived through a household's utility function, and indirect contributions that are realised through economic production processes. Hence the term 'production function' is used in the context of the production physical goods (e.g. timber products) rather than also referring to the value associated with the non-material benefits derived from ecosystems (e.g. cultural services).

[9] In terms of economic analysis, a production function quantifies the relationship between one or more inputs to production and the productive output. Typically, production inputs are raw materials, labour and financial capital. The change in output that occurs when the level of an input changes – holding all others constant – is the marginal (physical) product. Multiplied by the output price for the product (good/service), this provides an estimate of the marginal revenue product of the input.

[10] A further distinction to make here is that the household's utility function will feature the final good or service that is dependent on biodiversity as an input, rather than the particular aspect of biodiversity. This is why the relationship between economic welfare and biodiversity is 'indirect'. For example, 'more' biodiversity in terms of the abundance of wild pollinators leads to higher supply of pollination services. Individuals, though, do not value the abundance of insect pollinators *per se*, but the production process to which they contribute, which is to help produce food. Therefore, food consumption features in the household utility function and the relationship with biodiversity is indirect because individuals care about the consequence of this aspect of biodiversity, not the biodiversity feature itself; i.e. insect pollinators. A similar reasoning applies to the relationship with respect to regulating services. For example, individuals will have preferences for reducing flood risk and potential damages to property and risks to human life. Ecosystem functioning influences the level of flood risk, but the household utility function features the consequences (avoided damages) not the process-related to biodiversity.

flood). Future prices for outputs are also uncertain. Land managers – farmers and foresters – therefore face uncertain future income streams.

Forest owners make risky investments when they plant new forests or change long term management practices. They face a probability distribution of possible returns (income) over time (future outputs from the forest are not known for sure). If higher levels of biodiversity mean lower variability in possible returns (which occurs if the risks from the different outputs from a forest are negatively correlated or uncorrelated), then there is an insurance value from this aspect of biodiversity. This is the economic translation of the portfolio effect of biodiversity where ecosystem functioning incorporates redundancy, and dependency is based on diversification rather than specialisation.

Correspondingly, risk-averse forest managers would be willing to pay for the risk reduction which more diverse forests offer (see Baumgärtner, 2007; Finger and Buchmann, 2015; and Bartkowski, 2017). This represents a risk premium that is a measure of the insurance value of biodiversity. This insurance value will vary according to the risk preferences of land managers. Annex 1 summarises the results from studies that have examined the insurance effect, including for forests.

Conceptually the insurance value is additive to value associated with the output of the final goods associated with provisioning services; hence the indirect contribution of biodiversity to the production of final goods and service is equivalent to its marginal revenue product plus the allied insurance value (Pascual et al. 2015). Insurance value may also apply to regulating services but defined as it is above in relation to reducing income risks to producers it is more readily interpreted as an additive value for provisioning services.

Resilience value

The insurance value associated with biodiversity can be viewed as a narrow economic interpretation of the resilience property that biodiversity ensures in ecological functions and provisioning services. It specifically relates to one aspect of resilience, which is the maintenance of specific ecosystem service outputs despite variability, disturbance and management uncertainty. This results in a lower risk of producers being impacted by a disturbance event and reduces the potential size of the loss income from an event.

As described in Section 2.1, resilience is a property of underlying ecosystem functions – rather than necessarily an attribute of any single ecosystem service – and is defined against some threshold level; i.e. the ability of an ecosystem to respond to future shocks (e.g. fire, disease) and retain its functioning within certain bounds. From an economic perspective, biodiversity can be thought of as a stock which can confer higher resilience in a system. For example, assuming that resilience is increasing in some measure of biodiversity such as species richness, then if biodiversity is depleted, the stock of resilience falls. This means that even if there is no detectable change in current period outputs from the forest despite pressures on the system, the forest moves closer to a threshold or tipping point, beyond which it will move into a different level of functioning and different levels of service outputs (these could be better, but are often thought of as worse)[11]. There could also be a hysteresis effect in operation, which means that the costs of returning to the original threshold greatly exceed the costs of preventing a movement past the threshold.

[11] Similar conclusions appear to be drawn in the current discourse related to ecosystem accounting where resilience and the role of biodiversity in maintaining ecological functioning is viewed as the capacity to provide future flows of ecosystem service and benefits (King et al., 2019.).

Walker et al. (2010) were the first to show formally in an economic model how, in principle, changes in the stock of resilience in an ecosystem can be valued. Whilst their framework is conceptually elegant (and fully consistent with a comprehensive wealth-based system of natural capital accounting), it is challenging to apply in practice in a way which is strictly separable from other economic values of biodiversity. **Annex 1** summarises the main results from Walker et al. (2010) along with a further example that examines resilience in the context wild insect pollinators.

Option value (accounting for irreversible effects)

Some decisions over forest management may involve irreversible impacts on biodiversity. An example would be a decision not to protect an ancient woodland, resulting in its destruction; there is no practical sense in which this outcome could be reversed, once enacted. Krutilla and Fisher (1975) highlighted that such irreversible losses need to be treated differently in economic analyses (e.g. cost-benefit analysis), since they imply foregoing an infinite stream of conservation benefits into the future; and since information gained after the decision to fell the forest on the value of biodiversity has no value once felling has occurred. Deciding to protect the forest today yields an option value which represents this potential value of information. Such option values should be included in a cost-benefit analysis of forest management decisions when irreversible losses are at hand.

The Krutilla-Fisher model has previously been applied to issues over biodiversity conservation in the UK. Hanley and Craig (1991) used the approach to evaluate afforestation proposals in the “Flow Country” of Northern Scotland and showed that afforestation (which led to a loss of rare wader species and other birds) had a negative net present value. The Krutilla-Fisher model is also of relevance to the issue of changing real benefits over time, since it allows for different growth/decay rates for biodiversity conservation benefits compared to economic development benefits foregone (in the case of Hanley and Craig, these were the value of timber harvests).

Valuing the overall contribution of biodiversity

In principle the overall contribution of biodiversity to individual and social welfare is the sum of the direct utility values (use and non-use values, including option value) and the range of indirect values associated with biodiversity as input (one of many) to an ecosystem production function that generates a flow of ecosystem services. If it was possible to quantify (estimate) this production function empirically, then it could be used to show how changes in final ecosystem service values (provisioning services such as timber, regulating services such as carbon storage) result from a specific change in forest biodiversity (i.e. the marginal revenue product of biodiversity). The economic value of the change in these ecosystem service outputs is then an estimate of the indirect benefits of biodiversity *providing that all of these indirect links can be quantified.*

However, even if it were possible to quantify all of the ways in which biodiversity directly and indirectly delivers benefits in a forest, the sum of these changes in ecosystem service would underestimate the total value of the biodiversity change, since it would likely neglect any insurance or resilience value. Insurance values could be included if a portfolio of ecosystem service outputs was considered. As noted above, empirically representing the resilience value of biodiversity is more challenging.

2.3 What are the uses of forestry biodiversity values?

Role of economic analysis and valuation

The role of economic analysis is to support decision-making, including the scrutiny of business cases by government departments and agencies, the regulatory impact assessment process, and options appraisals for projects or programmes (HM Treasury, 2018). Fundamentally it is concerned with the principle that “scarcity implies choice” (Robbins, 1935) and it is not possible to achieve all objectives simultaneously, so trade-offs, whether implicit or explicit, are inevitable (Costanza et al., 2011).

Economic valuation helps assess trade-offs in explicit terms and in a commensurate unit of measure (i.e. money). It can be applied in a broad set of decision-contexts and evidence need settings, including:

- Demonstrating ‘value for money’ for raising awareness and securing funding;
- Project/policy appraisal, impact assessment;
- Prioritising investments;
- Planning/location decisions;
- Pricing decisions: fees, payments, compensation;
- Monitoring and evaluation/review of decisions;
- Natural capital accounting and ecosystem accounting; and
- Communication, advocacy.

Each of these settings may call for different data, methods, scope, and different requirements for accuracy and research expenditure commensurate with the decision or policy context.

Biodiversity and the perspective of economic analysis

Past and present loss of biodiversity, coupled with increasing recognition of its importance in underpinning multiple ecosystem functions and benefits, make biodiversity and ecosystem conservation, restoration and management important public policy priorities. There may also be legally binding requirements for landowners in the case of certain priority species and habitats. However, biodiversity is often damaged by human activities and has been declining globally for a sustained period of time (WWF, 2018). At present the principle driver of change in biodiversity is agricultural land use management, although the influence of climate change grows with both detrimental and beneficial effects for species. In the UK, the most recent State of Nature Report (RSPB, 2016) showed trends in abundance and occupancy for almost 4,000 terrestrial and freshwater species. Over the longer term between 1970 and 2013, 56% of species declined, with 40% showing strong or moderate decline. Forty four percent of species increased, with 29% showing strong or moderate increase. In the shorter term between 2002 and 2013, 53% of species declined and 47% increased.

Decision-contexts for forest biodiversity

Table 2.2 shows the variety of forestry sector decision-contexts and evidence needs related to changes in biodiversity and biodiversity values. The 'forest management' and 'demonstrating value' decision contexts sit within the overall strategic aims for the forestry sector in the UK, which, in general terms are to support rural development, economic regeneration, recreation access and tourism, and nature conservation. Specific policy objectives centre on improving the resilience of trees, woodland and forest to threats such as climate change and disease, expanding woodland coverage and the contribution to economic growth, individual and social wellbeing (Defra, 2013; Scottish Government, 2018; Welsh Government, 2018). A different perspective is taken by an 'ecosystem accounting' context. Whilst still aimed at informing policy making, ecosystem accounting sits outside of the economic efficiency principles that guide the allocation of resources to projects and management actions.

Forest management

Forest-level management decision-contexts are primarily conventional comparative assessment settings, comparing 'business as usual' (BAU) to alternative options or scenarios that stem from particular management or policy objectives. Generally – but not necessarily in every case – these assessments are conducted within a CBA framing to identify the preferred management option or prioritise a set of interventions. Costs and benefits are projected over the lifetime of the intervention. Impacts on biodiversity may feature as either a cost or a benefit within the analysis (or both), depending on the specific details (e.g. avoided loss of habitat vs. active management enhancing specific biodiversity features). Resource costs include the inputs required to implement the alternative options (e.g. capital expenditure, equipment, labour). Benefits include a mix of market (e.g. timber sales) and non-market (e.g. informal recreation) outcomes. Both the direct and indirect contributions of biodiversity to economic welfare are relevant to the benefits assessments.

- ***Woodland creation and restoration***: expansion of woodland cover is a key objective for the UK forestry sector, with particular emphasis on increasing native woodland through creating new woods, restoring native woodlands, or converting non-native woodland sites, which implies trade-offs in terms of gains in woodland biodiversity and losses in farmland biodiversity. Restoration actions may also include improvements to semi-natural habitats, and actions related to priority species and habitats (UKFS, 2017). Evidence on the benefits helps differentiate alternative land use options in terms of the different profiles of ecosystem service provision over time.

Table 2.2: Decision-making contexts and biodiversity value evidence needs

Decision / policy context		Economic analysis – application	Biodiversity dependency and value(s)
Forest management			
Woodland creation	Conversion of open habitats to forest habitat	Benefits assessment (CBA): changes in value of ecosystem service provision from alternative land management options	Indirect: composition (habitats, communities) and functional roles that underpin provision of different ecosystem services Direct: species diversity (e.g. wildlife-based recreation)
Operational management	Species selection (e.g. monoculture vs. diversified) and age structure, harvesting system (clear felling vs. CCF[a])	Benefits assessment (CBA): trade-offs between value of production output (e.g. standing sales) and enhanced/deteriorated provision of other ecosystem services	Indirect: structure and functional diversity Direct: species diversity (e.g. wildlife-based recreation)
Plant health, invasive species, pests & pathogens	Active management actions that increase resilience of forests (e.g. species diversification)	Benefits assessment (CBA): comparing opportunity cost of management actions to potential loss of productive output and provision of other ecosystem services	Indirect: stock of resilience in natural capital stock Direct: nature conservation
Biodiversity targets	Management actions that deliver against national targets for conservation and enhancement of biodiversity	Benefits assessment (CBA): comparing opportunity costs of management actions (e.g. habitat restoration) to biodiversity conservation benefits	Indirect: structure and functional diversity Direct: nature conservation
Demonstrating value			
'Public money for public goods'	Management/stewardship of the natural environment to meet strategic or national policy objectives (including payments for ecosystem services)	Measuring outcomes and impacts associated with management inputs and resources. This could be within a CBA framework or potentially within a natural capital accounting framework	Indirect: diversity, composition, functional roles that underpin provision of different ecosystem services Direct: nature conservation
Ecosystem accounting			
Core ecosystem accounts	Measure the condition of natural assets and monitor trends	Flow values: provision (supply and use) of ecosystem services Asset values: value of the stocks of ecosystems assets, based on the basket of ecosystem services that they produce	Indirect: diversity, composition, functional roles that underpin provision of different ecosystem services Direct: species diversity (e.g. wildlife-based recreation)
Thematic account for biodiversity	Current status and trends in biodiversity		

Notes: [a] CCF = continuous cover forestry

- ***Operational management***: alternative management options for forests and forest stands in terms of structure, species, age class, and harvesting approach imply various trade-offs between productive output and the provision of other ecosystem services (e.g. carbon sequestration), including biodiversity outcomes (e.g. maintaining habitats for priority species[12]). UKFS (2017) states that forests and woodlands should be managed in a way that conserves or enhances biodiversity and that opportunities for enhancing biodiversity should be considered within forest management plans. In this setting benefit assessment helps weigh-up the trade-offs between alternative local level management options.

- ***Plant health, invasive species, pests and pathogens***: tree health resilience strategies focus on improving the resilience of forests and woodland through actions that increase woodland extent, connectivity, (genetic) diversity, and the condition of forests. At the strategic policy level, the rationale for action is framed by the natural capital asset value of trees and woodland, which implicitly includes resilience in the stock of natural assets (e.g. Defra, 2018). At the local forest level, plant health actions are a subset of operational management that require more active management of stands and greater within-species diversity, diversification of tree species, and/or structures. These actions imply opportunity costs and trade-offs in the provision of ecosystem service outcomes that need to be accounted for in management plans.

- ***Biodiversity targets***: the UK 'Post-2010 Biodiversity Framework' (JNCC and Defra, 2012) implements the UN CBD Aichi targets and the EU 2020 Biodiversity Strategy. It outlines how current targets will be achieved through biodiversity strategies in the UK. The overall aim is for sustainable management that balances social, environmental and economic benefits to ensure forest benefits are maintained over the long term (UKFS, 2017). The international process for determining post-2020 CBD targets is underway. It is expected that post-2020 CBD targets will place emphasis on biodiversity net gain (over no net loss) – an ambition that is also indicated in the 25 Year Environment Plan for England (HM Government, 2018) - and could set more defined targets related to incentives for biodiversity conservation and the management of resources within safe ecological limits[13]. Again, this will imply actions at the forest management level and associated trade-offs between management costs and ecosystem service outcomes.

At first glance, the distinctions between different forest management decision-contexts may not appear to be that significant. Indeed, biodiversity conservation resilience objectives are integral to the UKFS (2017) which guides overall management practices. However, analysing the different drivers for each decision context separately may show that the dependency on biodiversity that underlies the management objective can differ; i.e. the relative importance of species diversity, abundance, or function versus abiotic and other management factors. As a result, there may be different evidence needs for decision-making, in order to understand the trade-offs for biodiversity that result from different scenarios and options.

[12] Protected and high priority species (e.g. Wildlife and Countryside Act, 1981; Natural Environment and Rural Communities (NERC) Act, 2006; EU Habitats and Birds Directives) are effectively a constraint on operation management; i.e. this aspect of biodiversity cannot be traded-off against other management outcomes.

[13] See: https://www.cbd.int/bogis-bossey-2017/

Demonstrating value

Recent work by Forestry England (FE) has sought to demonstrate the natural asset value of the Nation's Forests (formerly the 'Public Forest Estate') via natural capital accounting (e.g. Forestry England, 2019). Currently this represents a unique perspective and use of economic valuation evidence concerning ecosystem service provision. From a public policy perspective, the 'natural capital balance sheet' provides a transparent way of demonstrating the overall value to society generated by the publicly funded management of the forest estate, showing how the costs associated with maintaining natural assets and managing the provision of different ecosystem service outcomes contribute to sustaining multiple benefits over time.

At present, it is the indirect contribution of biodiversity that is mainly captured in the Forestry England natural capital account, in terms of the provision of benefits such as timber, carbon sequestration, and recreation. The contribution, however, is not explicitly measured or reported in monetary terms; instead it is implicit within the flow of values that are reported for different aspects of ecosystem service provision. Qualitative and quantitative measures of biodiversity are included in the account's supporting asset register, which reports on trends for the extent and condition of features such as woodland habitat area (e.g. native, plantation), SSSI designation, and the woodland ecological calculator index[14].

Ecosystem accounting

The aim of the System of Environmental and Economic Accounting – Experimental Ecosystem Accounts (UN et al. 2014) is to provide an integrated view of the contribution that ecosystems provide to overall social wellbeing. The purpose is to extend the principles of the System of National Accounting (SNA) – which forms the basis for the economic statistics that are used to measure the productive output of national economies in terms of GDP – to measure the productive value of the natural environment.

The SEEA-EEA structure, which is currently subject to practical testing, prescribes a set of core accounts and accompanying thematic accounts:

- Core biophysical accounts: for extent and condition of ecosystems in terms of size and state. Various aspects of biodiversity can feature as characteristics of ecosystem assets and accordingly associated metrics and indicators may be used to measure the condition of the assets. The biophysical flow accounts (supply and use) record flows (quantities) of ecosystem services to society and identifies its users. Biodiversity can feature as a cultural ecosystem service related to habitat and biodiversity with associated benefits in terms of recreation (e.g. nature-based tourism), physical and mental health, and artistic inspiration (King et al., 2019; Haines-Young & Potschin, 2018).

- Core monetary account: service flows are measured in monetary terms in the monetary ecosystem service supply and use accounts, which implicitly capture the indirect and direct contributions of biodiversity to the provision of these services. An important distinction regarding valuation of assets and flows in the SEEA-EEA setting is the requirement to assign exchange values to monetary flows rather than welfare-based measures of economic value (see Section 3.2). The stock value of ecosystem

[14] This is a set of 16 indices developed by the National Forest Inventory project showing the condition of native woodlands and an overall ecological score for non-native woodlands. These indicators are reported on a five-year basis in terms of the percentage (%) in favourable condition ('requires no work') versus 'room for improvement', within which are the conditions 'intermediate' and 'unfavourable'.

assets is recorded in the monetary asset account, which, outside of the cultural ecosystem services, again implicitly captures the contribution of biodiversity. Where biodiversity is viewed as an asset that maintains capacity for future ecosystem service deliver, the stock value would reflect both the value of present flows and benefits, and also the capacity for sustaining future flows and benefits. In principle this definition captures some aspects of the resilience of ecosystems to tolerate disturbances and maintain the same level of ecological functioning (King et al., 2019).

- Thematic accounts (carbon, biodiversity, water and land): the intention of the thematic accounts is to provide information for the policy making processes in its own right. Specifically, they allow for a systematic and cross-cutting analysis of issues that need deeper investigation (e.g. complex ecosystem assets, multiple services). For biodiversity this allows a more complete account of its multifunctionality as both an asset and service, which otherwise is fragmented over the separate ecosystem service flows in the core accounts. Indeed, whilst biodiversity may be accounted for as an asset that maintains the capacity for future ecosystem service in a particular ecosystem account (e.g. woodland), the overall asset value for 'biodiversity' will be recorded across separate ecosystem accounts.

On the whole, the perspective taken in the SEEA-EEA is that biodiversity is a characteristic that is directly relevant in measurement of the condition of ecosystem assets. It is emphasised that is important to distinguish between abundance and variation when measuring species-level biodiversity. Final goods and services, such as bird-watching or recreational fishing are considered to be derived from biodiversity rather than being flows of biodiversity services in their own right. The purpose of this is to emphasise that other (capital) inputs are required to generate these benefits. Instead, biodiversity is viewed as an indicator of flows of final ecosystem services where individuals gain benefit from experiencing the diversity of nature. In practice this means that biodiversity conservation actions can increase the supply of these goods and services but does not have a value itself in terms of conservation of species (particularly the associated non-use value) within the SEEA-EEA framework. Section 3.2 considers this point further.

3. Opportunities and challenges

This section reviews the key challenges and associated opportunities for practical benefits assessments that attempt to link biodiversity to economic values. The treatment of 'biodiversity values' within ecosystem accounting approaches is also considered.

3.1 Requirements for practical benefits assessments

Objective for economic valuation

Economic valuation focuses on changes in provision of final goods and services. This is consistent with underlying analytical principles that are concerned with measuring changes in individual and social welfare. In practical benefits assessments featuring biodiversity related-impacts, the objective therefore is to value the outcomes – i.e. changes in the provision of final goods and services - associated with biodiversity. In more formal terms, biodiversity should be valued at the point where it enters utility functions (Landers and Nahlik, 2013).

There are two main implications of this requirement. First, it ensures that there is no double-counting of benefits (or costs) in economic assessments. The main risk in the context of biodiversity is adding the indirect value (e.g. the contribution of a food crop pollinator) to the value of the associated final good or service (i.e. the food products that are consumed). Double-counting occurs because the indirect value is embedded within the value of the final good or service. In contrast, direct values for biodiversity (e.g. wildlife-based recreation) can be added to other values for final goods and service when estimating total benefits of an option. This is because, by definition, they are separate (independent) final services.

The shortcoming, however, is the inability to clearly demonstrate the overall contribution of biodiversity. When the focus is on weighing-up the outcomes of management or policy decision in terms of final goods and services, the indirect contribution remains largely implicit within assessments. For example, actions to enhance food production by eliminating pests have eliminated essential pollinators, in part, because their value has not been explicit and hence not part of the balance of costs and benefits. Similarly, managing forests for pure tree strains may have eliminated genetic diversity necessary for resistance to new diseases because the genetic diversity was perceived as a cost in terms of lower market values.

There is also the risk that the value of biodiversity is perceived to be just the aspects that are visible in terms of direct values. This limitation is further exacerbated by the challenges associated with reliably valuing the non-market components of the direct, particularly, non-use values (Hanley and Perrings, 2018). As a result, the treatment of biodiversity is not only partial, but it is also often not accounted for in monetary terms. Conceivably this could have an undue influence on decision-making. Where direct values are monetised – or even simply better accounted for in qualitative terms - and material to the balance of costs and benefits, there is potential to channel management efforts to (or away from) the aspects of biodiversity that support their continued provision. Yet, this could also be to the detriment of the aspects of biodiversity that underpin its indirect contribution to welfare. For example, actions to conserve an iconic or charismatic species may come at the expense of some other function of biodiversity in an ecosystem, which compromises its resilience to external shocks in the longer term.

As a result, economic assessments that weigh-up the trade-offs between final goods and services cannot be assumed to automatically reflect the longer-term consequences of changes in biodiversity, such as changes in the capacity of ecosystems to produce certain outcomes under future and changing environmental conditions. This means that in order for economic assessments to provide a fuller view of the contribution of biodiversity, the objective for economic valuation has to be to value the outcome *and* account for the associated dependencies on biodiversity.

Appropriately accounting for the dependency of economic values on biodiversity requires consideration of how the production function(s) through which biodiversity indirectly contributes can be unpicked, so that the full contribution is shown in more explicit terms. Empirical analysis to estimate the production function relationship would quantify the importance of different inputs to production to determine the contribution of natural capital inputs (as opposed to other capital inputs) and measure how final values change with changes in specific inputs (e.g. an attribute of biodiversity). The feasibility and requirement for such analysis depend on context such as the decision to be made, the planning timescale, the level of uncertainty that can be accommodated, and data requirements. Alternative options are qualitative assessments that provide a narrative for interpreting the economic value of final goods and services and supporting metrics and indicators that inform on the condition and trend (i.e. stable, deteriorating, etc.) in the contributing inputs.

Estimating benefits

At the basic level, a benefits assessment quantifies two items: (i) the change in the provision of the final good or service (Q), which could be a quantity change or quality change; and (ii) the (marginal) value or 'price' (P) of that change, which measures the change in individual or social welfare. Ordinarily this is calculated as an annual flow value that is aggregated over: (a) the affected population (i.e. users and non-users); and (b) the time. The basic formula (*Benefit = P x Q*), however, underplays the intricacy of developing a practical benefits assessment that accounts for the dependency of economic values on biodiversity.

On the value side of the formula, (*P*), there is the need to consider the factors that influence economic values, particularly in terms of the beneficiary population and their characteristics, including use of the final goods/services, socio-economic and demographic profile, and the availability and quality substitute goods and services. All of these factors influence the marginal value of the change and, in principle, should be accounted for in benefits assessments; for example, by applying a 'distance-decay' function in the aggregation across the beneficiary population (see below). Added to this is choice of the economic valuation method or evidence source, which determines the extent of TEV that is captured within an assessment. Of note too, is that the measures of this value, such as WTP to secure the change (or avoid the change) in provision of the final good or service are defined by individuals' current preferences and income constraints. Typically, it is assumed that these underlying preferences hold over the timescale of the assessment, although adjustment can be made for expected growth in income and how this may result in real changes in WTP[15].

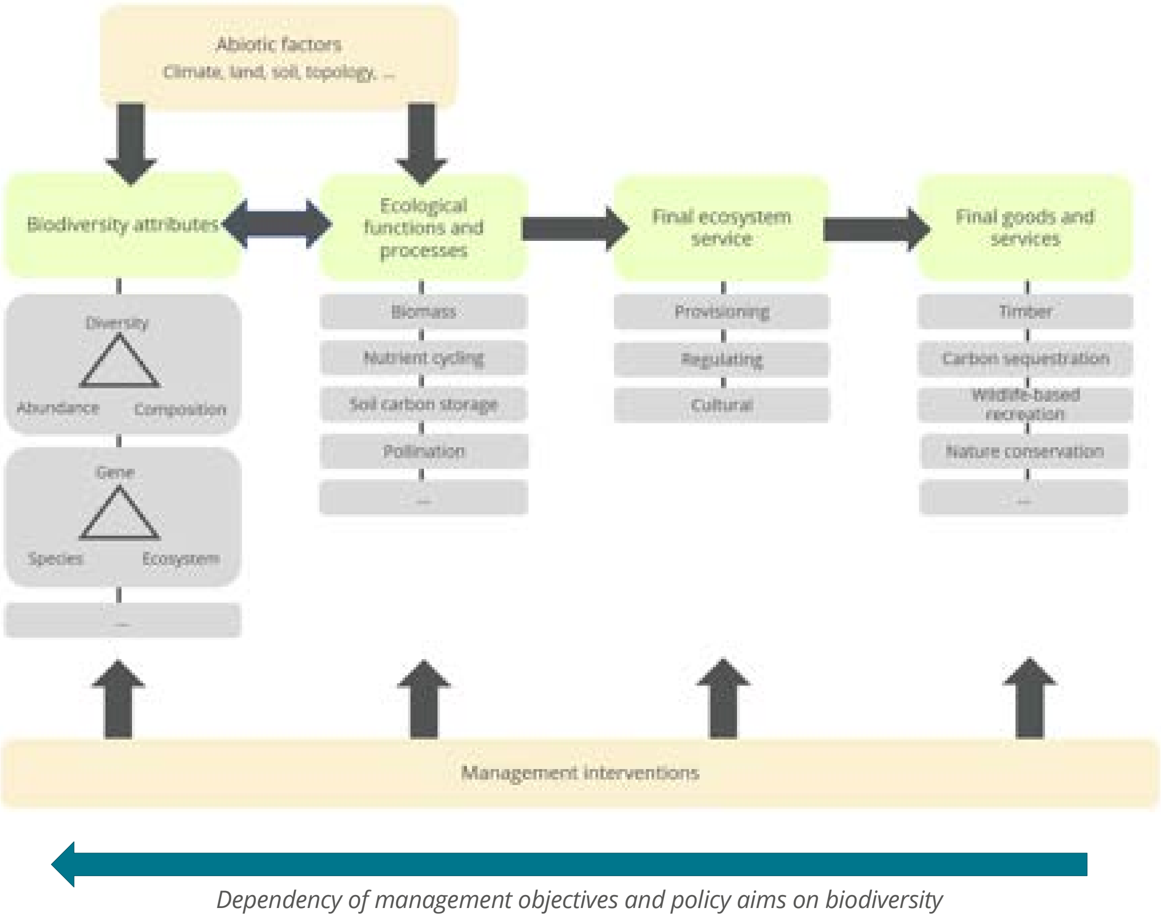
Reducing the change in provision of the final good that results from a management or policy action to simply '*Q*', significantly understates the multi-disciplinary analytical requirement for a benefits assessment that accounts for the dependency of economic values on biodiversity. Often, the science linking the action (e.g. changes in land-use or management) to the changes in the environment and the changes in final goods and services (the end-points) relevant to valuation is missing. For example, understanding how changing tree species mix to increase resilience to new pests and diseases affects timber values in the future through effects on growth rates and disease spread. Or the effects of age re-profiling on the distribution and abundance of forest birds. Without these scientific linkages in place (see below), the scope of economic valuation to meaningfully inform benefits assessment can be limited.

Logic chains and impact pathways

Logic chains are increasingly used as analytical tools to represent the relationships between ecosystem assets, flows of ecosystem services, and the provision of final goods and services. They are synonymous with the ecosystem services approach that attempts to understand the processes that affect the provision of final goods and services. Typically, logic chains combine tools such as the 'impact pathway' or 'pressure-state-response' models that have been used to describe the change in the provision of final goods and services that results from a management or policy action[16]. A generalised logic chain that links the dependency of economic values to the specific dimensions of biodiversity that support the critical ecological functions and processes is shown in **Figure 3.1**.

[15] 'Real' values are adjusted for inflation, hence WTP can be compared across time periods to understand how factors such as relative scarcity and income growth result in change in the value of final goods and services. 'Nominal values' measure the value of a good or service in current price terms.
[16] **Annex 2** provides examples of logic chains and impact pathways that illustrate the use of these analytical tools.

Figure 3.1: **High-level biodiversity dependency logic chain**



Notes: Biodiversity responds to both environmental conditions and drives ecosystem functioning. Land management can impact both biotic and abiotic factors. Assessing the dependency of management objectives or policy aims on biodiversity, requires tracing back along the pathway from economic values for final goods and services to the biodiversity attributes that underpin the critical ecological functions that support the provision of ecosystem services.

The practical challenge for improving how benefits assessments account for dependencies on biodiversity is to develop logic chains for combinations of final goods – final ecosystem services. Efforts to address this challenge would also assist in developing the narrative that accompanies the benefit assessment in terms of describing the underlying production function, the key influencing factors and the trade-offs that different management or policy options may imply for biodiversity. The extent to which the dependencies on difference aspects of biodiversity can be generalised across habitat types, locations, and other context-dependent factors requires further consideration. This includes establishing which specific measures of biodiversity offer a meaningful interpretation for the capacity of an ecosystem to sustain a specific ecosystem service or set of services in the future. It is likely that the appropriate measure will vary on a case-by-case basis.

Linking biodiversity to ecosystem service provision

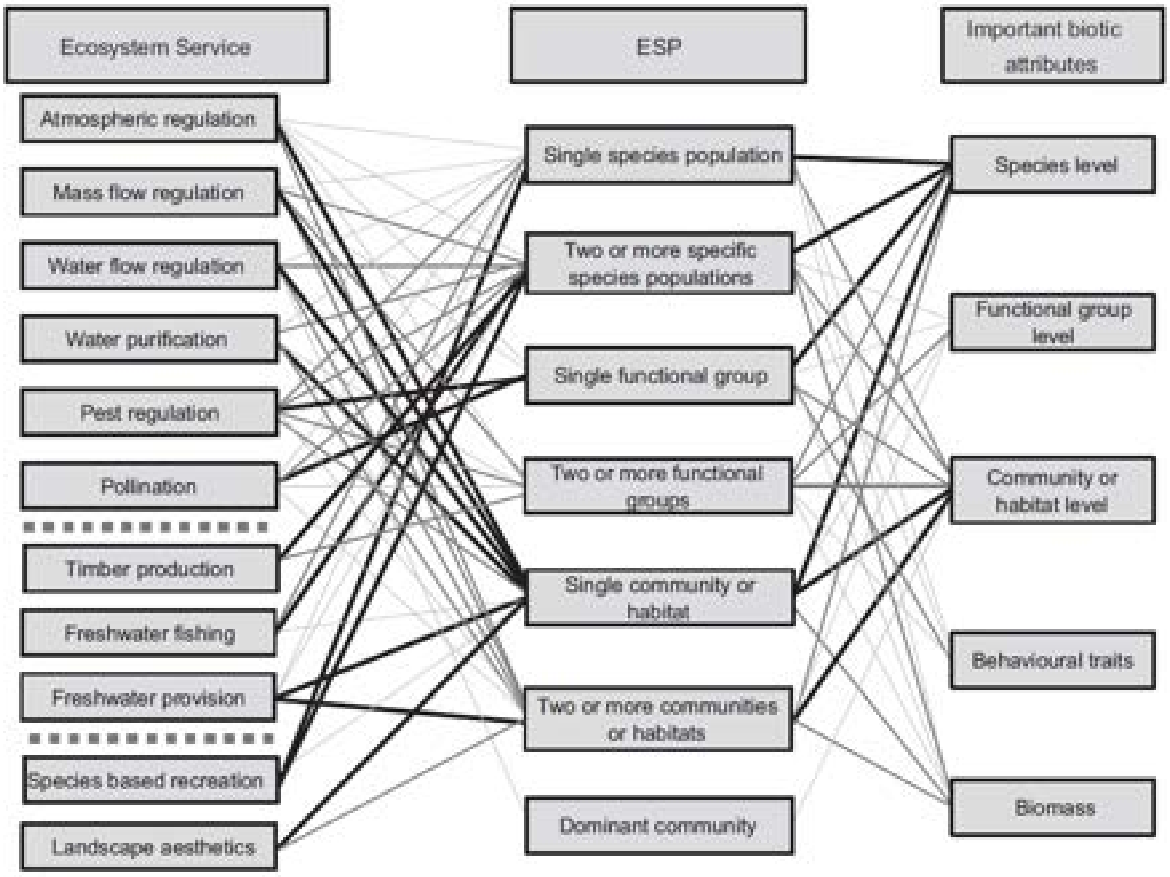
Various studies have examined the links between biodiversity, ecological functioning, and ecosystem service provision. Although these studies are not specifically concerned with applications of their findings to economic analyses, they provide insights that help build logic chains and establish which biodiversity metrics and indicators are important and why.

Fons van der Plas (2019), for example, focuses on how biodiversity drives ecosystem functioning (e.g. biomass, decomposition, soil organic carbon, pollination, etc.) and the relative importance of diversity compared to functional composition and abiotic factors. Based on findings from a systematic review, indicators of functional diversity are generally found to be stronger predictors of ecosystem functioning than species-based measures. Moreover, abiotic factors (e.g. climate, soil type, topography) and functional composition (the presence of certain functional groups, including the substitutability between species) tend to have a stronger influence on ecological functioning than species diversity.

Harrison et al. (2014a; 2014b) take a broader perspective, with a systematic review of literature to examine the relationships between different biodiversity attributes and 11 ecosystem services. **Figure 3.2** presents a summary of the observed findings in terms of the number of studies that provide evidence of a link. Overall each ecosystem service is linked to multiple levels of biodiversity (biotic attributes) with various interdependencies across spatial scales, although the distinction between critical and marginal dependencies is not drawn out.

In many cases, Harrison et al. find that the primary link exists at the level of the entire community or habitat. For forests this corresponds to carbon storage or flood regulation. In these cases, there is often a simple positive relationship between habitat extent (area) and the level of provision. Composition – the physical structure of the community – is also an important factor for some ecosystem services. More complex structures such as old-growth forests are often found in studies to provide higher levels of ecosystem service provision. Positive links between species richness and functional diversity and the level of ecosystem service provision are also often reported. This is explained by the concept of niche complementarity, where more variety in functional groups (e.g. prey types, root depths, or canopy heights) allows communities to more fully exploit resources such as water, sunlight or nutrients more fully.

Figure 3.2: **Linkages between biodiversity attributes and ecosystem service provision (Harrison et al. 2014)**



Notes: ESP = 'ecosystem service providers', which is a representation of population dynamics within an ecosystem. Thickness of connecting lines represents number of studies providing evidence of a link (thickest lines correspond to most frequently cited links).
Source: Harrison et al. (2014a).

For some provisioning and regulating services, Harrison et al. note the main linkage observed is often the abundance of a single species or small number of species. This is because these species are suited to commercial uses (e.g. timber from particular tree species) or other management objectives (e.g. trees that sequester and store greater amounts of carbon). Harrison et al. also note that species diversity can be important for cultural services, such as nature-based recreation, but the abundance (and sometime size) of certain charismatic species is also relevant. There are also negative associations between biodiversity and ecosystem service provision. For example, several aspects of forest biodiversity (forest area, tree size, tree age, and root density) tend to decrease the level of freshwater provision as trees intercept rainfall and absorb groundwater (and/or slow the flow of water). The same aspects, thought, have a positive link to flood risk attenuation, which illustrates that there can be temporal variation in ecosystem service provision. Harrison et al. highlight that other negative links arise in relation to non-native species (e.g. invasive alien species) that do not have natural predators, and mono-culture tree plantations.

Understanding how changes in biodiversity impact the provision of final goods and services

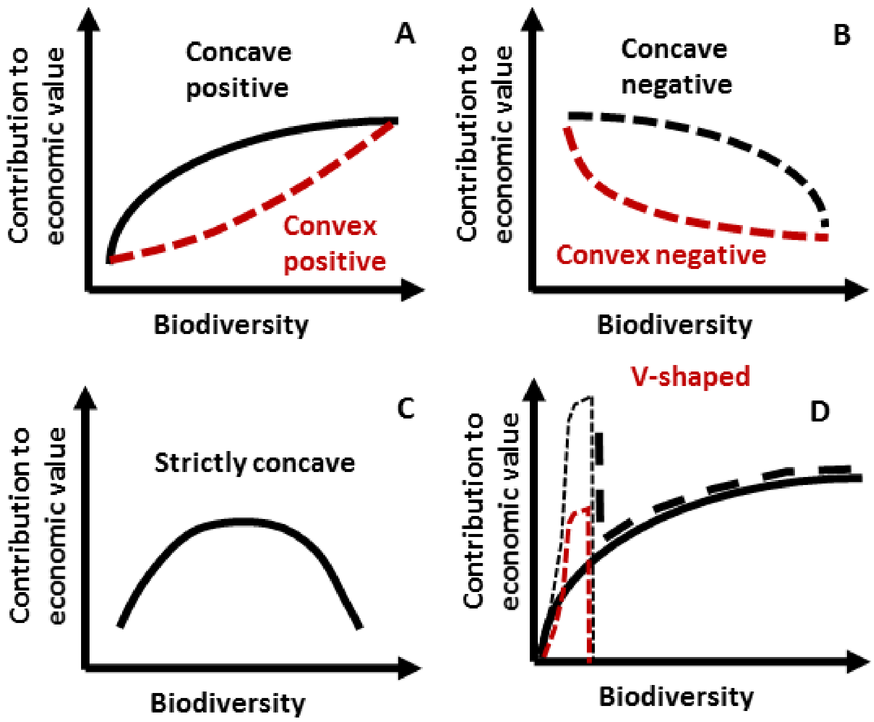
Whilst it is necessary to establish and understand the underlying links to biodiversity, benefits assessment is fundamentally concerned with the (economic) implications of *changes* in biodiversity or environmental conditions due to management actions (e.g. changing the age profile of a forest stand) or policy decisions (e.g. funding more native woodland planting). The requirement is to understand the effect and the scale of the change in both the present and future. Logic chains and the underpinning scientific understanding indicate which factors need to be taken into account, but, in effect, the change is viewed from a production function perspective. As Binner et al. (2017) point out, there is no single production function, but multiple productive processes with a defining split between those that occur naturally (i.e. ecological functions and processes) and those that are part of economic systems combining multiple inputs and sources of productive capital.

Indeed – conceptually – some sort of production function relationship exists for each link in the logic chain. Paul et al. (2019) review ecological evidence on the role of biodiversity in terrestrial ecosystem functioning to suggest a range of possible shapes for the overall relationship between biodiversity and economic value; i.e. across all links in the logic chain. Their analysis considers mainly indirect economic values. They point out that the shape of the biodiversity-economic value function depends on three linkages:

- In a specific ecosystem, how a change in biodiversity results in a change in ecosystem functioning;
- Given the change in ecosystem functioning, what the resulting effect is on the supply of ecosystem services; and
- Given the change in the supply of ecosystem services, how this impacts economic values.

Figure 3.3 presents a range of potential relationships which summarise the links and effects between biodiversity – ecosystem function – ecosystem service – economic value.

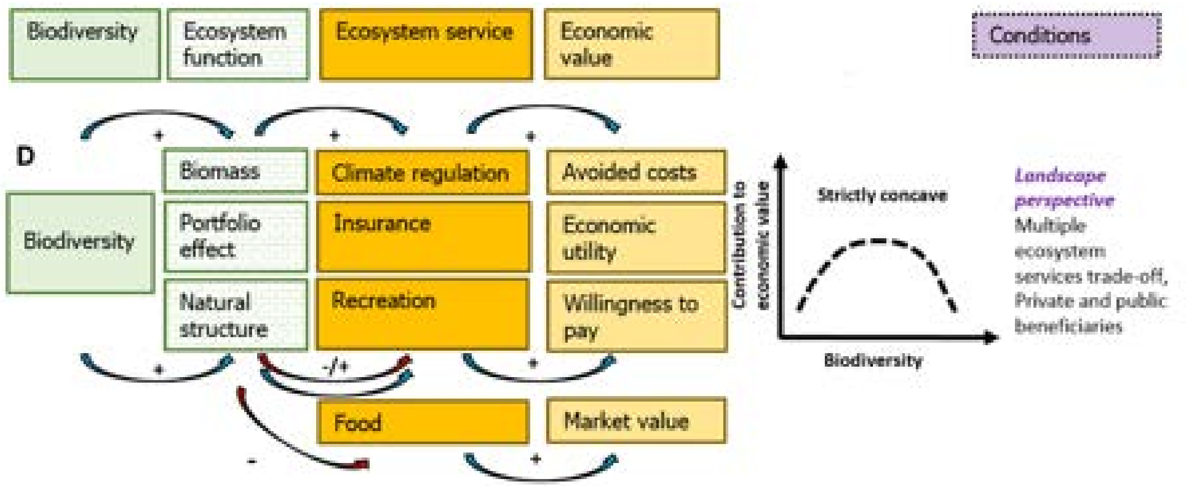
Figure 3.3: **Potential biodiversity – economic value relationships (Paul et al. 2019)**



Notes: Panel A (concave positive) shows the case of single ecosystem service and a homogeneous final good (e.g. carbon sequestration) and no trade-offs. Panel B (concave negative) shows the case of single ecosystem service but with high management costs factored in to (net) economic return. Panel C (strictly concave) introduces trade-offs between ecosystem services, multiple management objectives for ecosystem service provision, and/or risk-averse decision makers. Panel D (v-shaped) accounts for the potential substitution between biodiversity and management inputs (fertiliser, irrigation, pesticides). Source: Paul et al. (2019)

As Figure 3.3 suggests, economic value can be increasing (A), decreasing (B) or rising then falling (C) with increasing biodiversity. Paul et al. note the relationship that will be observed in a specific ecosystem depends on the characteristics of that system and crucially, whether an assessment is accounting for one or several ecosystem service benefits. In the latter case, the trade-offs and complementarities between these multiple ecosystems in terms of biodiversity as an *input* are crucial. To further illustrate, **Figure 3.4** sets out a 'landscape level' perspective with multiple trade-offs in ecosystem service provision between private beneficiaries (e.g. agriculture) and public beneficiaries (e.g. climate). In this case, it is unlikely that increasing level of some aspect of biodiversity is positively associated with all ecosystem services and their economic values. Hence, in terms of generating economic value, there is an optimal position.

Figure 3.4: Ecosystem multifunctionality and trade-offs between ecosystem service provision (Paul et al. 2019)



Notes: '+' sign indicates a positive link/correlation; '-' sign indicates a negative link/correlation in the biodiversity – ecosystem function – ecosystem service – economic value pathway.

Estimating economic values

In benefits assessments, it is challenging not only establishing the change to be valued, but also the value to apply. For both direct and indirect biodiversity values, markets fail, to differing degrees, in revealing the benefits to individuals and society overall. For example, if more diverse forests generate an insurance value by reducing the risks of losses in timber output due to a future pest or disease outbreak (MacPherson et al., 2017), the marginal social benefits of the avoided losses are indicated by the market price of timber. But for many aspects of biodiversity value, such as its direct contribution to utility, markets fail to signal that most individuals are willing to pay for such benefits. In these cases, non-market valuation methods must be used to estimate these values.

Separating the direct and indirect benefits due to changes in biodiversity may be difficult. For example, a major category of non-market benefit associated with UK forests is recreation. The value of a day spent recreating in a forest will depend partly on different measures of diversity in the forest (Hanley and Ruffell, 1993a). Recreation is a use value, since only users benefit from it. Greater abundance (i.e. visibility) of widely appreciated species may increase this use value if forest visitors get extra consumers surplus per trip from, say, more bird species in a forest. But if higher biodiversity means, say, more oak processionary moths, it could reduce the use values. In some cases, it may be desirable to include such aspects of the value of biodiversity in the assessment of recreation benefits but identifying the statistical relationships will often be difficult. This is because: (i) not all forest visitors will place the same value on how this measure of diversity contributes to their enjoyment of a day visit; and (ii) there may be very different associations between changes in different measures of diversity (e.g. bird species richness or invertebrate species richness, or the species richness of lichens) and the value of recreational day visits.

It is possible to estimate stated or revealed preference models of the effects of one or more measures of biodiversity on recreational day visits. For example, Hanley and Ruffell (1993b) use a travel cost model to show how forest recreation values varied with age and species diversity of UK forests. In a non-woodland setting, Roberts et al (2017) use choice modelling to separate out the contribution of marine species diversity to recreational dive values for coral reefs.

Non-use values

Non-use values can be an important component of a benefits assessments, but reliable evidence on how non-use values should be aggregated over beneficiary populations in different ecosystem contexts is still lacking. This represents a distinct gap in the evidence base that would support improved economic analyses of the value of biodiversity.

There is evidence of weak but significant distance decay effects for non-use values for some environmental assets (e.g. rivers in the UK; Hanley et al., 2003). This implies that, all else remaining the same, an individual's non-use value for a forest can be higher, the closer that forest is to them. For instance, a person may feel more cultural ownership over conserving a forest 20 miles away from their home than an equivalent forest 200 miles away. However, empirical evidence of distance decay functions related to biodiversity non-use values is lacking.

Non-use values are direct utility benefits, since they accrue directly to those who care about some aspect of forests even though they do not visit them, rather than being mediated through some production function as an indirect value. A key question to consider, though, is whether all (forest) non-use values arise due to biodiversity alone. Biodiversity is related to the landscape value of a forest, but landscape values are use benefits in the sense that they are generated in-situ; an individual only derives an aesthetic benefit from a forest landscape when they look at it, either from a train, from their property, or whilst they are walking in it. Therefore, the contribution of biodiversity to landscape values is not part of non-use value.

However, there should be factors other than biodiversity that help determine of the scale of non-use value for a specific forest. Non-use values are generally motivated by two main factors: (i) the pleasure that individuals take from the knowledge of the existence of something; and (ii) their altruistic preferences that mean they derive a personal utility from the degree to which others, now or in the future, can enjoy forests. In both cases, biodiversity is not the only determinant of non-use value, although it can be an important determinant. Altruism means that an individual should care about the determinants of use value to other users; they may care more about larger forests than smaller forests being conserved because more ("relevant other") people may benefit from it. Therefore, more biodiverse forests may attract higher non-use values than less biodiverse forests. But biodiversity is not the only determinant of these non-use values and further research is required to improve the account for these factors.

Assessing economic values over time

Benefits assessments concerning changes to forest management or woodland creation need to consider whether the (real) value of biodiversity is likely to change over time (in addition to changes in biophysical flows and/or natural asset stocks). This is particularly relevant for direct values such as WTP for biodiversity conservation. Changes in real values could happen for three reasons:

- *A relative scarcity effect*: if biodiversity in the UK is declining over time, then economic theory suggests that maximum WTP per individual for projects which invest in biodiversity would rise over time as biodiversity gets scarcer. However, there appears to be limited empirical evidence that currently demonstrates this effect (e.g. WTP for conserving rare species).

- *An income effect*: economic growth means that average incomes rise over time in real terms. The effect on direct biodiversity values depends on the 'income elasticity of WTP'. Empirical evidence from a meta-analysis of global studies for non-use values for biodiversity showed that this income elasticity took a value of around +0.38 (Jacobsen and Hanley, 2009). This means that if incomes rise by 10%, mean WTP for biodiversity conservation rises by 3.8%. More recent work (Barber et al., 2016) looked at WTP for marine/coastal water quality improvements (so not biodiversity itself) across nine countries in Northern Europe and found the income elasticity to vary from around +0.2 to around +0.7 depending on people's household income. Higher income households had a higher income elasticity of WTP. But again, this means that environmental quality is not a luxury good.

- *An increase in use*: if biodiversity changes affect recreational users' values of a day in the forest, then changes over time in the number of recreational visits will affect the economic value of biodiversity improvements per hectare. Any such change in visit frequency could be due to the biodiversity change itself, or to other factors such as transport infrastructure or housing developments.

In combination these factors need to be considered in practical benefits assessments, although often in absence of supporting evidence the default assumptions are to assume no change over time in real values. Ideally all of the implications of these assumptions should be tested to understand if they have a material impact on aggregate benefit estimates over time that would change CBA decision conclusions.

Value transfer and the 'temporal' reliability of the evidence base

A second dimension for practical benefits assessments to consider in cases where value transfer is used to source economic values, is the 'shelf-life' of the evidence base. Specifically, the time scale over which estimates of marginal WTP be considered valid for value transfer. This issue has been most frequently examined via stated preference methods to test whether preferences for environmental outcomes (e.g. forest conservation) change in the short and/or medium term. In particular, 'test-retest' studies involve repeating the same survey with samples from the same population over – usually a relatively short – timescale (e.g. 6 months to a year).

Few studies have been undertaken in the context of forests and/or biodiversity conservation. Czajkowski et al. (2016) use a discrete choice experiment (DCE) to estimate WTP for possible management changes to the Białowieża forest in Poland. The attributes used in the survey were: areas of forest managed for different levels of "naturalness" over time; changes in visitor numbers; and the cost to taxpayers. The same survey was repeated with samples obtained 6-months apart from each other. The individuals sampled in the second, later survey were a sub-set of those who completed the first survey. The authors fail to reject the null hypothesis of equal mean WTP values for changes in each of the attributes between the two waves of the survey: but do reject the null hypothesis of equal variances. Overall, they conclude that preferences for forest conservation appear to be stable over the 6-month time period, and WTP estimates un-changing.

Another relevant study is Schaafsma et al. (2014). They used a one-year interval to conduct a test-retest DCE survey of people in Flanders for changes in regional "nature areas", including heathlands and forest, across the regional landscape. The same individuals took part in each wave of the survey. The authors found that there were no significant changes in marginal WTP for changes in each type of nature area over this interval. Nevertheless, they note that there is potential for different CBA results for alternative policy scenarios when the value for each type of nature area from the two study waves are summed up and compared.

Contingent valuation (CV) test-retest procedures have also been conducted by Loomis (1989) on lake water quality, Carson et al. (1997) on protecting marine ecosystems, and Brouwer (2006 and 2012) on bathing water quality. In all cases, two surveys were carried out over an interval ranging from two weeks to two years. The results in all cases indicate that the average WTP value is stable.

Test-retest procedures have been applied to several other environmental settings within DCEs. Bliem et al. (2012) compare preferences for river restoration options in Austria from two surveys undertaken one year apart, finding no difference between preferences in the samples. Liebe et al. (2012) compare preference and WTP estimates in two samples collected 11 months apart. Choices over on-shore wind power options were reasonably consistent over the interval, but WTP estimates differed significantly for around half of the attribute values.

Further relevant contributions include Dupont et al. (2014), who compare estimates of WTP for health end points related to water quality in Canada across surveys undertaken in 2004 and 2012, using both CV and DCE. The health end points relate to illness and death cases from microbial infections and bladder cancer. They found that whilst there was a significant change in estimated WTP values across time when values were elicited using CV, there was no such significant change for the same values elicited using DCE.

Overall, then, such evidence as exists from stated preference exercises points to a considerable degree of temporal stability in WTP values for environmental change in the short term (i.e. around a year). Over the medium term (i.e. 3 - 5 years), it is likely that practical benefits assessments would need to consider the influence of scarcity, income and use effects on direct values for biodiversity. These factors have predictable influences on economic values in accordance with underlying theory – hence the requirement is mainly to ensure there is suitable evidence available to calibrate these assumptions. In the longer term, these calibrations can still be applied, but it is likely that less confidence can be placed in the resulting values that are used in benefits assessments.

Learning and experience effects in stated preference studies

Due to a combination of conceptual (e.g. non-use values) and practical (e.g. data) reasons, stated preference methods are typically the main source of estimates for direct values for biodiversity. Being survey-based methods that elicit individual's WTP through simulated markets, the reliability and validity of inputs to benefits assessment is dependent on the study results being consistent with underlying economic theory ('expectations-based validity') and demonstrating that respondents understood the simulated market and engaged in meaningful trade-offs for the provision of the good in question ('content validity') (Johnston et al., 2017).

A key area of focus concerning the validity of stated preference methods is the relationship between stated WTP and individual's knowledge of the good being valued. Where the good is unfamiliar to individuals and existing knowledge levels are low, the impacts of information provided in the survey instrument may be crucial. With specific regard to biodiversity, it may well be that those aspects of biodiversity which the researcher wants to value are those which 'ordinary people' know the least about. This issue gave rise to studies which used novel methods to get across information about unfamiliar biodiversity concepts or species to respondents in an effective manner (e.g. Christie et al., 2006; MacMillan et al., 2002). It also gave rise to papers which were concerned with investigating whether simply naming a species changed the value people placed on it (Jacobsen et al., 2008).

More recently, stated preference researchers have tried to distinguish between the effects of information provided as part of a survey, how much of this information is learned by respondents, and how this relates to: (i) their knowledge and thus (ii) their WTP for conservation actions (e.g. Needham et al., 2018). Perhaps of most relevance to this report is the work of LaRiviere et al. (2014), who studied the WTP of Norwegian citizens for conservation of deep-sea cold-water corals. These ecosystems are highly valued in terms of their biodiversity, but very unfamiliar to most people due to their inaccessibility (located deeper than 200m). LaRiviere et al. used an experimental design which allowed them to measure prior knowledge levels, and then observe how this changed as people were provided with information in the choice experiment survey. They could then relate knowledge levels and changes in knowledge to willingness to pay. Moreover, a subset of respondents was given feedback on their knowledge of the good (its extent and veracity).

The paper's main finding is that informing a subject of their test score when they are well-informed causes a significant increase in stated WTP of between $150 and $200 for establishing a large marine protected area. Further, the channel for this treatment effect occurs through existence values. This effect is not found for individuals who are not well-informed. A further result was that better-informed subjects had a higher WTP for cold water coral conservation and made more deterministic choices than less well-informed subjects. However, it is noted it cannot be assumed that providing more information in a stated preference survey leads to higher willingness to pay for biodiversity conservation. In a different context (wetlands restoration), Needham et al. find that more information increases knowledge, at a decreasing rate, but does not increase WTP for wetland restoration once prior levels of knowledge are allowed for (higher prior knowledge is, however, associated with higher WTP).

Cost-based values

The theoretically correct approach for benefits assessment and valuation in a CBA-setting requires the use of welfare-based measures of economic value - willingness to pay (WTP) or willingness to accept compensation (WTA). eftec (2015) notes, however, that in some select cases it may be appropriate to use proxy measures that are based on the costs of delivering biodiversity outcomes, particularly where valuation evidence is unreliable or not available.

Ordinarily, cost-based proxies for biodiversity values such as replacement costs and avoided costs should be treated with caution because the relationship between the cost of providing an outcome (e.g. habitat restoration) and the value of the benefits of that outcome (the use/non-use value) is not clear. Cost-based proxies could correspond to entire ecosystems (e.g. the cost of providing new habitats to compensate for habitat losses) or replacement of specific ecological functions with engineered alternatives (e.g. the cost of wastewater treatment plants instead of wastewater processing by natural systems such as saltmarshes). In either case it may be hard to determine a proxy value for biodiversity separate from the value that could be attributed to other inputs that are also proxied by the cost-based measure (e.g. abiotic, management inputs). Hence, whilst a cost-based proxy may have some merit in terms of ensuring a value is assigned to the provision of some final good or service, the ability to attribute a value to the indirect contribution of biodiversity may be limited. In these instances, using cost-based estimates is, at best, a second-best approach; i.e. to be preferred only if the alternative is a default value of zero for a final ecosystem good or service.

The exception, though, is in relation policy objectives that set specific targets for biodiversity. In these instances – assuming that the policy targets have been set in an appropriate manner – the focus is on achieving the desired biodiversity outcomes in a least-cost manner[17]. Whilst there are no current biodiversity-related examples, the basis for this approach can be seen in the UK's methodology for valuing greenhouse gases based on the marginal abatement costs of meeting international commitments (Department for Business, Energy and Industrial Strategy, 2018). The rationale for this approach is twofold: (i) the benefits of abatement are long-term, complex (covering all ecosystems and services globally), uncertain and dependent on assumptions (such as the discount rate) that make valuation challenging; and (ii) irrespective of the emissions target and the damage values, achieving efficient emissions reduction requires equalising the marginal abatement cost across all sources (eftec, 2015).

A similar approach can be envisaged for biodiversity, based for example on a 'No Net Loss' or 'Net Gain' restoration targets. The approach would require the estimation of the least-cost solution for delivering the agreed 'level' of biodiversity, taking account of any impacts on other costs and benefits (e.g. impact on provisioning services such as crop production). If there are political agreements regarding the socially desirable level of biodiversity (such as Net Gain), then there is some justification for using costs associated with this level of provision in lieu of welfare-based values. However, even if the approach is 'valid', there still can be challenges in reliably estimating costs, accounting for local level factors that might cause costs to vary, and avoiding double-counting if measures result in multiple benefits (i.e. a combination of direct and indirect values associated with biodiversity). The potential for double-counting can be avoided if values for other final goods and services are excluded from benefits assessments, or if values are broken down into component parts to isolate the marginal cost associated with biodiversity provision. The feasibility of this can only be determined on a case-by-case basis, but regardless the point to note is that a target-based cost approach does not necessarily imply a simpler or easier analytical approach than a conventional benefits assessment set around welfare-based values for biodiversity.

[17] In a similar vein, Bateman et al. (2014) and Natural Capital Committee (2017) emphasise the use of cost-effectiveness analysis in decision-contexts that are primarily concerned with actions related to targets and regulations for the conservation of certain species and habitats in EU and national level designations; i.e. when trade-offs are not 'permitted' the need for benefits assessment evidence is less pressing. Or alternatively, that conservation objectives represent a constraint on decision-making, such that proposed investments do not have effects which run counter to existing targets and regulations, and that instead they secure or improve the status of affect habitats and/or species.

3.2 Requirements for ecosystem accounts

Objective for ecosystem accounts

Ecosystem accounting - particularly in terms of the perspective taken by the System of Environmental and Economic Accounting – Experimental Ecosystem Accounts (SEEA-EEA) (UN et al. 2014) - is concerned with extending the principles of the System of Natural Accounts (SNA) to measure the productive value of the natural environment (**Box 3.1**). This differs from the benefits assessment context reviewed in Section 3.1, which is concerned with valuing the *overall* contribution of biodiversity to social wellbeing in line with the principles of welfare economics. The overall contribution includes both the economically productive (market / exchange) value and other contributions to human wellbeing.

Box 3.1: Ecosystem accounting and natural capital accounting

The SEEA Experimental Ecosystem Accounting Technical Recommendations (2017) describe ecosystem accounting as a framework for integrating measures of ecosystems and the flows of services from them with measures of economic and other human activity. The intention is to provide a common platform for combining information on: (a) ecosystem assets (such as ecosystem extent, ecosystem condition, ecosystem services and ecosystem capacity); (b) existing accounting information on economic and other human activity that is dependent upon ecosystems; along with (c) the associated beneficiaries (households, businesses and governments). Whilst initially conceived as a national accounting level framework, the scope has widened to the regional and sub-regional level.

Primarily ecosystem accounting can provide a basis for:

1. Monitoring the status of ecosystem assets through both biophysical indicators and monetary valuations;
2. Measuring the 'supply' of ecosystem services, either at an aggregated level (e.g. 'top-down') or a spatially explicit and disaggregated level ('bottom-up'); and
3. Recording trends/changes in ecosystem assets (1) and ecosystem service provision (2) over time.

The SEEA-EEA Technical Recommendations suggest that once established an accounting system could then inform a range of policy and decision-making contexts, such as monitoring the effectiveness of policy interventions, or extending the indicators that are used to measure economic performance (e.g. national income, savings and productivity). In the case of biodiversity, the Technical Recommendations suggest that ecosystem accounting can provide a more coherent approach for monitoring compared to existing systems, for example, for species or habitats that are of particular concern (e.g. rare, threatened species).

A broader scope is implied by 'natural capital accounting' since this encompasses both biotic and abiotic aspects of the natural environment. For example, the spatial boundary of the UK Natural Capital Accounts is the land area of the UK plus the Exclusive Economic Zone (marine area) and sub-soil resources (oil, gas, minerals) and the atmosphere above/below. The UK Natural Capital Accounts focus on the ecosystem as a whole linking assets to the 'basket' of services they provide – with less emphasis on accounting for individual components of ecosystems (e.g. soil, land, biodiversity) (ONS 2017). Principles concerning the measurement of stocks and flows, and valuation of assets and flows (and any extensions of their scope) are though intended to be broadly consistent with the SEEA-EEA framework.

Ecosystem accounts, therefore, do not have the same underpinning as benefits assessment for valuing biodiversity. Whilst they both can be concerned with measuring changes in forest values over time, use analytical tools such as logic chains to represent the relationship between the stocks of natural assets and the flows of ecosystem services, and be based on the same data sources for measuring and monitoring biodiversity, there are differences in requirements for and interpretations of valuation evidence.

Accounting structure

The principle view in the SEEA-EEA is that biodiversity is a feature of the condition of ecosystem assets. Ecosystem and species level measures of biodiversity inform on the stock of ecosystem assets, where degradation or enhancement of biodiversity can impact the 'production' of flows of ecosystem services and the income that is generated from natural assets. Biodiversity comes closest to a (final) ecosystem service in the cases of nature and wildlife-based recreation and value attached to conserving iconic species. The SEEA-EEA Technical Recommendations suggest that this flow would be recorded in an 'ecosystem capacity account'; i.e. the capacity of ecosystems to supply ecosystem services, rather than an ecosystem services flow account, *per se*[18].

An illustration of the linkages between biophysical accounts in the SEEA-EEA framework is provided in **Figure 3.5**. Effectively, the structure is intended to consolidate data on the state of the natural environmental from monitoring systems. Accounts for biodiversity and ecosystem condition are the main reference point for biodiversity measures and indicators; although it is recognised that indicators for different aspects of biodiversity could be appropriate indicators in associated accounts (e.g. carbon; tree species). Indicators from a biodiversity account would be one set of characteristics that inform on ecosystem condition, alongside components such carbon, water and soil. The purpose of an ecosystem condition account is to record via a set of key indicators the state or functioning of an ecosystem in terms of its ecological condition and the capacity to supply ecosystem services.

Biodiversity metrics and indicators

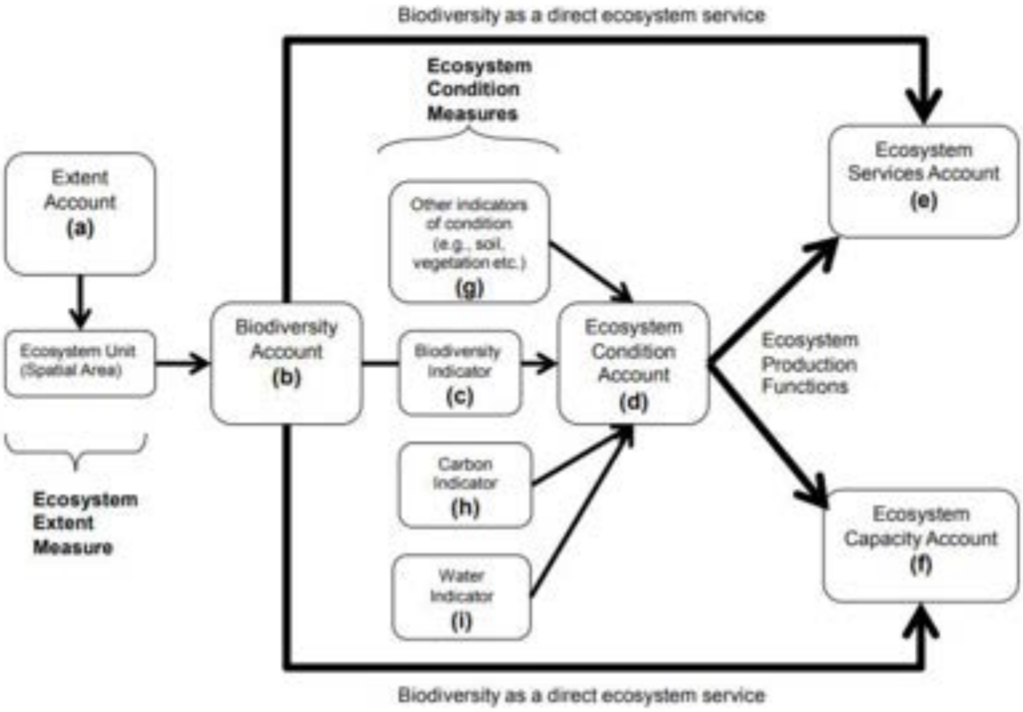
In principal, biodiversity and ecosystem condition accounts can bring together a host of information on different aspects of biodiversity. The SEEA-EEA Technical Recommendations suggest that biodiversity indicators could inform on:

- The *condition* or *state* of an ecosystem;
- The ability of biodiversity to support other services such as nature-watching (i.e. *capacity*); or
- The appreciation of biodiversity itself such as providing a habitat for endemic species (a *cultural service*).

The extent to which this is possible depends on what is currently monitored and/or can be reliably inferred from existing data. In turn this determines whether an account is simply consolidating indicators on the *state* of particular aspects of biodiversity, or whether it is also bringing forward information about composition, functioning and resilience as measures of *change*.

[18] A distinction made in the SEEA EEA framework is between flows of ecosystem services (i.e. production, consumption, and income – essentially the 'benefits' in terms of goods and services) and flows that are changes in stocks, that reflect the capacity of ecosystems to generate ecosystem services due to factors such as degradation, extraction, or growth, or improvements in condition.

Figure 3.5: Illustration of SEEA-EEA framework for biophysical accounts (UNEP-WCMC, 2015)



Notes: It is recognised that this 2015 representation of the SEEA-EEA framework precedes the 2017 Technical Recommendations, which presents a revised structure and uses some slightly different terminology in places. In the Technical Recommendations biodiversity, water, land and carbon are shown as thematic accounts that provide supporting information for all ecosystem accounts. However, the above representation is used since it directly illustrates information from a 'biodiversity account' inputting to an ecosystem condition account, which is still the essence of the Technical Recommendations.

The Technical Guidance for biodiversity accounts (UNEP-WCMC, 2015) primarily references measures related to ecosystem and species diversity. A reasonable interpretation of this, is that: (a) ecosystem diversity measures of biodiversity are inputs to ecosystem extent, condition and services accounts; and (b) species levels measures of biodiversity are inputs to 'biodiversity accounts' (as depicted in Figure 3.5), which would in effect be species diversity or abundance accounts. Indeed UNEP-WCMC highlight categorisations for land cover, land use, and habitat as providing information on ecosystem diversity, species count, richness, and population size (abundance) for aspects of species diversity. Largely the examples are based on data that is expected be available[19] and follow from Hein (2014), which lists potential indicators at both levels (**Table 3.1**).

[19] It is also noted that due to data and measurement challenges, any account would be selective in the species that would be included. A better view of species diversity would be provided by accounts that have a greater representation of taxonomic groups (e.g. plants, birds, mammals etc.) and their particular attributes (e.g. keystone species), which starts to broaden the view towards some of the functional aspects of biodiversity and the importance of composition and functional traits in determining ecosystem functioning (UNEP-WCMC, 2015).

Table 3.1: Potential species and ecosystem level indicators for biodiversity accounts

Indicator	Coverage
Species level indicators	
Number of species in specific classes	Selected indicators of species richness at a taxonomic level (e.g. mammals, woodland birds), providing a basic measure of diversity (i.e. presence of a species, but not whether the population is viable).
Biodiversity indices	Indicators such as Simpson and Shannon indices that measure species diversity as a function of species richness and relative abundance.
Mean species abundance	An indicator of the intactness of biodiversity or naturalness – measured relative to the abundance of a species in an 'undisturbed' ecosystem.
Numbers of red-list and/or endemic species	Indicators for the number of species within an ecosystem that are of particular concern for nature conservation.
Populations of keystone species	Potentially an indicator that informs on the functioning of an ecosystem, based on the notion that a keystone species has a unique and critical role in regulating ecosystem processes. For example, apex predators that regulate herbivore populations in forest ecosystems; or microorganisms (bacteria) in soils that convert ammonium to nitrite, and nitrite to nitrates, as part of the nutrient cycle.
Ecosystem level indicators	
Presence of species that are indicative for environmental quality	Indicators for species that signal disturbances in environmental conditions, particularly species that have narrow ecological niches and high degree of vulnerability to change.
Habitat for specific species	Cases where the presence of specific species is dependent on certain thresholds related to environmental conditions (e.g. an intact food chain).
Land cover change	An indicator of the physical loss of ecosystems, for example through land conversion; however, degree of disturbance to specific species and ecological processes can be difficult to infer.
Extent and effectiveness of protected areas	In combination – extent and effectiveness – a potential indicator for the conservation of biodiversity at a high level – i.e. not necessarily informing of what is being conserved.
Naturalness	An indicator for human influence on, or disturbance of ecosystems, defined relative to a set of conditions that reflect lower levels of external influence.

Practical applications

Examples of the practical application of the SEEA-EEA framework for biodiversity accounts and indicators are limited[20]. Overall, the lack of applied examples that demonstrate the accounting principles make it difficult to draw conclusions at this stage, particularly in terms of the types of data that can be included, and ultimately how the results would be interpreted, either as a standalone account or feeding into a system of linked accounts. Certainly, though, any attempt to produce an account faces similar challenges to those set out Section 3.1 regarding data and selecting the indicators that have a meaningful interpretation as to the capacity of ecosystems to provide ecosystem services. Based on the current guidance and recommendations, the extent to which composition and functional diversity aspects of biodiversity would be represented – and hence the role in ensuring the sustained provision of ecosystem service benefits overtime via a stock of resilience to certain shocks and pressures – appears to be an open

[20] For example, under the SEEA-EEA framework, experimental accounts for the Great Barrier Reef (GBR) published by the Australian Bureau of Statistics (2017) include species accounts (species abundance) for threatened species in the GBR Region (threatened bird, reptile, mammal, fish and invertebrate species) in accordance with the Queensland Nature Conservation Act 1992. Although not an explicit 'biodiversity account', a range of biodiversity indicators are featured in the Defra/ONS experimental spatially disaggregated woodland ecosystem account, as listed in Box 2.1. These cover a select set of species diversity and ecosystem functioning indicators.

question. In a recent review, King et al. (2019) also identify this as a separate component of biodiversity, reflecting on the concepts of option value, insurance value and resilience, and state that these also need to be captured in accounts[21].

The level of meaningful aggregation that can be achieved in an account is also a consideration. This is particularly challenging if indicators that are in some way spatially specific need to be aggregated beyond their intended scale. The SEEA EEA Technical Recommendations cite the need for biodiversity data that can be aggregated in a composite indicator of the condition of biodiversity (e.g. an index or aggregation using a common reference condition), so that the observed change between accounting periods provides an indication of the net biodiversity balance[22].

Overall, it is evident that testing the framework will be a considerable undertaking and there is much 'learning by doing' needed. Even with this though, only partial coverage of biodiversity will likely be possible. This is in part due to data constraints and difficulty with monitoring. More importantly, the aspects of biodiversity that are measured and monitored at present (i.e. state/condition) are not necessarily the critical indicators of ecosystem functioning (current or future). In time data constraints can be addressed, particularly if efforts to develop accounts drive better data collection, analysis, and ultimately the incorporation of this information into decision-making. Yet this is dependent on collecting data for the 'right' indicators.

Indeed, caution is needed in understanding what conclusions can be drawn from any particular component, such as a biodiversity account focused on species-level biodiversity. The risk with an incomplete set of accounts and the 'wrong' indicators is that role of biodiversity in supporting ecosystem service provision is mis-represented and changes in aspects that really do matter are not captured. A straightforward starting point would be clear labelling; for example, referring to a 'species diversity account' rather than a biodiversity account if it is primarily comprised of species level indicators.

The potential for a broader cross-cutting thematic biodiversity account is envisioned in the SEEA EEA framework. However, this must incorporate the view that biodiversity is an asset that it maintains the capacity for future ecosystem service delivery (i.e. resilience value), alongside it being a feature of the condition of ecosystem assets or associated with the measurement of cultural ecosystem services. Moreover, constructing an account does not automatically equate to it being useful for policy and management. It is one thing to observe change in an indicator. It is another thing to interpret that that change in terms of the drivers of change; the associated risks and opportunities given the range of dependencies that might be involved and taking note of time lags, potential for non-linearities and threshold effects.

Given the multi-functional aspects of biodiversity in determining ecosystem functioning and the processes, a thematic biodiversity account that can show such links would be a foundation on which individual ecosystem accounts could then be built. Arguably what is most valuable is this exercise is determining what should feature in such an account and drawing out the (implicit) logic chains that trace back the dependency

[21] King et al. describe resilience and insurance value concepts in a regulating services context, which differs to some extent to the definitions set out in Section 2.2. However, King et al. note that terminology and treatments vary across the literature. Moreover, the general message is that this a dimension of value that must be viewed from an asset-based perspective, in terms of maintaining ecological functions that underpin the ongoing delivery of ecosystem goods and services into the future.

[22] The Simpson Diversity index is cited as an example in SEEA EEA Technical Recommendations. It describes the likelihood of encountering different species within a community (UNEP-WCMC, 2015).

of each final good/service to the aspects of biodiversity that matter for its provision. Whilst this is an ambitious exercise, it would demonstrate the links between aspects of biodiversity, ecosystems, and ecosystem services. It would also provide a checklist for the indicators that should then feature in the core ecosystem accounts and for comparing and interpreting biodiversity indicators between accounts.

Valuation perspectives

As an *economic* concept, the value of natural capital and ecosystem assets – including the value of biodiversity as a 'stock' of resilience - sits within a more general framework variously referred to as comprehensive wealth accounting, total wealth accounting (World Bank, 2006) and inclusive wealth accounting (UN, 2012). These all refer to the same basic idea which derives from the economics of weak sustainability (Arrow et al, 2012). This is that: (i) future human well-being depends on a stock of capital or assets; (ii) changes in the stock of such assets in the present have implications for future well-being; and (iii) an indicator of such changes in the total value of the asset stock is a forward-looking predictor of sustainability (known as Genuine Savings or Comprehensive Investment: Greasley et al., 2014).

Within this framework, natural capital is a subset of all the wealth/capitals (produced capital, natural capital, human/social capital, and net foreign assets) that underpin the income that a country generates. This may also be taken further, with a recognition that natural capital underpins all other capitals. Notwithstanding, degradation of natural capital is equivalent conceptually to depreciation of produced capital, human capital or social capital, since under the weak sustainability assumption all capital types are inter-changeable at some price. The key question is how such losses of natural capital (for example, if a forest is felled, or a new coal mine opened) should be valued in a natural capital account (**Box 3.2**).

Box 3.2: Valuing natural assets

The value of changes in natural capital assets is measured through shadow prices, which are defined in a very specific way. Namely, the shadow price for any natural capital asset is equal to the change in discounted future welfare from a one-unit loss in this asset. Empirically, this can be approximated by evaluating the lost net benefits over some discrete time period (e.g. 30 years) from having one less hectare of wetland, one less tonne of coal, one less hectare of ash woodland etc, and discounting these lost future benefits back to the present at some constant social rate of discount.

For forest biodiversity, the key question is how to assess biodiversity as a stock that generates well-being over time, where losing some of this stock means losing future benefit flows. Whilst it is possible to think of a stock of flora or fauna, it is perhaps more useful to think of a stock of forests as the key asset of focus. Every year, the task would be to estimate the area of remaining forest, and what future direct and indirect benefit flows arise from this. Then, measure what changes in this forest areas and what changes in biodiversity within the forest area have occurred since the previous year.

Valuation methods can then be used to ask the question: does the configuration of biodiversity and forest area in year *t* generate more or less in terms of discounted future benefit flows than the equivalent forest area and biodiversity in year *t-1*? If the answer is yes – a loss of biodiversity this period, for instance, means that even though the area of forest has not changed, the predicted future benefit flows have fallen. It is the discounted value of the *change* in future benefit flows due to the change in biodiversity which is used to adjust the natural capital account. If the area of forest has changed too, the account reflects both the quantity change and the quality change (here, the alteration in forest biodiversity) in comparing the value of forests as a natural capital asset in year *t* to year *t-1*.

In this framing of a natural capital accounting approach, it is likely that insurance and resilience values for forest biodiversity will gain higher relative importance relative to CBA approaches, since by definition they relate to variability in the supply of benefits into the (far) future. However, in a series of papers, Fenichel and Abbott (2014) have criticised approaches to measuring natural capital changes for ignoring ecosystem linkages in coming up with shadow prices. As Fenichel and Abbott (2014, p. 2) say: "*Despite years of progress in the valuation of ecosystem service flows and the application of capital theory to natural resources and progress by natural scientists, the value of natural capital often remains crudely measured at best*".

Their point is a simple one conceptually: if we want to know how a decline in the population of a given fish species (through e.g. increased fishing or rising pollution) affects future well-being in a country, accounting for the change in that species is not sufficient. We also need to account for how changes in that species produce cascade effects within the ecosystem; and how these changes on species higher up the trophic level combine to produce an effect on the future flow of benefits from the fishery. To figure this out, a bio-economic model of the fishery is required to trace the effects of a change in one species on multiple species.

Based on ecosystem models for two different fisheries, Fenichel and Abbott show that the "correct" shadow prices obtained for fish lower down the trophic scale (prey species) were systematically higher than market prices – since their role in ecosystem functioning is not reflected by the market – whilst the shadow value of predator species were consistently lower than the market price. The implication being that natural capital gains and losses are incorrectly measured when market prices are used as shadow prices. This is a widely recognised result, but what is also revealed is the quantitative analysis that demonstrates the implication for all other species and functions that change (i.e. the dependencies).

However, the data needs and complexity of modelling needed to measure the correct shadow prices is high. Moreover, Fenichel and Abbott show that the shadow price of natural capital evolves over time as the condition of stock changes, which depends on how human behaviour responds to the change in the stock, and how the stock responds to changing human pressures. It is possible to think of equivalent ecosystem dependency models for forests, even though this would be a very considerable task. For example, insects or seeds used by birds as a food source in the food web can be linked to forest management models via feedback loops incorporating manager response to changes in system condition and existing institutional rules (e.g. planting and management rules, guidelines and subsidies), and then linked to the value of ecosystem services delivered by the forest. Thus, natural capital accounting for changes in biodiversity adds a considerable level of complexity, either in CBA or ecosystem accounting uses. As King et al. (2019, p. 13) state *"Techniques for measuring or modelling changes in the capacity of an ecosystem to deliver services into the future as an explicit function of changes in the current stock of biological diversity within that system, while holding considerable promise, are very much in their infancy".*

Overall, the approach outlined above is based on what economists would recognise as the dominant intellectual model of capital accounting for sustainable development. With respect to the SEEA-EEA framework, the key issue is that welfare-based values include consumers surplus, since they show the maximum that individuals are willing to pay for different goods and services. The System of Natural Accounts (SNA) that the SEEA EEA framework is intended to emulate is made up of market exchange values which omit such surpluses. In short, welfare-based values are not consistent with an SNA- income account. But this does not in any way prevent them being implemented in a theoretically consistent natural capital account, as explained above, and reported apart from the SEEA. Indeed, the potential for a cross-cutting wealth-based account for biodiversity is suggested in several recent papers (e.g. Badura et al., 2017; King et al., 2019).

4. Options for valuing biodiversity

This section outlines in the context of benefits assessments how different aspects of biodiversity values can be estimated for different ecosystem services using economic valuation methods.

4.1 Developing a practical approach

Sections 2 and 3 show that a wide range of factors need to be taken into account when setting out to understand the economic value of biodiversity. Navigating a practical approach that takes account of gaps in knowledge and data and produces meaningful and useful information for decision-making is challenging. It is helpful, therefore, to break the requirement down into discrete steps, which can, as they are achieved, build-up the complete assessment. This will likely provide a better basis for understanding the degree of effort that will be needed in a given situation.

At the highest level, the three basic stages for a decision-context (e.g. forest management) are:

A. Identify management outcomes or policy objectives and establish the economic values that need to be estimated, in terms of the change in provision of final goods and services.

B. Identify, describe and/or assess the change in provision in terms of ecosystem service provision and beneficiaries (i.e. users and non-users), drawing out the potential trade-offs between provisioning, regulating and cultural services.

C. Identify the dependencies on biodiversity in terms of supporting the underlying ecological functions and the implications of the change for sustained provision of ecosystem services and economic values over time.

Stages (A) and (B) are the conventional components of a benefits assessment (i.e. *Benefit = P x Q*), which would include direct values from biodiversity and the indirect contribution embedded in the provision of other goods and services. Stage (C) is the added element that provides for an explicit account of the overall contribution of biodiversity, helping to provide a fuller recognition of indirect values in an assessment.

4.2 Options for valuation

Two specific aims for this study are to: (a) determine which aspects of the contribution of biodiversity to welfare it is appropriate to value; and (b) assess which valuation methods are appropriate to capture these values. **Figure 4.1** presents a 'reference card' that breaks down the different elements of the value of biodiversity from the perspective of economic analysis. Drawing on the preceding discussion in the report it shows the distinction between direct and indirect contributions to individual and social welfare and highlights some of the principle valuation methods and approaches that can be used to estimate 'biodiversity values' in a benefits assessment context. A more detailed version of the reference card is provided in **Annex 3**, which provides a fuller view of the range of valuation methods that can be applied.

Figure 4.1: Options for valuing the contribution of biodiversity

		Indirect contribution				Direct contribution	
		Total economic value	Biodiversity = input to production of final good/service			Total economic value	Marginal value
E/S category	Final good/service category		Marginal value of biodiversity	Insurance value	Final good/service (biodiversity value embedded)		Biodiversity = final good/service
Provisioning	Timber products	Consumptive use value	Production function approach	✓	Market prices	-	-
	Food (agriculture)	Consumptive use value	Production function approach	✓	Market prices	-	-
	Food (wild foods)	-	-		-	Consumptive use value	Revealed preference; stated preference
	Energy	Consumptive use value	Production function approach	✓	Market prices	-	-
	Pharmaceuticals	Consumptive use value	Production function approach	-	Market prices	-	-
Regulating	Water quality	Non-consumptive use value	Production function approach	-	Replacement cost	-	-
	Flood alleviation	Non-consumptive use value	Production function approach	-	Avoided damage cost	-	-
	Local climate (temperature regulation, shade)	Non-consumptive use value	Production function approach	-	Replacement cost	-	-
	Air quality	Non-consumptive use value	Production function approach	-	Avoided damage cost	-	-
	Carbon sequestration	Non-consumptive use value	Production function approach	-	Avoided damage cost	-	-
Cultural	Nature conservation (species, habitats)	-	-		-	Non-use value	Stated preference
	Wildlife-based recreation	-	-		-	Non-consumptive use value	Revealed preference; stated preference
	Recreation (general)	Non-consumptive use value	Production function approach	-	Revealed preference; stated preference	-	-
	Health	Non-consumptive use value	Production function approach	-	Treatment costs	-	-
	Learning, education and volunteering	Non-consumptive use value	Production function approach	-	Revealed preference; stated preference	-	-
	Artistic	Non-consumptive use value	Production function approach	-	Revealed preference; stated preference	-	-
	Cultural and spiritual	Non-consumptive use value	Production function approach	-	Revealed preference; stated preference	-	-

Notes

Qualitative	Monetary valuation less likely to be required/feasible - for example, due to lack of empirical studies; and/or due to double counting where the indirect contribution of biodiversity is embedded in the value of a final good and service and this is already included in a benefits assessment.
Monetary	Monetary valuation should be attempted - subject to data and evidence availability and materiality of impact.

The key elements in Figure 4.1 are: (a) the final good/service category; (b) the component of total economic value (TEV); (c) the contribution of biodiversity to welfare (direct/indirect); and (d) the 'principle' valuation method(s). The extended detail provided in Annex 3 also distinguishes between the appropriate measures of economic value for the direct and indirect contributions of biodiversity[23].

[23] Both producers and households derive value from biodiversity. The household value is realised through the consumption of final goods and services in terms of consumer surplus. This is measured in monetary terms by either by WTP and WTA for securing/avoiding changes in the provision of final goods. Direct values for biodiversity fall within consumer surplus measure, along with the value of final goods and services that biodiversity contributes to via the indirect route. The producer value can be associated with either: (a) inputs to production; and/or (b) the consumption of final goods and services. The principle distinction is that (a) represents inputs into the production function of the firm, whilst (b) is relevant in terms of the ecosystem service provision benefits that – similar to households – firms may experience, e.g. for example, the benefits of flood risk protection within a catchment. Monetary valuations for producers are measured in terms of changes in marginal revenue product or producer WTP. For the most part, the indirect value of biodiversity falls within the producer surplus measure.

The main points of interpretation are:

- *Categorisation of final goods and services*: an aggregated list is used, based on Binner et al. (2017), with some amendments to reflect distinctions between abiotic and biotic elements of ecosystem services frameworks.

- *Component of TEV*: in broad terms the categories of final good/service can be aligned to the main aspect of TEV that they reflect; i.e. consumptive use values associated with provisioning service final goods, non-consumptive use values associated with regulating and cultural service final goods. Note that option value is intentionally omitted from this categorisation as its estimation is an extension of future use and non-use values in the context of irreversible effects (Section 2.2). Non-use value features once in the classification. This follows from the way in which valuation methods are matched to the valuation of changes in the provision of final goods and services (see below).

- *Indirect vs. direct value*: direct biodiversity values are realised through the consumption of final goods and services by households in terms of consumer surplus. This is measured in monetary terms by either WTP and WTA for securing/avoiding changes in the provision of final goods. The value of the final goods and service that depend on biodiversity via the indirect route also fall within consumer surplus measure. The indirect value of biodiversity can be associated with either: (a) inputs to production; and/or (b) the consumption of final goods and services. The principle distinction is that (a) represents inputs into the production function of the firm, whilst (b) is relevant in terms of the ecosystem service provision benefits that – similar to households – firms may experience, e.g. for example, the benefits of flood risk protection within a catchment. Monetary valuations for producers are measured in terms of changes in marginal revenue product or producer WTP, including for risk reductions via the insurance value of biodiversity. For the most part, the indirect value of biodiversity falls within the producer surplus measure.

- *Valuation method(s)*: Annex 3 provides an overview of the range of valuation methods that can be used to value the direct and indirect contributions of biodiversity. Figure 4.1 indicates what might be considered the 'principle' approach for a good or service. This is not intended as a formal classification or recommendation, rather it is to illustrate which methods are typically used to measure the value of interest (e.g. market prices as the basis for measuring the value of final goods/services provided in markets). In some cases, there is no obvious distinction between the available options.

  With respect to the range of methods highlighted, the main considerations are:

  - Production function approach(es): estimate the values of the environment as an input to production. Conceptually this is the 'correct' approach for estimating indirect values. The contribution of some aspect or measure of biodiversity is captured as a factor input in the production of a good or service that generates utility.

  - Market prices: values based on market prices/revenues, adjusted for distortions (tax/subsidies) to reflect opportunity costs, and hence the trade-off associated with securing its provision. Premiums paid for certain product characteristics (sustainable production) could be interpreted to reflect values specific to biodiversity (if relevant) and may embody both use and non-use values.

- Revealed preference methods: provide estimates of use values for forest attributes (potentially including measures of biodiversity) usually in relation to observed household behaviour (e.g. general recreation values, or wildlife-based recreation values).

- Stated preference methods: likely to capture both use and non-use values. The extent to which depends on the specifics of the valuation scenario and simulated market. Attribute-based approach (DCE) could capture contribution to welfare that is specific to certain aspects of biodiversity (e.g. presence of specific species).

- (Avoided) damage cost: represent values (opportunity costs or resource costs) associated with environmental 'bads'. In general, avoided costs can be broadly defined to include costs associated with natural events (e.g. flood damages to property) and longer-term deficits in environmental quality (e.g. drinking water treatment costs associated with raw water quality). Following from the points highlighted in Section 3.1, damage costs may represent a lower-bound cost since they do not reflect the full welfare impact of events such as flooding (i.e. the stress and inconvenience experienced).

- Replacement cost: the cost of replacing a specific outcome (good/service) associated with ecosystem service provision can be used as a proxy for welfare-based measures of value (i.e. producer surplus and consumer surplus). This is because the cost of replacing a service is independent of the benefit derived from its use. Again, the proxy value is ordinarily interpreted as a minimum benefit value. For example, in relation to flood risk reduction, the cost of physical defences as a proxy for loss of flood attenuation by wetland.

- Treatment cost: resource costs to health services from treating physical or mental health conditions. Strictly this is not a component of household utility, but it may be used as a cost-based proxy or would represent a lower bound estimate of the value of an impact (i.e. excluding welfare impact).

Note that value transfer is not included within the set of valuation methods, but in practical assessments it is likely to be the principal way in which valuation evidence would be applied.

In principle, the choice of valuation method in terms of the evidence source will determine the components of TEV that are captured. For example, if stated preference values are applied, it is likely that they capture both use and non-use values. In general, a benefits assessment would not attempt to split the respective components; rather the distinction would be made between the users, and (if relevant) the non-users when aggregating individual values across the affected population. Notwithstanding this observation, the principal element of non-use value with respect to biodiversity is for nature conservation outcomes. Wider aspects of non-use value that would be captured are the benefits to others for provision of other final goods and services (not the contribution of biodiversity *per se)*[24].

- *Monetary versus qualitative assessment*: the final element included in Figure 4.1 is the colour-coding which considers the feasibility of acquiring monetary valuation evidence. The main conclusion is that in most cases the production function element would not be empirically assessed (although there could be exceptions where this would be required). The rationale for this is twofold. The first is the rule to value final goods and services to avoid double-counting of the indirect contribution of biodiversity (Section 3.1). The second is that in general the empirical evidence concerning the indirect contribution of biodiversity is lacking and where it is available the results from production functions are less transferable (they are usually very context dependent).

In summary, the approach suggested in Figure 4.1 retains the convention of valuing final goods and services, recognising that this is not sufficient by itself to provide a satisfactory account of the contribution to biodiversity to overall social welfare. The assumptions used to aggregate benefits over time need to be informed by an appropriate level of supporting evidence that describes the dependency of the values on biodiversity, expectations as to the capacity to sustain the values, and the potential trade-offs in doing so. This requires new tools and evidence to support benefits assessments – a requirement that is addressed in the concluding section of this report.

[24] In addition, stated preference and revealed preference methods can pick-up values for biodiversity attributes if they use a discrete choice / random-utility framework. For simplicity, however, these values would still be classified under the 'nature conservation' aspect or 'wildlife-based recreation'. Hence, this illustrates the point that the results from a single study need not be confined to a good or service in Figure 4.1. For instance, a (stated preference) choice experiment study could give values for multiple rows across the provisioning, regulating and cultural service categories.

5. Conclusions

This section concludes with a summary of the main points for valuing the contribution of biodiversity to individual and social wellbeing. High-level recommendations for further research and guidance are also provided.

5.1 Summary

Ecosystem service frameworks emphasise the importance of a healthy environment to provide services that are essential for individual and social wellbeing. Yet these frameworks often do not demonstrate the dependency of service provision on biodiversity and the underlying ecological processes it drives. This is particularly the case for the economic analysis component that (correctly) concentrates on the value of final goods and services. The result is that the contribution of biodiversity is largely implict and embedded in valuations that mostly reflect the present service flows and stocks of natural assets. Therefore, the information that feeds into decision-making is partial: the dependency on biodiversity for sustaining economic values *over time* is not recognised, and not fully accounted for. Moreover, because different types of management outcomes can rely on different dimensions of biodiversity, the potential trade-offs between management alternatives may not be apparent.

Improving the way that the value of biodiversity is accounted for in decision-making requires a refinement of the objective of economic valuation. This is not a fundamental change in approach but rather a need to provide a more comprehensive assessment of the final outcomes and their dependencies on biodiversity. In particular, a mix of monetary, quantitative and qualitative evidence is required to assess the direct and indirect contributions of biodiversity to ecosystem service provision over time. It is also important to qualify the circumstances under which the economic values apply – i.e. the boundaries in terms of the status and condition of the biodiveristy attributes of interest.

5.2 Research recommendations

The approach to valuing biodiversity set out in Section 4.2 requires new tools and guidance to support benefits assessments. The broad concepts and analytical frameworks (e.g. natural capital, ecosystem services) are in place, as is the overall economic analysis guidance (e.g. Green Book, value transfer). However, the existing evidence and associated understanding of the dependency of economic values on biodiversity is limited. More work is needed via a combination of new research and consolidation of existing evidence to set the 'groundwork' before more generalised benefits assessment tools and guidance can be developed.

The following high-level recommendations for further research are intended to set a direction of travel for improving the evidence base and demonstrating more of the ways in biodiversity contributes to welfare.

1. *Undertake new research to estimate non-use values for forest biodiversity*. The current default non-use values in benefits assessments are around 20-years old. These values are an important aspect of the direct value contribution, but presently they centre on a fairly narrow (but important) aspect of

biodiversity in terms of tree species mix. A new research study provides an opportunity to produce new values for alternative management and nature conservation outcomes associated with forests, and to address issues concerning aggregation (e.g. distance decay in non-use values) and transferability across decision-contexts.

2. *Consolidate understanding and evidence concerning biodiversity dependencies*. Research is needed to develop biodiversity logic chains for a range of final goods/services that can provide demonstration or reference cases for practical benefits assessments. This is a multi-disciplinary research task that should trace through the biodiversity – ecosystem function – ecosystem service – economic value links. The paper by Paul et al. (2019) makes a start in this direction. Initial scoping will be required to determine the level at which meaningful generalisations can be made, but the aim is to develop the framing for the qualitative narrative and - where possible – quantitative evidence that supports the understanding of the contribution of biodiversity in terms of indirect (particularly) and direct values.

3. *Develop case study evidence on insurance values and resilience values for forests.* Qualitative assessments are a minimum requirement for providing an improved account of the indirect contribution of biodiversity. This is reasonable in circumstances where the biodiversity value is embedded within the value of final goods and services that are monetised in benefits assessments. Insurance values and resilience values, however, are ordinarily not embedded in these outcomes. The concept of resilience in particular needs to be better understood and demonstrated, as any assessment will be partial in nature (the resilience of what, to what?). The first step to improve understanding of these issues and their relevance to decision-making and to raise awareness of their materiality but also context-specific interpretation. A case study approach would be ideal, applying the empirical approaches that have been developed (see Annex 1) to a relevant forest management context (e.g. climate change adapation measures). The purpose would not be to produce generalisable (transferable) results but instead highlight within the suggested approach set out in Section 4.1 the importance of taking insurance and resilience values into account.

A useful direction of research for ecosystem accounting would be to determine the feasibility of producing a cross-cutting biodiversity account that augments indicators for *state* of species and ecosystems with measures of *change* in terms of composition, functioning and resilence. To be relevant for policy making, an account needs to signal what the consequences of changes in biodiversity are; for example an increasingly vulnerability to changing environmental conditions such as disease, invasive species, drought, and the ecosystem service benefits that are at risk. As with the benefits assessments context, the challenge is to ensure that biodiversity dependencies are embedded with the accountiing framework.

The recommendation with respect to ecosystem accounting is to:

4. *Conduct a scoping study for the production of a thematic experimental biodiversity account*. Forestry represents an ideal case study given the evidence base and work conducted so far on national level, disaggregated ecosystem accounts, and corporate accounts. The objective would be to determine the feasibility and requirements for producing an account, with two main areas of focus:

    a. The foundations of the account in terms of a set of logic chains tracing out the biodiversity dependency relationships. This task is complementary to Recommendation (2) since part of the requirement will be to determine the level at which logic chains can be generalised. From this basis, the indicators that have meaningful interpretation for ecosystem service provision now and in the future should be: (i) identified, covering stocks and flows, physical and monetary measures, direct and indirect contributions; (ii) assessed as to whether appropriate measures and the data to construct them exist; and (iii) linked to other components of the UK natural capital accounts).

b. The appropriate basis for valuation, including considering the possibility of using a wealth accounting framework for measuring the overall productive value of biodiversity (i.e. natural capital accounting for changes in biodiversity). Given the various ways in which biodiversity contributes to welfare (direct, indirect; use values, non-use values, etc.) a wealth accounting approach likely provides a better framing reflecting the overall productive value in the *present* and *future*. Given the positioning as a cross-cutting thematic account, this framing would not compromise objectives concerned with ensuring consistency with SNA that stem from the application of SEEA EEA Technical Recommendations in core ecosystem accounts. Rather it would provide a supplemental set of results intended to reflect the scale of the contribution of biodiversity, including dimensions of the stock of resilience in natural assets.

The main output from the scoping study would be recommendations for developing an account, including breadth of coverage and interpretation of the account, principles for measuring and valuing the components parts (e.g. asset values that reflect resilience and insurance values), and timescales for development. The desired outcome would be to set expectations as to what is realistically achievable and the extent of its policy relevance.

Glossary

(Avoided) damage cost	Opportunity costs or resource costs associated with environmental impacts. Can include costs associated with natural events (e.g. flood damages to property) and longer-term deficits in environmental quality (e.g. drinking water treatment costs associated with poor water quality).
Abiotic	Physical aspects of ecosystems such as climate (temperature, wind) and sunlight, geology, and water availability.
Altruistic value	Non-use value that individuals derive from the knowledge that other people benefit from (final) goods and services.
Benefits transfer	See '*value transfer*'.
Bequest value	Non-use value that individuals derive from the knowledge that natural resources and the benefits gained from them are conserved for future generations.
Biodiversity	The variability among living organisms from all sources, including terrestrial, marine, and other aquatic ecosystems and the ecological complexes of which they are part. Biodiversity includes diversity within species, between species, and between ecosystems.
Biomass	The mass of (living) biological organisms in an ecosystem. Net primary production is a measure of the change in biomass.
Biotic resources	Living components of an ecosystem such as animals, plants, fungi and bacteria.
Consumer surplus	Net benefit derived from consumption of a good or service, measured by the difference between an individual's maximum willingness to pay and the actual price paid.
Consumptive use value	Benefits derived by individuals from the consumption or use of a good (e.g. timber, food products).
Content validity	A test of the reliability of a stated preference survey in terms of framing (e.g. balance/neutral information provision) and respondent understanding (e.g. the overall topic area, clarity of definitions and descriptions in survey material).
Contingent valuation	Stated preference method that elicits an individual's willingness to pay or willingness to accept compensation for a specified change in provision of a good or service.
Convergent validity	Component of the construct validity of a stated preference survey that compares empirical results to findings from other methods (e.g. revealed preference, proxy markets).
Cultural services	Non-material benefits that individuals derive from ecosystems, such as recreation, aesthetic enjoyment, health and wellbeing, knowledge gain, cultural identity and spiritual reflection.
Direct contribution to welfare (biodiversity)	Benefits from aspects of biodiversity that are final goods or services and contribute directly to individual and household wellbeing, such as wild food or wildlife-based recreation (e.g. bird watching).
Choice experiment (or discrete choice experiment; or stated choice experiment)	Stated preference method that elicits an individual's willingness to pay or willingness to accept compensation for incremental changes in the provision of goods or services. Ordinarily survey respondents are presented with alternative bundles of provision, which are differentiated in terms of the different characteristics (individual attributes and their levels). Respondents are asked to choose their most preferred alternative in a series of repeated choices.
Economic value	A measure of the benefit or wellbeing associated with the provision of a good or service. Ordinarily this is measured in monetary terms by an individual's willingness to pay (WTP) or willingness to accept (WTA) to secure or forego the good/service.
Ecological community	A group of plants, animals and other organisms that interact within a specific habitat.

Ecological processes	Interactions among organisms that typically regulate the dynamics of ecosystems and the structure and dynamics of biological communities (e.g. biomass production, pollination).
Ecosystem accounting	An integrated approach for assessing the productive capacity of the natural environment, through the measurement of ecosystems, and measurement of the flows of services from ecosystems into economic and other human activity. Typically, the approach is grounded in the (developing) approach of the System of Environmental-Economic Accounting – Experimental Ecosystem Accounting (SEEA EEA) which attempts to extend the principles of the System of National Accounting (SNA) to measure the natural environment.
Ecosystem diversity	The variety of ecosystems within a given area, including the communities of organisms within it.
Ecosystem functioning	The biological, geochemical and physical processes and components that take place or occur within an ecosystem. In effect, the biological underpinning of ecosystem service provision through processes such as pollination and pest control.
Ecosystem multifunctionality	A concept that recognises the potential of ecosystems to simultaneously provide multiple functions and benefits to society.
Ecosystem services	The outputs of ecosystems processes that provide benefits to individuals and society as a whole, such as crop and timber production, carbon sequestration, flood risk attenuation.
Exchange value	Monetary outlays and revenue for all quantities of a product that are sold/bought, which is equal to the market price multiplied by the quantity transacted. Exchange values are calculated from observed transactions and underpin national accounts. Under the assumption that all purchasers pay (and producers receive) the same price on average, exchange values exclude consumer surplus (i.e. they do not measure the net benefit that individuals derive for the consumption of a good or service).
Existence value	Non-use value that individuals derive from knowing that a resource continues to exist, regardless of use made of it, now or in the future.
Final good/service	The commodities, products, and services that individuals derive wellbeing from; i.e. the items that feature in a household's utility function.
Flow	The provision of a good, service, impact, benefit, cost, etc. measured over an interval of time (i.e. tonnes per year).
Functional composition	A combination of factors, such as the presence or relative abundance of certain species, groups of species and their functional traits (characteristics).
Functional diversity	The range of roles that organisms perform in an ecological community or ecosystem.
Functional redundancy	The tendency for different species to perform similar functions but exhibit different response traits to environmental changes and therefore act as substitutes for the contribution of each to ecosystem processes.
Functional trait	Characteristics that define species in terms of their ecological roles, such as how they interact with other species and influence ecosystem functioning.
Genetic diversity	The number and variety of genetic characteristics within a particular species (i.e. within species diversity).
Indirect value/ contribution (of biodiversity)	Contribution of some aspect of biodiversity – as an input - to the production of final goods and services, both market (e.g. timber) and non-market (e.g. air quality).
Insurance value	An aspect of economic value that relates to uncertainty over future flows of income and benefits due to unpredictable factors such as weather, disease, and fire. It is measured by the amount that a producer (i.e. forest manager) is willing to pay for the risk reduction that more diverse forests offer; for example accepting a lower

	average future return because it has lower variability (i.e. less risk of large falls in output), compared to higher returns but greater risk in terms of variability.
Logic chain	Conceptual model for linking ecosystem service provision to underlying ecosystem attributes that influence their provision.
Marginal revenue product	The additional revenue generated from one more unit of a productive input.
Market prices	The price at which buyers and sellers agree a transaction for good or service (see also 'exchange value').
Natural capital	The stock of renewable and non-renewable resources (e.g. plants, animals, air, water, soils, minerals) that combine to yield a flow of benefits to people.
Non-consumptive use value	Benefits derived by individuals from a good, service or resource that is not diminish by its use (e.g. nature watching).
Non-use value	Economic value derived from a good or service that is independent of, or not associated with its use, but is due to motivations based on altruistic, bequest and existence values.
Nutrient cycling	An ecological process that involves the movement and exchange of organic and inorganic matter back to the production of living matter (e.g. carbon cycle, nitrogen cycle).
Option value	The economic value associated with the potential future use of a resource (i.e. future use value).
Productive capacity	The ability of the (natural) asset to continue to provide ecosystem services and/or flows of resources.
Producer willingness to pay (WTP)	Conceptually producer WTP should be equivalent to the marginal revenue product of an input to production. This represents the most a producer would be willing to pay for one more 'unit' of input and traces out their (derived) demand for the input.
Production function	Describes the relationship between inputs to a production process and the outputs in terms of quantities produced (i.e. of a good or service).
Production function approach(es)	Practical estimation of a production function for a good or service, for example to measure how changes in an environmental input (e.g. quantity or quality) change the level of output. Conceptually this is the 'correct' approach for assessing the indirect values of biodiversity, where some aspect of biodiversity is a factor input in the production of a good or service that generates utility.
Productivity cost (labour)	The value of lost productive output due to physical or mental health conditions affecting workers (e.g. measured through marginal productivity of labour / wage rate).
Provisioning services	Material or energy-based outputs from ecosystem service provision, such as crops and food, timber, and pharmaceutical properties.
Recreation demand models	Revealed preference non-market valuation methods that use information on costs and time spent by individuals to visit sites to estimate demand for recreation and the use value benefits. Different approaches can be used to analyse different aspects of individuals' decisions concerning recreation sites including (i) the demand for recreation visit to a site (travel cost method) and (ii) the choice of which site to visit (discrete choice / random utility models).
Regulating services	Beneficial outcomes that come from the capacity of ecosystems to regulate climate, hydrological and bio-chemical cycles, earth surface processes, and a various biological processes, such as water purification, natural hazard regulation (e.g. flood protection), assimilation of waste, local air quality regulation.
Replacement cost method	A proxy approach for measuring for the value of a good or service that is based on the cost of replacing it using a substitute technology if it is lost or if its productivity

	decreases; for example, valuing wild insect pollination based on the cost of hand pollination.
Resilience	The degree to which a specific ecosystem function can resist or recover from an environmental or external shock and maintain a level of functioning above a specified level or threshold.
Resilience value	The economic value that can be attributed to maintaining specific ecosystem service outputs over time despite risk factors like variability in environmental conditions, disturbance due to external pressures, and management uncertainty.
Revealed preference methods	Economic valuation methods that estimate the use value of non-market goods and services based on observed behaviour for related to market goods and services (e.g. avertive behaviour, travel cost method / recreation demand models, and hedonic pricing method).
Shadow price	An estimated value of a good or service in cases where market prices are not available or where they do not reflect its scarcity or opportunity cost.
Species abundance	Number of individuals of a species expressed per unit area or volume of space (equivalent to species population density).
Species diversity	The variety of species within a habitat or community. It accounts for both species richness and species evenness (which measures the relative proportion of different species in a community).
Species richness	A measure that is a count of the number of different species within a community (with no account for the relative abundance)
Stated preference methods	Economic valuation methods that use survey-based (questionnaire) approaches to elicit individuals' for changes in the provision on non-market goods or services preferences (i.e. measures of willingness to pay and/or willingness to accept).
Stock	The quantity or value of a capital asset at a specific point in time.
Supporting / intermediate services	Ecosystem services that underlie and are necessary for the provision of all other ecosystem services (provisioning, regulating, cultural), such as soil formation and retention, nutrient cycling, and water cycling.
Total economic value	The sum of use and non-use values derived from a good, service or resource.
Travel cost method	See recreation demand models
Treatment cost	Resource costs to health services from treating physical or mental health conditions. Strictly this is not a component of household utility, but it may be used as a cost-based proxy or would represent a lower bound estimate of the value of an impact (i.e. excluding welfare impact).
Use value	The economic value that is derived from using or having potential to use a resource. It is the net sum of direct use values, indirect use values and option values.
Utility function	A representation of an individual's preferences for the consumption of goods and services (market and non-market), based on the net benefit that is derived.
Value transfer (benefits transfer)	A set of approaches to economic valuation that uses readily available evidence from existing studies to estimate the value of goods and services in a new context for which valuation is required.
Wealth accounting	A methodology for measuring a broader definition of a country's wealth, beyond the System of National Accounting (SNA) and gross domestic product (GDP) as measure of economic performance. GDP only measures current income and production; it does account the assets that underpin current and future income. A comprehensive wealth account measures produced capital (e.g. buildings, machinery, infrastructure), natural capital, human capital, and net foreign assets (the value of the assets that country owns abroad, minus the value of the domestic assets owned by foreign countries).

Welfare	A measure of satisfaction or 'utility' gained from consumption or use of a good or service.
Willingness to accept	Monetary measure of the economic value or benefit that an individual derives from the provision of a good or service, measured in terms of the minimum amount of money (income) they are prepared to receive in compensation to forego its provision.
Willingness to pay	Monetary measure of the economic value or benefit that an individual derives from the provision of a good or service, measured in terms of the maximum amount of money (income) they are prepared to give up to secure its provision.

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Annex 1: Insurance and resilience values

Effects of higher diversity on economic returns and risks (provisioning services)

There are several papers which show that higher genetic diversity can reduce income risks for farmers (e.g. Di Falco and Perrings, 2005). For forests, two interesting papers are Greiss and Knoke (2013) and Paul et al. (2019). In the former paper, the authors compute differences in expected returns and in risks for different species mixtures in German forests. The only output being valued here is timber. Their main result is that, over some range, greater species diversity increases expected returns and reduces risks. For example, a spruce/beech mixture with 7% beech gives an 8% increase in expected return (ENPV) and a 18% reduction in risk over a monoculture of spruce. Above some level of mixing (e.g. 50:50 planting), expected returns decline, but the risk-reduction effect remains. The authors use a forest optimisation model with Monte Carlo simulations to get these results. Two key outputs are shown below. In their Figure 1, more diverse species mix leads to higher probabilities of a forest stand surviving fires, windthrow and pest outbreaks.

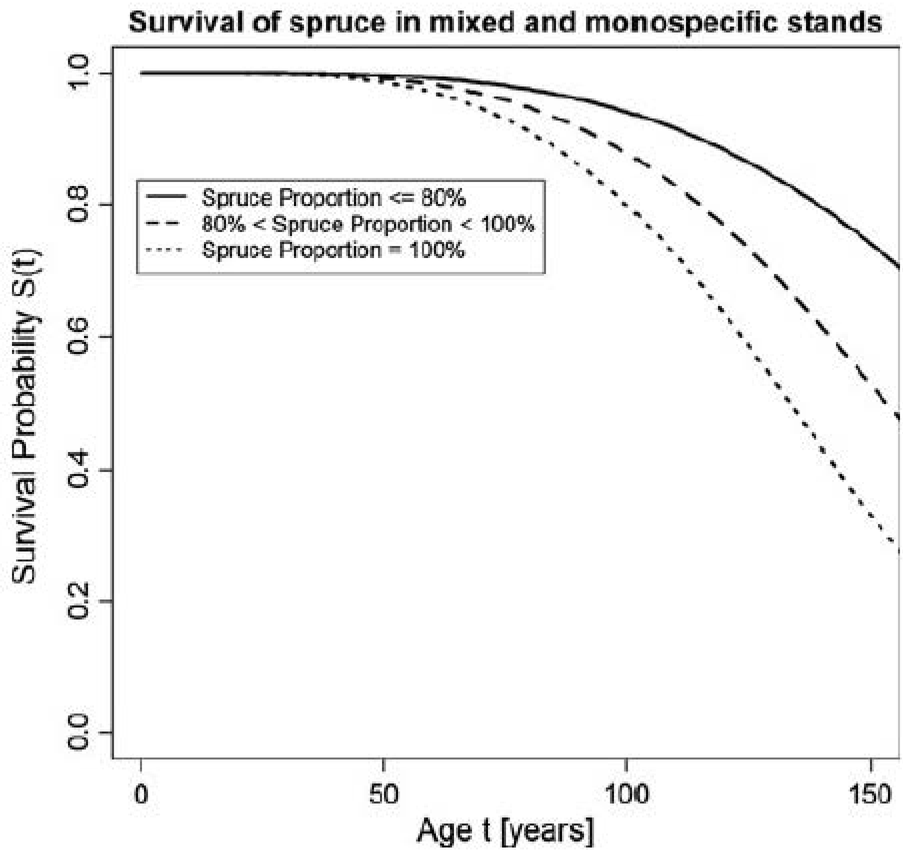


Fig. 1 Survival of spruce trees in mixed-and mono-species stands defined by spruce ratio. Survival probabilities were determined using a Weibull function (adopted from Griess et al. 2012)

In their Figure 3, a more diverse forest in terms of tree species planted leads to reductions in risk, but variable effects on expected returns over time, shown as the expected net present value (NPV).

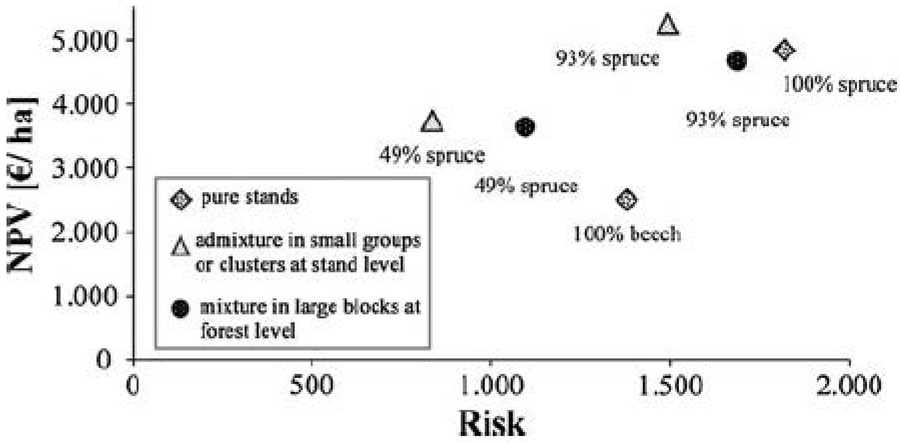


Fig. 3 Average NPV and risk (standard deviation) both in (€/ha) for the six stand types. (1) beech monoculture; (2) spruce monoculture; (3) 93 % spruce and 7 % beech, mixed in groups at the stand level; (4) 49 % spruce and 51 % beech mixed in groups at the stand level; (5) 93 % spruce and 7 % beech mixed in large blocks at the forest level and 49 % Spruce and 51 % beech mixed in large blocks at the forest level

Effects of biodiversity on insurance values

As noted by Baumgartner and Strunz (2014), an increase in resilience will always change expected incomes over time and may raise or lower income risks. This means that the insurance effect is an identifiable subset of the overall economic value of resilience.

The initial empirical paper on the effects of higher diversity on the economic value of resilience is Finger and Buchmann (2015). They note an ecological literature focussed on grasslands which finds some evidence that more diverse systems give higher net primary productivity over time and less vulnerability to pests and diseases. With respect to the latter effect, they note that risk-averse farmers will get utility (value) from this insurance function. They use a German experimental data set on grassland diversity and performance. They specify a yield function with a deterministic and a stochastic component. The latter is assumed to be a function of diversity. Assuming a utility function with constant relative risk aversion, they derive an expression for the risk premium as a function of diversity and this risk aversion parameter; then differentiate this to get the marginal effect of an increase in diversity on the risk premium.

There are thus two key “ingredients” to their empirical model: the biophysical/ecological effect of higher diversity on the variability of yields; and the utility function including its risk preference parameter which translates changes in expected returns and levels of risk into utility. Using both Shannon and Simpson biodiversity measures, they empirically estimate the biophysical/ecological effect of higher diversity on variability of output based on data from 82 plots over the period 1961-1990. See their Table 1 below:

Table 1
Estimation results of grassland production.

	Species diversity (D)	
	Shannon index	Simpson index
a) Expected yields (Eq. (6))		
Intercept	6.1866 (16.43)***	6.7791 (17.07)***
$D^{0.5}$	1.6099 (5.59)***	1.3719 (3.14)***
R^2_{adj} (and F-test)	0.16^{xxx}	0.15^{xxx}
b) Variance of yields (Eq. (7))		
Intercept	15.4379 (4.91)***	18.1902 (5.27)***
$D^{0.5}$	−3.9829 (−1.76)*	−9.52 (−2.64)***
R^2_{adj} (and F-test)	0.02^{xxx}	0.02^{xxx}

Numbers in parentheses are t-values. * and *** denote significance levels at the 10% and 1% level, respectively. ^{xxx} denotes that the null hypothesis, i.e., the explanatory variables do not explain variation in dependent variables could be rejected by the F-test at the 1% level. $D^{0.5}$ indicates the square root of the diversity index used (either Shannon or Simpson index). R^2_{adj} is the adjusted coefficient of determination. Note that plot location and year of the experiment have been accounted for using dummy variables (coefficients not shown), df = 1436.

Based on these econometric results, they can then show the insurance value of higher diversity as the reduction in the risk premium as diversity increases:

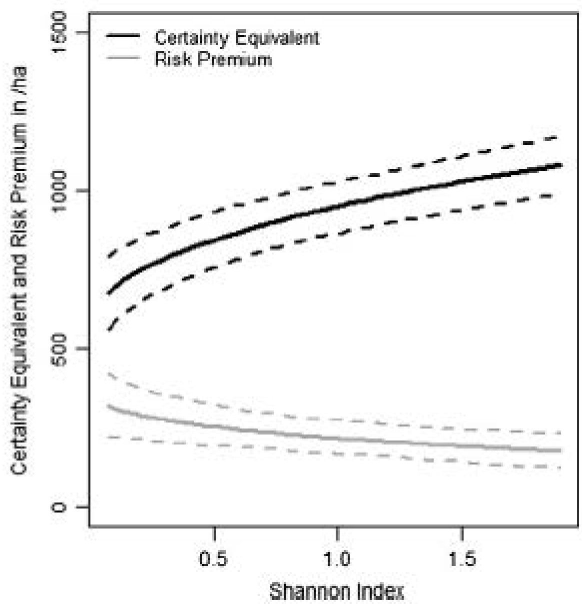


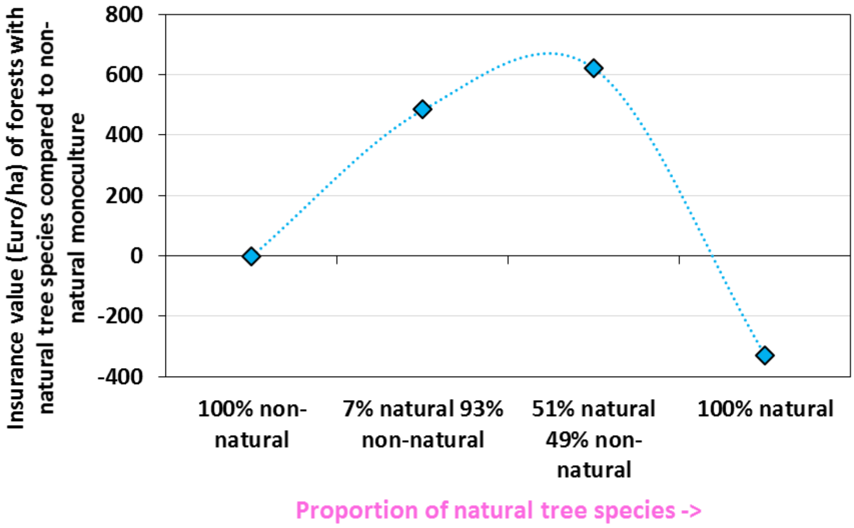
Fig. 1. Certainty equivalents and risk premium in relation to realized species diversity expressed with the Shannon index. Dotted lines represent 95% confidence intervals derived from non-parametric bootstrap.

Finger and Buchmann (2015) also note that other ecosystem service benefits will arise from higher diversity (such as pollination and prevention of nutrient leaching), not just higher yields.

Paul et al. (2019) use the same data as in Griess and Knoke (2013) along with the analytical framework of Finger and Buchmann, to estimate the insurance value of higher tree species diversity in German forests. This insurance value is the reduction in income risks to people (not the increase in expected returns). As noted above, measuring an insurance value in this way requires us to know two things:

- The biophysical/ecological effects of higher diversity on the chance or good or bad outcomes occurring in the future, and
- A measure of risk preferences of "the relevant population".

Using a functional form of utility which is increasing at a decreasing rate in income, they generate the following result:



Note: "100% non-natural" is 100% Norway spruce. The "natural" species is European beech.

At low levels of diversity, increasing diversity results in a positive insurance value of biodiversity, which is increasing up to around a 50% species mix. However, at very high levels, the fall in expected returns is such that a higher risk premium would be demanded by forest owners to invest in compared to a 100% spruce forest, since there is a high chance the forest will generate a negative commercial return.

Effects of diversity on resilience

We are only aware of two papers which empirically measure the economic value of changes in resilience of a natural capital system. These are Walker et al. (2010) – which does not focus on biodiversity – and Matsushita et al. (2018).

As Walker et al. (2010) state, the key question should always be "resilience of what, to what?" In their empirical application, they study the resilience of agricultural output over time in the Goulburn-Broken catchment (Australia) to changes in the water table, since a rising water table affects soil salinity and thus farm output. They identify two regimes for the system (soils salinized, soils not salinized), defined as whether the water table is higher or lower than a threshold value of 2 metres. The water table is viewed as a "slow changing variable" which determines the value of the natural capital asset "farmland soils". The regimes vary greatly in terms of agricultural productivity, so that the switch between regimes can be described as discontinuous. Moving back from the less desirable to the more desirable regime has much higher costs than preventing a switch from the desirable to the less desirable regime (hysteresis). As the water table rises, the resilience of the system falls as the threat of a sudden transition to the least desirable regime is increased – saline soils being much less use for farming.

The shadow price they wish to estimate shows this change in risk in terms of the (i) likelihood of transition to an undesirable regime and (ii) the discounted loss of farm incomes in the undesirable regime relative to the more desirable regime. Their "stock of resilience", X, is defined as the current distance of the water table from a threshold value of 2m below the soil surface. The economic value of this stock of resilience is part of inclusive wealth. They estimate a transition probability curve from the more desirable to less desirable regime which is a function of X. To get a measure of (ii), they need to estimate social welfare (here, farm profits) in the two regimes. For 2001, dairy profits are $448/ha in the more desirable state, and $44/ha in the less desirable state. For crops, the figures are $723/ha and $7/ha.

Their analysis shows that the change in the water table over the period 1991-2001 leads to a fall in inclusive wealth of $22million, equal to 7% of inclusive wealth under "normal" climatic conditions.

The Walker et al. (2010) paper is important because it provides the first example of an estimate of the economic value of changes in resilience, in a manner consistent with inclusive wealth measures of sustainable development. However, whilst they discuss how changes in native vegetation could be added to the empirical model as a second underlying "slow changing variable", they do not actually do this. So whilst their work is very relevant for the thinking about how forest biodiversity could be quantified in terms of its contribution to system resilience, it does not provide an example of how to do this.

The only empirical paper which includes a measure of biodiversity as a determinant of resilience and then estimates a value for this is Matsushita et al. (2018). The authors use the conceptual approach of Baumgartner and Strunz (2014) to estimate the value of resilience of low-intensity crop production in Japan with respect to populations of wild insect pollinators and the habitats which support them. Their Figure 4 shows how increasing abundance of two types of insect pollinator affect yields.

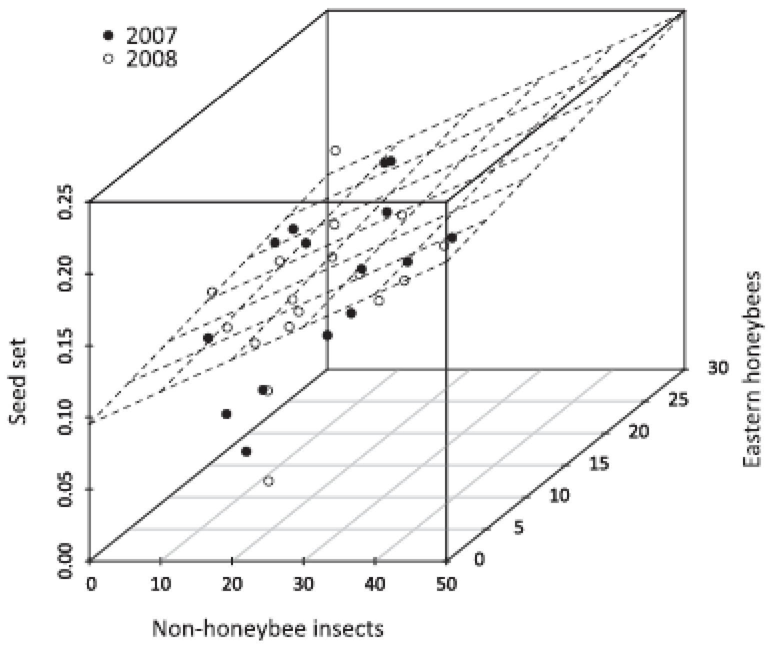


Figure 4. Wild pollinator abundance and seed set ratios in buckwheat production

The authors then identify likely threshold effects of (i) falling habitat on the populations of wild insect pollinators and of (ii) agricultural output (here, buckwheat yields) with respect to the supply of pollination services. They estimate an empirical model which tests for and establishes such threshold effects, and which quantifies how the chance of pollinator collapse is related to the remaining area of forest habitat. They show that as the forest area declines, the probability of a flip to a new regime increases (see below, their Figure 5).

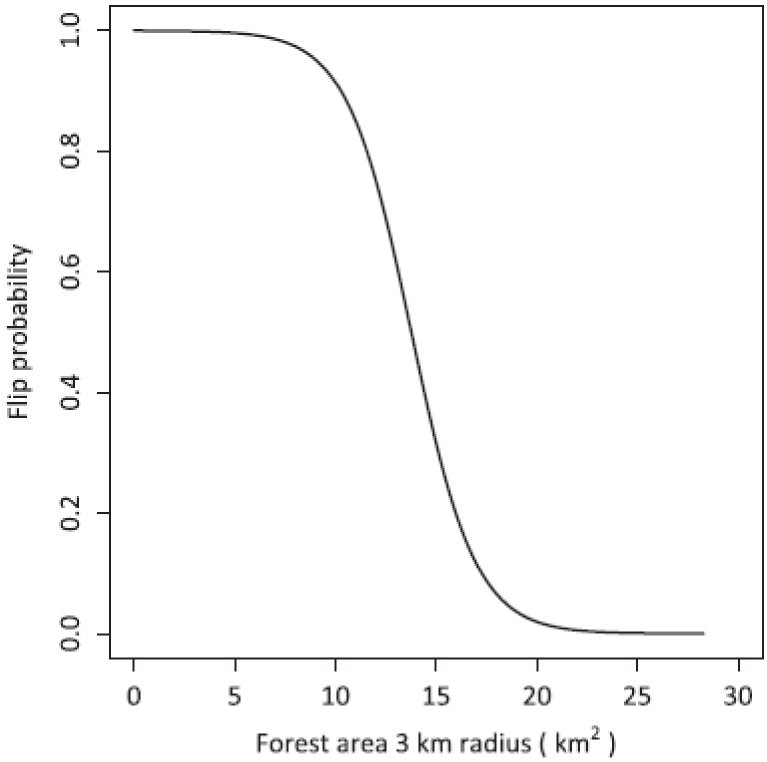


Figure 5. Flip probability of the ecosystems from a high-production regime to a low-production regime

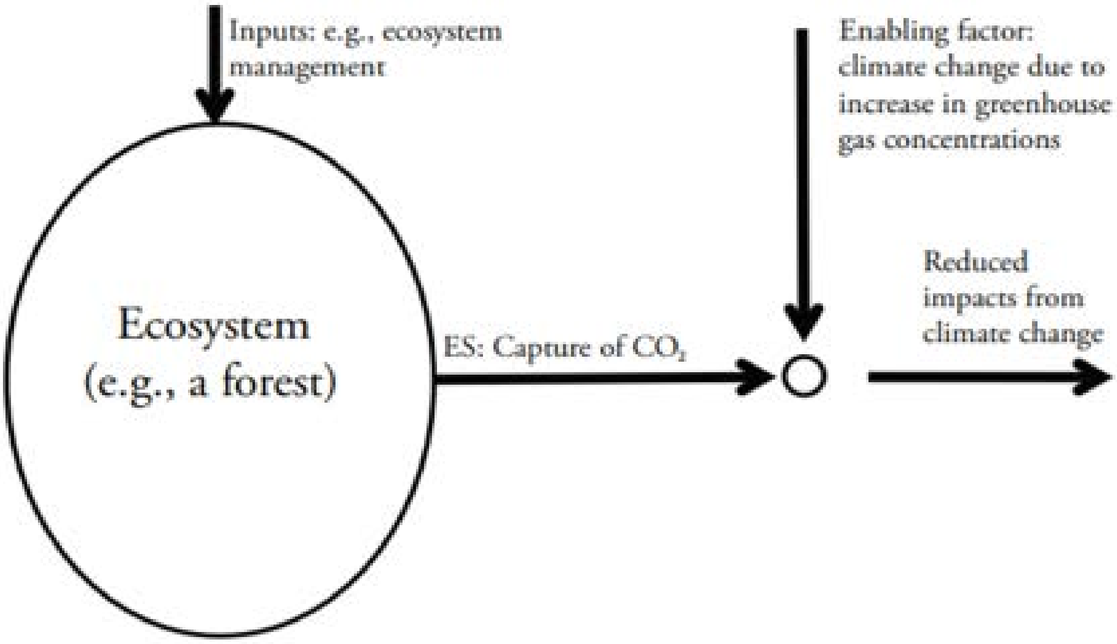
As required in this approach, the authors then have to specify a utility function to represent social welfare which includes risk aversion; and then estimate how the change in farm income under two regimes (no collapse, collapse) affects utility. Their main conclusion is that the shadow value of resilience is around half of the total value of the natural capital stock of the study system, at $531 per km 2 of forest land. As the authors state: *"..this finding indicates the importance of incorporating resilience values into the natural capital account".*

Annex 2: Logic chain examples

This annex presents examples of logic chains presented in SEEA-EEA (System of Environmental-Economic Accounting Experimental Ecosystem Accounts) (2014), King et al. (2019), eftec (2015), Binner et al. (2017) along with examples of the impact pathway approach (Defra, 2007), and pressure-state-response model (OCED, 2003).

The SEEA EEA (United Nations et al. 2014) framework considers the stock of ecosystem assets and the flows of ecosystem services through the use of chain models. Figure A.1 shows how a management intervention will affect an ecosystem asset, in turn impacting the level of sequestration of carbon, resulting in an impact on climate change. Reduced impacts from climate change provide economic benefits to society through avoided damages now and in the future.

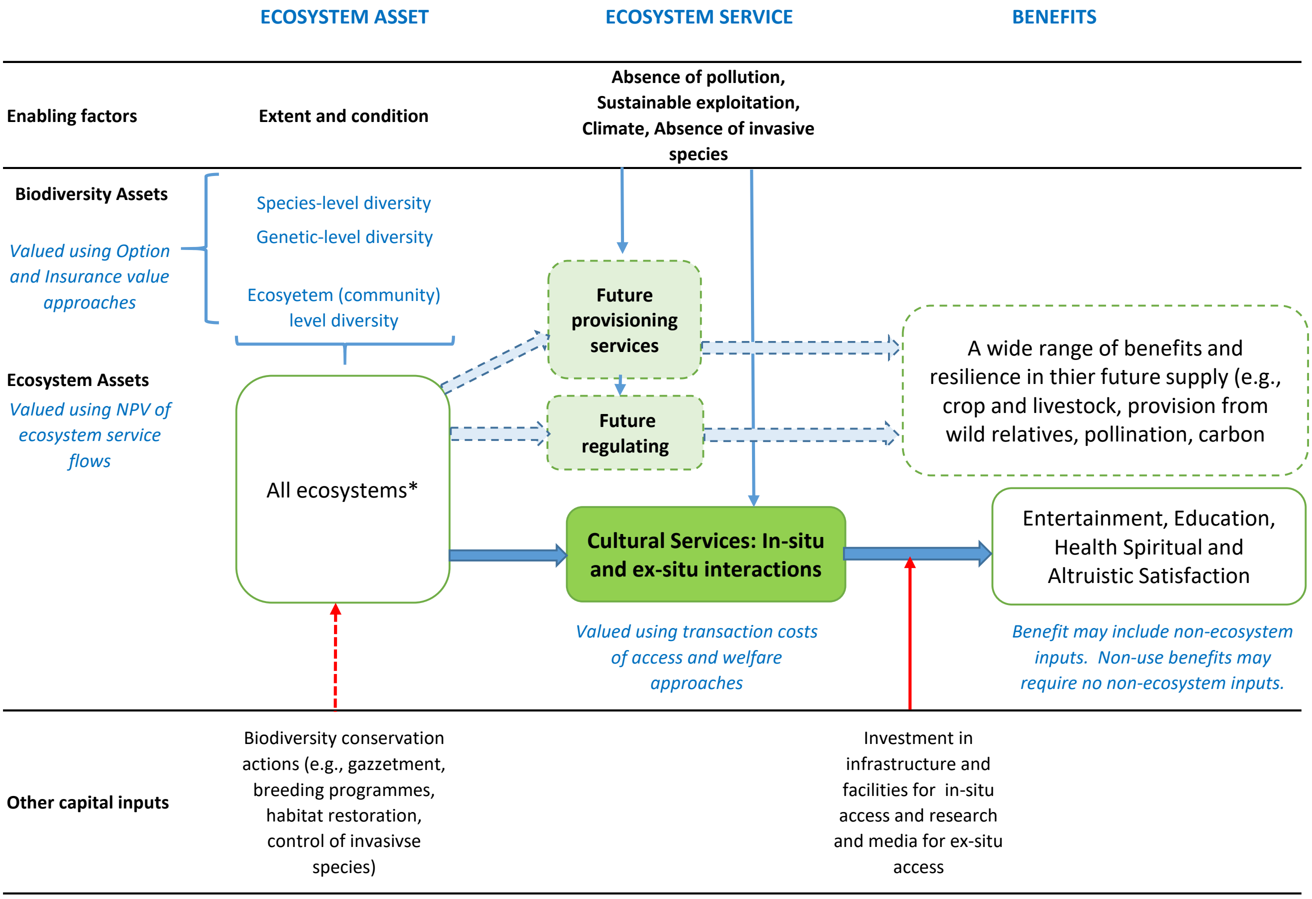
Figure A.1: Logic chain from SEEA EEA, 2014



King et al. (n.d.) adapt the SEEA EEA (2014) logic chain to consider biodiversity and habitat related cultural ecosystem services.

Figure A.2 shows how biodiversity assets (species diversity, genetic diversity and ecosystem diversity) impact the condition of the ecosystem assets subsequently affecting various cultural ecosystem services which in turn provide benefits to society in terms of entertainment or education. Additionally, the figure shows biodiversity as an asset that maintains capacity for future ecosystem service provision. For example, the ecosystem asset might not provide current services, but could be needed for the same services, or potentially new services, in the future. Consistent with Figure A.1, other capital inputs are required along the chain, from control of invasive species influence ecosystem assets to infrastructure requirements enabling ecosystem services to generate benefits.

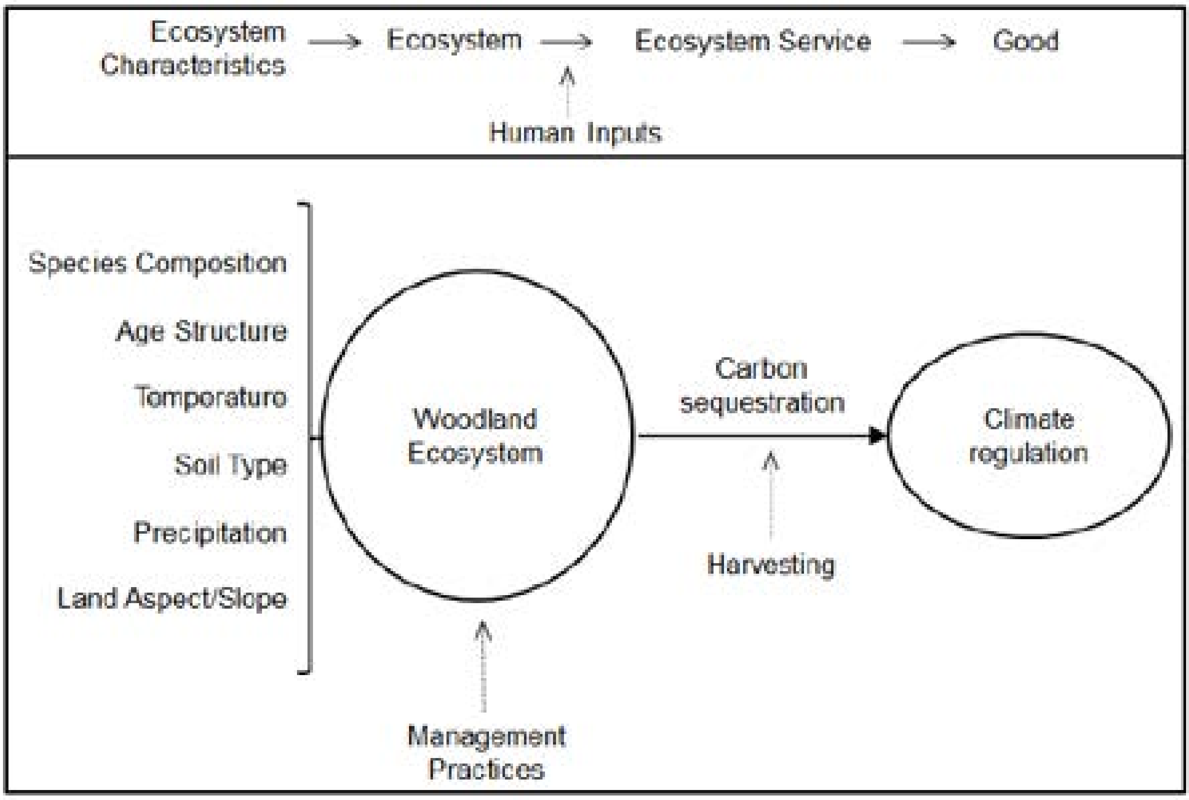
Figure A.2: Logic chain from King et al, unpublished



Notes: *There exists an important trade-off to consider in the management of biodiversity for current versus future ecosystem services supply.

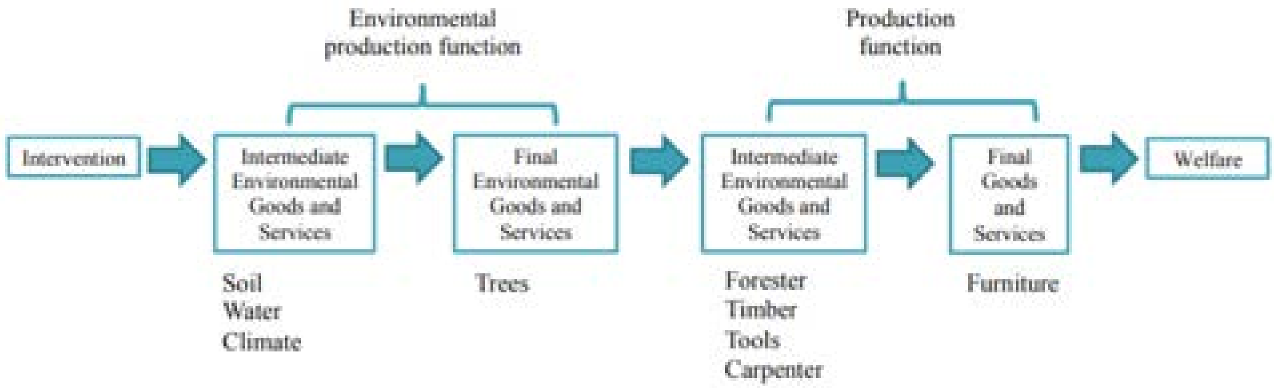
In a similar manner to SEEA-EEA and King et al., eftec (2015) uses a logic chain approach as the basis for disaggregated woodland ecosystem accounts. Figure A.3 sets out a logic chain for climate regulation from a woodland ecosystem asset. It shows the pathway by which ecosystem characteristics and ecosystem assets determine the potential to sequester carbon and thus generate benefits for society. The logic chain begins with 'ecosystem characteristics', which represent the primary abiotic and biotic factors that describe the ecosystem and determine the provision of ecosystem services. For climate regulation, the species composition, age structure and soil type are all important characteristics that affect the provision of the good. The approach requires a combination of an ecosystem asset and management practices and other capital inputs, such as harvesting, in order to benefit society through climate regulation from the provision of a final ecosystem service, i.e. carbon sequestration.

Figure A.3: Logic chain from eftec, 2015



Binner et al. (2017) adopts the ecosystem service approach to recognise the role of nature in human wellbeing. The form of logic chain in this approach combines environmental production functions and economic production function and recognises human welfare comprises of natural capital assets and other capitals. For example, the quality and quality of trees are dependent on the underlying condition of the natural capital assets. These environmental factors impact the final goods and services provided by the woodland, e.g. furniture, and ultimately affecting human welfare. Figure A.4 illustrates how a management intervention impacts an environmental production function, impacting a production function, ultimately effecting human welfare.

Figure A.4: Production function logic chain from Binner et al. (2017)

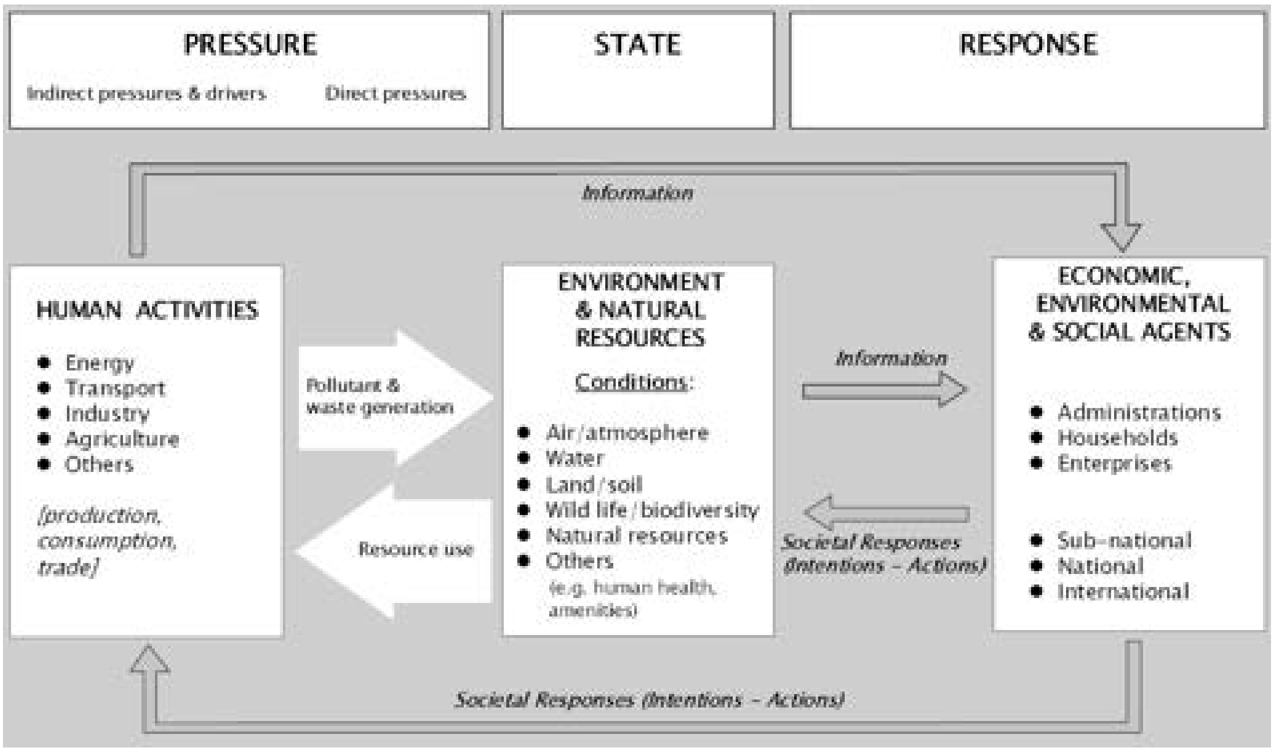


Defra (2007) sets out the impact pathway approach to value ecosystem services in a policy appraisal context. Figure A.5 illustrates how a policy change will affect human welfare through changes in ecosystems and ecosystem services. For example, a policy change in pollutant emissions restrictions will impact ecosystems through a change in pollutant concentrations, causing a change to species composition which can impact human welfare through altering aesthetic benefits, for example.

Figure A.5: Impact pathway approach from Defra (2007)

The OECD developed the pressure-state-response model for assessments of environmental policies. The model (Figure A.4) shows how human activities put pressure on natural resources through changes in the condition of these the natural resources; i.e. altering the state of the environment. The societal response subsequently is to change their behaviour to reduce the pressure on the natural resources. Society can response through changes to environmental programmes and/or policies, which will hopefully mitigate the pressure on natural resource.

Figure A.4: Pressure state response model from OECD (2003)



Annex 3: Valuation methods

Options for valuing the contribution of biodiversity

An extend version of the 'reference card' that breaks down how biodiversity values can be captured across different valuation methods and ecosystem service provision categories is provided in Figure A.7. It provides more detailed mapping out the relevant dimensions and fuller range of valuation methods (see Appendix below). Largely the summary is aimed at benefits assessments that are needed for forest management decision contexts (i.e. woodland creation, operational management, plant health, biodiversity targets) but it is more widely applicable (e.g. demonstrating value) and the general principles for valuing biodiversity are not confined to forests and woodlands.

Additional notes for interpreting the Figure A.7 include:

- *Measure of economic value*: both producers and households derive value from biodiversity. The household value is realised through the consumption of final goods and services in terms of consumer surplus. This is measured in monetary terms by WTP and WTA for securing/avoiding changes in the provision of final goods. The producer value can be associated with either: (a) inputs to production; and/or (b) the consumption of final goods and services. The principle distinction is that (a) represents inputs into the production function of the firm, whilst (b) is relevant in terms of the ecosystem service provision benefits that – similar to households – firms may experience, e.g., the benefits of flood risk protection within a catchment. Monetary valuations for producers are measured in terms of changes in marginal revenue product or producer WTP.

- *The contribution of* biodiversity *to economic welfare*: the indirect value associated with biodiversity sits within the producer perspective, representing the role of biodiversity as an input to the production of a final good or service. This contribution can be valued in monetary terms in terms of the value of the change in output (and possibly price) that arises from a change in the biodiversity input. For the most part this is associated with market goods (i.e. producer marginal revenue product) but is also relevant to non-market outcomes.

- A distinction is also made between the indirect value that is revealed in the production function relationship, and the potential insurance value component for market goods associated with provisioning services. Whilst resilience value is an indirect contribution, it is not directly associated with the provision of a specific final good – it is concerned with the capacity of ecosystems to sustain ecological functions and processes in response to changes in environmental condition, which underpins all contributions to welfare (measured as "income" in most insurance research).

- The direct value contribution of biodiversity is a final good/service that features within household consumption.

Figure A.7: Options for valuing the contribution of biodiversity

		Producer surplus / production function (Producer WTP or marginal revenue product)									
							Consumer surplus / household utility (Household WTP / WTA)				
		Indirect contribution							Direct contribution		
		TEV	Marginal value Biodiversity = input to production of final good/service				Marginal value Final good/service (biodiversity value embedded)		TEV	Marginal value Biodiversity = final good/service	
E/S category	Final good/service category		Production Function	Method(s)	Insurance value	Method(s)	Final good/ service	Method(s)		Household utility	Method(s)
Provisioning	Timber products	UV_c	✓	PF	✓	**MP**	✓	**MP**; RP; SP	-	-	-
	Food (agriculture)	UV_c	✓	PF	✓	**MP**	✓	**MP**; RP; SP	-	-	-
	Food (wild foods)	-	-	-	-	-	-	-	UV_c	✓	RP; SP; *MP*
	Energy	UV_c	✓	PF	✓	**MP**	✓	**MP**; RP; SP			
	Pharmaceuticals	UV_c	✓	PF	-	-	✓	**MP**; RP; SP	-	-	-
Regulating	Water quality	UV_n/c	✓	PF	-	-	✓	RP; SP; C_d	-	-	-
	Flood alleviation	UV_n/c	✓	PF	-	-	✓	**C_d**; C_r; RP; SP	-	-	-
	Local climate (temperature regulation, shade)	UV_n/c	✓	PF	-	-	✓	RP; SP; *C_r*	-	-	-
	Air quality	UV_n/c	✓	PF	-	-	✓	C_d; C_t; C_p; RP; SP			
	Carbon sequestration	UV_n/c	✓	PF	-	-	✓	**C_d**; RP; SP	-	-	-
Cultural	Nature conservation (species, habitats)	-	-	-	-	-	-	-	NUV	✓	**SP**; *CD*
	Wildlife-based recreation	-	-	-	-	-	-	-	UV_n/c	✓	RP; SP; MP
	Recreation (general)	UV_n/c	✓	PF	-	-	✓	RP; SP; MP	-	-	-
	Health	UV_n/c	✓	PF	-	-	✓	*C_t* + C_p; RP; SP	-	-	-
	Learning, education and volunteering	UV_n/c	✓	PF	-	-	✓	RP; SP	-	-	-
	Artistic	UV_n/c	✓	PF	-	-	✓	RP; SP	-	-	-
	Cultural and spiritual	UV_n/c	✓	PF	-	-	✓	RP; SP	-	-	-

Notes

Component of TEV

UV_c	Consumptive use value
UV_n/c	Non-consumptive use value
NUV	Non-use value

Valuation methods

PF	Production function approach(es)
MP	Market prices
RP	Revealed preference
SP	Stated preference
C_d	(Avoided) damage cost
C_r	Replacement cost
C_t	Treatment cost
C_p	Productivity cost (labour)
CD	Charitable donations

Valuation hierarchy

Bold	Primary method
Italic	Proxy approach for intended measure of value

Benefits assessment

- Monetary valuation (bright green)
- Qualitative assessment (pale green)

Appendix: summary of valuation methods

Type and methods	Description	Suitability for valuing biodiversity
Market-based information Market prices Production function approach	Values based on market prices need to be 'corrected' for distortions such as taxes and subsidies in order to reflect opportunity costs. Market prices are rarely equal to economic values since they do not include consumer surplus. Production function approaches relate changes in output (and the value) of marketed products to changes in productive input.	Market-based approaches capture the extent to which biodiversity supports current flows and values for market goods. They also provide the basis for assessing insurance values for provisioning services. Price premiums on some "green" products (e.g. Forest Stewardship Council (FSC) products) could reflect non-use values for conservation.
Revealed preference methods Travel cost Hedonic pricing Averting behaviour	Methods based on values for environmental goods and services that are 'revealed' by behaviour in associated (surrogate) markets.	Applicable to use values for recreation, including wildlife-based activities that are directly associated with biodiversity, and potentially aesthetic values. Methods cannot value non-use component of TEV. Some approaches (e.g. discrete choice model) can split out value of biodiversity as an attribute of a final good.
Stated preference methods Contingent valuation Discrete choice experiments	Survey-based methods in which individuals express preferences in simulated markets or choices about alternative states of the world.	Applicable to any good or service, including biodiversity, and capable of capturing non-use values as well as values of users and non-users.
Cost-based methods Avoided costs Replacement/restoration costs Treatment cost Productivity cost (labour)	Mix of methods and approaches that reflect different resource costs associated with ecosystem service provision. This includes cost incurred/avoided due to deteriorated environmental quality. In many cases cost-based methods represent a lower bound estimate as they do not include welfare impacts (consumer surplus), and/or a proxy – i.e. the costs that would be incurred to replace or restore the asset as a proxy for the loss of welfare.	Not welfare-based measures of value. Widely applicable to restoration of ecosystems and potentially where targets for conservation and restoration exist. Potential risk of partial double-counting if these are combined with values of services supported by the systems.
Charitable donations	A quasi-market value based on observed behaviour.	Provides a possible (limited) proxy for non-use value for specific issues/themes, but typically difficult to ascribe to a specific management action or policy intervention (i.e. it mainly reflects preferences for charitable theme or issue in general).
Value transfer Unit value transfer Function transfer Meta-analysis	Not a valuation method, but a means of allowing existing value evidence to be applied to new cases, with more or less sophisticated adjustments, avoiding the cost and time required for primary valuation studies.	Applicable but dependent on availability of suitable source studies from one or more of the above categories.

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