Forest Research

Research Note

Scenario analysis: exploring future woodland use and ecosystem benefits

Darren Moseley, Vanessa Burton, Louise Sing, Stephen Bathgate July 2022

Land use change has been one of the major influences on UK forests and wooded landscapes for many years, and is likely to be affected by climate change and human population pressure. This presents a challenge for the long-term planning and management of woodlands to provide the range of goods and benefits (ecosystem services) society requires. After introducing the different types of scenario, this Research Note uses three case studies to illustrate how scenario analysis can be used to investigate potential future changes and support better informed and rational decision-making. Case study one shows how scenarios have been developed for woodland expansion by incorporating visions into an agent-based model. Multi-scale application of the UK National Ecosystem Assessment is explored in case study two, where six indicators were used to compare the provision of forest ecosystem services. Case study three illustrates how exploratory scenarios can be co-developed with stakeholders to inform land management plans, in this case adopting a conifer species diversification approach based on ecological suitability. The limitations of scenarios regarding land-use planning are discussed, such as their lack of applicability in all circumstances, thus necessitating a zoning approach, or the difficulty in down-scaling national policies to the regional scale, which can be overcome by adopting a multi-scale approach. The Note concludes that scenario analyses can support decision- and policy-making processes in different contexts, and, when combined with participatory modelling, provide a means for stakeholders to increase their identification of management interventions and sustainable outcomes.

Introduction

Scenarios have been described as imagined but plausible futures with different drivers of change (Pinnegar *et al.*, 2006). They are often depicted with a storyline that describes how various driving forces may affect a starting point along a period of time. Traditionally, scenarios were applied within business and organisational management, but more recently the benefit of their use has been recognised within environmental and, in particular, global assessments (e.g. Audsley *et al.*, 2006; O'Neill *et al.*, 2008). There are different types of scenarios, with some overlapping elements. In this Research Note, we focus on:

- exploratory scenarios, which describe how the systems develop over a particular period (i.e. the time horizon);
- anticipatory (also termed normative) scenarios, which are often depicted as a 'vision' of a positive and desired future (Rounsevell and Metzger, 2010).

Exploratory scenarios are useful for understanding how systems interact, what changes may occur in the future and how robust current systems are against these changes. Anticipatory scenarios (or visions) aim to provide a description of how to achieve a desired future. Scenarios can be either qualitative (descriptive) or quantitative (and may use modelling to simulate change).

The development of scenarios is usually an iterative process, beginning by defining the base year (usually the present) and the time span of the scenarios, and identifying the driving forces that may affect the future. In producing scenarios, driving forces with high impact and high uncertainty are often considered, using a matrix that maximises spread within a plausible environment (Van der Heijden, 2004). Where two main drivers are used, this creates two axes, and the matrix is then used to characterise four worlds, creating storylines that illustrate how an end state is reached, through events, based on cause-and-effect logic. Several global, European and UK exploratory scenarios use this 'two axis' model to create four storylines representing a free-market model, a national security (NS) model, a sustainable (or green vision) model and a local stewardship model (Haines-Young *et al.*, 2011). The UK National Ecosystem Assessment (UK NEA) developed two further storylines to reflect a focus on ecosystem services delivery (Nature@Work) and a continuation of current policies (Go with the flow) (Haines-Young *et al.*, 2011).

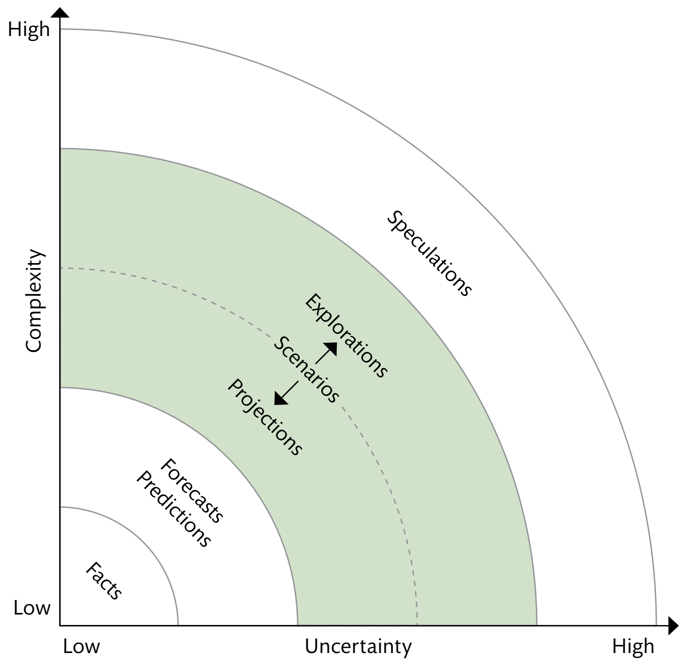
Aims

The aim of this research note is to provide an introduction to scenarios, highlighting their usefulness but also their limitations in exploring policy directions and land use planning. Using examples from case studies we describe: 1. how scenarios and visions are developed; 2. their expression through the multi-scale application of the UK NEA scenarios; 3. co-development of scenarios to inform forest planning.

How can scenarios be used?

Scenarios are not devices that forecast the future; rather, they are used to investigate potential future changes (Figure 1). In the context of ecosystem services (i.e. goods and benefits from ecosystems), scenarios can be used to assess the future implications of current environmental pressures or policies and to explore uncertain aspects of the future. By offering insight into uncertainties and the consequences of current and possible future actions, scenarios support more informed and rational decision-making in situations of uncertainty (Millennium Ecosystem Assessment, 2005). They can also be employed to assess the impact and raise awareness of future problems; for example: the threat to biodiversity from climate change; to illustrate the need for policies to address changes; to examine how robust current environmental policies are; and to combine quantitative and qualitative information to illustrate how environmental problems may unfold. At an operational scale they can be used to assess the outcome of different management approaches on the provision of ecosystem services; for example, the planting of non-wooded land, change of woodland type, provision of recreational facilities and the removal of trees on peatland.

Figure 1 Scenarios within gradients of complexity and uncertainty.



Source: Zurek and Henrichs (2007).

Case Studies

Three case studies are presented to illustrate how scenarios and visions can be co-developed with stakeholders, applied to existing models, or developed in a web-based application to help to inform planning of future forests.

Case study 1 – Developing visions for woodland expansion

The term 'woodland expansion' can mean different things to different people. To ensure that different visions were captured, organisations with a strong interest in or influence on forestry and woodland expansion in Scotland were selected, and their stated aims or visions for woodlands and forestry were analysed (Burton *et al.*, 2019). Using published content from these organisations and arranging it into themes in a two-by-two matrix, five visions (normative scenarios) for woodland expansion were developed (Figure 2). These were based on four key elements: utility to conservation on the horizontal axis, and land sharing (integrating conservation and production on the same land) to land sparing (separating conservation and production) on the vertical. The visions were discussed with stakeholders to confirm their saliency, credibility and legitimacy, and a narrative was developed to describe how each could potentially unfold over the timeline (2020 to 2100).

The visions were incorporated into an agent-based model (ABM) (Figure 3) to explore how the decision-making of a typology of land managers (agents) influences the provision of ecosystem services under each vision, and how these visions contribute towards woodland expansion goals. Key behavioural aspects explored were land managers 'willingness to diversify', or the extent to which traditional and sporting estate managers were prepared to introduce changes to their main form of land use.

Two of the visions (Green gold and Woodland culture) achieved the Scottish Government's targets of increasing woodland cover to 21% by 2032 and to 25% by 2050, irrespective of land managers willingness to diversify (Figure 4). Where traditional and sporting estate land managers were more willing to diversify land use, Wild woodlands met both targets. This enabled an exploration of how alternative woodland futures, based on different stakeholder objectives, may affect the likelihood of achieving land use targets. Other modelling outputs revealed the synergies and trade-offs between different ecosystem services, and whether novel governance mechanisms simulated within different visions could influence land manager behaviour. Modelling approaches of this kind, which combine spatially explicit data with processes and governance of the land use system, are currently underutilised, but they can be valuable decision support tools when built upon.

Figure 2 The two-by-two matrix used to develop the five woodland visions and descriptions of each vision.

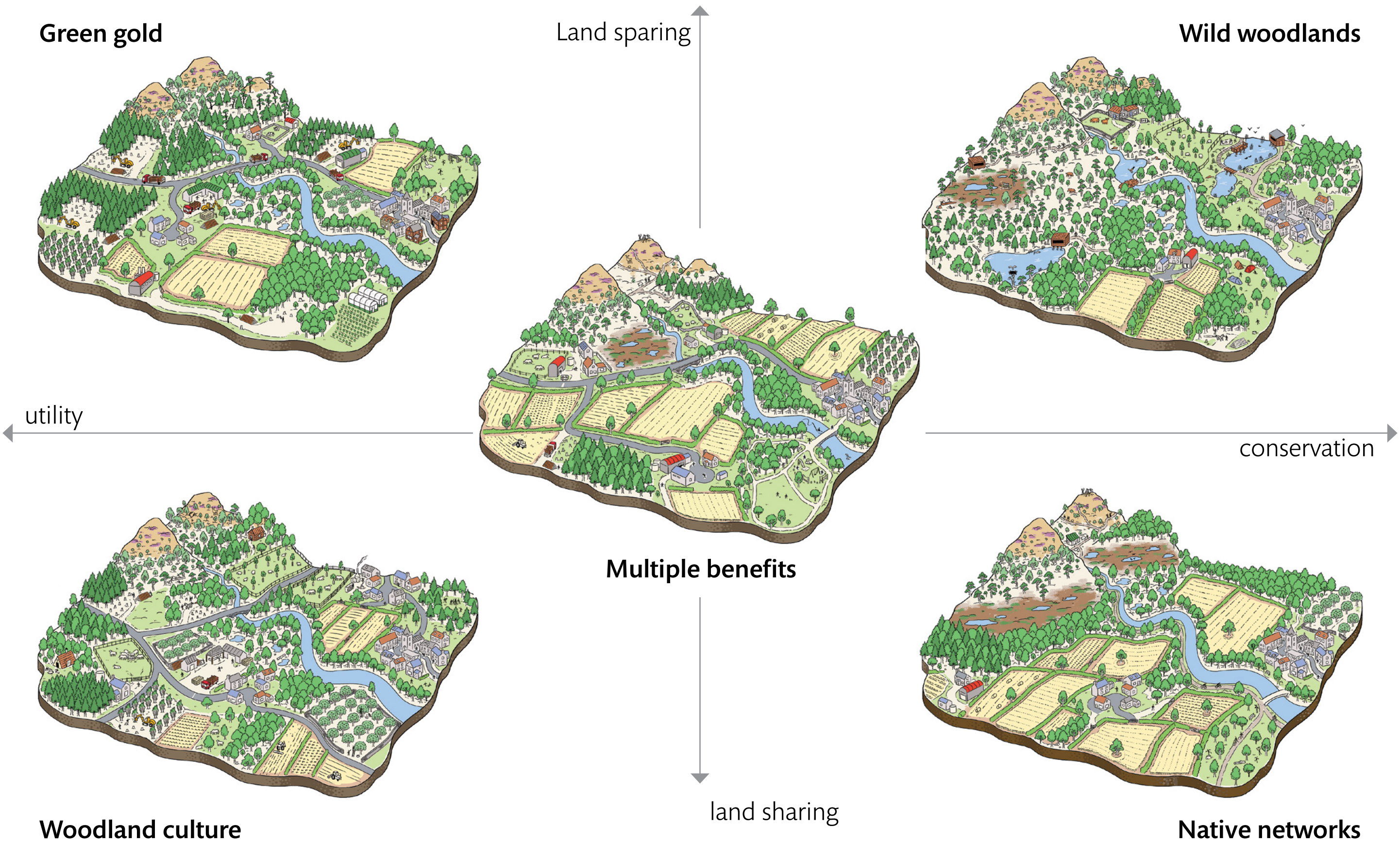
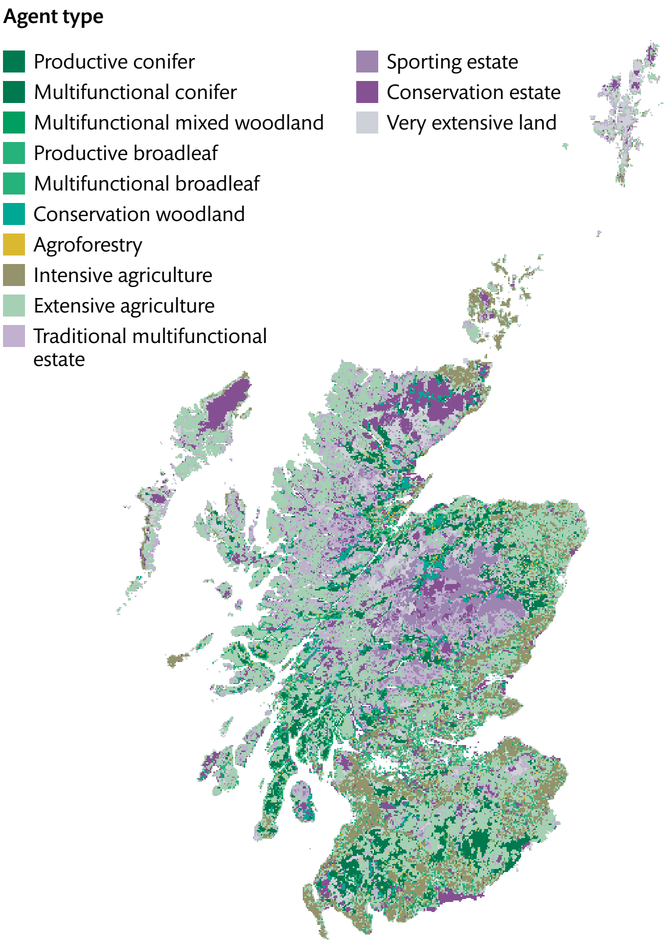


Figure 2 Continued.

Vision	Description
Green gold	Large scale productive, sustainable plantations adhering to high environmental standards are an integral part of Scottish land use and the national economy. High value timber plantations (e.g. non-native conifers), are designed with areas of native species, riparian buffers and open spaces. The carbon stored in forests and forest products are highly valued.
Multiple benefits	Sustainably managed trees and woodlands complement a diverse mix of land uses at the landscape scale, from conifer plantations for timber to riparian woodland for water regulation and native woodland prioritising biodiversity. Farmers and land owners manage agricultural land alongside forestry within their portfolio.
Native networks	Native and semi-natural woodlands are protected, restored and reconnected at all scales, enabling integration with other land uses and avoiding fragmentation of important open ground habitats. Natural regeneration is encouraged, and woodland networks play a valuable role in facilitating species movement, developing climate change resilience, and providing sustainable green travel routes for recreation.
Woodland culture	A well-forested and productive landscape, which encompasses small-scale diversity of tree species, woodland type and tenure. Communities are empowered and many manage local woodlands, with local people making their living from woodlands in a wide variety of ways. All woodland types are potentially productive, and small-scale processing technology is widely accessible, supporting local timber, woodfuel and non-timber forest product markets.
Wild woodlands	Larger areas of land are given over to natural processes, with widespread naturally regenerating native woodland being a key indicator of dynamic, biodiversity rich wild land. Productive forestry comprises native species (e.g. Scots pine), managed under continuous cover approaches. Natural transitions between land uses are encouraged and biodiversity is restored, including native species reintroductions.

Source: Burton *et al*. (2019).

Figure 3 The initial locations of all agent types, based on land use, land ownership and designations across Scotland.



Source: Burton *et al*. (n.d).

Figure 4 Changes in percentage woodland cover in Scotland from 2020 to 2100 for each of the five visions.

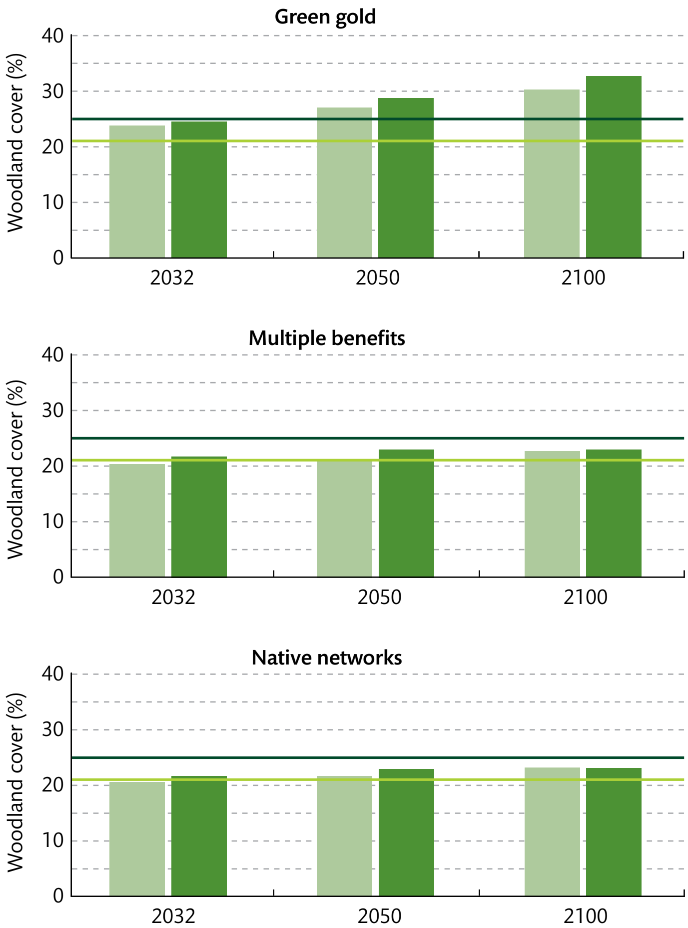
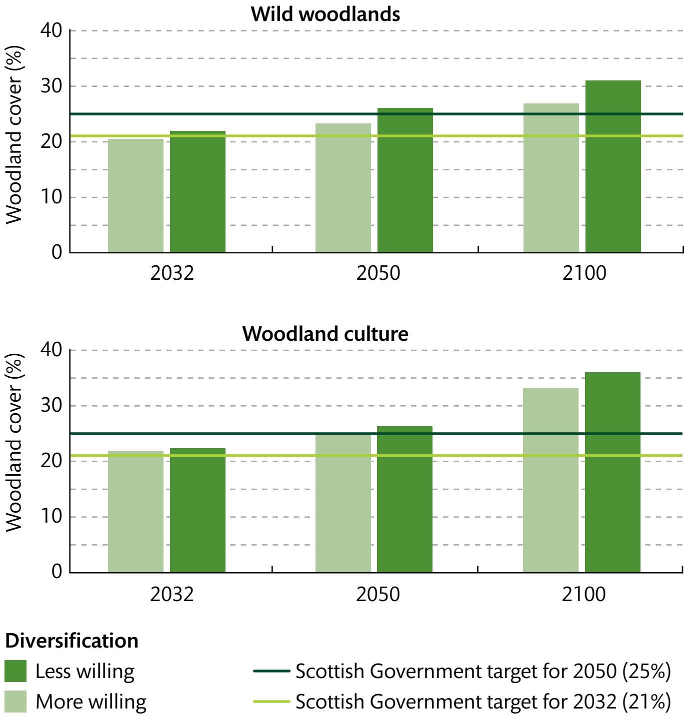


Figure 4 Continued.

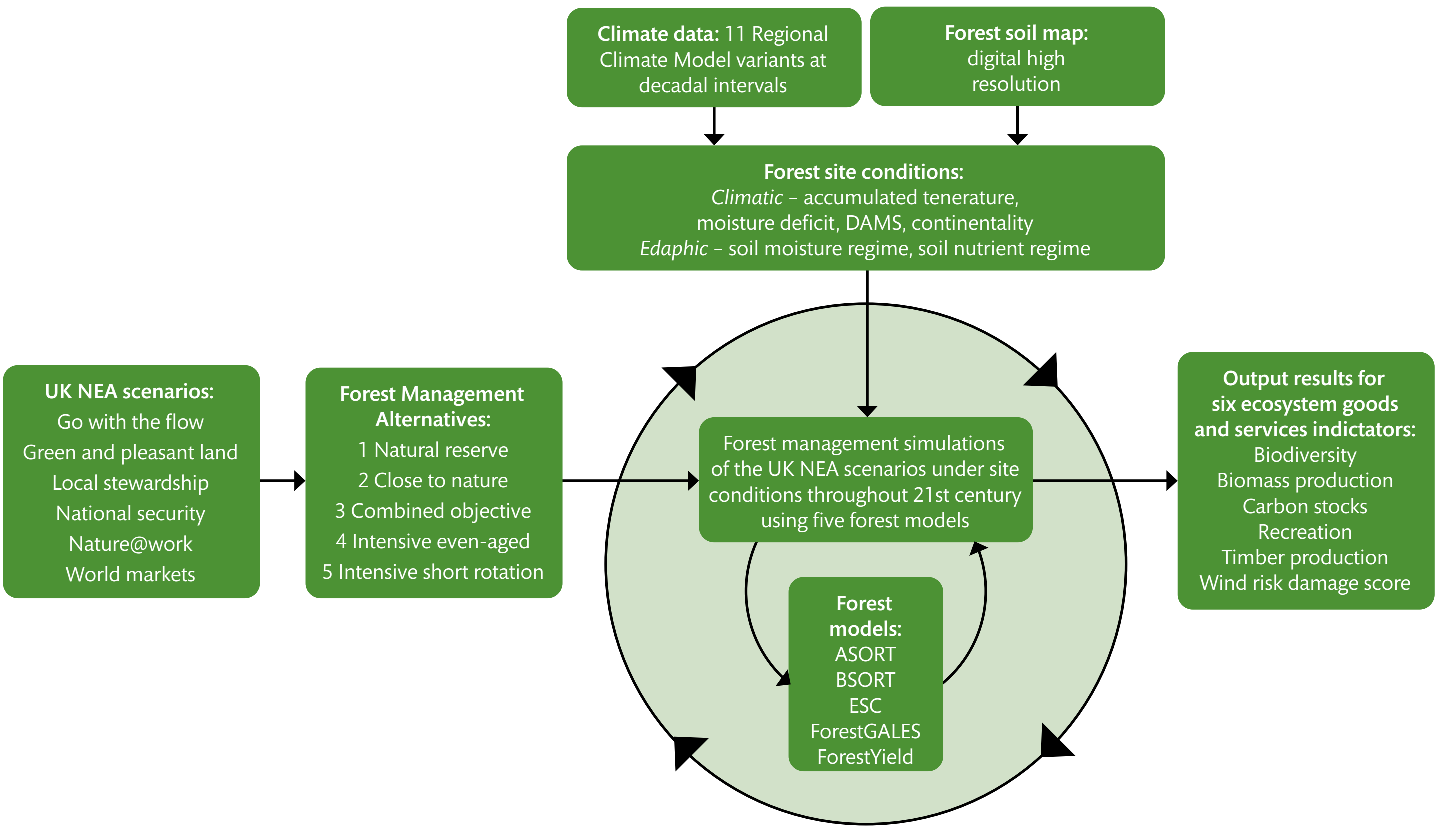


Note: 'Less willing' means that traditional and sporting land managers were more likely to continue managing for their main objectives (e.g. agriculture, grazing and sporting activities). 'More willing' means that managers were more likely to switch to other land uses (e.g. woodland) where suitable.
Source: Burton *et al.* (n.d.).

Case study 2 – Multi-scale application of the UK NEA scenarios

Quantitative data were used to explore the application of the UK NEA scenarios across the national Forestry and Land Scotland (FLS) estate (Figure 5, Table 1). The analysis incorporated a number of assumptions on the timing and type of management interventions that may not reflect contemporary FLS practice. The aim here was to investigate how forests may change over long time periods as forest planning usually considers periods of around 20 years. This longer time period enables multiple rotations (the period between the establishment and felling of a forest stand) to occur and the consequences of changes such as restructuring to be expressed. For each scenario, a modelling approach was used to compare the provision of ecosystem services under different climate change projections (Ray et al., 2014). Forest management alternatives (FMAs) (Duncker *et al.*, 2012), which ranged from low (FMA1, natural reserve) to high (FMA5, short rotation forestry) management intensity, were applied to the six UK NEA scenarios, which were then expressed in a model that simulates forest planning and management changes over time and under climate change uncertainty (represented by different climate projections). Six indicators were used to

Figure 5 Five dynamically coupled UK forest models (ESC, ForestGALES, ForestYield, ASORT and BSORT) used to simulate plantation forest planning, management, thinning and felling.



Abbreviations: ASORT, timber assortment; BSORT, biomass; ESC, ecological site classification decision support system; DAMS, detailed aspect method of scoring wind exposure; ForestGALES, wind damage risk decision support system; Forest Yield, yield model for forest management in Britain; UK NEA, UK National Ecosystem Assessment.
Note: outputs are transformed to a set of six indicator variables: biodiversity, biomass production, carbon stocks, recreation, timber production and wind risk damage score.

Table 1 An overview of the six UK NEA scenarios and their relevance to UK policy.

UK NEA scenario	Overview of scenario	Policy match/relevance
GPL	Focus on conservation and native species alongside increased public use of green spaces	Policies focusing on green infrastructure and biodiversity, particularly through increasing native tree species and rewilding
GWTF	Continuation of current policies	Continuation of current policies
LS	Counter-urbanisation and more efficient, sustainable use of resources	Crofting, localism and rewilding in some areas
N@W	Aim of maximising ecosystem services through a sustainable land management approach Perhaps the aim of many land managers	Most ecosystem services and natural capital agendas Mix of land sparing and land sharing to provide a balanced provision of ecosystem services
NS	National self-sufficiency in timber and biomass production	Protectionist policies to promote UK production Focus on land sparing (for production) rather than land sharing
WM	Lack of focus on home forestry leads to abandonment	Deregulated markets and little UK support, WTO terms

Abbreviations: GPL, Green and pleasant land; GWTF, Go with the flow; LS, local stewardship; N@W, Nature@work; NS, National security; UK NEA, UK National Ecosystem Assessment; WM, World markets; WTO, World Trade Organisation.

compare the provision of forest ecosystem goods and services from each scenario.

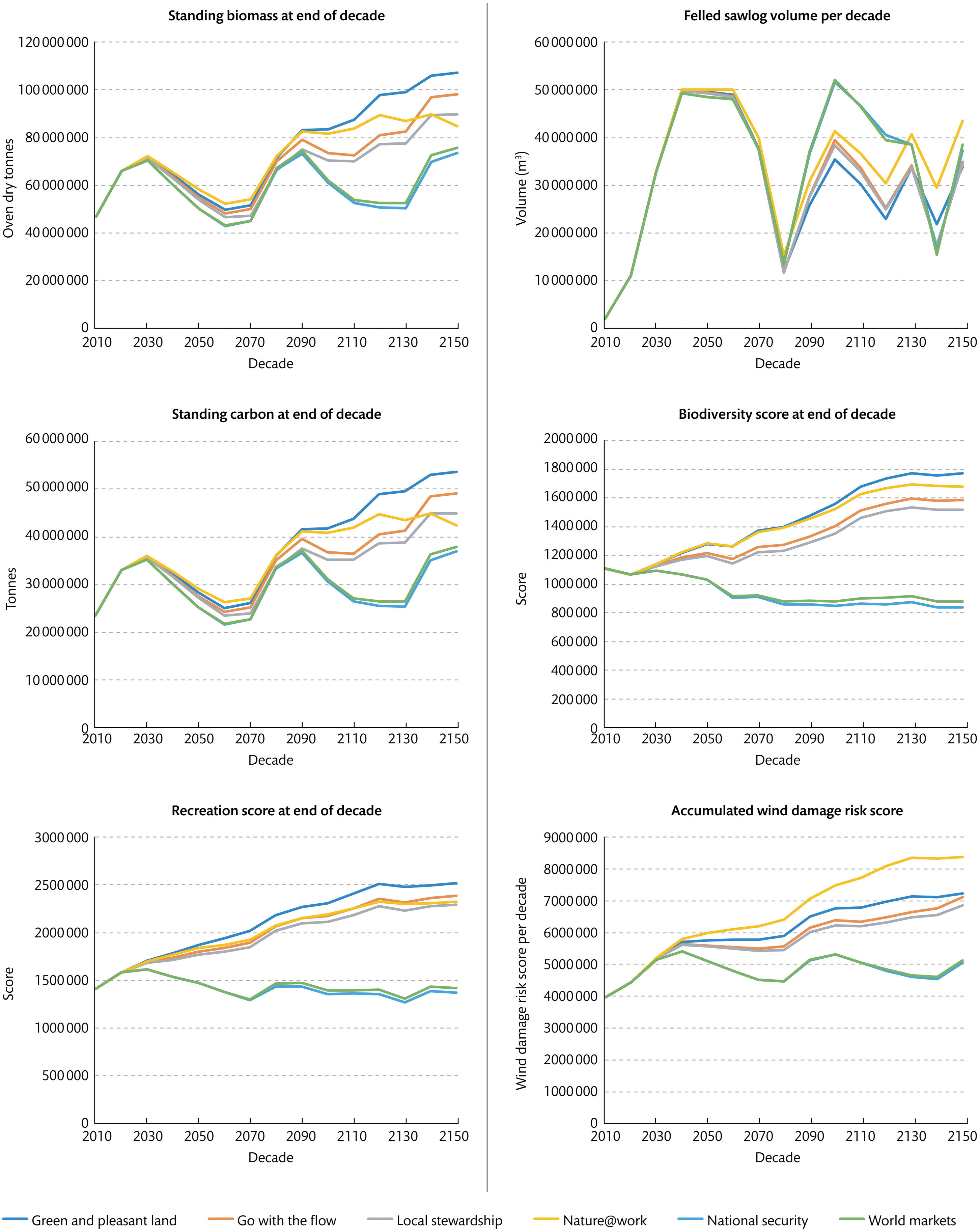
The results can be reported at national, regional and local scales to inform policy development, strategic planning and land management planning. Figure 6 shows the results of an analysis of Scotland's national forest and land estate for six ecosystem services indicators from 2010 to 2150. Starting from the same point, ecosystem services delivery begins to diverge as forests are restructured to follow the scenario narratives. Major divergence begins around 2030 for biodiversity, recreation and wind damage risk, where the stand composition and structure of all scenarios except national security (NS) and world markets (WM) sees large increases in broadleaved species managed under low intensity silvicultural systems. For other ecosystem services, the scenarios diverge around 2070 to 2080, reflecting changes to stand composition and structure, when many stands reach their felling age and are restocked with different species and managed according to a new FMA. Green and pleasant land (GPL) results in higher standing biomass and stocks of carbon than all the other scenarios because more trees are managed for long-term conservation. Nature@work (N@W) aims to deliver a broad range of ecosystem services and, as a result of producing more sawlogs than the other scenarios (except for NS and WM), there are lower quantities of standing biomass and carbon in the forests. It is important to note that carbon captured in harvested wood products, not captured in this analysis, will provide an additional contribution towards carbon net zero goals.

Case study 3 – Application of scenarios with stakeholders to inform land management plans

One application of exploratory scenarios involved working closely with a forest planner to assess how to achieve conifer species diversification for biodiversity and resilience objectives, while maintaining or accepting small reductions in timber production. This required the same modelling approach as used in case study 2, but instead of applying UK NEA scenarios, management trajectories (or management pathways) were defined by the forest planner. These consisted of conifer species diversification based on ecological suitability scored using ecological site classification (Pyatt, Ray and Fletcher, 2001) and two diversification approaches based on species achieving 80% and 90% yields of Sitka spruce (Figure 7).

The results show that, under a number of climate projections, the 80% yield/diversification trajectory (LDP80) has the best balance for meeting timber and species diversity objectives, because it is able to maintain business-as-usual timber production rates over the long term and increase or exceed species diversification goals. The 90% yield/diversification trajectory (LDP90) increases supply, but the opportunities for species diversification are limited to small areas. Species diversification increases under the conifer species trajectory (LDP), although timber production falls. This approach was useful in identifying species and indicating suitable sites within the forest's primary production area for the development of the next management plan and for assessing the overall impact in the future.

Figure 6 Changes to the six ecosystem services indicators across the national forest estate of Scotland, reported at 10-year intervals, for each of the six UK NEA scenarios under a combined future climate.

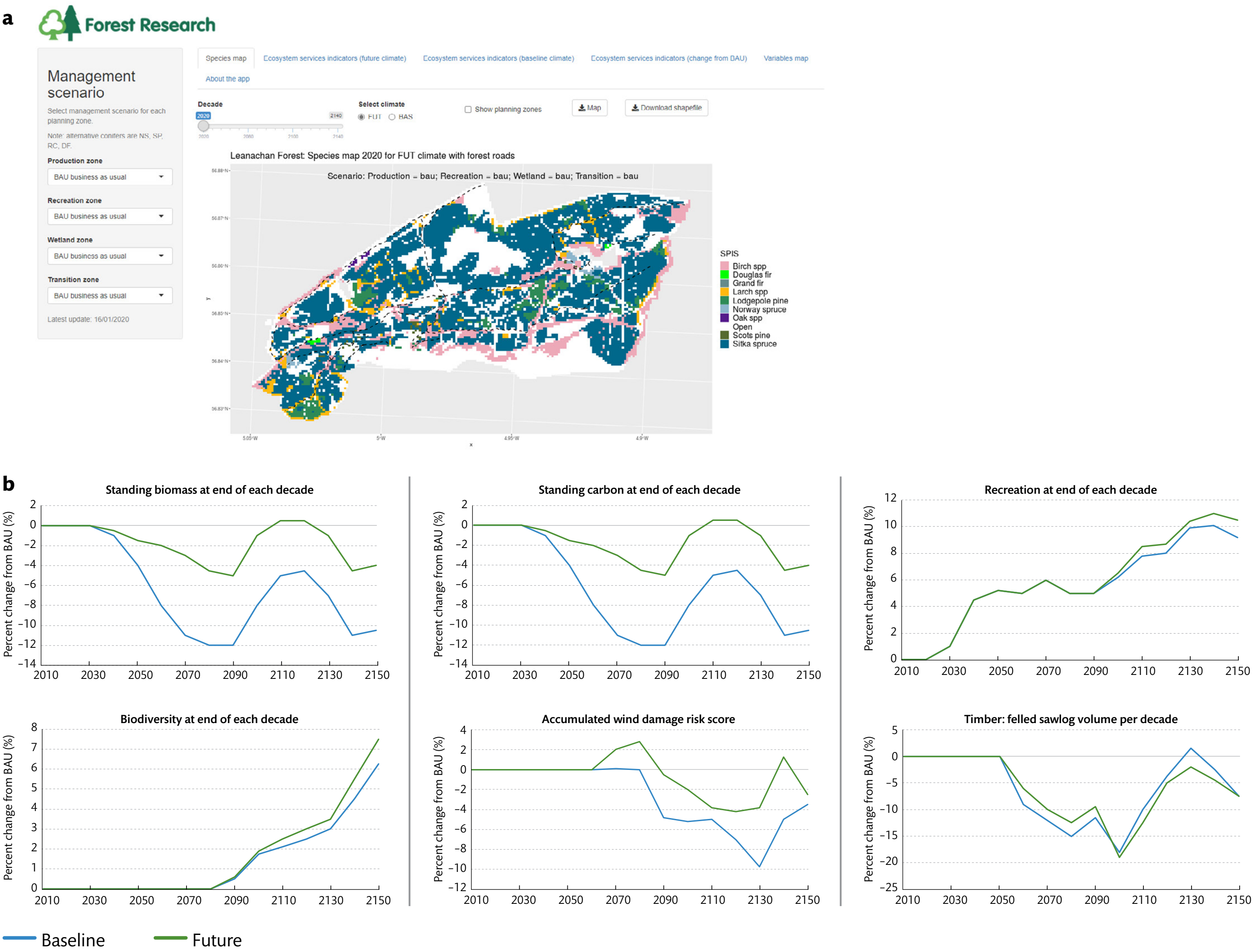


Two additional trajectories were also applied to the forest: native species and low impact silviculture, and a tool was constructed to allow different management trajectories to be applied to management zones within the forest (Figure 8). During the land management planning process, four zones were identified according to their primary objective: timber production, recreation, wetland and upland transition. The tool then calculates the total suite of ecosystem services supplied from the customised trajectory. This approach allows different combinations to be tested and demonstrates the impact of changes in management intensity (FMA) and species choice on ecosystem services. In this way, scenarios can be spatially targeted at the sub-forest scale and provide evidence and quantification of changes to support long-term decision-making.

Figure 7 Changes in species composition (a) and timber yield (b), from three management trajectories for increasing conifer species diversification while maintaining future timber supply, using climate change projections from the UKCP09 11-member regional climate model.

Abbreviations: LDP, conifer species trajectory; LDP80, 80% yield/diversification trajectory; LDP90, 90% yield/diversification trajectory; UKCP09, UK Climate Projections 2009.
Note: The 11 climate projections are: 3Q0, 3Q3, 3Q4, 3Q6, 3Q8, 3Q9, 3Q11, 3Q13, 3Q14, 3Q16, 3QK. BAS is the baseline (no climate change).

Figure 8 Examples of outputs calculated by the Scenarios toolkit: (a) the species map, (b) mean changes in ecosystem services over time.



Note: The user selects the management trajectory for different zones within the forest and the tool calculates the species map (a) and mean changes in ecosystem services over time (b) for both the baseline and future climate. Note that the different zones are not shown on the map.

Discussion

This Research Note demonstrates how scenarios can be applied to support decision-making in different contexts, however, challenges accompany the application of scenarios in woodland planning. Scenarios are often presented as being applied uniformly across a landscape, which is useful to demonstrate how the future may unfold nationally, but may not be applicable in all situations. An attendee at a workshop to develop visions for woodland expansion (Hall, Moseley and Burton, unpublished) thought it unlikely that any one vision would represent a future reality on its own, it being more likely that some visions would be more applicable in particular areas than in others. It is for this reason that the zoning approach was developed (see case study 3), which demonstrates how different scenarios can be applied in particular areas to deliver a range of ecosystem services across a forest. The zoning approach could also be used to assess scenario options for different regions of a country. Another challenge, highlighted by Vervoort *et al.* (2014), is the difficulty in down-scaling national policies to the regional scale because of a lack of mechanisms and resources. However, the multi-scale approach outlined in case study 2 provides a useful tool for exploring how national policies could be adapted to take account of regional variations, for example, the capacity for productive conifer forests in a region.

Both the agent-based model (ABM) (case study 1) and the simulation modelling approach (case studies 2 and 3) reflect potential changes in land use: the ABM through the agent's decisions and the simulation models through a probability of change in species choice and forest management alternatives at each time step. The two approaches aim to reflect how landowners and managers may react to broader societal changes, but it is recognised that individual circumstances will influence decision-making.

Conclusions

Scenarios are not commonly used in forest planning in the UK; projections of forest stands tend to focus on management plans of around 20 years (sometimes up to 50 years) and focus on timber production from a range of tree species. With an increasing focus on the role that trees, woods and forests play in providing a range of ecosystem goods and benefits, their contribution to net zero goals and tackling the biodiversity crisis, scenarios can be a valuable tool to inform policy and practice decisions. They are not intended to be precise or to provide a blueprint to follow; rather they should be plausible, accepting that the directions explored may be considered to be unlikely. Events such as pandemics and major changes to political and economic alignment with Europe have highlighted that planning for situations other than 'business as usual' is prudent. New work is focussing on exploring how the delivery of ecosystem goods and benefits change as a consequence of implementing land management plans at a national scale, alongside the development of scenarios to explore how forests can sequester more carbon, provide habitats for biodiversity, meet our timber requirements and recover from a major pest outbreak.

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Enquiries relating to this research should be addressed to:

Darren Moseley
Forest Research
Northern Research Station
Roslin, Midlothian, EH25 9SY

+44 (0)300 067 5965

darren.moseley@forestresearch.gov.uk
www.forestresearch.gov.uk

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