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Abstract

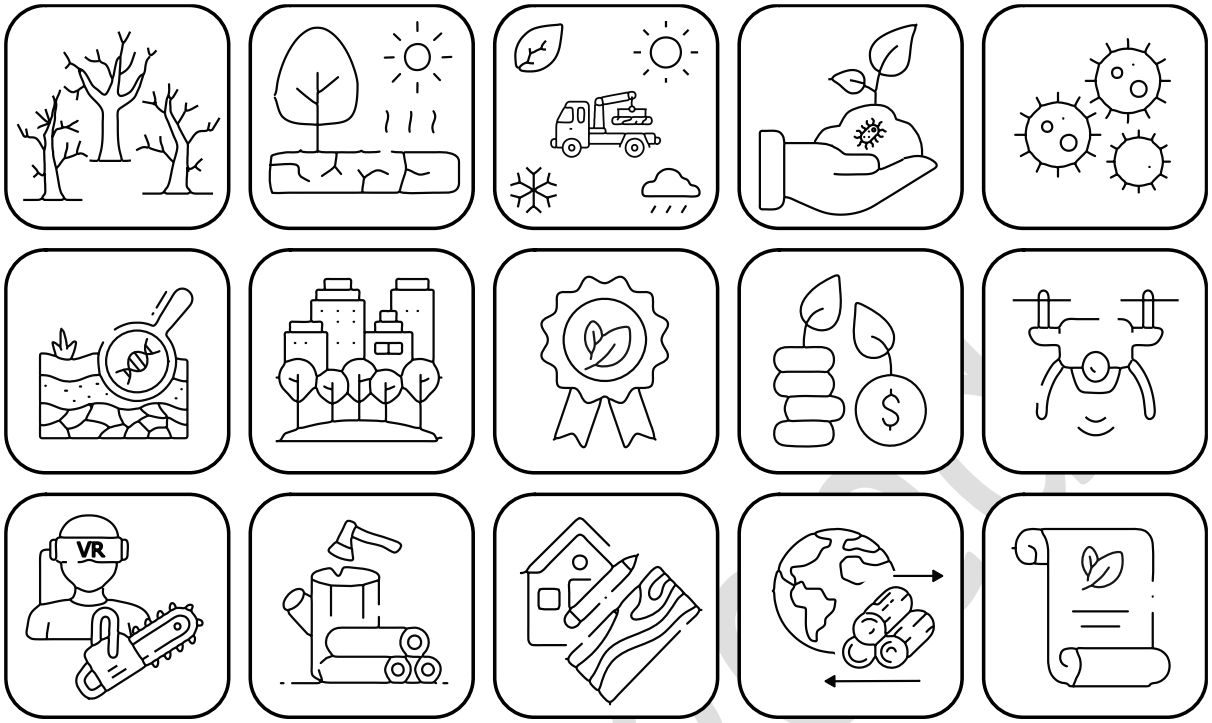
Forests are in the spotlight: they are expected to play a pivotal role in our response to society's greatest challenges, such as the climate and biodiversity crises. Yet the forests themselves, and the sector that manages them, face a range of interrelated threats and opportunities. Many of these are well understood, even if the solutions remain elusive. However, there are also emerging trends that are currently less widely appreciated. We report here the results of a horizon scan to identify developing issues likely to affect UK forest management within the next fifty years. These are issues that are presently under-recognised but have potential for significant impact across the sector and beyond. As the forest management sector naturally operates over long timescales, the importance of using good foresight is self-evident.

We followed a tried-and-tested horizon scanning methodology involving a diverse Expert Panel to collate and prioritise a longlist of 180 issues. The top

15 issues identified are presented in the Graphical Abstract. The issues represent a diverse range of themes, within a spectrum of influences from environmental shocks and perturbations to changing political and socio-economic drivers, with complex emerging interactions between them. The most highly ranked issue was 'Catastrophic forest ecosystem collapse', reflecting agreement that not only is such collapse a likely prospect but it would also have huge implications across the sector and wider society. These and many of the other issues are large scale, with far-reaching implications. We must be careful to avoid inaction through being overwhelmed, or indeed to merely focus on 'easy wins' without considering broader ramifications. Our responses to each of the challenges and opportunities highlighted must be synergistic and coherent, involving landscape-scale planning. A more adaptive approach to forest management will be essential, encouraging continual innovation and learning.

The 15 horizon scan issues presented here are a starting point on which to build further research, prompt debate and action, and develop evidence-based policy and practice. We hope that this stimulates greater recognition of how our forests and sector may need to change to be fit for the future. In some cases, these changes will need to be fundamental and momentous.

Graphical abstract



The 15 horizon scan issues identified, from left to right and top to bottom:

1. Catastrophic forest ecosystem collapse
2. Increased drought and flooding change the social costs and benefits of trees
3. Forest management becomes more challenging due to changing seasonal working windows
4. Protecting and enhancing soil microbial ecology becomes a higher priority
5. Viruses and viroids emerge as pathogens of increasing importance for trees
6. eDNA revolutionises our understanding of forest ecosystems
7. Trees are at the heart of future urban planning
8. The Taskforce on Nature-related Financial Disclosures (TNFD) drives transparency and investment in nature-positive management
9. Natural capital funding streams are greatly upscaled
10. New technologies facilitate widespread adoption of smart silviculture
11. New technologies improve worker health and safety
12. New wood product markets stimulate more active forest management
13. UK commercial forest resources may not match future value chains
14. Unpredictable supply and demand dynamics in global wood product markets
15. International commitments will spotlight ecosystem integrity and drive monitoring efforts.

Icons adapted from images from Flaticon.com.

Introduction

Forests and woodland are expected to play a pivotal role in our response to some of society's greatest challenges, particularly climate change, biodiversity loss, supply of raw materials and human wellbeing. In the UK, this is expected to be delivered largely through the creation of significant areas of *new* forest and improving the management of *existing* forests, many of which have no recognised management plans (Hemery et al., 2020). The UK government's ambitious target is to plant 30,000 hectares of forest per year by 2025, more than doubling current planting rates (HM Government, 2021). In addition, increasing societal engagement with forests is critical, particularly for a progressively urbanised society. Time spent among trees is known to promote individual wellbeing and forests deliver many wider benefits to society (Cudworth and Lumber, 2021; Forestry England, 2023; Saraev et al., 2021).

The UK is one of the least forested countries in Europe, with a total forest area of 13% in contrast to the European average of 46% (Forest Research, 2022). From an already low baseline a thousand years ago (perhaps (15-25%), tree cover steadily declined to just 5% immediately following the First World War. This led to the formation of the Forestry Commission in 1919, with a brief to increase tree cover and provide a strategic UK timber resource. Forest management priorities have evolved over the past 100 years, from an initial focus on timber production, via afforestation with primarily non-native, monoculture plantations; to a widening of objectives towards multipurpose forestry in the 1970s; to adoption of sustainable forest management principles in the 1990s; to devolution of agriculture, forestry and land-use policy in each of the four nations in the last decade (Raum, 2017). Today, different public, private and charitable ownership models deliver a wide range of objectives, including commercial timber production, biodiversity conservation and recreation opportunities (Urquhart and Courtney, 2011). 'Forest' and 'woodland' are frequently used interchangeably, although they tend to have different connotations for objectives (e.g. production versus

158 conservation) or size (e.g. large versus small); for consistency we use the term forest throughout this
159 paper.

160 The UK's forest area is approximately 3.2 million hectares, split evenly between conifers and
161 broadleaves across the UK as a whole, although there are significant regional differences (Forest
162 Research, 2022). There are an additional 0.75 million hectares of trees outside forests (Great Britain
163 figure, there is no current estimate for Northern Ireland; Forestry Commission, 2017). The UK is the
164 second largest net importer of forest products in the world with a relatively small forestry sector,
165 directly employing 32,000 workers, indirectly supporting a range of other jobs and delivering a gross
166 value added of £2.3 billion to the UK economy (Forest Research, 2022). However, the forest resource
167 is also recognised for its huge non-market value to society: the total natural capital asset value
168 estimated for UK forests is just over £350 billion (Office for National Statistics, 2022).

169 In common with other temperate regions, forests in the UK are facing a plethora of challenges
170 including climate change, biodiversity loss, invasive species, damage from mammals such as deer
171 (multiple species) and grey squirrels (*Sciurus carolinensis*), and an exponential increase in the
172 number of tree invertebrate pests and pathogens (Freer-Smith and Webber, 2015; Hayhow et al.,
173 2019; Potter and Urquhart, 2017; Spake et al., 2020; Yu et al., 2021). There is also a critical skills
174 shortage in the forestry sector, jeopardising the capacity for and quality of forest management and
175 the ability to deliver tree planting targets (Institute of Chartered Foresters, 2021). Competition for
176 rural land is acute, particularly from agriculture and nature conservation, and the needs of a growing
177 population require us to manage land more efficiently (Godfray et al., 2023). Public support is
178 fundamental, yet significant shifts in the demands for different ecosystem services such as carbon
179 sequestration, flood mitigation, recreation and wellbeing, affect the location, type and management
180 of forests required.

181 Many of these challenges and opportunities are relatively well understood, even if the solutions
182 remain elusive. In contrast, there are other emerging and developing trends currently largely

unknown to both the sector and researchers, that may transform forests and society's interaction with them in future, and thus warrant increased attention.

Horizon scanning is a subset of foresight analysis that aims to identify new trends, opportunities and threats (Cuhls, 2020; Sutherland and Woodroof, 2009). It is a form of intelligence gathering, searching for information about the medium- and long-term future in a systematic way. Horizon scanning is distinct from a research prioritisation exercise: although it attempts to highlight issues that are likely to be of future importance, it does not prioritise these relative to other well-known trends. However, it is a crucial first step in informing the development of forward-thinking strategy and research and helping society to be better prepared for the future. In this paper, we present the results from a systematic horizon scan of issues affecting UK forests over the next 50 years.

Methods

We followed the tried-and-tested methodology developed for horizon scanning in biological conservation, which has been honed over 15 years (Sutherland et al., 2019, 2007). Global conservation horizon scans have highlighted several issues pertaining to forests; for example, 'challenges to tree plantations as a simple carbon sequestration solution' (Sutherland et al., 2021) and 'countering the expansion of invasive tree monocultures by genome editing' (Sutherland et al., 2023). However, this is the first horizon scan to focus solely on UK forests, and we therefore anticipated greater specificity to the regional context.

The horizon scan method uses a modified Delphi process to select issues, ensuring transparency, repeatability and inclusivity (Mukherjee et al., 2015). Figure 1 outlines the process.

A Steering Group was convened to guide the exercise, with representatives from each UK country. The Steering Group defined the scope of the horizon scan as "*Emerging issues and opportunities affecting the use, development and management of woodland in the UK over the next 50 years.*

These include but are not limited to environmental, social, economic and political factors."

'Woodland' was defined as for the National Forest Inventory, i.e. a minimum area of 0.5 hectares under cover of trees with, or with the potential to achieve, tree crown cover of more than 20% of the ground (Forest Research, 2019). We note that some segments of the sector, and wider society, have specific types of treescape in mind when referring to 'woodlands' versus 'forests', therefore in this paper we just use the term 'forest' to describe areas of trees, including those with a wide range of different tree species compositions or management objectives.

The Steering Group brought together an Expert Panel to represent a range of perspectives and expertise (e.g. research, public land management, commercial forestry, wood-processing and timber technology, nature conservation, recreation, health), organisations (e.g. academia, public service, non-governmental organisations, private businesses) and geographies (England, Scotland, Wales, Northern Ireland, wider Europe). Forty-seven individuals participated in the Expert Panel. Six panellists were unable to attend the final workshop (although there was one substitution), leaving 42 members of the Expert Panel with one independent Chair.

Each member of the Expert Panel submitted 2-5 issues to an initial longlist, based on the best ideas gathered through wide consultations with their networks. Over 1200 people were directly engaged (i.e. discussed the exercise in meetings or responded to information requests) and calls for ideas went out to at least 7000 people across the sector through email, newsletters, etc. The 180 submitted issues were collated and organised into broad themes based on the titles, brief explanatory paragraphs and supporting references provided by the panellists.

For the first round of scoring, each panellist was randomly assigned 80 issues to review. Every issue was reviewed by at least 19 panellists (mean = 20.9, mode = 20 and 21). The panellists were randomly assigned to three different groups, with each group receiving the issues in a different order to eliminate the impacts of scoring fatigue. For each of their 80 issues, panellists indicated

whether they had heard of the issue before (a binary yes/no) and gave it a unique score between 0-1000 based on their judgement of the issue's likelihood and potential impact.

The individual panellist's scores were converted to an issue rank then the median rank across all panellists for each issue was calculated. The proportion of panellists who had heard of each issue was converted into a 'familiarity percentage' (range 17.4%-100%). As we were searching for emerging issues that were not well-known across the sector, we first discarded issues that were above the mean familiarity threshold (64.3%). The top 30 highest-ranking issues were taken forwards to a shortlist.

There was considerable overlap between some of the issues (i.e. a similar idea was submitted by more than one panellist). Therefore, duplicates and closely linked issues were amalgamated to a final shortlist of 24 issues by the project lead. All the background information from the original submissions was retained for review by the Expert Panel. To draw out the key novelty and essence of each idea, a horizon scan framing was suggested for each issue.

The final shortlist was circulated to the Expert Panel for review (see Supplementary Material for issue titles). In addition, 1-2 issues were assigned to each panellist for in-depth critical evaluation to ensure that each issue was reviewed in detail prior to the final round of scoring.

At a predominantly in-person workshop (including four online attendees), each issue on the shortlist was debated for 10 minutes by the Expert Panel. To create a forum where it was comfortable to openly critique or endorse an issue, anonymity was enforced, i.e. neither the original authors nor those who had been assigned the issue for critical evaluation declared their position for each issue. All panellists were given an opportunity to give their views on the suitability of each issue for inclusion in the final list of 15 horizon scan issues, and those who had critically evaluated the issue discussed their findings. Panellists were asked to focus on whether the issue concerned a development or change that was likely to occur and whether it would have far-reaching impacts on

254 UK forests and the wider forestry sector. The group also refined the framing of the issues. Following
255 the discussion, each panellist re-scored the issue, confidentially and again on a scale of 0-1000.

256 Following the same method as before, each panellist's scores were converted to ranks and the
257 median rank across all panellists was calculated for each issue. The highest-ranked 15 issues were
258 discussed. Where issues were similar, a vote was held on whether they should be kept distinct or
259 combined, resulting in an amalgamation of two issues. Two issues were tied for 16th place according
260 to the rankings so a vote was taken to determine which issue would be upgraded to the final list of
261 15 issues.

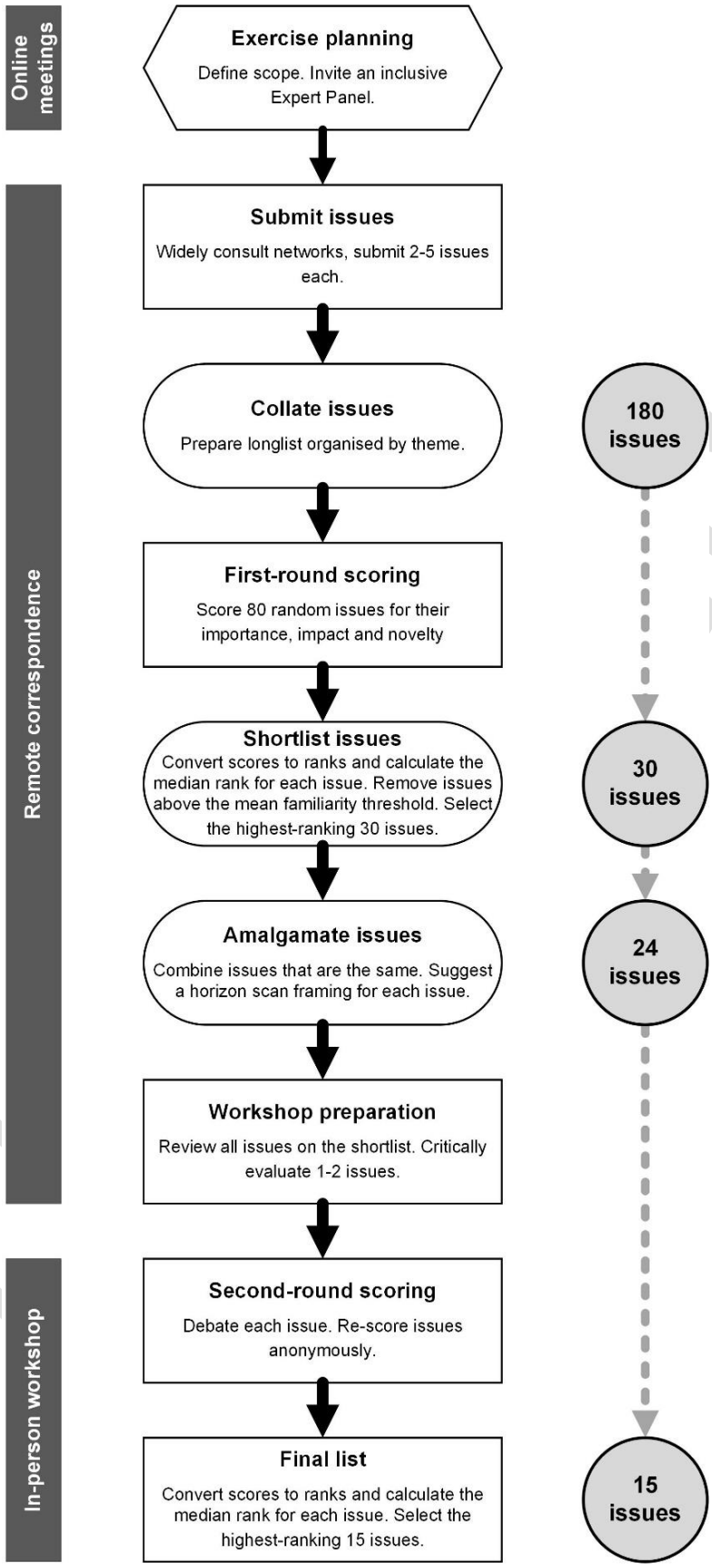


Figure 1: Flow diagram of the horizon scan process. Hexagonal, rectangular and rounded boxes indicate tasks completed by the Steering Group, Expert Panel and Project Lead, respectively.

Thematic analysis

Methodological discussions about the use of the Delphi technique stress the importance of undertaking a thematic analysis of the qualitative data. Insights from participants' comments aid this analysis by providing a picture of the important issues, concepts and explanatory frameworks that underpinned participant deliberations and led to the outcomes (Alder et al., 2018; Beiderbeck et al., 2021; Brady, 2015). Therefore, comprehensive notes were taken summarising discussions in the second-round scoring workshop. Content analysis (Kleinschmit et al., 2009) was later applied by researchers, to find the underlying themes. These themes were then organised into a schematic model representative of the discursive models underpinning Expert Panel understanding of forest futures. The final list of 15 priority issues was mapped onto this scheme, showing where each was placed, and to check the relevance and salience of the resulting thematic model.

Results

We present the top 15 issues identified through the horizon scan, grouped by theme rather than rank order. We do not report the final ranks here because that would imply relative importance or likelihood, which is not justified by the methodology. However, we note that Issue 1 ('Catastrophic forest ecosystem collapse') was the most highly ranked issue, with 64% of the Expert Panel ranking it as their top issue and 88% ranking it within their top three.

1. Catastrophic forest ecosystem collapse

There is clear evidence of increasing natural disturbance to European forests, particularly caused by wind, fire and bark beetles, and often exacerbated by past management strategies that have simplified forest ecosystems (Patacca et al., 2023). Large-scale disturbance events are increasingly affecting forests in the UK; for example, winter storms in 2021 caused the loss of 12,750 hectares of forests to windblow in Great Britain (Forestry Commission, 2022). Climate change projections

include greater frequency and severity of extreme weather events, such as heatwaves, droughts, floods and storms (IPCC, 2023). In future, it is likely that multiple, interrelated hazards and their cascading effects will lead to partial or even entire collapse of forest ecosystems, in terms of their ecological communities and the ecosystem services they generate. Lindenmayer and colleagues (2016) define forest collapse as an "*abrupt, long-lasting, and widespread change in ecosystem state and dynamics that has major negative impacts on biodiversity and key ecosystem services*" but the precise definition of what constitutes forest collapse will vary according to the local context. Changes may therefore be abrupt or gradual, comprising multiple and uncertain successional pathways and knock-on effects such as wildfires or insect outbreaks. Impacts on the provision of ecosystem services will be substantial (Cantarello et al., 2017). Timber productivity is likely to decrease; salvage and phytosanitation logging will represent an increasing proportion of harvesting efforts; and timber markets will be subject to greater fluctuation due to unpredictable timber surplus and deficit, both in the UK and throughout the global supply chain. There would be significant changes to ecological communities and even potential for species extinction (Martin et al., 2015). Forest collapse will have significant short- and long-term implications for the sector, and wider environment, economy and society. It is a fundamental issue that underpins the future potential of UK forests.

2. Increased drought and flooding change the social costs and benefits of trees

Climate change is predicted to increase the seasonality of rainfall patterns and the severity of both flooding and drought events (Kendon et al., 2023). Trees can limit the impacts of flooding, with forests already providing an average annual flood regulation value of £420 million to society in Great Britain (Broadmeadow et al., 2023). However, in drier regions the water demand from trees will exceed inputs from precipitation, potentially depleting local water resources and coming into conflict with water abstraction for domestic, industrial and irrigation supply (Tew, 2019). The impacts of climate change on forest-water dynamics are complex, being affected by tree species,

forest management, soil properties and local hydrology (Zhang et al., 2022). However, whilst the ecological and silvicultural implications of climate change for forest dynamics are already widely considered, the evolving social impacts have received little attention. Social considerations will arguably become much more significant for land use policy, particularly with a growing population and pressure on other industries. In England alone, an extra 3435 million litres of water per day will be required by 2050 to meet future demand if no mitigatory action is taken (such as to reduce consumption or leakage), of which about 50% will be needed in the south-east (Environment Agency, 2020). Forestry policy and practice will need to address the impacts of forests on water and the balance of social benefits and disbenefits from trees, including how the flow of ecosystem services from different forest types will change in a warming climate.

3. Forest management becomes more challenging due to changing seasonal working windows

The acceptable seasonal working window for carrying out forest management operations (such as thinning and harvesting) has historically narrowed due to limitations surrounding biodiversity disturbance and soil damage. Climate change projections point towards an increase in the frequency and intensity of extreme weather events ((IPCC, 2023); see Issue 1). Wetter winters will make winter working more challenging and, in some cases, impossible. Greater public awareness and concern about biodiversity decline and environmental damage will increasingly hold the industry to account. Summer working will be challenged by health and safety considerations associated with outdoor working in extreme heat; for example, in 2022 several MPs backed a campaign for a legal limit of 27°C for strenuous work ((UK Parliament, 2022); see Issue 11). The sector will need to become more flexible and better at adjusting management operations to cope with unpredictable and extreme weather (see Issue 10). Responding to greater fluctuations in wood supply will require new approaches to forest management, including more efficient and effective methods of storing roundwood to ensure that it is available for processing on-demand throughout the year. Tightening

working windows and increased health and safety risks will also exacerbate the challenge of securing skilled labour for time-bound forest work. Many of these challenges are not unique to the forestry sector, so collaboration with other industries will be an important part of finding solutions.

4. Protecting and enhancing soil microbial ecology becomes a higher priority

Forest soil microbial communities are responsible for fundamental ecological processes such as nutrient cycling, decomposition, soil formation and regulation of mycorrhizal symbiosis, and thus underpin ecosystem health and functioning (Mishra et al., 2023). Research and understanding of soil microbial ecology has grown greatly over the last decade, thanks to technological advances such as DNA barcoding (see Issue 6). However significant gaps remain, such as the contribution of individual species to ecosystem functioning or the role of soil bacteria (Baldrian, 2016; Lladó et al., 2017). New research is likely to strengthen our understanding of the critical importance of the soil microbiome for forest functioning, resilience and delivery of ecosystem services like carbon sequestration and human health benefits (Roslund et al., 2020) with important forest management implications. In parallel, popularisation of concepts such as the 'Wood Wide Web', although critiqued in academic research (Karst et al., 2023), is raising the general public's awareness of the importance and complexity of soil, and hence potential concern about the effects of forest operations. This may necessitate changes in policy and practice to ensure that soil health is appropriately conserved (see Issue 3). Management practices that enhance soil functioning, for example different ground preparation approaches or planting 'soil improving' tree species, are likely to be given more attention.

5. Viruses and viroids emerge as pathogens of increasing importance for trees

The number of plant pests and pathogens arriving from abroad is growing due to trade globalisation and climate change (Spence et al., 2019). The UK Plant Health Risk Register tracks UK plant health risks and prioritises them for action (Defra, 2023). The largest group of pathogens on the register

overall are viruses or viroids (around 14%), yet they make up a very low proportion of the pests and pathogens that are registered for trees. While there are many examples of significant viral diseases in crop plants and fruit trees such as *Citrus* and *Prunus* (Timmer et al., 2000), fewer are known for forest tree species (including commercially important timber species), and their impact is largely unknown (Büttner et al., 2023; Nienhaus and Castello, 1989). Fungi, bacteria and invertebrate pests may cause more overt symptoms than viruses, and this may bias data on prevalence and impacts of viral or viroid diseases. Equally, viral or viroid infections may go undetected because symptoms are subtle, gradual and inconspicuous, or easily confused with other stresses. This in turn may result in a lack of targeted surveillance. Consequently, the impact of virus or viroid tree pathogens may be overlooked, leaving the sector unprepared, especially if effects are cumulative and interact with other tree stressors. More generally, we lack understanding of the important wider role that viruses and viroids play in forest ecosystem functioning, such as phage viruses limiting the expansion of bacterial populations. This poor understanding threatens the economic and ecological values provided by trees and leaves the industry vulnerable.

6. eDNA revolutionises our understanding of forest ecosystems

Our ability to understand forest biodiversity, and how it is affected by our management, is being revolutionised through sampling of environmental DNA (eDNA) (Cordier et al., 2021). In particular, eDNA *meta*barcoding now allows the identification of entire ecological communities from small environmental samples such as soil or water (as opposed to conventional eDNA barcoding, which is used to detect the presence of individual species). This is transforming ecological monitoring because large areas can be surveyed more quickly, cheaply and comprehensively than traditional ecological methods. Although the technology has been used in scientific research for around a decade (e.g. Epp et al., 2012), we are now likely to see large-scale deployment across the forest sector, following the leadership shown by large landowners and flagship monitoring programmes. Rapid improvements to the technology are strengthening its reliability, sensitivity and capacity to

386 estimate species abundances, and cost-effectiveness is also improving as testing volumes increase.
387 Importantly, eDNA metabarcoding can be used to survey taxa and habitats traditionally
388 understudied yet crucial in ecosystem functioning, such as soil fungal communities (see Issue 4). This
389 could transform our understanding of how forest management affects ecological functioning and
390 resilience, offers the potential to quantify the differences in biodiversity associated with different
391 forest types, monitory biodiversity trends in detail and detect pests more effectively. eDNA
392 metabarcoding is also likely to provide greater evidence for currently contentious topics, such as the
393 impacts of compaction from machinery on soil communities (see Issue 3) and the biodiversity value
394 of non-native conifer plantations. The widespread use of eDNA metabarcoding will bring an
395 ecological data explosion that will require a similar expansion of effort in how these data are
396 presented, interpreted and used.

397 ***7. Trees are at the heart of future urban planning***

398 The benefits of trees and forest within and around urban settings are increasingly well understood,
399 including health and wellbeing, environmental cooling, air quality improvements, managing
400 stormwater, promoting social ties and even boosting academic performance (Bateman et al., 2022;
401 Turner-Skoff and Cavender, 2019). Trees have long been considered in urban planning through the
402 arboricultural sector, with arboriculture defined as 'the science and practice of the cultivation,
403 establishment and management of amenity trees for the benefit of society' (Arboricultural
404 Association, 2022). However, many UK urban centres have low canopy cover and lack easy access to
405 forests; this will become more problematic with growing urbanisation and as cities prioritise climate
406 change adaptation. There are two ways in which this is likely to be addressed. Firstly, trees will need
407 to continue to be integrated into urban settings, with appropriate consideration given to tree
408 requirements and the arboricultural sector. Although trees are already widely included in urban
409 planning, there is likely to be a step-change in the scale at which this occurs. Secondly, new forests
410 will be created in urban peripheries, as 'forest lungs' for the conurbation ('forest cities' – where large

urban areas are integrated directly into existing forests – are being developed in other countries). Both will necessitate a more deliberate incorporation of trees into urban and peri-urban planning. A shift is needed in the way that citizens, institutions and societies relate to and value nature (SEI & CEEW, 2022), Given that the UK is one of the least nature-connected societies in Europe (White et al., 2021), integrating treescapes into and around urban areas will bring important opportunities to transform the ways society relates to and values nature and thereby protects biodiversity and responds to climate change (Richardson et al., 2020). These challenges and new objectives will have significant implications for both the forestry and arboricultural sectors, which will need to work closely together.

8. The Taskforce on Nature-related Financial Disclosures (TNFD) drives transparency and investment in nature-positive management

The Taskforce on Nature-related Financial Disclosures (TNFD) is creating an integrated framework for companies and investors to monitor, assess and disclose their risks, dependencies and impacts on nature (TNFD, 2023). Although not currently mandatory, it is expected to become so, following the model of the Task Force on Climate-related Financial Disclosures (TCFD, 2022). The UK was the first country to commit to mandatory reporting for large companies to align with the TCFD (requiring comprehensive annual reports), a significant step-change beyond voluntary disclosure programmes such as through CDP (which generate simple broad scores). The UK has already invested in the development of the TNFD. International and domestic rules around sustainability and environmental reporting are expected to continue to strengthen following global commitments such as the Kunming-Montreal Global Biodiversity Framework; for example, the European Union's Corporate Sustainability Reporting Directive recently came into force (Official Journal of the European Union, 2022). Reporting under the TNFD will require businesses to fully disclose the direct and indirect impact of their activities and investments on nature, including through their supply chain impacts, so producers of raw materials such as timber will be closely scrutinised. Forestry companies will be

436 expected to publish their impacts on biodiversity, which will necessitate standardisation and
437 investment in ecological monitoring (e.g. see Issue 6). This transparency could lead to differentiation
438 between those forestry companies whose activities have negative impacts on biodiversity and those
439 with nature-positive management. A greater diversity of forestry approaches could become
440 commercially viable, ranging from the traditional model of fast timber-volume production to
441 biodiverse, nature-first approaches.

442 ### *9. Natural capital funding streams are greatly upscaled*

443 The natural capital approach places the state of the environment at the heart of policy and decision-
444 making, linking the environment to economic prosperity and human wellbeing. The foundations and
445 framework are well developed, feature in environmental and social governance by companies and
446 are increasingly used by government (Dasgupta, 2021; Natural Capital Committee, 2020). For
447 example, Forestry England publishes an annual natural capital account for the nation's forests,
448 detailing the condition of environmental assets (forests and other habitat types) as well as their
449 economic value to society; in 2021/22 the annual value to society of ecosystem services from the
450 nation's forests was estimated to be £2 billion (Forestry England, 2023). Although the marketing and
451 trading of ecosystem services as an alternative income stream for forestry has been discussed for
452 some time, this has so far only been practically delivered for carbon markets. However, rapid
453 methodological improvements are now driving the development of standards and trading models to
454 value, register and market a greater range of ecosystem services, following the precedent set by the
455 Woodland Carbon Code. A shift to stacking, bundling and rationing ecosystem services in practice to
456 create scarcity and marketability will generate new funding streams for forest owners and
457 incentivise multipurpose management. A major challenge will be demonstrating additionality:
458 ensuring that payment for ecosystem services credits will support the creation of new benefits
459 rather than what is already delivered. Standardisation and certification to ensure quality and to
460 provide transparency and investor confidence are important initiatives, such as the British Standards

Institute Code of Practice for Natural Capital Accounts and a woodland creation natural capital 'Canopy' certification scheme developed by Grown in Britain and the Forest Canopy Foundation (British Standards Institution, 2021). Once tradeable products are developed and can be registered, then natural capital banks and trading platforms will facilitate investment and significant upscaling of funding streams, providing that scale can be achieved. This market stimulation could support woodland creation and better forest management, particularly through filling the critical economic gap between planting and harvesting.

10. New technologies facilitate widespread adoption of smart silviculture

Forest management decision-making is becoming more complex in response to the shifting demands of society and to increase resilience to environmental factors such as climate change (Messier et al., 2019; Radke et al., 2020). In particular, adaptive forest management – the continuous development of practice through close monitoring of forest management outcomes – will become ever more important in improving the resilience of forests (D'Amato et al., 2023; Lawrence, 2017) and maintaining ecosystem function (Palik et al., 2022). A constellation of emerging technologies including machine learning, artificial intelligence, remote sensing and eDNA (see Issue 6) will support better forest design, management and monitoring, reducing the time and resources needed and the cost of data collection and interpretation. The emergence of 'smart silviculture' underpinned by new technologies will enable more agile, interconnected and value-focussed decision-making from the landscape to individual tree scale. Examples include high-precision species-matching to site conditions, targeted responses to pathogen outbreaks, managing growth and form within mixed-species, uneven-aged stands, precision tree breeding, and selective product felling to meet specific and time-bound market demand. The adoption of such 'smart silviculture' may, however, only be achievable at certain scales or might be limited by resources (e.g., skills or finances).

11. New technologies improve worker health and safety

The combined agriculture, forestry and fishing sector has the highest rate of workplace injury in Great Britain, with a fatality rate 21 times higher than the workplace average (Health and Safety Executive, 2022). Improving health and safety is therefore of paramount importance. Reducing risk is driven by a hierarchy of controls: removing or replacing the hazard, isolating people from the hazard, changing the way people work (including training), and Protective Personal Equipment (National Institute for Occupational Safety and Health, 2023). Technology is driving improvements in all these areas for the forestry sector. There is increasing investment in automated processes and remote-controlled devices, particularly by the New Zealand and Scandinavian forest industries, such as harvesting tools carried by drones and remotely operated forwarders and scarifiers (Visser and Obi, 2021). These both move the worker out of immediate risks from the operating environment (such as falling trees) and eliminate exposure to health hazards such as machine vibration. Theyalso lessen the need for manually demanding work, a skilled area that the sector is struggling to resource. Extended reality is already routinely used in training in other sectors, such as medicine and aviation; in forestry, simulators and virtual reality have been successfully used in training trials for harvesting machinery and chainsaw handling (Capecchi et al., 2023). Improved digital connectivity to remote areas and evolving Global Position System trackers that can accurately operate under tree cover will greatly increase detection and speed of response to accident or safety alerts. Technological improvements will revolutionise working practices and deliver significant improvements for health and safety across the sector, if harnessed effectively.

12. New wood product markets stimulate more active forest management

Technological innovation is increasing the role of timber and other wood products as a substitute for less sustainable and more carbon-intensive materials such as steel, concrete and plastic. This includes development and market expansion for products such as engineered wood, clothing fibre,

plastic substitutes and silvichemicals (Hetemäki et al., 2020). Adoption of these materials has the potential to utilise wood from a wider range of tree species, sizes and shapes. In addition to a continuing focus on tall, straight trees to supply the timber industry, increased demand for a diversity of wood products will interact with changes in silviculture and species diversification and an increase in harvesting and planting to provide supply. The residue and biomass markets generated by current demand for woodfuel demonstrate how rapidly a product can become established with a coordinated approach to stimulating confidence through the supply chain. There may be an opportunity for new products to create an economic incentive to bring smaller, less commercially viable forests into management and unlock greater flexibility from all parts of the sector. As lack of forest management can be one of the key factors causing biodiversity decline in the UK (Hayhow et al., 2019), this could have significant positive environmental benefits. However, careful monitoring will be required to ensure harvests are sustainable and do not result in environmental damage or unacceptable reductions in carbon stocks (Clarke et al., 2021).

13. UK commercial forest resources may not match future value chains

UK commercial forests currently provide wood for construction, fencing, pallets, boards and other markets with economic and social value. However, demands for alternative products are likely to emerge bringing opportunities for more efficient utilisation of the whole harvested wood biomass (see Issue 12). It is therefore important to learn the lessons from the past when forests were established to serve contemporary markets (such as oak for shipping and poplar for matchsticks) that had changed by the time of harvest (Wynne-Jones et al., 2022). Additionally, careful consideration must be given to the technical wood properties that may be required in future, which will be determined by both new end uses and new production technology and processes. For example, whilst structural timber is important in modernising and decarbonising construction, building safety constraints impose tight restrictions on tree species and necessary properties (Ridley-Ellis et al., 2022). As commercial forests transition to a wider range of tree species, genotypes and

silvicultural practices (to increase resilience to factors such as climate change and pathogens; see Issue 1), there is a risk that the wood produced may not meet future market requirements. Therefore, the sector needs to invest in research and development throughout the forestry and wood processing value chain, particularly for resource characterisation, and improve collaborative planning. A continued focus on production in terms of wood properties and yield is necessary, alongside developing a portfolio forest estate that can flexibly serve a range of future product markets.

14. Unpredictable supply and demand dynamics in global wood product markets

Unlike food security, timber security rarely features in current land use discussions in Britain. The UK imports 80% of its wood products, with the net quantity of imports second only to China (Forest Research, 2022). A reduced overall demand seems unlikely because of increasing substitution of wood products for other materials (see Issue 12) and continued urbanisation and development globally (FAO, 2022). Increased domestic supply might arise from technological advances that will improve growth and yield (see Issue 10) and new forests created in response to the biodiversity and climate crises. However, not all new forests will contribute to wood supply, for example due to tree species composition or other objectives. Additionally, environmental standards such as required by the UK Forestry Standard, whilst securing wider benefits, will reduce the productive area when restocking existing forests after harvesting (Forestry Commission, 2017b). The UK's dependency on imports reflects a policy based on global trade, which is a credible strategy for such a densely populated nation. However, it carries risk that global market prices might increase sharply or even supply be interrupted, especially as much of the global timber supply is controlled by relatively few countries. There is also increasing concern about the global environmental and social impact of 'offshoring' timber production, particularly to countries with less stringent sustainability standards. Unpredictable supply and demand dynamics globally will have important ramifications for the UK

forests sector, which must have increasing flexibility to adapt to changing market prices or availability of different types of timber.

15. International commitments will spotlight ecosystem integrity and drive monitoring efforts

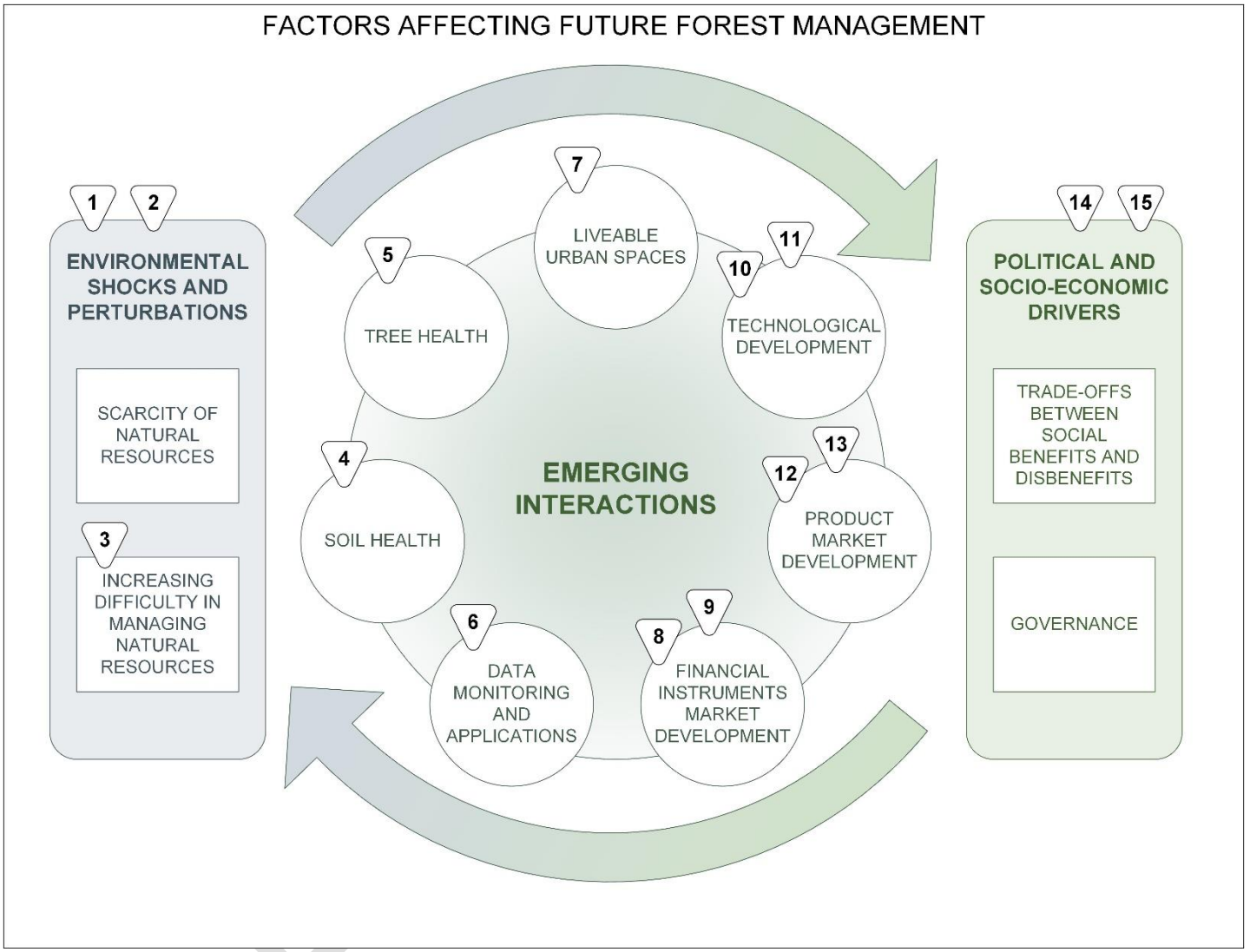
The UK government recently agreed to the goals and targets of the Global Biodiversity Framework (GBF) at the Kunming-Montreal COP15 (CBD, 2022a). These will bring new challenges for forest management and reporting of ecological condition. Proposed indicators include the newly defined Ecosystem Integrity Index to assess ecosystem structure, composition, and function and a related indicator for genetic diversity (CBD, 2022b; Heuertz et al., 2023; Hill et al., 2022). However, their definitions and means of assessment are currently vague, and application to UK forests is uncertain. The integration of these indicators into the sector will require wide-ranging evaluation of current practices such as guidance on forest reproductive materials (Forestry Commission, 2019) and an assessment of whether current forest inventories capture the necessary data. New technologies such as eDNA may greatly improve capacity for the new monitoring required (see Issue 6). More broadly, ecosystem integrity is not widely understood or prioritised by forest practitioners, nor included as a concept in national policy, despite its fundamental importance in forest resilience and the stable delivery of ecosystem services (Rogers et al., 2022). Therefore, if applied well, the GBF indicators have great potential to increase understanding and integration of this critical concept into forest management.

Thematic analysis

Figure 2 presents the model resulting from the thematic analysis. Eleven significant themes were identified from the discussions at the second-round scoring workshop. These are grouped into three major categories: environmental shocks and perturbations, political and socio-economic drivers, and

580 emerging interactions between the two. Many issues could be attributed to several themes but
581 Figure 2 indicates the theme to which each issue is most closely aligned.

582 The model reflects a strong and consistent discussion about the complex interactivity between the
583 social and ecological systems inherent to forest management. Reminiscent of social-ecological
584 systems theory (Berkes et al., 2001; Cote and Nightingale, 2012; McGinnis and Ostrom, 2014),
585 changes in environmental conditions (left of the diagram) were understood to impact, and be
586 impacted by, changes to political and socio-economic drivers (right of the diagram). While some
587 issues could be more clearly assigned to either side of this spectrum, 10 of the 15 issues were placed
588 in the nexus between the two.



589 *Figure 2: Thematic analysis of workshop discussions. The coloured panels on the left and right, and circle in the middle, indicate the three major categories*
590 *that were identified. Key themes are indicated by the white squares and boxes. Rounded triangles denote issue numbers placed against the part of the model*
591 *they most closely align to.*

Discussion

The next 50 years will bring huge changes to UK forests, the way that we manage them, and the benefits they deliver to society. While horizon scanning cannot accurately predict the future, it is a useful tool to highlight issues that deserve increased attention across research, policy and practice. The issues identified in this exercise, operating alone or synergistically, have the capacity to fundamentally alter our approach to forest management in the UK. Some threaten the very survival of the sector, others could precipitate far-reaching changes to forestry operations that would be unrecognisable today.

The 15 issues identified in this paper represent a diverse range of themes. We present them as a starting point on which to build further research, prompt debate, and to develop evidence-based policy and practice. Workshop discussions highlighted that all issues sit within a spectrum of influences, between environmental shocks and perturbations, and political and socio-economic drivers (Figure 2) but most issues are an emerging interaction between these influences. Even those issues placed towards one end of the spectrum will still have implications for the other; for example, 'Increased drought and flooding change the social costs and benefits of trees' (Issue 2) is caused by environmental perturbations but will have significant ramifications for political and social decision-making. The model reflects our awareness that forests – and our management of them – are influenced by a complex suite of interrelated drivers; indeed, meeting these diverse needs is the fundamental concept of sustainable forest management (Forestry Commission, 2017b).

While it is tempting to assign issues into discrete categories such as environmental, social, economic or political, each issue is usually caused by, and responses must consider, multiple factors. Acknowledgement of this was an important theme throughout the workshop discussions, and we therefore avoided the temptation to do a 'tick-box exercise' of ensuring coverage across overarching themes, such as environmental or social factors. We do not place emphasis on the precise issue

rankings, as we judge it unhelpful to imply priority of one over another, and a different Expert Panel may have identified different issues and scored them differently. However, it is notable that Issue 1 ('Catastrophic forest ecosystem collapse') was so highly ranked by the Expert Panel (64% ranked it as the top issue, 88% ranked it within the top three). This reflects agreement that not only is such collapse a likely prospect but would also have huge implications across the sector and wider society. Indeed, large-scale forest collapse would greatly reduce the impact of the other identified issues, if not render them meaningless. Catastrophic forest ecosystem collapse is currently under-appreciated in the UK context, despite witnessing similar events in other temperate regions such as continental Europe and North America (Lindenmayer et al., 2016; Patacca et al., 2023). While there are of course regional differences, the UK is not immune to comparable events caused by unpredictable interactions between unprecedented climate change, pests and pathogens, and forest management.

Catastrophic forest ecosystem collapse is a sobering prospect that, in common with broader trends such as climate- or eco-anxiety and paralysis, risks inaction through overwhelming feelings of helplessness and disengagement (Innocenti et al., 2023). However, there is also evidence that realistic, 'fear-based' messaging combined with concrete action pathways is necessary to sustain and stimulate urgent and effective action (Hornsey and Fielding, 2020). Fortunately, the UK forest sector does broadly understand what needs to be done to increase forest resilience and reduce the likelihood of catastrophic ecosystem collapse, for example increasing tree species and structural diversity, promoting wider ecosystem integrity and supporting biodiversity (Lindenmayer et al., 2016). There are undeniable challenges, not least limited capacity and resources, but we already have a range of well-established guidance, support and focus groups, such as the Forestry and Climate Change Partnership (FCCP, 2023; Forest Research, 2023; Tew et al., 2021). We hope the results from this horizon scanning exercise serve as an urgent call to action to build on and dramatically upscale this action to increase forest resilience.

This exemplifies the overarching theme that many issues are large scale, with far-reaching and almost unimaginable implications. We must be careful to avoid inaction through being overwhelmed, or indeed to merely focus on 'easy wins' without considering the broader ramifications. Therefore, our responses to each of the challenges and opportunities highlighted here must be synergistic, and additionally consider the more well-known issues and drivers that the sector is already responding to. For example, climate mitigation is already a well-established policy driver for woodland expansion in the UK (HM Government, 2021). This expansion will also have a pivotal role to play in the UK contribution to meeting the goals of the Kunming-Montreal Global Biodiversity Framework (CBD, 2022a). However, the evidence base concerning the extent to which climate change and biodiversity interventions can be implemented synergistically to deliver genuine nature-based solutions remains limited (Pettorelli et al., 2021). Amongst the 15 issues summarised, the Taskforce on Nature-related Financial Disclosures (TNFD) and the proposed Ecosystem Integrity Index have both been identified as potentially key drivers of nature-positive management and its monitoring and evaluation across UK forests (Issues 8 and 15), offering important opportunities to both simultaneously deliver climate change and biodiversity aspirations and grow this critical evidence base.

Additionally, to deliver effective responses to the issues presented, a coherent and evidence-based landscape-scale approach is necessary. No isolated forest can provide all the benefits required nor be resilient to all the threats. The uncertainty and unpredictability highlighted in the horizon scan issues require a wide diversity of forest types to spread risk and deliver against all of society's needs. There is likely to be a greater blurring of boundaries between urban and rural areas, with dramatic upscaling in green infrastructure and connectivity. The forestry and arboricultural sectors will need to work closely together, with multi-agency discussions about how trees and forests are effectively integrated into urban, peri-urban and surrounding areas. A multifunctional approach to land-use decision-making must be embraced, which can effectively address trade-offs between different types of land management (such as the forestry 'triad' approach that zones different types of

management for different purposes) (Betts et al., 2021; Godfray et al., 2023). The new land use framework being developed for England is expected to provide a useful starting point (Defra, 2022; Land Use in England Committee, 2022). This will require much greater collaboration and cooperation between landowners and throughout the supply chain (in the UK and in overseas countries from which wood products are imported to UK), which in turn needs more attention to the governance and networking measures that can facilitate it, build confidence and secure investment. While the patterns of land tenure vary from country to country (Nichiforel et al., 2018), the UK has much to learn from experience elsewhere (Lawrence et al., 2020; Wong et al., 2019).

A cross-cutting theme across the 15 issues is the urgent need to adopt a more adaptive approach to forest management in the UK. Many of the challenges identified will involve rapid, complex change with uncertain outcomes, taking us beyond the lessons of existing experience and scientific knowledge. This is in addition to the other well-known challenges that forests face, including climate change and biodiversity loss as well as pest and pathogen threats. A major cultural shift across the sector is required to help forest managers continually innovate, monitor, reflect, adapt and share their learning (Lawrence, 2017). This has implications for organisational governance and regulatory principles, importantly the acceptance of unpredictability. Institutions will need to develop a hierarchy of plans applying over different temporal scales, identifying where adaptive capacity can be built in, such as contingencies to respond to urgent challenges (Nagel et al., 2017). Emerging technologies will be important but future forest managers will need a new skillset, combining an excellent silvicultural foundation with strong innovation and critical evaluation skills.

Concluding remarks

Trees and forests are in the spotlight; it has never been more important to be forward-thinking in policy, practice and research, and to anticipate trends, opportunities and threats. The issues identified in this horizon scan and the supporting thematic model underline the perennial challenge

690 that most decisions at the forest scale are affected by broader drivers at large scale. This makes
691 horizon scanning especially important for forest management, so that the sector has an opportunity
692 to consider and respond to these challenges and opportunities before they become critical.

693 The relative significance of the issues for forest management in the UK will ultimately depend on the
694 wider social, geopolitical and environmental context. However, each issue is currently relatively
695 unknown to the sector but with potential for significant impact. Alone or acting in synergy, they may
696 revolutionise what our forests can deliver and how the sector approaches management. We hope
697 that this exercise stimulates wider recognition of these issues, a greater appreciation of their
698 importance, and careful consideration, examination and debate, as we develop research, policy and
699 practice to ensure that UK forests, and the sector that supports their management, are fit for the
700 future.

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703 ## Supplementary material

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716 Data availability statement

717 The 24 issues shortlisted for the second-round scoring workshop are provided in the online
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