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Baird, Aileen; Pope, Francis

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REVIEW

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'Can't see the forest for the trees': The importance of fungi in the context of UK tree planting

Aileen Baird[1,2] | **Francis Pope**[1,2]

[1]School of Geography, Earth & Environmental Sciences, Birmingham, UK

[2]Birmingham Institute of Forest Research, Birmingham, UK

Correspondence
Aileen Baird and Francis Pope, School of Geography, Earth and Environmental Sciences, University of Birmingham, Birmingham, B152TT, UK.
Emails: abb324@student.bham.ac.uk (AB); f.pope@bham.ac.uk (FP)

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Abstract

Tree planting now forms a major part of the UK climate mitigation strategy, with targets to increase the forest cover from the current 13% to 17%–20% by 2050. A tree planting strategy on this scale requires a significant amount of planning, bringing together expertise from a wide range of practitioners. We highlight four key reasons why fungi should be considered in tree planting strategies:

1. Fungi can cause severe tree disease.
2. Fungi can cause significant human health burdens.
3. Forest soil carbon and nutrient cycling is controlled by fungi.
4. Climate change is already affecting fungi.

Following from these four reasons, we explore the ways in which the negative effects of fungi, such as plant and human disease, can be mitigated against, whilst also protecting and promoting the benefits of fungi in carbon storage and biodiversity. Based on this, we outline seven guidelines which should be integrated into existing tree planting guidelines and UK policy:

A. Monitor tree fungal disease emergence and spread, including in source material trade (e.g. seeds and saplings).

B. Choose tree species combinations appropriate to the specific habitat and appropriate for biodiversity and carbon storage goals.

C. Develop and implement a widely accessible fungal spore forecast to complement existing pollen forecasts.

D. Protect existing ancient and mature woodlands.

E. Promote planting on suitable land types, avoiding grasslands and wetlands.

F. Assess proposed and existing forest sites, ideally using a combination of fungal fruit body surveys and eDNA techniques.

G. Develop and implement the UK Fungi Red List into UK law.

KEYWORDS

afforestation, carbon stocks, climate change, mycology

1 | INTRODUCTION

Climate change is the largest challenge facing the UK in the next 100 years. In the UK, the top 10 warmest years have occurred since 1990, with 2008–2017 being on average 0.8°C warmer, and having 5% more rainfall, compared with the 1961–1990 baseline period (Met Office, 2019). The longest running temperature record in the UK indicates that current temperatures are on average 1°C warmer than pre-industrialisation (Met Office, 2019). A number of different climate projections are available for the UK depending on the extent of mitigation strategies achieved; the high emission scenario RCP8.5 predicts that summer temperatures will increase by 0.9°C–5.4°C by 2070 (Met Office, 2019).

In accordance with the 2015 Paris Agreement, and the target to keep global temperature increases below 2°C, the UK has a range of climate mitigation strategies, both to decrease carbon emissions by 68% by 2030 (compared with 1990 levels), but also to increase the UK carbon sink (Department for Business, Energy, & Industrial Strategy, 2020). One of the measures set by the UK government to increase the carbon sink is to significantly increase forest cover from the current 13%, to 17%–20% by 2050 (The Climate Change Committee, 2020). At present, the UK has a low percentage forest cover, at only 13%, compared with the average of 38% across Europe (FAO Global Forest Resources Assessment, 2015). Although the primary goal of this large tree planting scheme is to increase the national carbon sink, variables such as location and tree species amongst many others, will have significant impacts on how much carbon sequestration is achieved, in addition to the wider environmental and biodiversity impacts that a tree planting strategy on this scale could cause. It is therefore essential to consider in-depth, the wider environmental contexts and consequences of this tree planting scheme.

The aim of climate mitigation tree planting initiatives, such as the UK strategy, is to increase the forest carbon sink by increasing the percentage of land under forest cover. The global net forest sink between 2001 and 2019 was estimated at $-7.6 \pm 49\,\text{GtCO}_2\text{e}$ per year, around 47% of which was in temperate woodlands, including those in the UK (Harris et al., 2021). Although a large proportion of this carbon sink is made up of tree biomass, an estimated 35% of this global forest carbon sink is made up of the deadwood, litter, soil and harvested wood (Pan et al., 2011).

Fungi are involved in almost all of the carbon stores in forests, but particularly in deadwood, litter and soil, where saprotrophic fungi control decomposition of dead plant matter, and mycorrhizal fungal biomass store significant proportions of carbon in soil organic matter (Heilmann-Clausen et al., 2015). Fungi can also have effects on other sinks, for example pathogens affecting tree health and growth will affect carbon stored in tree biomass (trunk, leaves, roots) (Hicke et al., 2012).

Although fungi, and microbes more broadly, have significant impacts on forests, they are frequently poorly represented in forest carbon modelling, or accounted for in tree planting initiatives (Ouimette et al., 2020). A number of papers have demonstrated that including more in-depth specifications of soil and rhizosphere fungal processes could improve the current uncertainty in global climate modelling (Hararuk et al., 2015; Ouimette et al., 2020; Rinne-Garmston et al., 2019). Meanwhile, despite these complex roles that fungi play in forests, there is very limited policy and guidance to inform tree planting. There are currently no requirements to survey an area for rare fungi before tree planting (or completing other work), like you might for protected animal species in the UK such as bats or great crested newts. Only three fungi are listed on the global Red List of species at high risk of extinction (which comprises a total of 45,000 species), and although significant work has taken place to develop and inform it, the UK fungal Red List is not currently officially recognised (Dahlberg et al., 2010). This lack of legal protection not only hinders the ability to protect rare fungal species and minimise biodiversity loss, but also discourages development of wider fungal ecology monitoring, and our overall understanding of the forest system. Without this vital data it is difficult to maximise the large carbon sequestration and biodiversity benefits of fungi in tree planting, whilst mitigating appropriately against the plant and human disease risks.

Considering this apparent disconnect between the importance of fungi, and the lack of policy surrounding them, in this review we highlight four key reasons why fungi should be included in all UK tree planting and restoration initiatives, identifying the current state of the research:

1. Fungi can cause severe tree disease
2. Fungi can cause significant human health burdens
3. Forest soil carbon and nutrient cycling is controlled by fungi
4. Climate change is already affecting fungi

Following these four reasons, we suggest a seven-step policy framework (Section 3) which aims to maximise carbon sequestration by fungi, mitigate against fungal threats and protect rare fungi. This framework could be incorporated into existing tree planting guidance (e.g. Brancalion & Holl, 2020; Sacco et al., 2021).

2 | FOUR REASONS WHY FUNGI ARE IMPORTANT TO CONSIDER WHEN PLANTING TREES AND RESTORING FORESTED HABITATS

2.1 | Fungi can cause severe tree disease

Fungi cause the most plant disease of any group of organisms and are responsible for a number of severe tree disease outbreaks in the UK in the past 50 years, most notably Dutch elm disease (*Ophiostoma ulmi*) and Ash dieback (*Hymenoscyphus fraxineus)* (Santini et al., 2013). Ash (*Fraxinus* spp.) dieback, caused by the fungus *H. fraxineus*, was first detected in the UK in 2012 and is currently the largest disease threat to British trees (Broome et al., 2019). *Hymenoscyphus fraxineus* causes severe tree disease, and it is estimated that it will kill around 80% of UK ash trees and cost £14.8 billion over the next 100 years (£7.6 billion of which will occur over the next 10 years) (Hill et al., 2019; The Woodland Trust, 2021). In addition to the financial implications of losing trees, ash trees account for 12% of broadleaved trees in Great Britain, and form ecological associations with almost 1000 other species, including 68 free-living fungi and 548 lichens; demonstrating that their loss will result in a significant loss of carbon storage and biodiversity (Forest Research, 2020; Mitchell et al., 2014). Other major tree disease outbreaks in the UK include Dutch elm disease (*Ophiostoma ulmi*), which resulted in the loss of 30 million elm trees in the UK (Potter et al., 2011). In addition, the fungal-like oomycete *Phytopthora ramorum*, which is known to infect 109 host species (including oak trees), has been responsible for the loss of the majority of the UK's 154,000 acres of larch trees, and the fungus *Dothistroma septosporum*, which causes needle blight in conifers, predominantly affecting pine plantations in the UK (Fisher et al., 2012; Forest Research, 2021; Potter et al., 2011; The Woodland Trust, 2021). Tree disease is one of the largest threats to the health and survival of trees, with clear implications on the carbon sequestration outcomes of tree planting. It is therefore essential to consider the disease risk of the tree and wood products, the established disease in a location, and the individual tree species at risk when establishing a plantation.

Climate change is also expected to impact the tree disease burden, and therefore affect any tree planting strategies currently being planned in the UK. La Porta et al. (2008) identify the key factors which could alter fungal disease risks as: a) abiotic stresses (e.g. drought), b) temperature and moisture changes altering sporulation and spore dispersal, c) migration of pathogens to a new geographical range and finally d) new threats appearing because of a change in tree species composition. These four factors are all applicable to the UK treescapes. Significant temperature and rainfall changes are already being measured in the UK, global trade and travel are increasing pathogen migration, and the new national tree planting initiative, all of which could be expected to affect overall UK tree species composition. There is currently a lack of experimental studies testing these four effects of climate change in the UK on fungal pathogens, but non-UK studies suggest that changing conditions caused by climate change are likely to affect pathogens also present in the UK. For example, in their review, Woods et al. (2016) demonstrated that weather conditions strongly affect the life cycle of the fungal pathogen *D. septosporum*, suggesting that future climates are likely to promote disease growth. Model simulation and review have also demonstrated the likely expansion of *P. cinnamomi* under climate change (Bergot et al., 2004; Brasier & Scott, 1994).

2.2 | Fungi cause significant human health burdens

Due to their high concentrations of fungi, forests are a source of airborne fungal spores, which can spread over significant distances, causing high concentrations of fungal aerosols, not only close to forests, but also in nearby towns and cities (Sadyś et al., 2014). As forests are a large and significant source of fungal bioaerosols, the UK government initiative to increase the forest land area by 5%–6% could also significantly increase the population-weighted aerosol exposure. Despite the numerous positive mental and physical health benefits of forests, a possible change in bioaerosol concentrations of this magnitude should also be taken seriously due to the negative human health implications of bioaerosols.

The most widely studied, and some of the most common, UK aeroallergens are *Alternaria* and *Cladosporium* species, however, many other fungal spores are prevalent in the atmosphere (e.g. basidiomycetes), and more research is needed to understand the impacts of other fungi (Caillaud et al., 2018; Gabriel et al., 2016; Grinn-Gofroń et al., 2019; Skjøth et al., 2016). Despite these gaps in our knowledge of airborne fungal spores, it is clear that they can cause a range of human diseases, with allergenic diseases such as childhood asthma being the most common (Caillaud et al., 2018; Harley et al., 2009; Rodrigues et al., 2016; Welsh et al., 2020). The global occurrence of allergic rhinitis (caused by pollen, in addition to other bioaerosols including fungal spores, pet dander, etc.) has been increasing for decades; however, the reasons for this remain unclear (Cox & Calderon, 2010). Symptoms reduce life quality and can be associated with an increased risk of asthma exacerbation, leading to hospitalisation

(Compalati et al., 2010). Significant reductions in mental and physical health, and working and learning capabilities are commonplace in adults and children, which has implications for quality of life, as well as financial and healthcare system burdens (Wright, 2020). A number of studies, both in the UK and in other countries have demonstrated links between increased airborne fungal spore counts and hospital asthma admissions (D'Amato et al., 2020; Dales et al., 2003; Pulimood et al., 2007). As yet, there is limited research connecting forest bioaerosol concentrations or composition and human health outcomes.

In addition to potential increases in population-weighted fungal spore concentrations due to increased tree numbers, climate change is also likely to influence fungal spore concentrations and seasonal patterns. There have been well-documented extensions to the length of the fungal fruiting season in the UK, both in the autumn and spring, which could in turn alter the seasonality of airborne fungal spore concentrations (Andrew, Heegaard, Høiland, et al., 2018; Gange et al., 2007). Altered seasonality of airborne fungal spores could increase occurrences of combined allergenic reactions to pollen and fungal spores, as well as increasing the likelihood of seasonal cold/flu viruses being combined with the start or end of the airborne fungal spore season (D'Amato et al., 2015). Meteorological variables (e.g. rainfall, temperature, relative humidity, storms) have all been demonstrated to affect airborne concentrations of fungal spores, all of which will be altered under a changing climate (Grinn-Gofroń et al., 2019; Sadyś et al., 2016; Sadyś et al., 2016). There is not an equivalently large body of research investigating the impact of elevated atmospheric CO_2 concentrations on fungal spore concentrations; however, the existing studies suggest that there are species-specific responses to CO_2. For example, Wolf et al. (2003) tested the response of 11 arbuscular mycorrhizal fungi to elevated CO_2 (eCO_2) at the BioCON FACE grassland experiment, but only a single *Glomus* species produced additional spores in the soil. Similarly, in a *Populus tremuloides* open-topped chamber CO_2 fumigation experiment, Klironomos et al. (1997) found that airborne fungal spore concentrations increased, which they suggested was due to corresponding increases in spore concentrations in the leaf litter.

2.3 | Forest soil carbon and nutrient cycling is controlled by fungi

Over 50 years of research have demonstrated that fungi hugely influence carbon and nutrient cycling in forest soils (Gadgil & Gadgil, 1971). It is, therefore, essential to consider these fungi, and the implications (positive and negative) that they could have in a tree planting initiative which has a primary goal of increasing carbon sequestration (Gadgil & Gadgil, 1971; Rygiewicz & Andersen, 1994). A significant proportion of forest carbon is stored as fungal biomass, with some studies reporting up to 21% of net primary productivity (NPP) being allocated to ectomycorrhizal fungi (Hobbie, 2006; López-Mondéjar et al., 2018). Cheeke et al. (2017) found that forests dominated by ectomycorrhizal fungi (ECM) (as opposed to arbuscular mycorrhizal [AM] fungi) had three times more fungal biomass, representing a significant carbon sink. Trees predominantly associate with either AM or ECM fungi, so climate, disease, or planting-triggered shifts in tree species could have significant implications for mycorrhizal type and therefore belowground carbon storage.

In addition to carbon stored as fungal biomass, fungal saprotrophs also release significant quantities of carbon during decomposition of deadwood and leaf litter (Tláskal et al., 2021). The potentially 'competing' interactions between saprotrophic and mycorrhizal fungi have long been debated with numerous papers investigating 'Gadgil' and 'priming' effects, but there still is not a consensus within the scientific community on a mechanism by which saprotrophs (decomposing and releasing CO_2) may interact with mycorrhizal fungi (harvesting nutrients and storing carbon as fungal biomass), and the combined effects that this may have on the total carbon balance of forests (Fernandez & Kennedy, 2016; Frey, 2019). It seems likely that soil nutrient availability, primarily nitrogen, is at least partly responsible for the current variability (and therefore uncertainty) in the mycorrhizal/saprotroph interactions, and potentially causes shifts in the type of mycorrhizal fungi seen- which may explain results such as those seen by Cheeke et al. (2017) (Averill et al., 2018; Hobbie, 2006; Kicklighter et al., 2019; Parihar et al., 2020; Schulte-Uebbing & de Vries, 2018; Treseder & Allen, 2000). We also have a limited understanding of the early stages of tree establishment in-situ, and how seeds and saplings interact with mycorrhizal, saprotrophic, and pathogenic fungi during this time.

Despite these current uncertainties, it is clear that the significant shifts in fungal communities currently happening with climate change (as discussed in section 4.4) are concerning for the overall carbon cycling in forests. Several studies have reported that ECM fungi are more susceptible to climatic changes than other fungal groups, and could consequently decrease in richness, potentially causing decreases in soil fungal biomass (Bennett & Classen, 2020; Miyamoto et al., 2018; Steidinger et al., 2020; Větrovský et al., 2019). Sapsford et al. (2017) discussed a 'chicken and egg' theory about tree decline and mycorrhizal fungi, whereby it is unclear whether global stressors are causing tree loss due to lack of mycorrhizae or vice versa.

2.4 | Climate change is already affecting fungi

There is strong evidence from the UK, and wider studies in similar temperate climates, that fungal fruiting seasonal patterns and community structures are already significantly affected by climate change. Fungal fruiting seasons have been lengthening, both starting earlier, and ending later (Ágreda et al., 2016; Andrew, Heegaard, Gange, et al., 2018; Andrew et al., 2016; Andrew, Heegaard, Høiland, et al., 2018; Boddy et al., 2014; Gange et al., 2007; Kauserud et al., 2012). At the BangorFACE experiment, researchers found that ECM sporocarp (fungal fruit body) biomass increased under elevated CO_2 treatments, with similar increases in ECM fruit body production shown at Aspen FACE experiment (Andrew & Lilleskov, 2009; Godbold et al., 2015). Whilst in investigations of temperate forest data, Ágreda et al. (2016) found that fungal fruit body yields were strongly positively correlated with temperature, and that although effects were species-specific, more fungal species decreased fruiting under climate change than fungi which increased fruiting.

In addition to changes in fungal fruiting phenology, the spatial and host distributions of fungi are likely to change in response to climate change. For example in 2017, the first Périgord black truffle (*Tuber melanosporum*) was harvested in the UK, which is the northernmost record of this fungus (Thomas & Büntgen, 2017). Gange et al. (2018) showed that in the north of the UK ECM fungal fruiting has increased and saprotrophic fruiting decreased, with the opposite trends seen in the south, which they link with increasing autumnal mean daily temperatures and rainfall, as well as concurrent phenological changes in the fungal host trees due to elevated CO_2 and other climatic changes. The Wood Ear fungus, *Auricularia auricula*, was originally only found growing on a single host tree (*Sambucus nigra*, Elder), but over the last 50 years has extended its host range to 16 tree species (Gange et al., 2011).

These changes in fruiting, spatial distributions and tree hosts demonstrate the effect that climate is already having on fungal populations, which has clear implications for forest tree planting. To the best of our knowledge, there have been no studies investigating the impact of fungal community composition on tree establishment or tree community composition, however, there have been multiple studies investigating the impact of trees (and plantations in particular) on fungal communities. There is evidence to suggest that tree species composition and biodiversity-promoting forest management strategies do affect the species composition of fungal communities in forests (Asplund et al., 2019; Brazee et al., 2014; Gunina et al., 2017; Jönsson et al., 2017; Kutszegi et al., 2015, 2020; Müller et al., 2007; O'Hanlon & Harrington, 2012a, 2012b; Purahong et al., 2018; Rodriguez-Ramos et al., 2021; Tomao et al., 2020; Varenius et al., 2016). However, the overall fungal richness is often not affected by tree species composition, and a number of studies have demonstrated the potential of plantation forests (including non-native tree species) to support and maintain fungal populations (Humphrey, 2005; Humphrey et al., 2000; Komonen et al., 2016; Leski et al., 2019; Newton et al., 2002; O'Hanlon & Harrington, 2012a; Quine & Humphrey, 2010). In a comparison of ECM fungal richness and community composition in ancient (>1000 years) vs. over-mature planted forest (~180 years), fungal richness and community composition were strongly correlated with tree diversity, and were similar across both ancient and mature planted forests (Spake et al., 2016). This shows that plantation forests can have good fungal biodiversity outcomes, with the authors also suggesting that older plantation stands could act as 'ecological corridors', allowing fungi (particularly dispersal limited and rare fungi) to travel between the sparsely situated ancient woodlands in the UK (Spake et al., 2016). These data demonstrate that good biodiversity outcomes can be achieved with plantations, particularly older plantations. However, it is important to remember that changes in community composition are still likely, particularly in young plantations, and this may result in the loss of more rare fungi, which are also more susceptible to climate change (Lonsdale et al., 2008; Zhou et al., 2020).

3 | MAXIMISING THE BENEFITS OF FOREST FUNGI WHILST MITIGATING AGAINST NEGATIVE OUTCOMES: SEVEN POLICY GUIDELINES

Tree planting is an important component of the UK's climate mitigation strategy, and has the potential to result in significant carbon sequestration, as well as numerous other benefits. It is also clear that fungi have significant positive and negative outcomes on tree planting outcomes, and it is therefore essential to consider fungi in any well-planned tree planting strategy.

Fungi remain the largest cause of plant diseases (Section 2.1), with threats such as Dutch Elm disease, and the newly spread Ash dieback continuing to cause problems for both established forests and new plantations (Santini et al., 2013). The increase in global trade of plants, seeds, and wood products, combined with climate change has significantly increased the rate of fungal disease spread, both of which are factors that will continue to affect forests over the next 30 years and beyond.

A dramatic and sudden increase in tree numbers in the UK could significantly increase allergic bioaerosols (fungal spores and pollen) (Section 2.2), which already cause a significant number of respiratory illnesses. Climate change is likely to affect the seasonality and quantity of bioaerosols produced, which in combination with the increased forest coverage could further increase the incidence of allergenic disease.

Fungi are an essential group of organisms for carbon storage in forest soil (Section 2.3), with key processes such as nutrient delivery to trees completed by mycorrhizal fungi, mycorrhizal fungi storing significant carbon in their biomass, and saprotrophic fungi essential in the decomposition of dead wood and leaf litter. However, we still have gaps in our knowledge regarding the interactions between mycorrhizal fungi and saprotrophs, and what impact these interactions have on the overall carbon balance of the forest.

Fungal fruit body phenology, hosts, and geographical distributions are being significantly affected by climate change (Section 2.4); however, it remains unclear what effects these phenological changes may have on carbon storage and the overall ecology of the system. Previous studies in plantation and more mature forests suggest that plantations can support a diverse community of fungi, however, it is likely that a plantation fungal community composition would be different from an ancient woodland fungal community composition- and we do not know if this will affect carbon storage or the overall survival of rare fungal species.

Given the research gaps that remain, we promote a 'precautionary principle' approach, as a strategy to protect the fungal biodiversity and highest carbon sequestration outcomes as far as possible despite our knowledge gaps of the system (Kriebel et al., 2001). Based on this principle and the current state of the knowledge, we have outlined seven policy recommendations (Figure 1) that can either be immediately started or implemented on a short (five year) timescale, that would mitigate some of the potential negative consequences of forest fungi, protect existing biodiversity, and promote increased carbon sequestration; and would complement ongoing and future forest research.

A summary of these policy recommendations is listed below:

A Monitor tree fungal disease emergence and spread, including in source material trade (e.g. seeds and saplings)
B Choose tree species combinations appropriate to the specific habitat, and appropriate for biodiversity and carbon storage goals
C Develop and implement a widely accessible fungal spore forecast to complement existing pollen forecasts
D Protect existing ancient and mature woodlands
E Promote planting on suitable land types, avoiding grasslands and wetlands
F Assess proposed and existing forest sites, ideally using a combination of fungal fruit body surveys and eDNA techniques
G Develop and implement the UK Fungi Red List into UK law

3.1 | Monitor tree fungal disease emergence and spread, including in source material trade (e.g. seeds and saplings)

Monitoring the progression, and effects, of fungal disease on UK forest health requires early detection systems so that disease spread can be managed. The UK Plant Health Risk Register is a tool currently being developed to improve the information on plant diseases available to government, industry and stakeholders. The Register currently lists 1215 pests, 173 of which are fungi (Department for Environment, Food, & Rural Affairs, 2021). Other initiatives include the community science project 'Observatree', which trains volunteers to identify and report tree pests and diseases (Observatree & Forest Research, 2018). Continuing to gather field data on fungal pathogens as climate change progresses is important, as risks may be altered significantly depending on temperature and meteorological conditions.

Finally, genetic approaches to studying disease susceptibility are developing further, with a significant number of projects currently investigating why some ash tree individuals are resistant to ash dieback. There is the potential of developing genetically modified trees which are more disease or climate resistant, but in these cases it is important to consider public and forest manager responses, as there is often reluctance towards any type of genetic modification initiative (Jepson & Arakelyan, 2017; Marzano et al., 2019).

3.2 | Choose tree species combinations appropriate to the specific habitat, and appropriate for biodiversity and carbon storage goals

In addition to the managing the spread of emerging diseases, it is also important to deal with the consequences of diseases: tree death. Where severe tree diseases cause death, replacement trees will be needed in existing

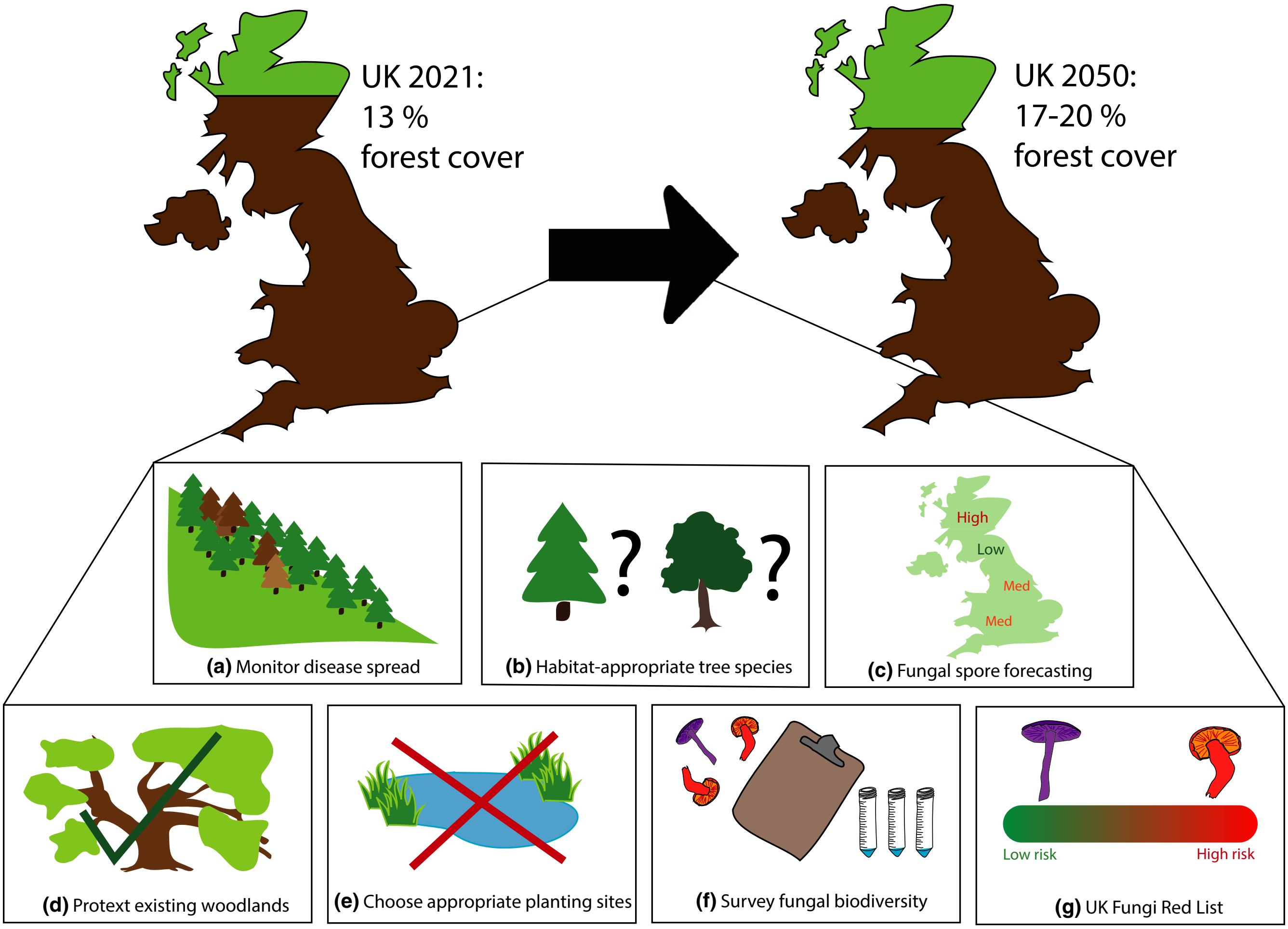

FIGURE 1 Conceptual diagram showing the seven guidelines to consider in the large UK tree planting initiative. The seven guidelines have different, but overlapping goals, which refer to the four main areas in which fungi are important in forests. Guideline A and B aim to minimise harm from fungal tree pathogens. Guideline C aims to minimise harm from human lung allergic reactions and disease from airborne fungal spores. Guidelines A, C, D and E are designed to maximise carbon sequestration. Finally, guidelines F and G aim to protect fungal biodiversity, both in existing and new forests

forests, as well as carefully choosing alternative trees for new plantations. In a series of studies, Mitchell et al. (2016) studied the suitability of replacement trees for ash (in the context of replicating biodiversity), advocating for an approach that considers the wider functioning of the ecosystem in addition to the species-specific biodiversity implications (e.g. plant, fungus, animal species that form associations with ash that may be lost if ash is lost). They suggest that oak (*Quercus* spp.) and beech (*Fagus sylvatica*) are the most likely species to replace ash by natural regeneration, with sycamore (*Acer pseudoplanatus*) identified as a good non-native plantation candidate (Broome et al., 2019; Mitchell, Hewison, et al., 2016; Mitchell, Pakeman, et al., 2016). Most importantly, these works show that there is not a single tree species that is an appropriate replacement for ash in all habitats, with different replacement trees suiting different habitats, as well as considering combinations of trees.

In addition to highlighting that replacement tree species choices are often habitat-specific, this type of study has not been completed for all the major UK tree species that are currently under threat from fungal pathogens and so the information is not universally available. The best recommendations for choosing replacement trees can be to look to the best available research at the time, as well as drawing on expert and local knowledge of the habitat, and choosing site-specific trees, remembering that natural regeneration is often an excellent option, particularly for already existing mixed forests (Mitchell et al., 2019; Mitchell, Pakeman, et al., 2016; Sacco et al., 2021).

Finally, although we are lacking in data from large scale mixed species plantation experiments, it seems highly likely from current research that monoculture forests should be avoided entirely, as they are poor for biodiversity, and are likely more susceptible to disease, as well the risk of the death of an entire forest in the case of a new invasive disease (Verheyen et al., 2016).

3.3 | Develop and implement a widely accessible fungal spore forecast to complement existing pollen forecasts

Airborne forest fungal spores pose a risk to human health, and the population-weighted concentration of fungal bioaerosols is likely to increase as the number of trees also increases. Changes in frequency of extreme weather events and overall meteorological trends (e.g. increases in temperature) are also likely to affect fungal bioaerosols, although there is likely to be species-specific differences between fungi, so an overall effect of climate change on bioaerosol concentrations is currently hard to predict.

Despite these uncertainties, the consequences of fungal-induced asthma attacks or other allergenic lung diseases can be severe, particularly in children, and so the precautionary principle should be applied. Pollen forecasting is already widespread and well used by the British public, appearing on most UK weather forecasts. Annual fungal spore data and forecasting is becoming available online, but is not currently broadcast to the public at the same level as pollen forecasting (Midlands Asthma & Allergy Research Association, 2021; University of Worcester, 2021). Integrating fungal spore forecasting into the current pollen forecasting approach would make information more widely accessible to the public, would allow at-risk persons to manage the personal risk of high concentration fungal spore events, and allow health systems to plan for high demand periods. These systems would easily integrate into existing systems, and minimise individual risk, whilst continuing with large-scale forest establishment and the numerous other benefits it offers.

3.4 | Protect existing ancient and mature woodlands

There are many benefits of establishing new forests, and the evidence does show that plantations can support diverse fungal communities. However, it is still unclear how quickly fungal communities and carbon storage establishes in a new plantation, how climate change will affect forest fungi, and what effect the differing fungal communities between plantations and mature woodlands has on forest functioning. It is clear that a plantation cannot exactly replicate an existing forest. It is therefore essential to protect our existing forests, as well as establishing new wooded areas (Abrego, Oivanen, et al., 2016; Pasanen et al., 2014; Sacco et al., 2021). These existing forests already have significant carbon stocks, and are essential habitats for fungi, particularly rare fungi which exist in smaller ecological niches.

Some experiments have investigated the possibility of translocating soil or individual rare fungi in order to replicate existing ancient woodlands and protect rare species (Abrego, Oivanen, et al., 2016). There is a lack of evidence for the impact of soil translocations on fungal communities in the donor or recipient woodland as the limited number of studies have focussed on plant communities, and the practice of individual fungal translocations is also very new. Existing studies have demonstrated that translocations do not replicate the donor site entirely, and the phenological timing and gentle soil handling is important to maintain as much biodiversity as possible (Craig et al., 2015). Rare and infrequently occurring plant species were also shown to not survive translocation (Buckley et al., 2017). Translocation should not replace the protection and conservation of ancient habitats, and may also not provide a solution if a species is being excluded by climatic changes (Nordén et al., 2020; Pérez et al., 2012).

3.5 | Choose tree-planting sites carefully, avoiding grasslands and wetlands

In addition to the protection of existing forest sites, sites for new forest plantations should be chosen carefully to promote carbon storage, and avoid new carbon loss. Suitable target sites include previously forested areas, rather than grasslands, moorlands and peatlands which have all been shown to result in no net carbon sequestration or even significant carbon losses when trees are planted (Sacco et al., 2021; Veldman et al., 2015). For example a recent study by Friggens et al. (2020) in Scotland, showed that net carbon sequestration was not achieved when planting native tree species into heather moorland. A number of studies also suggest that natural regeneration of previously forested areas may have the greatest benefits for carbon sequestration and biodiversity, with significantly less requirements for expertise, time, and money than large tree planting strategies (Lewis et al., 2019; Sacco et al., 2021).

3.6 | Develop and implement the UK fungi red list into UK law

Tree planting is likely to have large impacts on the fungal ecology of the site, particularly for rare species, however, without a good understanding of the species at risk, or laws that protect them, it is difficult to make lasting conservation changes.

The primary target for conserving fungal diversity must be to continue the development and implementation of the UK fungal Red List (Dahlberg & Mueller, 2011). Fungal conservation is still limited in the UK by the lack of policy, with only four fungal species currently protected in UK law (Dahlberg et al., 2010). Without the legal requirements to protect fungi by surveying sites, choosing tree species carefully, etc., it is difficult to enforce these biodiversity promoting initiatives, when the primary goals of tree planting projects are not biodiversity focussed (e.g. carbon sequestration, timber production). However, as numerous studies have shown (e.g. Section 2.3), changes in fungal speciation can also affect the carbon storage in a system, and the lack of understanding of the fungal kingdom also hinders progression for the other tree planting goals.

The development of the Fungi Red List is dependent on data, which can be challenging given the lack of financial and infrastructure support for mycology. Recent initiatives to improve the data on UK threatened fungal species include the successful 'Lost and Found Fungi Project' (LAFF Project) which called on community mycologists to submit field records of 100 potentially threatened UK fungi (Royal Botanic Gardens & Kew, 2019; The British Mycological Society, 2015). The LAFF Project also ran a series of DNA sequencing workshops using Bento Lab devices to improve community access, and improve fungal identification for people without access to laboratories (Bento Lab, 2021; Ellingham, 2019). In addition, the new 'Darwin Tree of Life' fungal launch is an ambitious project, aimed at collecting and barcoding all (~17,000) known fungal species in the UK, involving close collaboration between community mycologists and academics (Darwin Tree of Life, 2020). Finally, the UK is home to the largest fungarium in the world, host to 1.25 million fungal specimens, and is a wealth of data. Exploiting these already existing collections is an important source of data, as well as being a useful historical dataset to investigate the effects of climate change on fungal communities (Andrew et al., 2019; Royal Botanic Gardens & Kew, 2021).

3.7 | Assess proposed and existing forest sites, ideally using a combination of fungal fruit body surveys and eDNA techniques

Climate change is already affecting fungal fruiting patterns, as well as altering the host ranges of a number of fungi, and changing the geographical range where fungi can exist. However, it remains unclear exactly how these changes to fungal phenology affect the reproductive success of fungi, their functioning in forest systems, and carbon sequestration.

Without understanding of the effects of fungal biodiversity loss or change on forest ecosystems, the approach must be to preserve fungal communities to preserve the functioning of forest ecosystems, as well as for the inherent value of the fungi (Heilmann-Clausen et al., 2015). It seems likely that plantations can support diverse fungal communities, despite these communities probably being different in their composition from existing mature and ancient woodlands.

To more fully understand the effects that tree planting has on fungal communities, a site surveying approach combining both fungal fruiting body surveys and eDNA techniques both allows the identification of rare fungi that may be extirpated by tree planting, but also to assess the changes in fungal communities over time (Runnel et al., 2015). Potential planting sites should be surveyed for rare fungi before planting (as you would for other ecological surveys for rare species, e.g. great crested newts). In addition to surveys pre-planting, surveys at regular intervals after planting would assess the fungal populations over time, and provide further information of how young plantation forests can support or alter fungal communities (Abrego et al., 2016). These surveys should also be completed on established forests of a variety of ages and management styles, to allow comparison between new plantations and other forest types. These measurements could then be integrated into a wider network of forest monitoring measurements, improving our understanding of the wider system as well as the fungal communities.

Site surveys can be challenging, particularly due to the time and expertise required. Field taxonomy skills are becoming increasingly rare, with most field mycology experts being amateurs, and often remaining separate from academic researchers (British Mycological Society, 2008; Buyck, 1999; Wilson, 2017). Even with the sudden rise in popularity (and concurrent decrease in price) of molecular tools such as high throughput DNA sequencing, these technologies are still unavailable to the vast majority of people due to lack of expertise and funding. One solution to the lack of mycology expertise is to identify suitable indicator species of fungi, which are both relatively easily identified, in addition to being good indicators for the state of the rest of the habitat. These type of indicator species have been used before, but are often chosen without much consideration, therefore the development of a suitable list of species by UK forest mycology experts would be a useful and important tool (Halme et al., 2017).

4 | CONCLUSION

In summary, the new UK tree planting strategy whereby forests are increased from 13% to 17%–20% has the potential to result in large climate mitigation benefits; however, it is likely to significantly affect UK ecology, and requires careful planning to result in success.

We have highlighted four key reasons (sections 2.1 – 2.4.) why fungi are essential to consider in tree planting initiatives, identifying both the benefits of fungi for carbon sequestration and biodiversity, and the disadvantages of fungi for plant and human health. We have identified the current state of UK forest mycology research, and identified seven policy recommendations (Figure 1 and Section 3.1 – 3.7) that should be implemented during the planning stage of this tree planting strategy. These recommendations aim to maximise the benefits of fungi for carbon sequestration, minimise the harm to plants and humans from fungal risks, and to protect fungal biodiversity from the potential large ecological changes that tree planting on this level will result in.

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ORCID

Aileen Baird https://orcid.org/0000-0001-7340-6085

REFERENCES

Abrego, N., Halme, P., Purhonen, J., & Ovaskainen, O. (2016). Fruit body based inventories in wood-inhabiting fungi: Should we replicate in space or time? *Fungal Ecology*, *20*, 225–232. https://doi.org/10.1016/j.funeco.2016.01.007

Abrego, N., Oivanen, P., Viner, I., Nordén, J., Penttilä, R., Dahlberg, A., Heilmann-Clausen, J., Somervuo, P., Ovaskainen, O., & Schigel, D. (2016). Reintroduction of threatened fungal species via inoculation. *Biological Conservation*, *203*, 120–124. https://doi.org/10.1016/j.biocon.2016.09.014

Ágreda, T., Águeda, B., Fernández-Toirán, M., Vicente-Serrano, S. M., & Òlano, J. M. (2016). Long-term monitoring reveals a highly structured interspecific variability in climatic control of sporocarp production. *Agricultural and Forest Meteorology*, *223*, 39–47. https://doi.org/10.1016/j.agrformet.2016.03.015

Andrew, C., Diez, J., James, T. Y., & Kauserud, H. (2019). Fungarium specimens: A largely untapped source in global change biology and beyond. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *374*, 20170392. https://doi.org/10.1098/rstb.2017.0392

Andrew, C., Heegaard, E., Gange, A. C., Senn-Irlet, B., Egli, S., Kirk, P. M., Büntgen, U., Kauserud, H., & Boddy, L. (2018). Congruency in fungal phenology patterns across dataset sources and scales. *Fungal Ecology*, *32*, 9–17. https://doi.org/10.1016/j.funeco.2017.11.009

Andrew, C., Heegaard, E., Halvorsen, R., Martinez-Peña, F., Egli, S., Kirk, P. M., Bässler, C., Büntgen, U., Aldea, J., Høiland, K., Boddy, L., & Kauserud, H. (2016). Climate impacts on fungal community and trait dynamics. *Fungal Ecology*, *22*, 17–25. https://doi.org/10.1016/j.funeco.2016.03.005

Andrew, C., Heegaard, E., Høiland, K., Senn-Irlet, B., Kuyper, T. W., Krisai-Greilhuber, I., Kirk, P. M., Heilmann-Clausen, J., Gange, A. C., Egli, S., Bässler, C., Büntgen, U., Boddy, L., & Kauserud, H. (2018). Explaining European fungal fruiting phenology with climate variability. *Ecology*, *99*, 1306–1315. https://doi.org/10.1002/ecy.2237

Andrew, C., & Lilleskov, E. A. (2009). Productivity and community structure of ectomycorrhizal fungal sporocarps under increased atmospheric CO2 and O3. *Ecology Letters*, *12*, 813–822. https://doi.org/10.1111/j.1461-0248.2009.01334.x

Asplund, J., Kauserud, H., Ohlson, M., & Nybakken, L. (2019). Spruce and beech as local determinants of forest fungal community structure in litter, humus and mineral soil. *FEMS Microbiology Ecology*, *95*, fiy232. https://doi.org/10.1093/femsec/fiy232

Averill, C., Dietze, M. C., & Bhatnagar, J. M. (2018). Continental-scale nitrogen pollution is shifting forest mycorrhizal associations and soil carbon stocks. *Global Change Biology*, *24*, 4544–4553. https://doi.org/10.1111/gcb.14368

Bennett, A. E., & Classen, A. T. (2020). Climate change influences mycorrhizal fungal–plant interactions, but conclusions are limited by geographical study bias. *Ecology*, *101*, e02978. https://doi.org/10.1002/ecy.2978

Bento Lab (2021). *Bento Lab | The mobile genetics setup | Science Unbound [WWW Document]*. Bento Lab. Retrieved from https://www.bento.bio/

Bergot, M., Cloppet, E., Pérarnaud, V., Déqué, M., Marçais, B., & Desprez-Loustau, M.-L. (2004). Simulation of potential range expansion of oak disease caused by *Phytophthora cinnamomi* under climate change. *Global Change Biology*, *10*, 1539–1552. https://doi.org/10.1111/j.1365-2486.2004.00824.x

Boddy, L., Büntgen, U., Egli, S., Gange, A. C., Heegaard, E., Kirk, P. M., Mohammad, A., & Kauserud, H. (2014). Climate variation effects on fungal fruiting. *Fungal Ecology, Fungi in a Changing World: The Role of Fungi in Ecosystem Response to Global Change*, *10*, 20–33. https://doi.org/10.1016/j.funeco.2013.10.006

Brancalion, P. H. S., & Holl, K. D. (2020). Guidance for successful tree planting initiatives. *Journal of Applied Ecology*, *57*, 2349–2361. https://doi.org/10.1111/1365-2664.13725

Brasier, C. M., & Scott, J. K. (1994). European oak declines and global warming: A theoretical assessment with special reference to the activity of Phytophthora cinnamomi. *EPPO Bulletin*, *24*, 221–232. https://doi.org/10.1111/j.1365-2338.1994.tb01063.x

Brazee, N. J., Lindner, D. L., D'Amato, A. W., Fraver, S., Forrester, J. A., & Mladenoff, D. J. (2014). Disturbance and diversity of wood-inhabiting fungi: Effects of canopy gaps and downed woody debris. *Biodiversity and Conservation*, *23*, 2155–2172. https://doi.org/10.1007/s10531-014-0710-x

British Mycological Society (2008). *House of Lords - Science and Technology - Written Evidence [WWW Document]*. Retrieved from https://publications.parliament.uk/pa/ld200708/ldselect/ldsctech/162/162we10.htm

Broome, A., Ray, D., Mitchell, R., & Harmer, R. (2019). Responding to ash dieback (*Hymenoscyphus fraxineus*) in the UK: Woodland composition and replacement tree species. *Forestry: An International Journal of Forest Research*, *92*, 108–119. https://doi.org/10.1093/forestry/cpy040

Buckley, P., Helliwell, D. R., Milne, S., & Howell, R. (2017). Twenty-five years on – vegetation succession on a translocated ancient woodland soil at Biggins Wood, Kent, UK. *Forestry: An International Journal of Forest Research*, *90*, 561–572. https://doi.org/10.1093/forestry/cpx015

Buyck, B. (1999). Taxonomists are an endangered species in Europe. *Nature*, *401*, 321. https://doi.org/10.1038/43762

Caillaud, D., Cheriaux, M., Charpin, D., Chaabane, N., & Thibaudon, M. (2018). Moisissures extérieures et santé respiratoire. *Revue Des Maladies Respiratoires*, *35*, 188–196. https://doi.org/10.1016/j.rmr.2018.01.001

Cheeke, T. E., Phillips, R. P., Brzostek, E. R., Rosling, A., Bever, J. D., & Fransson, P. (2017). Dominant mycorrhizal association of trees alters carbon and nutrient cycling by selecting for microbial groups with distinct enzyme function. *New Phytologist*, *214*, 432–442. https://doi.org/10.1111/nph.14343

Compalati, E., Ridolo, E., Passalacqua, G., Braido, F., Villa, E., & Canonica, G. W. (2010). The link between allergic rhinitis and asthma: The united airways disease. *Expert Review of Clinical Immunology*, *6*, 413–423. https://doi.org/10.1586/eci.10.15

Cox, L., & Calderon, M. A. (2010). Subcutaneous specific immunotherapy for seasonal allergic rhinitis: A review of treatment practices in the US and Europe. *Current Medical Research and Opinion*, *26*, 2723–2733. https://doi.org/10.1185/03007995.2010.528647

Craig, M., Buckley, P., & Howell, R. (2015). Responses of an ancient woodland field layer to soil translocation: Methods and timing. *Applied Vegetation Science*, *18*, 579–590. https://doi.org/10.1111/avsc.12170

D'Amato, G., Chong-Neto, H. J., Ortega, O. P. M., Vitale, C., Ansotegui, I., Rosario, N., Haahtela, T., Galan, C., Pawankar, R., Murrieta-Aguttes, M., Cecchi, L., Bergmann, C., Ridolo, E., Ramon, G., Diaz, S. G., D'Amato, M., & Annesi-Maesano, I. (2020). The effects of climate change on respiratory allergy and asthma induced by pollen and mold allergens. *Allergy*, *75*, 2219–2228. https://doi.org/10.1111/all.14476

D'Amato, G., Holgate, S. T., Pawankar, R., Ledford, D. K., Cecchi, L., Al-Ahmad, M., Al-Enezi, F., Al-Muhsen, S., Ansotegui, I., Baena-Cagnani, C. E., Baker, D. J., Bayram, H., Bergmann, K. C., Boulet, L.-P., Buters, J. T. M., D'Amato, M., Dorsano, S., Douwes, J., Finlay, S. E., … Annesi-Maesano, I. (2015). Meteorological conditions, climate change, new emerging factors, and asthma and related allergic disorders. A statement of the World Allergy Organization. *World Allergy Organization Journal*, *8*, 25. https://doi.org/10.1186/s40413-015-0073-0

Dahlberg, A., Genney, D. R., & Heilmann-Clausen, J. (2010). Developing a comprehensive strategy for fungal conservation in Europe: Current status and future needs. *Fungal Ecology, Rare and Endangered Fungi*, *3*, 50–64. https://doi.org/10.1016/j.funeco.2009.10.004

Dahlberg, A., & Mueller, G. M. (2011). Applying IUCN red-listing criteria for assessing and reporting on the conservation status of fungal species. *Fungal Ecology, Conservation Underground: Fungi in a Changing World*, *4*, 147–162. https://doi.org/10.1016/j.funeco.2010.11.001

Dales, R. E., Cakmak, S., Judek, S., Dann, T., Coates, F., Brook, J. R., & Burnett, R. T. (2003). The role of fungal spores in thunderstorm asthmaa. *Chest*, *123*, 745–750. https://doi.org/10.1378/chest.123.3.745

Darwin Tree of Life (2020). *All Things Fun-GAL [WWW Document]*. Retrieved from https://www.darwintreeoflife.org/2020/07/20/all-things-fun-gal/

Department for Business, Energy & Industrial Strategy (2020). *The UK's Nationally Determined Contribution under the Paris Agreement [WWW Document]*. GOV.UK. Retrieved from https://www.gov.uk/government/publications/the-uks-nationally-determined-contribution-communication-to-the-unfccc

Department for Environment, Food & Rural Affairs (2021). *UK Plant Health Risk Register [WWW Document]*. Retrieved from https://secure.fera.defra.gov.uk/phiw/riskRegister/

Ellingham, O. (2019). Day 1.5 of the @LostFoundFungi community DNA workshop and we're grinding fungal specimens, mixing PCR ingredients, and running @theBentoLab. Please pray for our success! https://t.co/fZUszBtasN @PowderyM URL Retrieved from https://twitter.com/PowderyM/status/1155058834026745856

Fernandez, C. W., & Kennedy, P. G. (2016). Revisiting the 'Gadgil effect': Do interguild fungal interactions control carbon cycling in forest soils? *New Phytologist*, *209*, 1382–1394. https://doi.org/10.1111/nph.13648

Fisher, M. C., Henk, D. A., Briggs, C. J., Brownstein, J. S., Madoff, L. C., McCraw, S. L., & Gurr, S. J. (2012). Emerging fungal threats to animal, plant and ecosystem health. *Nature*, *484*, 186–194. https://doi.org/10.1038/nature10947

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS GLOBAL FOREST RESOURCES ASSESSMENT, 2015. https://www.fao.org/3/i4808e/i4808e.pdf

Forest Research (2020). *Forestry Statistics 2020 [WWW Document]*. Retrieved from https://www.forestresearch.gov.uk/documents/7806/CompleteFS2020.pdf

Forest Research (2021). *Dothistroma needle blight (Dothistroma septosporum) [WWW Document]*. Forest Research. Retrieved from https://www.forestresearch.gov.uk/tools-and-resources/pest-and-disease-resources/dothistroma-needle-blight/

Frey, S. D. (2019). Mycorrhizal fungi as mediators of soil organic matter dynamics. *Annual Review of Ecology Evolution and Systematics*, *50*, 237–259. https://doi.org/10.1146/annurev-ecolsys-110617-062331

Friggens, N. L., Hester, A. J., Mitchell, R. J., Parker, T. C., Subke, J.-A., & Wookey, P. A. (2020). Tree planting in organic soils does not result in net carbon sequestration on decadal timescales. *Global Change Biology*, *26*, 5178–5188. https://doi.org/10.1111/gcb.15229

Gabriel, M. F., Postigo, I., Tomaz, C. T., & Martínez, J. (2016). *Alternaria alternata* allergens: Markers of exposure, phylogeny and risk of fungi-induced respiratory allergy. *Environment International*, *89–90*, 71–80. https://doi.org/10.1016/j.envint.2016.01.003

Gadgil, R. L., & Gadgil, P. D. (1971). Mycorrhiza and litter decomposition. *Nature*, *233*, 133. https://doi.org/10.1038/233133a0

Gange, A. C., Gange, E. G., Mohammad, A. B., & Boddy, L. (2011). Host shifts in fungi caused by climate change? *Fungal Ecology, Conservation Underground: Fungi in a Changing World*, *4*, 184–190. https://doi.org/10.1016/j.funeco.2010.09.004

Gange, A. C., Gange, E. G., Sparks, T. H., & Boddy, L. (2007). Rapid and recent changes in fungal fruiting patterns. *Science*, *316*, 71. https://doi.org/10.1126/science.1137489

Gange, A. C., Heegaard, E., Boddy, L., Andrew, C., Kirk, P., Halvorsen, R., Kuyper, T. W., Bässler, C., Diez, J., Heilman-Clausen, J., Høiland, K., Büntgen, U., & Kauserud, H. (2018). Trait-dependent distributional shifts in fruiting of common British fungi. *Ecography*, *41*, 51–61. https://doi.org/10.1111/ecog.03233

Godbold, D. L., Vašutová, M., Wilkinson, A., Edwards-Jonášová, M., Bambrick, M., Smith, A. R., Pavelka, M., & Cudlin, P. (2015).

Elevated atmospheric CO2 affects ectomycorrhizal species abundance and increases sporocarp production under field conditions. *Forests*, *6*, 1256–1273. https://doi.org/10.3390/f6041256

Grinn-Gofroń, A., Nowosad, J., Bosiacka, B., Camacho, I., Pashley, C., Belmonte, J., De Linares, C., Ianovici, N., Manzano, J. M. M., Sadyś, M., Skjøth, C., Rodinkova, V., Tormo-Molina, R., Vokou, D., Fernández-Rodríguez, S., & Damialis, A. (2019). Airborne alternaria and cladosporium fungal spores in europe: Forecasting possibilities and relationships with meteorological parameters. *Science of the Total Environment*, *653*, 938–946. https://doi.org/10.1016/j.scitotenv.2018.10.419

Gunina, A., Smith, A. R., Godbold, D. L., Jones, D. L., & Kuzyakov, Y. (2017). Response of soil microbial community to afforestation with pure and mixed species. *Plant and Soil*, *412*, 357–368. https://doi.org/10.1007/s11104-016-3073-0

Halme, P., Holec, J., & Heilmann-Clausen, J. (2017). The history and future of fungi as biodiversity surrogates in forests. *Fungal Ecology, Fungi in Natural Forests*, *27*, 193–201. https://doi.org/10.1016/j.funeco.2016.10.005

Hararuk, O., Smith, M. J., & Luo, Y. (2015). Microbial models with data-driven parameters predict stronger soil carbon responses to climate change. *Global Change Biology*, *21*, 2439–2453. https://doi.org/10.1111/gcb.12827

Harley, K. G., Macher, J. M., Lipsett, M., Duramad, P., Holland, N. T., Prager, S. S., Ferber, J., Bradman, A., Eskenazi, B., & Tager, I. B. (2009). Fungi and pollen exposure in the first months of life and risk of early childhood wheezing. *Thorax*, *64*, 353–358. https://doi.org/10.1136/thx.2007.090241

Harris, N. L., Gibbs, D. A., Baccini, A., Birdsey, R. A., de Bruin, S., Farina, M., Fatoyinbo, L., Hansen, M. C., Herold, M., Houghton, R. A., Potapov, P. V., Suarez, D. R., Roman-Cuesta, R. M., Saatchi, S. S., Slay, C. M., Turubanova, S. A., & Tyukavina, A. (2021). Global maps of twenty-first century forest carbon fluxes. *Nature Climate Change*, *11*, 234–240. https://doi.org/10.1038/s41558-020-00976-6

Heilmann-Clausen, J., Barron, E. S., Boddy, L., Dahlberg, A., Griffith, G. W., Nordén, J., Ovaskainen, O., Perini, C., Senn-Irlet, B., & Halme, P. (2015). A fungal perspective on conservation biology: Fungi and conservation biology. *Conservation Biology*, *29*, 61–68. https://doi.org/10.1111/cobi.12388

Hicke, J. A., Allen, C. D., Desai, A. R., Dietze, M. C., Hall, R. J., Ted Hogg, E. H., Kashian, D. M., Moore, D., Raffa, K. F., Sturrock, R. N., & Vogelmann, J. (2012). Effects of biotic disturbances on forest carbon cycling in the United States and Canada. *Global Change Biology*, *18*, 7–34. https://doi.org/10.1111/j.1365-2486.2011.02543.x

Hill, L., Jones, G., Atkinson, N., Hector, A., Hemery, G., & Brown, N. (2019). The £15 billion cost of ash dieback in Britain. *Current Biology*, *29*, R315–R316. https://doi.org/10.1016/j.cub.2019.03.033

Hobbie, E. A. (2006). Carbon allocation to ectomycorrhizal fungi correlates with belowground allocation in culture studies. *Ecology*, *87*, 563–569. https://doi.org/10.1890/05-0755

Humphrey, J. W. (2005). Benefits to biodiversity from developing old-growth conditions in British upland spruce plantations: A review and recommendations. *Forestry: An International Journal of Forest Research*, *78*, 33–53. https://doi.org/10.1093/forestry/cpi004

Humphrey, J. W., Newton, A. C., Peace, A. J., & Holden, E. (2000). The importance of conifer plantations in northern Britain as a habitat for native fungi. *Biological Conservation*, *96*, 241–252. https://doi.org/10.1016/S0006-3207(00)00077-X

Jepson, P. R., & Arakelyan, I. (2017). Developing publicly acceptable tree health policy: Public perceptions of tree-breeding solutions to ash dieback among interested publics in the UK. *Forest Policy and Economics*, *80*, 167–177. https://doi.org/10.1016/j.forpol.2017.03.002

Jönsson, M. T., Ruete, A., Kellner, O., Gunnarsson, U., & Snäll, T. (2017). Will forest conservation areas protect functionally important diversity of fungi and lichens over time? *Biodiversity and Conservation*, *26*, 2547–2567. https://doi.org/10.1007/s10531-015-1035-0

Kauserud, H., Heegaard, E., Buntgen, U., Halvorsen, R., Egli, S., Senn-Irlet, B., Krisai-Greilhuber, I., Damon, W., Sparks, T., Norden, J., Hoiland, K., Kirk, P., Semenov, M., Boddy, L., & Stenseth, N. C. (2012). Warming-induced shift in European mushroom fruiting phenology. *Proceedings of the National Academy of Sciences*, *109*, 14488–14493. https://doi.org/10.1073/pnas.1200789109

Kicklighter, D. W., Melillo, J. M., Monier, E., Sokolov, A. P., & Zhuang, Q. (2019). Future nitrogen availability and its effect on carbon sequestration in Northern Eurasia. *Nature Communications*, *10*, 3024. https://doi.org/10.1038/s41467-019-10944-0

Klironomos, J. N., Rillig, M. C., Allen, M. F., Zak, D. R., Pregitzer, K. S., & Kubiske, M. E. (1997). Increased levels of airborne fungal spores in response to *Populus tremuloides* grown under elevated atmospheric CO $_2$. *Canadian Journal of Botany*, *75*, 1670–1673. https://doi.org/10.1139/b97-880

Komonen, A., Sundström, L. M., Wall, A., & Halme, P. (2016). Afforested fields benefit nutrient-demanding fungi. *Restoration Ecology*, *24*, 53–60. https://doi.org/10.1111/rec.12282

Kriebel, D., Tickner, J., Epstein, P., Lemons, J., Levins, R., Loechler, E. L., Quinn, M., Rudel, R., Schettler, T., & Stoto, M. (2001). The precautionary principle in environmental science. *Environmental Health Perspectives*, *109*, 871–876. https://doi.org/10.1289/ehp.01109871

Kutszegi, G., Siller, I., Dima, B., Merényi, Z., Varga, T., Takács, K., Turcsányi, G., Bidló, A., & Ódor, P. (2020). Revealing hidden drivers of macrofungal species richness by analyzing fungal guilds in temperate forests, West Hungary. *Community Ecology*, *22*(1), 13–28. https://doi.org/10.1007/s42974-020-00031-6

Kutszegi, G., Siller, I., Dima, B., Takács, K., Merényi, Z., Varga, T., Turcsányi, G., Bidló, A., & Ódor, P. (2015). Drivers of macrofungal species composition in temperate forests, West Hungary: Functional groups compared. *Fungal Ecology*, *17*, 69–83. https://doi.org/10.1016/j.funeco.2015.05.009

La Porta, N., Capretti, P., Thomsen, I. M., Kasanen, R., Hietala, A. M., & Von Weissenberg, K. (2008). Forest pathogens with higher damage potential due to climate change in Europe. *Canadian Journal of Plant Pathology*, *30*, 177–195. https://doi.org/10.1080/07060661.2008.10540534

Leski, T., Rudawska, M., Kujawska, M., Stasińska, M., Janowski, D., Karliński, L., & Wilgan, R. (2019). Both forest reserves and managed forests help maintain ectomycorrhizal fungal diversity. *Biological Conservation*, *238*, 108206. https://doi.org/10.1016/j.biocon.2019.108206

Lewis, S. L., Wheeler, C. E., Mitchard, E. T. A., & Koch, A. (2019). Restoring natural forests is the best way to remove atmospheric carbon. *Nature*, *568*, 25–28. https://doi.org/10.1038/d41586-019-01026-8

Lonsdale, D., Pautasso, M., & Holdenrieder, O. (2008). Wood-decaying fungi in the forest: Conservation needs and management options. *European Journal of Forest Research*, *127*, 1–22. https://doi.org/10.1007/s10342-007-0182-6

López-Mondéjar, R., Brabcová, V., Štursová, M., Davidová, A., Jansa, J., Cajthaml, T., & Baldrian, P. (2018). Decomposer food web in a deciduous forest shows high share of generalist microorganisms and importance of microbial biomass recycling. *ISME Journal*, *12*, 1768–1778. https://doi.org/10.1038/s41396-018-0084-2

Marzano, M., Woodcock, P., & Quine, C. P. (2019). Dealing with dieback: Forest manager attitudes towards developing resistant ash trees in the United Kingdom. *Forestry: An International Journal of Forest Research*, *92*, 554–567. https://doi.org/10.1093/forestry/cpz022

Met Office (2019). *UK Climate Projections: Headline Findings [WWW Document]*. Retrieved from https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp-headline-findings-v2.pdf

Midlands Asthma and Allergy Research Association, 2021. Pollen and Spore Report [WWW Document]. MAARA. Retrieved from https://www.maara.org/2013-08-19-06-21-06/pollen-spore-report

Mitchell, R. J., Beaton, J. K., Bellamy, P. E., Broome, A., Chetcuti, J., Eaton, S., Ellis, C. J., Gimona, A., Harmer, R., Hester, A. J., Hewison, R. L., Hodgetts, N. G., Iason, G. R., Kerr, G., Littlewood, N. A., Newey, S., Potts, J. M., Pozsgai, G., Ray, D., … Woodward, S. (2014). Ash dieback in the UK: A review of the ecological and conservation implications and potential management options. *Biological Conservation*, *175*, 95–109. https://doi.org/10.1016/j.biocon.2014.04.019

Mitchell, R. J., Bellamy, P. E., Ellis, C. J., Hewison, R. L., Hodgetts, N. G., Iason, G. R., Littlewood, N. A., Newey, S., Stockan, J. A., & Taylor, A. F. S. (2019). *Oak-associated biodiversity in the UK (OakEcol)*. NERC Environmental Information Data Centre. https://doi.org/10.5285/22b3d41e-7c35-4c51-9e55-0f47bb845202

Mitchell, R. J., Hewison, R. L., Hester, A. J., Broome, A., & Kirby, K. J. (2016). Potential impacts of the loss of *Fraxinus excelsior* (Oleaceae) due to ash dieback on woodland vegetation in Great Britain. *New Journal of Botany*, *6*, 2–15. https://doi.org/10.1080/20423489.2016.1171454

Mitchell, R. J., Pakeman, R. J., Broome, A., Beaton, J. K., Bellamy, P. E., Brooker, R. W., Ellis, C. J., Hester, A. J., Hodgetts, N. G., Iason, G. R., Littlewood, N. A., Pozsgai, G., Ramsay, S., Riach, D., Stockan, J. A., Taylor, A. F. S., & Woodward, S. (2016). How to replicate the functions and biodiversity of a threatened tree species? The case of Fraxinus excelsior in Britain. *Ecosystems*, *19*, 573–586. https://doi.org/10.1007/s10021-015-9953-y

Miyamoto, Y., Terashima, Y., & Nara, K. (2018). Temperature niche position and breadth of ectomycorrhizal fungi: Reduced diversity under warming predicted by a nested community structure. *Global Change Biology*, *24*, 5724–5737. https://doi.org/10.1111/gcb.14446

Müller, J., Hothorn, T., & Pretzsch, H. (2007). Long-term effects of logging intensity on structures, birds, saproxylic beetles and wood-inhabiting fungi in stands of European beech *Fagus sylvatica* L. *Forest Ecology and Management*, *242*, 297–305. https://doi.org/10.1016/j.foreco.2007.01.046

Newton, A. C., Holden, E., Davy, L. M., Ward, S. D., Fleming, L. V., & Watling, R. (2002). Status and distribution of stipitate hydnoid fungi in Scottish coniferous forests. *Biological Conservation*, *107*, 181–192. https://doi.org/10.1016/S0006-3207(02)00060-5

Nordén, J., Abrego, N., Boddy, L., Bässler, C., Dahlberg, A., Halme, P., Hällfors, M., Maurice, S., Menkis, A., Miettinen, O., Mäkipää, R., Ovaskainen, O., Penttilä, R., Saine, S., Snäll, T., & Junninen, K. (2020). Ten principles for conservation translocations of threatened wood-inhabiting fungi. *Fungal Ecology*, *44*, 100919. https://doi.org/10.1016/j.funeco.2020.100919

O'Hanlon, R., & Harrington, T. J. (2012a). Similar taxonomic richness but different communities of ectomycorrhizas in native forests and non-native plantation forests. *Mycorrhiza*, *22*, 371–382. https://doi.org/10.1007/s00572-011-0412-0

O'Hanlon, R., & Harrington, T. J. (2012b). Macrofungal diversity and ecology in four Irish forest types. *Fungal Ecology*, *5*, 499–508. https://doi.org/10.1016/j.funeco.2011.12.008

Observatree, Forest Research (2018). *Observatree - An early warning system for tree health and tree disease [WWW Document]*. Observatree - the official project website. Retrieved from https://www.observatree.org.uk/

Ouimette, A. P., Ollinger, S. V., Lepine, L. C., Stephens, R. B., Rowe, R. J., Vadeboncoeur, M. A., Tumber-Davila, S. J., & Hobbie, E. A. (2020). Accounting for carbon flux to mycorrhizal fungi may resolve discrepancies in forest carbon budgets. *Ecosystems*, *23*, 715–729. https://doi.org/10.1007/s10021-019-00440-3

Pan, Y., Birdsey, R. A., Fang, J., Houghton, R., Kauppi, P. E., Kurz, W. A., Phillips, O. L., Shvidenko, A., Lewis, S. L., Canadell, J. G., Ciais, P., Jackson, R. B., Pacala, S. W., McGuire, A. D., Piao, S., Rautiainen, A., Sitch, S., & Hayes, D. (2011). A large and persistent carbon sink in the world's forests. *Science*, *333*, 988–993. https://doi.org/10.1126/science.1201609

Parihar, M., Rakshit, A., Meena, V. S., Gupta, V. K., Rana, K., Choudhary, M., Tiwari, G., Mishra, P. K., Pattanayak, A., Bisht, J. K., Jatav, S. S., Khati, P., & Jatav, H. S. (2020). The potential of arbuscular mycorrhizal fungi in C cycling: A review. *Archives of Microbiology*, *202*, 1581–1596. https://doi.org/10.1007/s00203-020-01915-x

Pasanen, H., Junninen, K., & Kouki, J. (2014). Restoring dead wood in forests diversifies wood-decaying fungal assemblages but does not quickly benefit red-listed species. *Forest Ecology and Management*, *312*, 92–100. https://doi.org/10.1016/j.foreco.2013.10.018

Pérez, I., Anadón, J. D., Díaz, M., Nicola, G. G., Tella, J. L., & Giménez, A. (2012). What is wrong with current translocations? A review and a decision-making proposal. *Frontiers in Ecology and the Environment*, *10*, 494–501. https://doi.org/10.1890/110175

Potter, C., Harwood, T., Knight, J., & Tomlinson, I. (2011). Learning from history, predicting the future: The UK Dutch elm disease outbreak in relation to contemporary tree disease threats. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *366*, 1966–1974. https://doi.org/10.1098/rstb.2010.0395

Pulimood, T. B., Corden, J. M., Bryden, C., Sharples, L., & Nasser, S. M. (2007). Epidemic asthma and the role of the fungal mold *Alternaria alternata*. *Journal of Allergy and Clinical Immunology*, *120*, 610–617. https://doi.org/10.1016/j.jaci.2007.04.045

Purahong, W., Wubet, T., Krüger, D., & Buscot, F. (2018). Molecular evidence strongly supports deadwood-inhabiting fungi exhibiting unexpected tree species preferences in temperate forests. *ISME Journal*, *12*, 289–295. https://doi.org/10.1038/ismej.2017.177

Quine, C. P., & Humphrey, J. W. (2010). Plantations of exotic tree species in Britain: Irrelevant for biodiversity or novel habitat for native species? *Biodiversity and Conservation*, *19*, 1503–1512. https://doi.org/10.1007/s10531-009-9771-7

Rinne-Garmston, K. T., Peltoniemi, K., Chen, J., Peltoniemi, M., Fritze, H., & Mäkipää, R. (2019). Carbon flux from decomposing wood and its dependency on temperature, wood N2 fixation rate, moisture and fungal composition in a Norway spruce forest. *Global Change Biology*, *25*, 1852–1867. https://doi.org/10.1111/gcb.14594

Rodrigues, J., Caruthers, C., Azmeh, R., Dykewicz, M. S., Slavin, R. G., & Knutsen, A. P. (2016). The spectrum of allergic fungal diseases of the upper and lower airways. *Expert Review of Clinical Immunology*, *12*, 531–550. https://doi.org/10.1586/1744666X.2016.1142874

Rodriguez-Ramos, J. C., Cale, J. A., Cahill, J. F., Simard, S. W., Karst, J., & Erbilgin, N. (2021). Changes in soil fungal community composition depend on functional group and forest disturbance type. *New Phytologist*, *229*, 1105–1117. https://doi.org/10.1111/nph.16749

. Royal Botanic Gardens, Kew (2019). *The Lost and Found Fungi Project [WWW Document]*. Retrieved from http://fungi.myspecies.info/content/lost-and-found-fungi-project

. Royal Botanic Gardens, Kew (2021). *The Fungarium [WWW Document]*. Retrieved from https://www.kew.org/science/collections-and-resources/collections/fungarium

Runnel, K., Tamm, H., & Lõhmus, A. (2015). Surveying wood-inhabiting fungi: Most molecularly detected polypore species form fruit-bodies within short distances. *Fungal Ecology*, *18*, 93–99. https://doi.org/10.1016/j.funeco.2015.08.008

Rygiewicz, P. T., & Andersen, C. P. (1994). Mycorrhizae alter quality and quantity of carbon allocated below ground. *Nature*, *369*, 58–60. https://doi.org/10.1038/369058a0

Sacco, A. D., Hardwick, K. A., Blakesley, D., Brancalion, P. H. S., Breman, E., Rebola, L. C., Chomba, S., Dixon, K., Elliott, S., Ruyonga, G., Shaw, K., Smith, P., Smith, R. J., & Antonelli, A. (2021). Ten golden rules for reforestation to optimize carbon sequestration, biodiversity recovery and livelihood benefits. *Global Change Biology*, *27*, 1328–1348. https://doi.org/10.1111/gcb.15498

Sadyś, M., Adams-Groom, B., Herbert, R. J., & Kennedy, R. (2016). Comparisons of fungal spore distributions using air sampling at Worcester, England (2006–2010). *Aerobiologia*, *32*, 619–634. https://doi.org/10.1007/s10453-016-9436-4

Sadyś, M., Kennedy, R., & West, J. S. (2016). Potential impact of climate change on fungal distributions: Analysis of 2 years of contrasting weather in the UK. *Aerobiologia*, *32*, 127–137. https://doi.org/10.1007/s10453-015-9402-6

Sadyś, M., Skjøth, C. A., & Kennedy, R. (2014). Back-trajectories show export of airborne fungal spores (Ganoderma sp.) from forests to agricultural and urban areas in England. *Atmospheric Environment*, *84*, 88–99. https://doi.org/10.1016/j.atmosenv.2013.11.015

Santini, A., Ghelardini, L., Pace, C. D., Desprez-Loustau, M. L., Capretti, P., Chandelier, A., Cech, T., Chira, D., Diamandis, S., Gaitniekis, T., Hantula, J., Holdenrieder, O., Jankovsky, L., Jung, T., Jurc, D., Kirisits, T., Kunca, A., Lygis, V., Malecka, M., … Stenlid, J. (2013). Biogeographical patterns and determinants of invasion by forest pathogens in Europe. *New Phytologist*, *197*, 238–250. https://doi.org/10.1111/j.1469-8137.2012.04364.x

Sapsford, S. J., Paap, T., Hardy, G. E., St, J., & Burgess, T. I. (2017). The 'chicken or the egg': Which comes first, forest tree decline or loss of mycorrhizae? *Plant Ecology*, *218*, 1093–1106. https://doi.org/10.1007/s11258-017-0754-6

Schulte-Uebbing, L., & de Vries, W. (2018). Global-scale impacts of nitrogen deposition on tree carbon sequestration in tropical, temperate, and boreal forests: A meta-analysis. *Global Change Biology*, *24*, e416–e431. https://doi.org/10.1111/gcb.13862

Skjøth, C. A., Damialis, A., Belmonte, J., De Linares, C., Fernández-Rodríguez, S., Grinn-Gofroń, A., Jędryczka, M., Kasprzyk, I., Magyar, D., Myszkowska, D., Oliver, G., Páldy, A., Pashley, C. H., Rasmussen, K., Satchwell, J., Thibaudon, M., Tormo-Molina, R., Vokou, D., Ziemianin, M., & Werner, M. (2016). Alternaria spores in the air across Europe: Abundance, seasonality and relationships with climate, meteorology and local environment. *Aerobiologia*, *32*, 3–22. https://doi.org/10.1007/s10453-016-9426-6

Spake, R., van der Linde, S., Newton, A. C., Suz, L. M., Bidartondo, M. I., & Doncaster, C. P. (2016). Similar biodiversity of ectomycorrhizal fungi in set-aside plantations and ancient old-growth broadleaved forests. *Biological Conservation*, *194*, 71–79. https://doi.org/10.1016/j.biocon.2015.12.003

Steidinger, B. S., Bhatnagar, J. M., Vilgalys, R., Taylor, J. W., Qin, C., Zhu, K., Bruns, T. D., & Peay, K. G. (2020). Ectomycorrhizal fungal diversity predicted to substantially decline due to climate changes in North American Pinaceae forests. *Journal of Biogeography*, *47*, 772–782. https://doi.org/10.1111/jbi.13802

The British Mycological Society (2015). *Conservation Policy [WWW Document]*. Retrieved from https://www.britmycolsoc.org.uk/mycology/conservation/policy

The Climate Change Committee (2020). *Sixth Carbon Budget [WWW Document]*. Retrieved from https://www.theccc.org.uk/publication/sixth-carbon-budget/

The Woodland Trust (2021). *Ash Dieback (Hymenoscyphus fraxineus) [WWW Document]*. Woodland Trust. Retrieved from https://www.woodlandtrust.org.uk/trees-woods-and-wildlife/tree-pests-and-diseases/key-tree-pests-and-diseases/ash-dieback/

Thomas, P., & Büntgen, U. (2017). First harvest of Périgord black truffle in the UK as a result of climate change. *Climate Research*, *74*, 67–70. https://doi.org/10.3354/cr01494

Tláskal, V., Brabcová, V., Větrovský, T., Jomura, M., López-Mondéjar, R., Monteiro, L. M. O., Saraiva, J. P., Human, Z. R., Cajthaml, T., da Rocha, U. N., & Baldrian, P. (2021). Complementary roles of wood-inhabiting fungi and bacteria facilitate deadwood decomposition. *mSystems*, *6*, e01078-20. https://doi.org/10.1128/mSystems.01078-20

Tomao, A., Antonio Bonet, J., Castaño, C., & de-Miguel, S. (2020). How does forest management affect fungal diversity and community composition? Current knowledge and future perspectives for the conservation of forest fungi. *Forest Ecology and Management*, *457*, 117678. https://doi.org/10.1016/j.foreco.2019.117678

Treseder, K. K., & Allen, M. F. (2000). Mycorrhizal fungi have a potential role in soil carbon storage under elevated CO2 and nitrogen deposition. *New Phytologist*, *147*, 189–200. https://doi.org/10.1046/j.1469-8137.2000.00690.x

University of Worcester (2021). *Pollen Forecasting [WWW Document]*. Retrieved from https://www.worc.ac.uk/about/academic-schools/school-of-science-and-the-environment/science-and-the-environment-research/national-pollen-and-aerobiology-research-unit/home.aspx

Varenius, K., Kårén, O., Lindahl, B., & Dahlberg, A. (2016). Long-term effects of tree harvesting on ectomycorrhizal fungal communities in boreal Scots pine forests. *Forest Ecology and Management, Special Section: Drought and US Forests: Impacts and Potential Management Responses*, *380*, 41–49. https://doi.org/10.1016/j.foreco.2016.08.006

Veldman, J. W., Overbeck, G. E., Negreiros, D., Mahy, G., Le Stradic, S., Fernandes, G. W., Durigan, G., Buisson, E., Putz, F. E., & Bond, W. J. (2015). Where tree planting and forest expansion are bad for biodiversity and ecosystem services. *BioScience*, *65*, 1011–1018. https://doi.org/10.1093/biosci/biv118

Verheyen, K., Vanhellemont, M., Auge, H., Baeten, L., Baraloto, C., Barsoum, N., Bilodeau-Gauthier, S., Bruelheide, H., Castagneyrol, B., Godbold, D., Haase, J., Hector, A., Jactel, H., Koricheva, J., Loreau, M., Mereu, S., Messier, C., Muys, B., Nolet, P., … Scherer-Lorenzen, M. (2016). Contributions of a global network of tree diversity experiments to sustainable forest plantations. *Ambio*, *45*, 29–41. https://doi.org/10.1007/s13280-015-0685-1

Větrovský, T., Kohout, P., Kopecký, M., Machac, A., Man, M., Bahnmann, B. D., Brabcová, V., Choi, J., Meszárošová, L., Human, Z. R., Lepinay, C., Lladó, S., López-Mondéjar, R., Martinović, T., Mašínová, T., Morais, D., Navrátilová, D., Odriozola, I., Štursová, M., … Baldrian, P. (2019). A meta-analysis of global fungal distribution reveals climate-driven patterns. *Nature Communications*, *10*, 5142. https://doi.org/10.1038/s41467-019-13164-8

Welsh, K. G., Holden, K. A., Wardlaw, A. J., Satchwell, J., Monteiro, W., Pashley, C. H., & Gaillard, E. A. (2020). Fungal sensitization and positive fungal culture from sputum in children with asthma are associated with reduced lung function and acute asthma attacks respectively. *Clinical & Experimental Allergy*, *51*, 790–800. https://doi.org/10.1111/cea.13799

Wilson, E. O. (2017). Biodiversity research requires more boots on the ground. *Nature Ecology & Evolution*, *1*, 1590–1591. https://doi.org/10.1038/s41559-017-0360-y

Wolf, J., Johnson, N. C., Rowland, D. L., & Reich, P. B. (2003). Elevated CO2 and plant species richness impact arbuscular mycorrhizal fungal spore communities. *New Phytologist*, *157*, 579–588.

Woods, A. J., Martín-García, J., Bulman, L., Vasconcelos, M. W., Boberg, J., Porta, N. L., Peredo, H., Vergara, G., Ahumada, R., Brown, A., & Diez, J. J. (2016). Dothistroma needle blight, weather, and possible climatic triggers for the disease's recent emergence. *Forest Pathology*, *46*, 443–452. https://doi.org/10.1111/efp.12248

Wright, R. J. (2020). Influences of climate change on childhood asthma and allergy risk. *The Lancet Child & Adolescent Health*, *4*, 859–860. https://doi.org/10.1016/S2352-4642(20)30315-1

Zhou, Z., Wang, C., & Luo, Y. (2020). Meta-analysis of the impacts of global change factors on soil microbial diversity and functionality. *Nature Communications*, *11*, 3072. https://doi.org/10.1038/s41467-020-16881-7

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