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The role of conservation organisations in the mitigation of ash dieback in Wales

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Stakeholder responses to tree pest and disease outbreaks across Wales



An MScRes Submission

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Submission information

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Submission declaration

I hereby declare that this thesis is the results of my own investigations, except where otherwise stated. All other sources are acknowledged by bibliographic references. This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree unless, as agreed by the University, for approved dual awards.

Yr wyf drwy hyn yn datgan mai canlyniad fy ymchwil fy hun yw'r thesis hwn, ac eithrio lle nodir yn wahanol. Caiff ffynonellau eraill eu cydnabod gan droednodiadau yn rhoi cyfeiriadau eglur. Nid yw sylwedd y gwaith hwn wedi cael ei dderbyn o'r blaen ar gyfer unrhyw radd, ac nid yw'n cael ei gyflwyno ar yr un pryd mewn ymgeisiaeth am unrhyw radd oni bai ei fod, fel y cytunwyd gan y Brifysgol, am gymwysterau deuol cymeradwy.

Project summary

This is a KESS 2 East funded MScRes project which aims to further the understanding of stakeholder responses to tree pest and disease outbreaks in Wales. It collates both desk-based and empirical research in order to describe woodland management behaviour and the factors that influence management decisions. Particular focus is given to the role of conservation organisations when faced with ash dieback in Welsh woodlands. The project takes a Welsh focus due to the documented widespread impact of ash dieback across the Welsh landscape. There is currently no literature regarding the role conservation organisations play when mitigating ash dieback. It also considers Wales due to the scope of the Social European Funding and project partners remit: Bangor University and Forest Research.

Literature review purpose:

A systematic literature review in the first instance outlines the current distribution of tree pests and diseases within Wales. It compares this with current policy and examples of best practice to mitigate subsequent outbreaks, as well as to what extent management undertaken reflects these suggested guidelines.

More information on the literature review purpose can be found on **page 2**

Literature review:

The review proposes that there is scope for improving the understanding of private woodland managers behaviour and the factors that influence their decisions. Particular focus should be given to approaches observed when they deviate unexpectedly from attitudes, motivations and objectives. Deviations in approaches were noted most commonly amongst private conservation focused, managers. Further research with these stakeholders is recommended particularly where they represent a dominant stakeholder as in the case of Wales, UK.

More information on the literature review can be found on **page 3**

Paper justification:

Conclusions drawn from the literature review suggested further research should incorporate conversations with woodland managers about their experience with tree threats including factors that influence their opinions and decisions (Marzano, Woodcock and Quine 2019). Conservation organisations are of particular interest in ash dieback management because ash has a high cultural and biodiversity value but less economic value than other species (Marciulyniene et al., 2017). Organisations often prioritise conservation value and are not restricted entirely by commercial outcomes therefore they could be more likely to take management approaches that maintain ash dieback in the landscape (Bengtsson and Stenström, 2017). Organisations also have an unusual role within management in Wales including public engagement, offering advice and facilitating stakeholder networks. Limited research into their involvement with ash dieback (Marzano, Woodcock and Quine, 2019) and lack of consideration in policy (Welsh Government, 2021) suggest their involvement could be being overlooked and potentially underestimated.

More information on the paper justification can be found on **page 68**

Research paper:

Semi-structured interviews collected information about conservation organisations experience with ash dieback in Wales. Conservation organisations exhibited high awareness and understanding of ash dieback and many roles have been established within organisations to mitigate its impact. Conservation organisations aim to maintain ash trees in the landscape for biodiversity value and to build woodland resistance to ash dieback. Organisations are playing a potentially underestimated but influential role in the mitigation of ash dieback (*Hymenoscyphus fraxineus*) in Wales. Organisations have a wide role managing woodlands, increasing public awareness of ash dieback, offering advice and facilitating tree health networking. Conservation organisations can utilise their influence, working with stakeholders to achieve common outcomes facilitating a cohesive response to the disease at the landscape scale.

More information on the research paper can be found on **page 75**

Key findings document:

An accessible two page document was produced to present the findings of the KESS 2 East funded MScRes project. The document summarises findings from a systematic literature review that aimed to further the understanding of private stakeholders and their experience with tree pests and diseases. Empirical research directed from the literature review is also summarised. The research considers the role conservation organisations play in mitigating the impact of ash dieback. It provides eight specific recommendations that will provide support to encourage and/ or enhance the role conservation organisations may play at the landscape scale. These recommendations are largely targeted around support that can be provided by Natural Resources Wales towards conservation organisation to continue and/ or enhance the role they play in mitigating ash dieback at the landscape scale in Wales. However, support should be obtained from several sources to provide the greatest level of support.

More information on the key findings document can be found on **page 108**

Conclusions, reflections and further directions:

The overall conclusion considers the findings of the project and its potential impact at different scales including how it fits into the wider literature and its policy influence. As such the conclusion discusses the recommendations for further support for conservation organisations to continue and/ or enhance the role they play in ash dieback mitigation in Wales.

More information on the key findings document can be found on **page 112**

Additional material:

Further information regarding the project is available in the appendices as additional material.

More information on the additional material can be found [here](#)

Contents

Literature review purpose	-----	Page 1
Literature review	-----	Page 2
Research paper justification	-----	Page 68
Research paper	-----	Page 75
Key findings explanation	-----	Page 107
Summary document	-----	Page 108
Conclusion	-----	Page 112
Overall conclusions, reflections and future directions	-----	Page 113
Appendices	-----	Page 113

Literature review purpose

A literature review was conducted as part of a KESS 2 East funded MScRes project which aims to further the understanding of stakeholder responses to tree pest and disease outbreaks across Wales. Initial research identifies that several stakeholders can be involved in the mitigation of tree pest and disease. Therefore, the review in the first instance outlines the current distribution of tree pests and diseases within Wales, current policy and best practice outlined to mitigate subsequent outbreaks, as well as to what extent management undertaken reflects these suggested guidelines.

The project takes a particular interest in the lack of literature about woodland managers which can be influential in the monitoring, reporting and reacting to tree pest and disease outbreaks. Therefore, a systematic review of the available literature in the UK was undertaken to understand their contribution to tree pest and disease management. This includes understanding management approaches as well as the factors that influence management decisions.

Moreover, the potential contribution of conservation focused organisations and their management is considered in this review. It is proposed that these organisations may not only have a direct impact on the mitigation of tree pests and diseases but indirectly through advice and support to other land managers. This contribution at present appears to be largely overlooked when considering stakeholder responses to tree pests and diseases in Wales. Whilst there is currently no literature available about conservation organisations, private woodland managers are considered in this review in detail. There is particular focus given to conservation focused decision making and the factors that affect those decisions.

The review forms the foundation for understanding the role conservation focused organisations may play in responding to tree pests and diseases in Wales. Analysis will provide invaluable insight into conservation driven management decisions. Moreover, it will provide direction for future in-depth conversations with conservation focused organisations which will provide further information about the role they may play in the mitigation of tree pests and diseases in Wales.

Tree pests and diseases in the UK: Management approaches and influencing factors



MScRes Submission: Literature Review

Abstract

The increasing introduction and establishment of tree pests and diseases are impacting forest health, structure, and services, globally. The trend observed can be exacerbated and accelerated by interconnecting relationships between threats and climate change, extreme weather events, and globalisation. In parallel, exploitation, fragmentation, and land use change within many wooded areas expose trees to stress (increased by climate and extreme weather) making them more susceptible to the detrimental impacts of tree pests and diseases once introduced and established. Tree pests and diseases have spread across commercial plantations as well as natural and semi-natural woodlands, impacting communities through their biodiversity, economic and social implications. Therefore, there is an expanding interest in the actions taken by woodland managers, who often act as the primary defence against the establishment and spread of many of these threats. However, documentation about management approaches, and the factors that affect management decisions, remains scarce.

As such, a systematic literature search was undertaken to understand the current understanding of woodland management behaviour and potential knowledge gaps when faced with tree pests and diseases in a British context. Informative assumptions could be drawn from critical analysis of the limited literature, whereby managers are managing threats in the UK to varying degrees. For the most part, managers are actively concerned about the threat of pests and diseases and demonstrate a willingness to adopt resilient approaches where resources allow. Approaches and decisions can be attributed to a combination of attitudes, motivations, and objectives as well as contextual and structural factors such as forest size, policy or markets. Translating concern for pests and diseases into management is prevented by several limiting factors, with planning for unknown outcomes the most common concern.

This review proposes that there is scope for improving the understanding of private woodland managers' approaches and factors that influence those decisions. Particular focus should be given to approaches observed when they deviate unexpectedly from attitudes, motivations and objectives. Deviations in approaches were noted most commonly amongst private conservation-focused, managers. Further research with these stakeholders is recommended particularly where they represent a dominant stakeholder as in the case of Wales, UK.

Background

1. Defining forests and woodlands

Currently, there are advancements in understanding the biodiversity contributions of forests and woodlands, as countries begin to prepare their post-2020 global biodiversity framework (FAO, 2020). Forests and woodlands can be broadly viewed and defined from two standpoints: the land cover perspective and the land use perspective (Chazdon et al., 2016). The land cover perspective considers forests and woodlands as a multitude of trees, plants, animals and microorganisms (FAO, 2020). However, it is important to note that forests and woodlands can also be defined by their legal designation, regardless of the current vegetation that resides there (Chazdon et al., 2016). There is also a differentiation that can be made between forests and woodlands themselves, with forests being extensive areas dominated by trees, whereas woodlands are often smaller with more open space (Scotland's Environment, 2019). Whilst there are some differences noted by the US National Classification system, 'forest' can often be used interchangeably with 'woodland' in both society and policy with reference to wooded areas (Mitchell, 2009). Henceforth this review will consider the terms interchangeably but it is noted that 'forest', is particularly used in a global context or when countries have large forest areas but 'woodland' is often coined when referring to countries like the UK where small fragmented wooded areas are prevalent.

2. Forest and woodland threats

Forests are under increasing pressure from global change (Bonan, 2008). Emerging threats such as climate change, invasive species, natural disasters, land use change, and pests and diseases are all impacting forest ecosystems (Randhir and Erol, 2013). Exploitation, fragmentation, and land use change within many wooded areas increases the vulnerability of forests to threats (Curtis et al., 2018; Davis et al., 2014; Kozak et al., 2018). Climate change can bring about changes in fire and drought, as well as insects and diseases affecting the entire structure of the forest (Dale et al., 2000). Forest species are heavily impacted by predation or in direct competition with non-native and invasive species (Wilcove et al., 1998). Globalisation has facilitated the movement of non-native invasives to new environments (FAO, 2020). Once the non-native invasives are introduced into new areas the lack of natural predators allows invasives to spread (Randhir and Erol, 2013). Destructive pests, such as the bark beetle, may be able to take advantage of stressed trees (by extreme weather events and climate) causing detrimental impacts once established in woodlands (Canadell and Raupach, 2008; Jennings et al., 2012; Marzano, Fuller and Quine, 2017).

Land use change poses a large threat to the health of forest ecosystems by exposing forests to a range of anthropogenic nutrient inputs (Randhir and Erol, 2013). Land use change in wooded areas also has the ability to alter the regional climate, and plant and animal species that are susceptible to changing conditions will have to adapt, move or their population may decline if they are unable to keep pace with this changing climate (Johnston et al., 2009). Forests are also under threat from a range of natural disasters like hurricanes which can cause sudden and widespread tree mortality and altered patterns of forest regeneration (Lugo, 2000; Lugo and Scatena, 1996). In addition, there is evidence that natural forests reduce the frequency and severity of flooding in developed countries but the quality of soil, geology, catchment and river morphology can all influence this ability (Randhir and Erol, 2013). Overall it is clear that a lot of threats facing forests globally often interconnect and one threat can exacerbate the impact of another threat. It is therefore proposed that resilient strategies will need to be implemented which allow different management approaches or solutions to be used in different situations (Weir, 2017; Willoughby and Peace, 2019).

3. Tree pests and diseases

Trees often have a key role in terrestrial ecosystem functioning but can be affected by a wide range of tree pests and diseases (Boyd et al., 2013; Freer-Smith and Webber, 2017). Awareness of the ecological and economic impacts of tree pests and diseases has increased in the last two decades (Aukema et al., 2010; Santini et al., 2013). The introduction and establishment of pests and pathogens have increased in recent decades, impacting forest health, structure, and services globally (Fisichelli et al., 2014; Freer-Smith and Webber, 2017; Graziosi et al., 2020). It is widely accepted that tree pests and diseases have spread by increased international travel and trade introducing novel pests and diseases to potential tree hosts (Aukema, 2010; Brasier, 2008).

The lack of co-evolution between the pest or disease and the novel host can cause the host to have no effective resistance mechanisms and so the detrimental impact of the alien pests and diseases can be substantially greater (Brasier, 2008). The increasing trend in the introduction and establishment of tree pests and diseases can be exacerbated by tree pests and diseases' interconnecting relationship with climate change, weather events and globalization (Meyerson and Mooney, 2007; Ramsfield et al., 2016; Teshome, Zharare and Naidoo, 2020). As pests and diseases spread across forests they can detrimentally impact communities through biodiversity, economic and social implications (Graziosi et al., 2020; Wingfield et al., 2015). In parallel, exploitation, fragmentation and land use change expose trees to stress often exacerbated by changes in climate (Curtis et al., 2018; Davis et al., 2014). This makes trees more susceptible to tree pests and diseases

once they are introduced and established in forests (Canadell and Raupach, 2008; Marzano, Fuller and Quine, 2017).

4. Global forest policy and tree health strategies

Preparations are underway to prepare the Post-2020 Biodiversity Framework which will be discussed and adopted at the United Nations (UN) Biodiversity Conference in May 2022 (United Nations, 2021). It is a new global framework for managing nature globally through to 2030 that builds on the Strategic Plan for Biodiversity 2011-2020. A key target proposes preventing or reducing the rate of introduction and establishment of invasive alien species by 50% and controlling or eradicating such species to eliminate or reduce their impacts. The United Nations Strategic Plan for Forests 2030 adopted in 2017 proposes a voluntary and universal plan for the sustainable management of forests and trees (United Nations, 2017). Tree pests and diseases are not mentioned directly but Goal 1 mentions broadly adopting a resilience and adaptive capacity to deal with natural disasters and climate change which encompasses tree pest and disease threats. This direct mention of invasive alien species in the Post-2020 Biodiversity Framework as a key target may represent the rising concern of invasive pests and diseases and their impact on nature.

The Food and Agriculture Organization (FAO) of the United Nations is a specialized department that facilitates global collaboration to defeat hunger and improve nutrition and food security (FAO, 2009). The FAO work on forest health at a global scale delivering programmes to assist, advise and support countries to protect the health and vitality of forests concerning tree pests and diseases. The FAO provides advice on the preventative measures of pests and disease management and offers advice on how to prevent spread. It offers assistance to countries not only in response to outbreaks and emergencies but also establishing long-term prevention and forest protection strategies (FAO, 2009). The International Plant Protection Convention (IPPC) is an international treaty aiming to prevent the spread and introduction of pests and diseases in plants and to promote appropriate measures for their control (FAO, 1997). The IPPC is governed by the Commission on Phytosanitary Measures which adopts standards approved through international consultation processes and is recognised under the World Trade Organisation (WTO) agreement (WTO, 1994). These standards have direct relevance to forest tree pests and diseases providing guidelines for pest risk analysis, pest reporting and monitoring as well as international trade regulation (FAO, 1997).

5. Forest policy and tree health strategies in the UK

The UK Forestry Standard (UKFS) is the reference standard for the sustainable management of forests in the UK. The UKFS has been agreed upon at international levels as an appropriate targeted method

for sustainably managing forests in the UK which are unique in characteristics (Forest Research, 2017). It outlines the context for forestry, setting out the UK's government approach to sustainable management including standards, and requirements and provides a basis for regulation and monitoring. The UKFS has been developed by the forestry authorities in England, Scotland Wales and Northern Ireland through a collaborative consultation process who are the managing authorities for forests across the UK. Therefore, the UKFS is endorsed by all countries within the UK and applies to all forests and woodlands. The UKFS alongside individual countries' policies and strategies provide the framework for the implementation of international forestry agreements.

The Plant Health Act of 1967 in England and Scotland identifies the Forestry Commission as the competent authority to prevent the introduction and spread of forestry pests and diseases (UK Government, 2022). The same Act identifies the Welsh Ministers as the leading authority responsible for tree pests and disease prevention and management. In Northern Ireland under the Plant Health Act (Northern Ireland) 1967 the Department of Environment and Rural Affairs is given the role of tree pests and diseases prevention and management. Statutory orders by the Plant Health Act prevent the introduction and spread of forest pests and diseases and must be complied with. Certain pests and diseases must be reported and inspectors must be given access to woodlands and their advice followed. In accordance with UKFS standards managers should be aware of risks and vigilant in monitoring tree health and suspected outbreaks should be investigated (Forest Research, 2017).

The Plant Biosecurity Strategy for Great Britain 2014 was created for the robust protection of crops, trees and other plants (DEFRA, 2014). It is a strategy developed in partnership with key stakeholders that outlines the actions that will be taken in a flexible and dynamic approach to be able to constantly evolve to keep pace with changing threats. This key strategy is a combined approach between England, Scotland and Wales as pests and diseases do not recognize national boundaries and will therefore require joined-up thinking. This strategy does not include Northern Ireland but works closely to ensure the best possible protection against pests and diseases as a whole can be achieved. Furthermore, this also involves working with the Republic of Ireland to strengthen the biosecurity of both islands in their entirety. The Plant Biosecurity Strategy for Great Britain 2014 strategy aims to ensure that activity is directed towards priority pests and pathways informed by sound evidence, it ensures all stakeholders understand their biosecurity roles and responsibility. It also suggests that those who benefit from plant biosecurity where appropriate should bear the cost of it and aims to ensure that Wales, Scotland and England as a whole is resilient, capable and prepared to respond effectively to new and emerging threats. Safeguarding plant health features as a key priority in all government forestry strategy. The Plant Health Services work with all devolved nations and international bodies to agree on appropriate plant health rules and coordinate their implementation.

5.1 Forest policy and tree health strategies in Wales

The Welsh Government's Woodland for Wales strategy made a commitment to manage more woodlands, expand woodland cover and improve the resilience of Welsh woodlands (Welsh Government, 2018a). This is framed to ensure that Welsh woodlands are in a favourable state to provide a number of benefits to the communities across Wales. The Welsh 'Government's tree health strategy has key the objective to proactively 'exclude, detect and respond to exclude, detect, and respond to, existing and new pests and pathogens of trees, whether of native or exotic origin. Take proactive measures to reduce the impact of pests and diseases on trees and woodlands in Wales.'

The actions that support this objective include enhanced research and monitoring, ensuring border controls are effective, and establishing clear governance procedures to provide direction, and accountability for dealing with existing and future pest outbreaks whilst encouraging the adoption of sound biosecurity practices and coordination across stakeholders. The Wales Tree Health Steering Group advises the government on methods of building resilience, coordinating strategic actions, identifying potential barriers and building skills and capacity in Wales to deal effectively with the risk of tree pests and disease in Welsh woodlands (Welsh Government, 2017).

Wales has been significantly impacted by the highly destructive fungal-like organism *Phytophthora ramorum* (*P. ramorum*) which has caused widespread death of a wide range of trees and shrubs (Welsh Government, 2019). *P. ramorum* is regulated under the Plant Health (Forestry) Order 2005 and Plant Health (Wales) Order 2018 (Welsh Government, 2005; Welsh Government, 2018b). Due to the large scale, economic, social and environmental impact on larch a specific Welsh strategy has been adopted. A specific strategy was needed to achieve the objectives laid out by the Plant Biosecurity Strategy for Great Britain 2014, the Environment (Wales) Act and the Wellbeing and Future Generation (Wales) Act 2015 (DEFRA, 2014; Welsh Government 2016; Welsh Government, 2015).

Decisions and changes to the strategy are made by the *Phytophthora* Operational Response Team (PORT) who advise with scientific understanding, risks and overall management. The *Phytophthora ramorum* strategy for Wales aims to monitor the spread of the disease, ensure the management is effective and encourage the management of larch woodlands in Wales. Measures are achieved by statutory plant health notices that require the felling/ killing of infected larch by a specified date as well as restricting the movement of infected material.

6. Tree pests and diseases in British woodlands

Forest and woodland structures are complex and diverse, changing over time with environmental management able to predict, monitor and where appropriate facilitate these changes (Pautasso,

Schlegel and Holdenrieder, 2015). However, habitat fragmentation, overexploitation and in some cases lack of management, are exposing trees and making them more susceptible to detrimental pests and diseases impacting tree health and forest ecosystem functioning (Davis et al., 2014; Roberge et al., 2011). Concurrently there have been observable increases in the introduction of exotic pests and diseases in UK forests in recent decades (Boyd et al., 2013; Potter and Urquhart, 2017). This is attributed to globalization (movement of woodland materials), climatic change and subsequent frequent extreme weather events (Ramsfield et al., 2016; Roux and Ham, 2020; van Lierop et al., 2015). Over time the same aforementioned factors are also expected to affect the behaviour of established, relatively well managed, threats so environmental managers will need to be able to adapt (Lawrence and Marzano, 2014; Linnakoski et al., 2015; Potter and Urquhart, 2017). Therefore, with more introductions of tree pests and diseases occurring, and forests becoming increasingly vulnerable when exposed to these threats, significant detrimental impacts could occur (Evans, 2019).

Furthermore, Anderson et al., (2004) argue that pest and disease outbreaks remain one of the most underestimated causes of anthropogenic environmental change. This concern is acknowledged in British policy but is often under-represented and action is underfunded and under-resourced (Marzano, Fuller and Quine, 2017; Tomlinson, Potter and Bayliss, 2015; Welsh Government, 2018a). Pests and pathogens currently of threat in the UK are from varying origins, with some native insects and microbes expanding their range due to climatic factors or adapting to detrimentally impact non-native tree species (Simler-Williamson et al., 2019; Lehman et al., 2020). Other issues occur when alien invasives attack novel hosts or impact native species in new environments (Ramsfield et al., 2016; Liebhold et al., 2017).

There are two main overarching approaches to active management of pests and diseases observed in the UK; preventing or removing pests and diseases that are yet to establish and monitoring, isolating and slowing the spread of those that cannot be eradicated (Marzano, Fuller and Quine, 2017; Tomlinson, Potter and Bayliss, 2015). These approaches can be achieved effectively through biosecurity controls at borders, early detection, eradication or containment alongside coordinating stakeholder action (Marzano, Fuller and Quine, 2017). Increasing occurrences of tree pest and disease introductions in recent decades have resulted in some of these threats establishing and spreading across British woodlands consequently reshaping forest landscapes through detrimental impact or as a result of management intervention (Potter and Urquhart, 2017; Wingfield et al., 2015). Evidence suggests that pests and diseases are not only affecting single-species plantations but are having a significant impact on both native forest systems and urban tree landscapes (Marzano, Fuller and Quine 2017; Roux and Ham, 2020; Tomlinson, Potter and Baylis 2015).

Therefore, effective strategies against tree threats, adaptable in a variety of contexts by a range of woodland stakeholders, are an important element for minimising damage to forest health and subsequently reducing the many services woodlands provide to society (Ayres and Lombardero, 2018; Chadès et al., 2017; Jactel, Koricheva and Castagneyrol, 2019; Shea et al., 2002; West, Beilin and Wagenaar, 2019). Recent outbreaks of Ash dieback, Oak Processionary Moth, and Asian Longhorn Beetle have demonstrated interdisciplinary collaboration and mobilisation of stakeholders alongside wider policy to support it are crucial in the fight against pests and diseases in British woodlands (Heuch, 2014; Tomlinson, Potter and Bayliss, 2015).

6.1 Tree pests and diseases in Welsh woodlands

Climate change and extreme weather events, and their facilitation of the introduction and establishment of tree pests and diseases, are bringing additional challenges to Welsh woodland managers (Meyerson and Mooney, 2007; Ramsfield et al., 2016; Teshome, Zharare and Naidoo, 2020). There are currently several invasive and non-native tree pests and diseases that are affecting woodland managers' ability to manage sustainably and reach the desired outcomes outlined by the Woodlands for Wales Strategy (Welsh Government, 2018a). Welsh woodlands are under threat from several tree pests and diseases most notably ash dieback and *Phytophthora ramorum* (Welsh Parliament, 2021). More in-depth analysis of these tree pests and diseases can be found in the following section. Management of tree pests and diseases currently takes a strategic and targeted manner at the landscape scale but the increase of overall forest resilience is widely encouraged in the fight against tree pests and diseases (Welsh Government, 2018a). The Welsh Government (2018a) acknowledges the increased threat from tree pests and diseases and is actively encouraging collaborative management approaches to mitigating the impact of tree pests and diseases. Furthermore, the aim is to provide a network of forest stakeholders that are comfortable about sharing success and lessons learnt from tree pests and disease experiences, which is believed will lead to higher standards of environmental stewardship throughout Wales (Welsh Government, 2018a).

6.2 Distribution and management of tree pests and diseases

Below is a brief overview of some notable woodland pests and diseases that have impacted British woodlands exhibiting different characteristics, impact and management requirements (Porth, Dandy and Marzono 2015). Increased pest and disease introductions have been accompanied by an observable improvement in pest and disease detection through remote sensing technology and microscopy analysis (Potter et al., 2011; Yuan et al., 2017). This has been matched with progress by forestry stakeholders working collaboratively against detrimental

threats with investment in research, more prominence in plant health policy and working with woodland managers to enhance silviculture strategies (Marzono, Fuller and Quine, 2017; Welsh Government, 2018a).

However, communicating and implementing resilient strategies in practice remains challenging due to financial constraints and a lack of resources (Marzono, Fuller and Quine 2017; Tomlinson, Potter and Bayliss, 2015). Furthermore, it is acknowledged that these strategies are often significantly hampered by the lag times between infection and visible symptoms on trees so even with the best management strategies substantial damage can already have occurred undetected for some time (Brasier, 2008). It is important to note that these pests and diseases are far from a conclusive list and more information can be found through the UK plant health services (Santini et al., 2013).

6.2.1 Dutch Elm Disease (DED)

Elm trees are a defining feature of British lowland landscapes with high ecological and cultural value (Potter et al., 2011). The Dutch Elm disease outbreak during the '60s and '70s destroyed more than 28 million trees and was identified as one of the most damaging environmental events in British woodlands in recent times (Tomlinson and Potter, 2010). Despite Dutch elm disease being known to woodland managers, well-established and relatively stable in the UK up until this point it was confirmed by later analysis (which was not available at the time) a more virulent form had been unknowingly introduced from North America (Brasier and Gibbs, 1973). The impact was devastating and relatively few mature elm trees managed to survive causing widespread public outcry (Potter et al., 2011). Many researchers have analysed the devastation caused and concluded the outbreak was met with a sense of complacency following the relatively low impact of the previous strain and management responses being delayed, under-resourced and underfunded (Potter et al., 2011).

This is of course the benefit of hindsight but the outbreak now forms a useful benchmark for current and future management strategies of not only Dutch Elm disease but other pests and diseases in British woodlands (Tomlinson and Potter, 2010). Dutch elm disease still poses a threat today, particularly in rural areas where monitoring is increasingly difficult and the promotion of healthy populations as a preventative measure is a priority (Bowditch and MacDonald, 2016). In areas where Dutch elm disease can be monitored, programmes implement prompt sanitation felling and burning of infected trees before a new generation of beetle can emerge during the

springtime (Bruin et al., 2013). Dutch elm disease is currently present in all parts of the UK including Wales (Forest Research, 2022).

6.2.2 Dothistroma Needle Blight (DNB)

Dothistroma needle blight (DNB) is widely distributed across the UK and affects trees in both plantations and natural woodlands, leading to the death of foliage, reduction of tree growth and sometimes widespread death of native *Pinus* species (Brown and Webber, 2008). The overarching management approach is reducing its impact through silvicultural manipulation, the use of chemical and biological agents as well as legislative measures as it can no longer be eradicated (Marzano, Fuller and Quine, 2017). Preserving the ecological value of Caledonian pine forests and the potential for the disease to spread to other commercial pine species make Dothistroma Needle Blight a management priority (Brown and Webber, 2008). The disease has been found in most parts of the UK and is found in Corsican pine stands (Forest Research, 2022).

6.2.3 Asian Longhorn Beetle (ALB)

The Asian Longhorn Beetle (ALB) is an insect of wood-boring nature, native to Eastern Asia, known to cause widespread tree mortality (MacLeod et al., 2002). Asian Longhorn Beetle outbreaks are of particular concern because the pest favours mature broadleaf trees and has been found to affect dozens of tree species (Haack et al., 2010). Asian Longhorn Beetles are likely to have been introduced into the UK through wood packaging and a rapid programme of 'sanitation felling' was implemented, similar to the action shown in North America and elsewhere in Europe (Palmer et al., 2014). Whilst the management was rapid and extensive, with detrimental social and economic impacts, the management response appears to have achieved eradication of the pest thus far (Porth, Dandy and Marzano, 2015). Asian longhorn beetles are not known to be present in the UK but an outbreak in Kent in 2002 was actively managed and the pest was successfully eradicated (Forestry Commission, 2022).

6.2.4 Oak Processionary Moth (OPM)

Oak Processionary Moth is an insect pest which has long been established in mainland Europe but was found in the UK for the first time in 2006 (Tomlinson, Potter and Bayliss, 2015). It is known to cause the defoliation of oaks which significantly weakens affected trees leaving them vulnerable to other stressors (Battisti et al., 2015; Groenen and Meurisse, 2012). Oak Processionary Moth also poses a public health risk with the caterpillar hair causing skin and respiratory irritation (Rahlenbeck and Utikal, 2015). By 2010 a policy of containment was adopted to minimise the

spread of the pest, whilst nest removal and chemicals spraying was suggested as the most appropriate management (Tomlinson, Potter and Bayliss, 2015). Oak processionary moth is established in the UK in Greater London and South East England but is not currently found in forests and woodlands outside of this area or in Wales or Scotland (Forestry Commission, 2022).

6.2.5 Ash dieback

Ash dieback is a disease caused by a fungal pathogen native to Asia that can cause bark lesions, leaf loss and crown dieback primarily to European ash, resulting in a high proportion of infected trees dying or becoming severely weakened and therefore susceptible to other threats (Skovsgaard et al., 2017). In the UK ash is the third most common broadleaf species and can grow in a range of habitats, withstanding significant climate changes (Pautasso et al., 2013). Ash has substantial environmental value and the management approach involves continuing to try to slow the spread of disease and where possible isolate infected material (Marzono, Woodcock and Quine, 2019). Current recommended management involves enhancing biosecurity controls, reforestation with alternative species, and the potential production of resistant ash species (Vasaitis and Enderle, 2017; Woodcock et al., 2018). Ash dieback is widespread throughout the UK, but there is significant ash dieback discovered throughout Wales and most recently the disease has been prevalent in North Wales (Forestry Commission, 2022).

6.2.6 Ash dieback in Wales

As outlined by Welsh Parliament (2021), ash dieback is one of two diseases causing significant problems for Welsh woodland managers. Ash dieback was first recorded in Wales in November 2012, nine months after being detected in England. Ash trees make up 6% of forest cover in Wales and ash dieback is more widespread across Wales than in any other UK nation. Since January 2020 ash trees can be imported from the EU and transported within Great Britain only under plant health regulations. An ash dieback action plan was established by the Wales Tree Health Steering Group in 2016. It states no ash should be planted in Wales with alternative broadleaf species preferred and remaining ash trees should be managed for public safety. The Forestry Industry Recovery Scheme gives specific support to forest managers undertaking tree safety work for trees affected by Ash dieback.

6.2.7 *Phytophthora ramorum*

The invasive pathogen *phytophthora ramorum* was responsible for the cause of sudden oak death in North America (Frankel, 2008). It has spread across Europe and since 2003 it was found

infecting rhododendron and woodland trees in Britain (Brasier et al., 2005). Infections remained relatively low until 2009 when extensive mortality was observed in juvenile plantations of Japanese larch where discolouration of needles and bleeding on trunks were observed (Webber et al., 2010). This pathogen is of great concern because it spreads rapidly and can cause substantial damage to commercial larch plantations (Lawrence and Marzano, 2014). Currently, there are no chemical treatment and felling of all infected trees are required including uninfected trees within an additional buffer zone radius (Harris and Webber, 2016). *Phytophthora ramorum* has been found throughout the UK but prefers Western wetter regions demonstrating prevalence throughout Wales and spreading across the country (Forestry Commission, 2022).

6.2.8 *Phytophthora ramorum* in Wales

The Welsh Parliament (2021) considers *Phytophthora ramorum* as the second of the two tree diseases causing substantial problems for Welsh woodland managers. The disease is present in all UK nations but is most prevalent in the South of Wales and the South West of England. The total area of larch in Wales was approximately 23,105 ha and in 2019 more than 20% of Wales's larch forests had been infected by *Phytophthora ramorum*. In 2019 a Welsh Government strategy was implemented identifying two core disease zones and a disease limitation zone with targeted strategies to mitigate the spread of the disease. Natural Resources Wales also has the power to serve Statutory Plant Health Notices requiring forest owners to fell infected larch trees. The Welsh Government aims to encourage the restocking of areas felled due to larch disease with a broader and more diverse range of tree species.

6.2.9 Emerald Ash Borer (EAB)

In addition to the aforementioned species, there are several future threats to British woodlands (Marzano et al., 2020). The most notable is Emerald Ash Borer a recently discovered exotic insect pest which is notoriously hard to detect until it has caused significant damage to ash tree species exhibited across North America (MacFarlane and Meyer, 2005). It is managed through extensive surveillance, a mixture of preemptive felling, chemical treatment and biological control which all have significant costs to public bodies and individual landowners (Marzano et al., 2020). Now it has reached Europe and British borders it is considered an imminent threat to already vulnerable ash species (Musolin et al., 2017). Emerald Ash borer is not yet present in the UK but is spreading across mainland Europe and its rapid spread poses a significant threat to British forests if introduced (Forestry Commission, 2022).

7. Stakeholders of tree health

Dandy et al., (2017) identify five categories of tree health stakeholders; vectors, governors, managers, monitors and networkers. These are essentially any individual or organisation that can affect, or be affected, by a forest pest or disease and involvement changes over time (Dandy et al., 2017). Currently, there are several human pathways through which pests and diseases can spread across woodlands and many different people (workers moving between sites, visitors and tourists) can act as vectors (Potter and Urquhart, 2017). Government bodies suggest and enforce plant health regulations although substantial woodland cover means in practice these regulations are not always enforceable (Tomlinson, Potter and Bayliss, 2015). The monitoring and detection of diseases in woodlands are notoriously difficult and there is often uncertainty about whose responsibility this should be, with financial resources limited (Marzano et al., 2020; Tomlinson Potter and Bayliss, 2015).

Networkers are important stakeholders who disseminate information to the forestry sector (Lawrence and Dandy, 2014). Woodland managers are becoming increasingly important as more threats enter and establish British woodlands acting on the ground to mitigate the impact. All of these tree health stakeholders have dynamic and interconnecting relationships combatting and minimising the impact of tree health concerns. Furthering the understanding of forestry stakeholders and their relationships can lead to improved interventions to better prevent or control future outbreaks of pests and diseases. As such the sector has begun taking stakeholder analysis and engagement far more seriously (Dandy et al., 2017).

7.1 Woodland managers

Woodland managers (tree health stakeholders) are individuals that possess the specific skills and capabilities to deal with a tree pest or disease outbreak (Dandy et al., 2017). Their attitudes and actions are increasingly recognised as an essential component of environmental management, particularly with reference to mitigating threats (Dandy et al., 2017; Marzano et al., 2020). Action taken by woodland managers on the ground can act as the first line of defence for mitigating the impact of tree pests and disease. Woodland managers can monitor and report outbreaks and carry out management activities that minimise impact across wooded areas (Marzano et al., 2020; Tomlinson, Potter and Bayliss, 2015). Therefore it is critical to understand the actions taken by woodland managers and the factors that influence their decisions.

In a British context, more than two-thirds of British woodland is privately owned, with the majority owning holdings of less than 10 hectares in size (Forest Research, 2016). Private woodlands are not always managed by the people who own them, but by agents who act as consultants providing

advice and services (Lawrence and Dandy, 2014). In cases where agents are managing woodlands, some management decisions may be seen as a reflection of woodland owners' wishes within the remit of British woodland regulations. Moreover, many of these decisions are made from their own expertise and experience. The use of agents and the complex landscape of private woodlands make influencing the decision-making of private woodland managers, particularly challenging, so governmental bodies focus on the provision of grants and advice (Lawrence and Marzano, 2014).

In the UK, there is no requirement to produce woodland management plans, therefore, there is often limited knowledge about private woodland health despite them having the largest spatial impact on pest and disease management over time (Marzano and Lawrence, 2014). Research has established that private woodland managers are not homogeneous and that behaviour and approaches to management vary (Ambrose-Oji et al., 2020). This is based on individual characteristics of managers (e.g. attitudes, motivations and management objectives) as well as contextual structural factors such as size, wider policy support or markets (Andersson, Keskitalo and Lawrence; 2017; Khanal et al., 2017). Understanding the characteristics of woodland managers can suggest how private woodland managers may respond to woodland threats and adoption of resilient practices in the future (Eriksson, 2018).

There is currently limited literature detailing the role of woodland managers are playing in tree health in Wales. There is even less consideration for the role private and third-sector woodland managers may play in tree health management outside of commercial enterprises. This review takes a closer look at the role woodland managers from these sectors play when faced with tree pest and disease outbreaks in the UK, with reference to Wales specifically where possible. Woodland managers in these sectors are of particular interest because they are responsible for managing large areas of woodland in Wales but action is rarely documented. Lying outside of both government jurisdiction and traditional commercial capacity it is largely undocumented what influences the management of these woodlands and to what extent they deviate from recommended guidelines and policy.

Moreover, organisations such as conservation charities that manage these woodlands are well respected by the public and are often observed providing advice and support to other landowners. This suggests that these woodland managers could have a potentially overlooked role in the management of tree pests and diseases across Wales.

8. Review justification

This review forms an initial response to the request by Forest research to further the understanding of management approaches undertaken to mitigate the impact of tree pests and diseases in Wales.

Identifying knowledge gaps in stakeholder responses will also direct further primary research in this area conducted by Forest Research and Bangor University. The review aims to collate empirical research currently available, detailing management responses and the factors that influence decisions. As outlined above (see 7.2) the review aims where possible to consider management responses that may be potentially undervalued and/or overlooked in the third sector or private sector that are not entirely managing woodland for commercial purposes. Analysis of the current literature aims to address the links between different characteristics, contextual and structural factors and observed management decisions. The review also aims to highlight any barriers that prevent managers from taking decisions they would want to when faced with an outbreak and how behaviour changes over time.

The publishing of multiple reviews about pest and diseases have produced informative literature about 'benchmark' management strategies and the policy available to support them that would mitigate the detrimental impact in British woodlands (Ayres and Lombardero, 2018). However, there remains relatively little literature about how closely these strategies are followed in practice and in which circumstances they may be adapted, substituted or even omitted by woodland managers (Marzano, Fuller and Quine, 2017). In the case of ash dieback understanding the third sector and non-commercial management is of interest because ash has high cultural and biodiversity value but less economic value to other species (Marciulyniene et al., 2017). There are several best practice guidance documents published by The Tree Health Council (2020) and Forest Research (2022a), as well as overarching policy (Welsh Government, 2016). Alongside this, there is a number of evidence-based recommendations predominately from experience in Europe as ash dieback has spread rapidly west from Poland since 1992 (Bengtsson and Stenström, 2017). However, again there remains relatively little literature about how closely these strategies are followed in practice.

The review will build on current work by Lawrence and Dandy (2014) and more recently Ayres and Lombardero (2018) which argue management of pests and diseases in the UK remains relatively understudied particularly in peer-reviewed studies. Thematically this review paper builds directly on Lawrence and Marzano's (2014) research which concludes that private woodland managers are a significant stakeholder in tree health management and are more concerned about tree threats than any other management challenge. However, it potentially identifies that private woodland management with regards to tree health could be currently simplified and management approaches may vary substantially based on third-sector and non-commercial woodland motivations.

Methodology:

This review will focus on management behaviour when faced with tree pests and disease outbreaks in a British woodland context. It will provide a foundation for the current literature available on the topic as well as identify gaps to direct a future qualitative study looking at the management action of Welsh woodland managers. This research is being conducted as a result of a collaborative partnership between Bangor University and Forest Research funded through the European Social Funded KESS 2 East programme.

The review itself does not aim to produce an evaluation of which management measures produce the best outcomes when faced with tree pests and diseases. Moreover, it aims to gain a better understanding of the actual actions taken (or not taken) by woodland managers during outbreaks. Furthermore, it aims to gain an understanding of the reasoning behind particular actions (or lack of action) with reference to manager characteristics, contextual and structural influences and how these influences can cause changes in management over time.

The review methodology was developed from Lawrence and Marzano's (2014) ad-hoc literature approach screening relevant peer-reviewed papers through databases containing scientific journals books and conferences. The initial search and screening of this review were conducted by selecting relevant articles from a collection of databases: Web of Science (WOS), Science Direct (SD), Science Tech Premium Collection and Google Scholar a freely accessible web search engine.

It was identified by initial background research that the interdisciplinary and collaborative approach to pest and disease outbreaks and the social dimension of management behaviour, the use of the different databases allow research published within biological, geographical and social disciplines would be identified to produce the most comprehensive review.

Forest Research outlined their requirement to understand the management behaviour when faced with tree pests and disease outbreaks, the factors that influence this behaviour as well as factors that change behaviour over time. Therefore the concept of 'adaptive strategies for the management of invertebrate pests and diseases in Wales' was identified as the key concept for the purpose of this review. This concept was analysed and expanded to find broader, related, terms (synonyms or closely related terms e.g. forest, woodlands) that provided studies that provide evidence for management behaviour, when faced with pest and disease outbreaks. Selection was then narrowed by combining associated search term combinations to yield more relevant results.

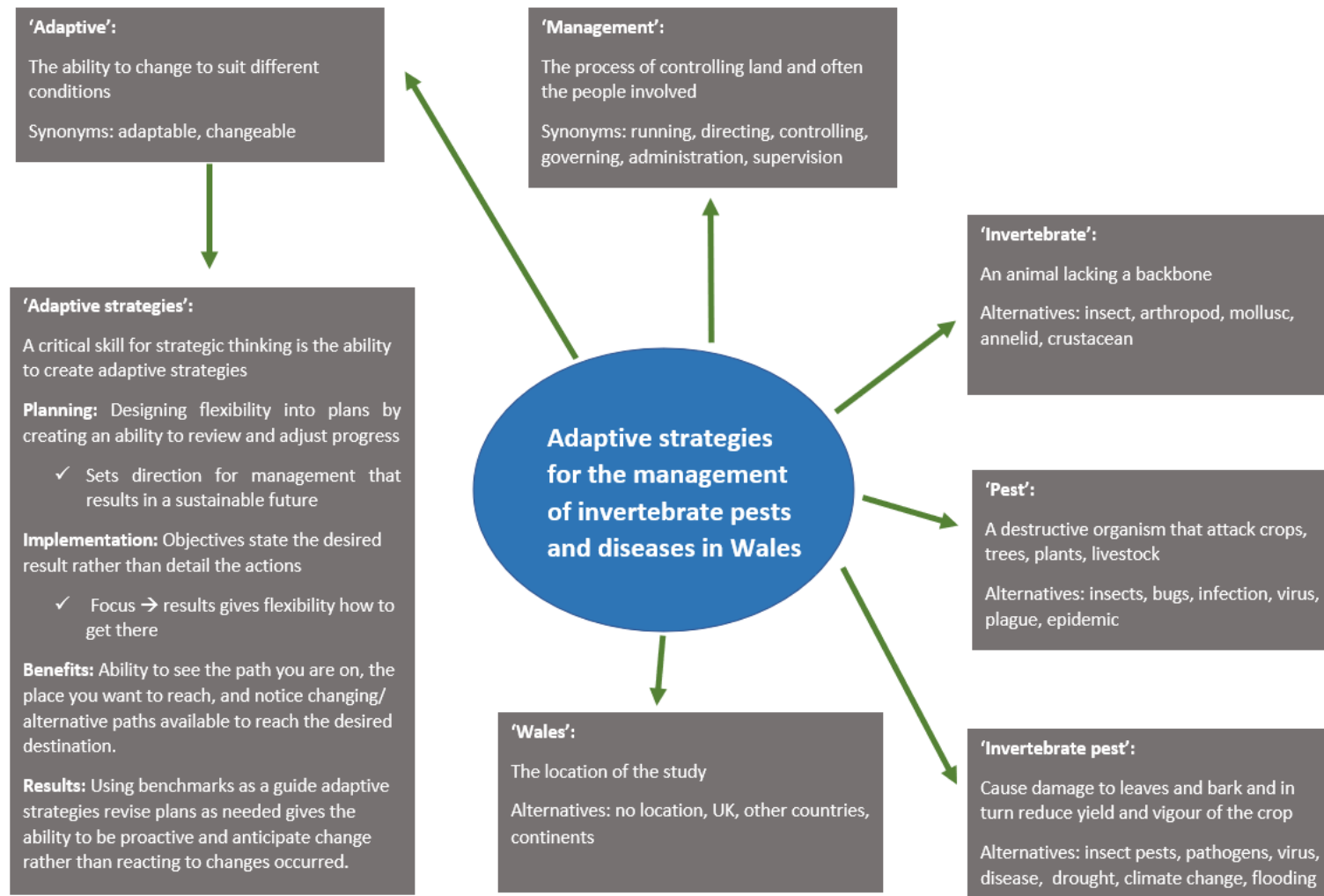


Figure 1. Demonstrates the process of expanding the key concept of the review by analysing broader concepts and narrowing searches by associated search term combinations.

The initial search, using terms outlined above (see figure 1), returned many results that demonstrated the spread of pest and disease outbreaks, ‘benchmark’ strategies of management and detection techniques (Ayres and Lombardero, 2018; Brown and Webber, 2008; Yuan et al., 2017). There were far fewer search returns about management behaviour, and papers were screened for relevance – with some cases providing perceived behaviour of woodland managers through key informant perspectives (Lawrence and Marzano, 2014) as well as direct behaviour detailed (Marzano, Fuller and Quine 2017). To screen and select the papers involved in this review systematically, an eligibility

Table 1. Demonstrates the inclusion criteria that was used through advanced filters in databases and the screening process to select papers for review.

criterion was produced. Utilising a similar approach by Lawrence and Dandy (2014) ensures that the quality and relevance of each study are appropriate.

Inclusion criteria	Example of application
Relevance	Relevance-based database searches (figure 1) and screened by a researcher
Data	Empirical data, not modelling or literature reviews
Study design	Qualitative studies using interviews, focus groups or surveys accepted
Perspective	Focus on ‘actual behaviour’ or perceived behaviour observed through key informants
Peer reviewed	All articles chosen were peer-reviewed
Publication date	Material must be no more than 12 years old (approx.. last two decades)
Language	All languages were accepted
Geography	UK papers were selected with the inclusion of papers from abroad focusing on imminent threats not yet arrived in British woodlands

Due to the large amount of data returned, and the aim to create an in-depth literature review of management action against pests and diseases, the above inclusion criteria (see table 1) was implemented. Papers were initially considered through database searches (see figure 1) and screened by a researcher. The review aimed to analyse empirical qualitative data obtained through interviews, focus groups, and surveys that detailed actual management responses or perceived management behaviour through key informants when faced with pest and disease outbreaks.

The information quality from the papers selected was assumed through the peer review process of article publication, as suggested by Lawrence and Dandy, (2014). The papers included in the review

Table 2. The papers included in the literature review based on woodland managers experience with pests and diseases.

had been published within the last two decades which correlates with an observable increase in pest and disease outbreaks observed in British woodlands (Boyd et al., 2013; Potter and Urquhart, 2017). Papers of all languages were considered for screening and geographically focused on British woodland managers. However, the inclusion of two papers that demonstrated international management behaviour of Emerald Ash Borer (EAB) was deemed relevant as it is considered an imminent threat to British woodlands. Studies were excluded if empirical data were not described and studies like Tomlinson, Potter and Bayliss (2015), which had a number of associated papers, the main report was analysed. In total 11 papers were picked for core analysis that met the relevant criteria and Microsoft was used to systematically record the data selected.

Author	Date	Location	Sample size	Sample	Methods	Behaviour	Focus
Lawrence and Marzano	2014	North Wales, United Kingdom	12 (8 face-to-face, 4 telephone)	Key informants (providing advice to the private forest sector)	Interviews (Semi-structured)	Perceived	Adapting to climate change
Marzano, Fuller and Quine	2016	United Kingdom	26 (6 face-to-face, 20 telephone)	Woodland managers	Interviews (Semi-structured)	Actual	Managing DNB
Tomlinson, Potter and Bayliss	2015	London, United Kingdom	20	Woodland managers and plant health representatives	Interviews (Semi-structured)	Actual	Managing the OPM outbreak
Young et al.	2018	United Kingdom	12 (1 face-to-face, 11 telephone)	Key informants (Senior policy actors who can provide insights on	Interviews (Semi-structured)/ Focus groups	Perceived	Managing resilient forest

				resilience) and tree professionals			
Marzano, Woodcock and Quine	2019	United Kingdom	22 (telephone)	Woodland managers and advisors	Interviews (Semi-structured)	Actual	Managing ash dieback/ resistant ash
Ambrose-Oji et al.	2020	United Kingdom	44	Woodland managers	Interviews (Semi-structured)	Actual	Influences for adaption
Urquhart et al.	2017	United Kingdom	37 (ash dieback 21; OPM 16)	Experts in pest and disease outbreaks (scientists, policy, woodland managers)	Interviews	Actual	Risk assessments of outbreaks
Porth et al.	2015	Kent, United Kingdom	11	Local stakeholders (residential owners, civil servants)	Interviews (Semi-structured)	Actual	Eradication of ALB
Marzano et al.	2016	Europe	392	Tree professionals (livelihood – forests)	Questionnaire survey	Actual	Awareness of pests and pathogens
Marzano et al.	2020	USA	12	Key informants with EAB experience	Interviews/ consultation	Perceived	Management of EAB
Mackenzie and Larson	2010	Canada	17 (face-to-face)	Local woodland owners/ managers	Interviews	Actual	Rapid response programmes

Background research by Marzano, Fuller and Quine, (2017) suggests that literature regarding woodland management behaviour, when faced with pests and outbreaks, is limited. This is represented in the selection of only 11 articles matching the eligibility criteria for analysis for this review.

This review does not suggest that every paper that meets the eligibility criteria is included for analysis due to time constraints. However, when the studies were analysed, it appeared that new themes were no longer emerging and that saturation of information had been achieved (Bryman, 2016). The papers all use qualitative data, with all but 1 paper using some form of interview technique to provide information about management behaviour. Some studies do mention the use of supplementary information to help demonstrate the management of an outbreak over time (Marzano et al., 2020; Tomlinson, Potter and Bayliss, 2015).

Of the papers selected, nearly three-quarters contain behaviour data by managers but just under a quarter of papers are through key informants who are believed to have a good knowledge of woodland manager behaviour (Young et al., 2018). It is important to note that the perceived behaviour of experts doesn't always equate to what managers are actually doing, but given the lack of literature in this area they are considered a relatively good source of information on woodland manager activity but this limitation should be taken into consideration in the following analysis (Lawrence and Marzano, 2014). Finally, in the following analysis, these papers are not meant to be directly compared but do provide invaluable insight into the available information about woodland manager behaviour regarding pest and disease outbreaks.

Results and discussion

The following analysis of papers eligible for review detail management experience of pests and disease outbreaks considering action and impact within a British context. This in-depth review reaffirms Porth et al., (2015) findings that understanding lived experience of managing pest and disease outbreaks over time is an under-researched component of plant health management within a forestry context. It also highlights the importance of carrying out further research in this area, to consider the role woodland managers have on the ground in managing pests and disease outbreaks (Lawrence and Marzano, 2014; Marzano, Fuller and Quine, 2017; Marzano, Woodcock and Quine, 2019; Tomlinson Potter and Bayliss, 2015; Young et al., 2018). With observable increases in pests and diseases in British woodlands, and the detrimental impact they have on the services woodlands provide to society there is an increasing demand to understand and influence woodland managers' decisions (Lawrence and Marzano, 2014; Marzano, Fuller and Quine, 2017; Tomlinson, Potter and Bayliss, 2015; Young et al., 2018; Ambrose-Oji et al., 2020; Urquhart et al., 2017; Porth et al., 2015; Marzano et al., 2016).

There are several management options against threats and diseases, and the options taken by woodland managers can be attributed to their awareness, understanding and value of plant health issues as well as contextual and structural influences (Ambrose-Oji et al., 2020; Lawrence and

Marzano, 2014; Marzano, Fuller and Quine, 2017; Tomlinson, Potter and Bayliss, 2015; Marzano et al., 2016). To influence management action it is therefore important to understand what management action decisions are taking place in practice on the ground and the factors that affect these decisions (Lawrence and Marzano, 2014; Marzano, Fuller and Quine, 2017; Marzano, Woodcock and Quine, 2019; Marzano et al., 2020). Therefore this review identifies and assigns thematic information within four main topics: woodland manager characteristics, structural and contextual influences, management approaches and barriers to implementing management strategies to further the understanding of management action during pest and disease outbreaks over time (Ambrose-Oji et al., 2020; Marzano, Fuller and Quine, 2017; Tomlinson, Potter and Bayliss, 2015).

1. Managers' characteristics, motivations and objectives

There are often difficulties in identifying and understanding the motivations of woodland managers for managing woodlands and the objectives they hope to achieve. This is because the private woodland manager landscape is complex and hard to access and there is no requirement for woodland managers to produce management plans that detail this information (Lawrence and Marzano, 2014; Tomlinson, Potter and Bayliss, 2015). However, Lawrence and Marzano (2014) acknowledge that woodland owners and managers are diverse in both objective and motivation. Understanding their motivations to manage woodlands are important because motivation is a psychological phenomenon (affected by several internal and external factors) forming the driving force for translating woodland managers' thoughts, feeling and ideas into management action. Better understanding can give a more thorough insight into management action and how to influence future management action (Ambrose-Oji et al., 2020; Lawrence and Marzano, 2014; Marzano et al., 2016; Marzano, Fuller and Quine, 2017; Porth et al., 2015; Tomlinson, Potter and Bayliss, 2015; Urquhart et al., 2017; Young et al., 2018).

Lawrence and Marzano (2014) identified six types of woodland owners, exhibiting different motivations for managing woodlands: forest management companies (motivated by profit), farmers (not particularly motivated to manage woodlands, predominately on land that can't be used for agriculture), private traditional estates (forestry management often secondary to other objectives – e.g. hunting), weekend woodlanders (a place to enjoy with family, an interest in woodlands but relatively little management experience), community groups (focus on local wellbeing) and individual investors (drawn by tax incentives). Motivation can suggest what objectives different woodland managers aim to achieve from community groups focusing on the production of native woodlands rich in diversity, in some cases unmanaged (Lawrence and Marzano, 2014; Tomlinson,

Potter and Bayliss, 2015) compared with forest management companies producing intensely managed Sitka spruce plantations (Ambrose-Oji et al., 2020; Marzano, Fuller and Quine, 2016).

Moreover, Ambrose-Oji et al., (2020) suggest that woodland managers' objectives and subsequent action can be attributed to an interlinked combination of manager motives (e.g. beliefs, worldviews) and structural factors (e.g. woodland size) and contextual factors (e.g. market demands). Ambrose-Oji et al., (2020) found woodlands greater than 50ha were identified as largely managed for timber objectives (profit-based motives) or enterprise-based objectives (using private and public goods from woodlands to make a profit) demonstrating a DSP (dominant social paradigm) worldview, with managers suggesting little is done to plan against threats, and meeting market demands requires growing more and larger areas of single species (Ambrose-Oji et al., 2020). This goes against research by Young et al., (2018) which suggests there is some manager support planning for pests and disease outbreaks by managing resilient forestry systems which would allow commercial plantations to withstand outbreaks and supply the demand sustainably.

Ambrose-Oji et al., (2020) identified small to medium-scale woodland managers (less than 50ha) were predominately multifunctional (actively managing land for private and social benefits) and eco-centric managers (managing for ecological benefits) and tend to hold a NEP (new ecological paradigm) worldview with many managers considering the impact of forestry material but also the impact on the planet. Interestingly, for the smallest of British woodlands (less than 5ha) whilst managers exhibited a NEP worldview there were elements of the DSP worldview evident. As many of the woodlands in the UK are small and diverse this could be a key area to understand the characteristics, motivations and objectives of these managers and their subsequent behaviour (Ambrose-Oji et al., 2020; Lawrence and Marzano, 2014; Tomlinson, Potter and Bayliss, 2015).

2. Managers' awareness and concerns for tree health

Concerns over tree health in the UK have increased dramatically in recent years with the introduction and spread of several pests and diseases (Marzano, Fuller and Quine, 2017). Young et al., (2018) suggests that woodland managers feel that proactive management to achieve resilience against several external threats (e.g. climate change, storms, floods) is important for protecting woodlands from the entry and establishment of pest and diseases. The most cited concern is changes in climate which cause stress and subsequent vulnerability to trees, stands and forests which have led them to being more vulnerable to established and new threats (Young et al., 2018). This finding was partly disputed by Lawrence and Marzano (2014) who found that despite the mixed landscape of woodland managers, the majority have low levels of concern about climate change; with the exception of conservation-focused managers, but the concern for pests and diseases is clear.

However, this disparity in views may be attributed to how some managers consider the impact of threats identified and how they understand any potential causal links between them (e.g. climate change leads to enhanced drought which leads to stressed trees leaving them more susceptible to pest and disease outbreaks). Alas, the key theme remains, respondents are largely focused on tree health regardless of the cause even if they are not yet reacting to it (Lawrence and Marzano, 2014). Furthermore, a manager from Young et al., (2018) study suggests a reason for the focus on pests and diseases at the management level over other threats is because you can plan for climate change in 50 years but outbreak threats are imminent and managers for the most part deal with the here and now so there is a forest standing in the future.

Marzano et al., (2016) concluded that the majority of respondents believe that further introductions of tree pests and diseases are likely. Porth et al., (2015) suggest woodland managers and owners were aware of pest and disease outbreaks globally and knowledge of the detrimental impact they could have. This motivated many woodland owners and managers to follow eradication plans or manage their land to remove pests and diseases despite the personal loss of losing trees on their land (e.g. negative impact on their business). Marzano and Lawrence (2014) concluded that woodland owners and managers are also concerned locally about the threat of pests and disease and consider outbreaks an imminent threat to the woodlands they manage highlighting the devastating impacts *Phytophthora ramorum* has had on Welsh forestry.

Marzano et al., (2016) suggested tree professionals have modest knowledge and awareness of pests and diseases and in general less than a quarter of tree professionals feel they know a lot about pests and diseases. This was confirmed by Young et al., (2018), who determined that there was limited knowledge about how pests and diseases were introduced into woodlands. Some individuals identified imported wood as the key entry pathway for insect pests and live plants for imported pathogens. Marzano, Fuller and Quine (2017) concluded that managers were aware that when trees become stressed they are more likely to be susceptible to pests and diseases and stressors can be linked to high-density stocking, site conditions, under management and external factors such as weather. Managers of Dothistroma needle blight had limited knowledge of how the disease spreads with some citing wind dispersal and infected stock (Marzano, Fuller and Quine 2017).

However, Young et al., (2018) suggested that managers did demonstrate an awareness of how pests and diseases spread through the unregulated plant material and acknowledged the lack of diversity of trees planted leading to more damaging impacts of pests and diseases and non-native tree species were perceived to have invasive potential to act as vectors for disease. Urquhart et al., (2017) support both papers in suggesting that there was a disparity in the awareness and understanding of

the spread of diseases and this can be attributed to manager demographics. Marzano et al., (2016) suggest that British tree professionals have the most knowledge about ash dieback and the least about Emerald ash borer. This could be attributed to the fact emerald ash borer is not yet in the UK and knowledge can be linked to management experience (Marzano et al., 2020). This can be supported by Marzono et al., (2016) findings that knowledge and awareness of pests and diseases rise with age, time in woodlands, and experience.

Young et al., (2018) highlighted that whilst most woodland managers believe a proactive stance against pests and diseases is necessary, terminology within management often caused confusion. 'Resilience' was used the most by woodland managers to describe the concept of preventing the entry and establishment of pests and diseases into forests but there was contradicting views about how easily the concept was understood and could be applied in practice with some suggesting that it was over complicated but others felt that the complex nature allowed the concept to be used and delivered in multiple contexts (Young et al., 2018). Furthermore, Marzano, Woodcock and Quine (2019) suggested that woodland managers preferred their own terminology to describe adaptive strategies when tackling pest and disease outbreaks and suggested techniques to create 'tolerant' species rather than 'resistant' species were important to them. This was because woodland managers want trees that can withstand threats because it is unlikely in practice for example ash trees will remain unaffected by ash dieback but the aim is for the impact to be minimised. Overall it is clear that language is important in the communication, education and mobilisation of woodland managers in tree health management, however, some woodland managers suggest using new or complex terminology doesn't automatically translate to management action (Young et al., 2018).

Marzano et al., (2016) indicated that the majority of tree professionals were considering pests and diseases within their management; purchasing plant materials from accredited sources with just less than two-thirds of tree professionals suggesting they would not buy imported plants. Lawrence and Marzano (2014) suggest a lack of knowledge and uncertainty about future risks and diseases influences the willingness of managers to take this action. Managers suggest that uncertainty around the value and future resilience of alternative species enhance the perceived risks of changing species, therefore, chose to remain with species they already know (Lawrence and Marzano, 2014). Urquhart et al., (2017) suggest tree experts are considering risk from attitudes and social-political and cultural views which change over time and are influenced by diverse information sources.

Marzano et al., (2016) suggest several factors, other than risk, play a part in management acting on concern about pests and diseases including, but not limited to, financial resources, lack of information, and perceptions of other people's behaviour. Overall there appears to be a strong

concern over the impact of pest and disease outbreaks with moderate awareness of the pests and diseases present in British woodlands (Lawrence and Marzano, 2014; Young et al., 2018). There still seem to be gaps in knowledge which limit what managers do to tackle pest and disease outbreaks but it appears there would be a willingness to learn (Marzano, Fuller and Quine, 2017; Urquhart et al., 2017). Even when awareness and concern for pests and diseases are high, there are several notable barriers that prevent effective management which need to be addressed in management plans and policy (Marzano et al., 2016).

3. Managers' attitudes to management of tree pests and diseases

Marzano, Fuller and Quine (2017) conclude that managers' attitudes and beliefs about tree diseases, and particularly how they perceive threats involved, are key factors in woodland management decisions. This review has highlighted the diverse attitudes and beliefs woodland managers have about tree pests and diseases, with several papers concluding management options taken when faced with outbreaks also varied as a result (Ambrose-Oji et al., 2020; Marzano et al., 2020; Tomlinson, Potter and Bayliss, 2015; Young et al., 2018). Tomlinson, Potter and Bayliss (2015) highlight that some managers believe tree health problems pose more of an issue in forestry areas where they can have an impact on commercial production but less in areas managed for biodiversity or recreation. Whilst in part this could be attributed to managers believing that tree health resources particularly offered by the government should be focused on commercial areas to protect market goods due to the perceived risks of adaptive management on these sites and associated livelihoods (Lawrence and Marzano, 2014; Tomlinson, Potter and Bayliss, 2015).

This view may also be supported by smaller non-commercial forest managers, particularly those who manage woodlands for biodiversity and public recreation. Ambrose-Oji et al., (2020) suggest that small non-commercial woodland managers believe that diversifying management approaches is an appropriate response to threats but this should occur as much as possible through natural processes facilitated by managers but the course of natural procession shouldn't be altered. However, Tomlinson, Potter and Bayliss (2015) also highlight, that still within an anthropocentric frame management attitudes shift when public health becomes a factor and management is considered a higher priority, particularly in urban areas and forests used for recreation.

Moreover, some woodland managers suggest that they already feel helpless against fighting pests and diseases due to the many ways in which they can spread and the detrimental effect they can have on a whole range of species (Young et al., 2018). This attitude is perhaps most concerning with the management preparation for mitigating the impact of new pests and diseases relying on the mobilisation of a complex landscape of woodland managers and the acceptance of management

approaches from other countries (Marzano et al., 2020; Tomlinson, Potter and Bayliss, 2015). The diverse range of attitudes regarding tree health management outlined above suggests that understanding the factors that influence management attitudes is one essential component for contextualizing management undertaken by woodland managers when faced with pest and disease outbreaks in woodlands.

3.1 Previous experience

Previous experience with pest and disease outbreaks affected managers' attitudes, risk perceptions and behaviour (Marzano, Fuller and Quine, 2017; Marzano, Woodcock and Quine, 2019; Marzano et al., 2020; Urquhart et al., 2017). Recollection of experience with pests and diseases varied from personal action and impact to media coverage and even childhood memories (Marzano, Fuller and Quine, 2017; Marzano, Woodcock and Quine, 2019; Urquhart et al., 2017). Marzano, Fuller and Quine (2017) stated that several woodland managers, after an experience with *Dothistroma Needle Blight*, concluded the disease was largely manageable with limited enhancement of silviculture management where possible. This suggests that managers are using, where possible, management techniques to bring the disease to suitable levels. Natural progression through the different seasons was noted as playing the biggest part in management control (Marzano, Fuller and Quine, 2017).

Several papers suggest managers consider the severity of current outbreaks and decide on management action based on past experience even if the pest or disease is different (Marzano, Woodcock and Quine, 2019; Marzano et al., 2020; Urquhart et al., 2017). Experience with Dutch Elm disease seems to have the biggest impact on current management decisions (Marzano, Fuller and Quine, 2017; Marzano, Woodcock and Quine, 2019; Urquhart et al., 2017). Marzano, Fuller and Quine (2017) suggest that woodland managers; with the exception of *Phytophthora ramorum*, consider that pests and diseases are spreading slowly across British woodlands. One manager reflected that Dutch Elm disease has taken his whole lifetime to spread from one area of the UK to another (Marzano, Fuller and Quine, 2017). This observed speed of spread has resulted, in potentially, a low perceived risk of pests and disease outbreaks and in some cases this risk is accurate (Marzano, Fuller and Quine, 2017). However, this could also be attributed to the long time frames associated with forestry and as a result a key barrier to mobilising managers to action.

On the other hand, Urquhart et al., (2017) suggest personal observations, recent experience of the Asian Longhorn beetle, and more distant memories of Dutch Elm disease, alongside media coverage, increased the concern managers had about the impact ash dieback. Moreover, those currently experiencing ash dieback that have also experienced mass species loss and associated ecosystem impact, particularly through Dutch elm disease, consider ash dieback a more imminent and serious

threat to native landscapes than those who have not had experience with Dutch elm disease (Marzano, Woodcock and Quine, 2019).

Overall this suggests that lived experience of pest and disease outbreaks particularly in recent times increase the concern for current and future pest and diseases (Marzano, Fuller and Quine, 2017; Marzano, Woodcock and Quine, 2019; Urquhart et al., 2017). The lack of concern over the speed of spread could also be attributed to long time frames associated with forestry and as a result a key barrier to mobilising managers to action. However, previous experience can be used effectively to direct the management of new pests and diseases. Marzano et al., (2020) found that managers of Emerald Ash Borer in an American context used the experience of successful preemptive felling of the Asian Long-horned beetle in the area which successfully eradicated increased participation in an eradication programme for Emerald Ash Borer.

3.2 Attitudes and proximity to outbreaks

Young et al., (2018) conclude that woodland managers' attitudes towards pest and disease outbreaks are influenced by both spatial and temporal scales. Marzano, Fuller and Quine (2017) suggest that the proximity of a pest or disease is a crucial component for influencing management attitudes and actions with forest managers less willing to adapt (often with costly processes) if they are not experiencing the detrimental impacts on their land. Marzano, Woodcock and Quine (2019) also conclude that attitudes towards pests and diseases, and proximity to outbreaks, are correlated. The closer a manager is working to the origins of the outbreak they have more experience with the loss of species and as a result, consider that particular pest or disease more of a threat than woodland managers located further away. This suggests that you would expect to see greater management action closer to the original outbreak site than in woodlands in other locations.

However, in some cases when a pest or disease becomes established and can no longer be eradicated, it might cause managers to feel helpless towards pest and disease outbreaks on their land and may undertake less management as a result (Young et al., 2018). In some cases where tree health resources are limited, and it is perceived that management would no longer 'be effective' agents and government bodies may shift their support to managers within a 'buffer zone' area therefore management actions can be location specific and influenced by the support available (Marzano, Fuller and Quine, 2017; Tomlinson, Potter and Bayliss, 2015). Some woodland managers argue that closer proximity to outbreaks demonstrates an increased perceived risk felt by woodland managers but does not minimise the actual risk of pests and diseases spreading across British woodlands (Marzano, Fuller and Quine, 2019; Young et al., 2018).

Managers argued that outbreaks should be tackled at the landscape scale and integrated land use management and diversification at all levels would make woodlands more resilient (Young et al., 2018). Furthermore, the influence of spatial scales on attitudes towards pest and disease outbreaks is important when considering how managers may be affected by carrying out obligative management action. Porth et al., (2015) and Marzano et al., (2020) conclude that global eradication programmes can be highly successful in the eradication of pests and diseases, however, this often has a significant detrimental impact on local people. Rapid eradication programmes are often produced and implemented quickly without consultation with woodland managers and often the management action required is obligatory (Mackenzie and Larson, 2010).

Rapid eradication programmes have been seen to affect the attitudes of woodland managers significantly, as the tradeoff between the removal of vast amounts of trees in local areas to prevent widespread damage across many woodlands throughout the country (Marzano et al., 2020). This was demonstrated in the outbreak of the Asian Longhorn beetle in the South of England whereby for the most part people with trees on their land understood the importance of felling but became disheartened when trees were removed even if the disease wasn't present (Porth et al., 2015). Despite the removal of trees being in a small geographic location, in this example, and the impact of eradication successful at a national scale, it is important to consider the negative social and cultural impacts of this programme on woodland managers.

3.3 Attitudes and proximity to outbreaks

Young et al., (2018) conclude that woodland managers acknowledge that dealing with threats in woodlands is challenging because of the long time frames associated. Marzano, Woodcock and Quine (2019) conclude that woodland managers can find the long time frames useful when planning against threats, suggesting with ash dieback that there would be 20–30 years to plan before the species would be at risk. This was also supported by woodland managers who suggest that most current pests and diseases spread sufficiently slowly enough that sufficient action can be taken within necessary timeframes to prevent large detrimental damage (Marzano, Fuller and Quine, 2017).

However, if the option was offered to manage more resistant species against pest and disease threats, those who supported these trees would want to access them as soon as possible (Marzano, Woodcock and Quine, 2019). Therefore despite the acknowledgement of long time frames, it appears, given an affordable and feasible option woodland managers would rather act now than wait for threats to arise. There are also notable increases in fast-spreading diseases and the potential for unknown pests to enter British woodlands that might not give managers such a time frame to act (Lawrence and Marzano, 2014; Marzano, Fuller and Quine, 2017).

Concurrently, managing woodlands across long timescales could become increasingly challenging with projected increased uncertainty, particularly through climate changes, therefore it is advised woodland managers should be aiming to manage resilient landscapes now but is often limited by policy, objectives and priorities (Young et al., 2018). Management of tree pest outbreaks often takes place in stringent time constraints and rapidly changing contexts, which presents substantial challenges for engaging woodland managers with wider stakeholders in management coordination which requires long-term interaction and trust building (Porth et al., 2015).

However when faced with a pest and disease outbreak woodland managers have the highest levels of concern in the early stages of an outbreak when scientific evidence may be limited and there may be a lack of clarity on management responsibility or regulatory mechanisms (Mackenzie and Larson, 2010; Urquhart et al., 2017). There is little evidence in the literature on how this concern translates to action and how attitudes and subsequent action would change over time as concern potentially decreases. This could be because whilst it might be expected less action takes place when the concern of the outbreak decreases this may not be the case. As evidence and clarity of management and regulations are increased, more management action may be taking place but it is less concerning to the woodland manager and the direction of necessary management is better understood. Overall there is still relatively little information about how woodland managers adapt over time when faced with an ongoing pest and disease outbreak in their woodland.

4. Contextual factors influencing management

Alongside woodland managers' understanding, objectives, and values, several contextual factors can influence management action against pest and disease outbreaks (Ambrose-Oji et al., 2020; Lawrence and Marzano, 2014; Marzano, Fuller and Quine, 2016; Tomlinson, Potter and Bayliss, 2015; Marzano et al., 2016). The coordination of pest and disease outbreaks (Marzano, Fuller and Quine, 2017; Porth et al., 2015), woodland managers engaging with outbreaks (Lawrence and Marzano, 2014; Mackenzie and Larson, 2010) and sharing information about the outbreak (Porth et al., 2015; Tomlinson, Potter and Bayliss, 2015) can impact management choices taken by woodland managers. Furthermore the quality of information and where and/ or whom it comes from (Lawrence and Marzano, 2014; Marzano, Fuller and Quine, 2017) can influence management decisions. Management of pests and diseases is also impacted by the feasibility of carrying out suitable action through the support of grants and in some cases obligatory action through policy legislation in plant health (Lawrence and Marzano, 2014; Tomlinson, Potter and Bayliss, 2015). Overall these factors impact management action alongside site-specific factors as well as pest and disease characteristics.

4.1 Coordination of pest and disease outbreaks

Marzano, Fuller and Quine (2017) suggest that as tree pests and diseases become more prevalent in forests, mobilising woodland managers and wider stakeholders to work together to counter threats is an essential component of effective management. In the case of Oak Processionary Moth the London Tree Officers Association were acknowledged as playing a central role in coordinating the outbreak response and woodland managers valued this association as a trusted source of knowledge (Tomlinson, Potter and Bayliss, 2015). The London Tree Officers Association also worked collaboratively with local authority officers who took a clear role of responsibility for the outbreak above and beyond their remit (Tomlinson, Potter and Bayliss, 2015). Marzano, Fuller and Quine (2017) suggest that the knowledge, trust and responsibility demonstrated by the coordinators above influenced woodland managers and wider stakeholders resulting in a successful coordination approach against the outbreaks. Despite some appreciation woodland managers acknowledged the coordination response was hindered by the complex woodland landscape, making engaging with wider stakeholders, explaining statutory duty, and mobilizing action challenging (Tomlinson, Potter and Bayliss, 2015). This led to delays in the response to the threat and impacted the effectiveness of the eradication programme (Tomlinson, Potter and Bayliss, 2015).

In the case of the Asian Longhorn Beetle, the coordination of the eradication response was heavily questioned, with managers and residents arguing that an earlier discovery had not been communicated or dealt with effectively and the eradication coordinators were, in some cases, causing unnecessary inconvenience despite the removal of trees being obligatory (Porth et al., 2015). Despite this, Young et al., (2018) argued that many woodland managers hope to work with a wide range of stakeholders to mitigate threats from pests and diseases including those who are often missed out on coordination conversations. This suggests that even if the management is considered necessary by woodland managers and the coordinators are trusted, outbreak-specific factors will; like social impact, and cost, need to be taken into account for a successful coordination approach (Marzano et al., 2020; Porth et al., 2015). Tomlinson, Potter and Bayliss (2015) highlight that external bodies should be used to coordinate pest and disease outbreaks which have sufficient resources and the ability to give unbiased advice.

4.2 Engaging managers with tree pest and disease outbreaks

Tomlinson, Potter and Bayliss (2015) demonstrate that pest and disease outbreak management relies on engaging effectively with woodland managers. Engagement relies on trustworthy and credible sources which are partnered with existing social networks that can increase the scope and effectiveness of engagement (Lawrence and Marzano, 2014). In the case of Emerald Ash Borer spread

in America, which can be greatly accelerated by accidental movement through people it was acknowledged that engagement activities about the pest and ways of reducing spread have been considered an essential component of management (Marzano et al., 2020). These engagement activities could be widely useful among woodland managers in the UK with Marzano et al., (2016) indicating that only 20% of tree professionals across Europe take biosecurity considerations when managing woodlands (e.g. clean footwear and vehicles) but are open to changing behaviour in the future. This may indicate that woodland managers may not be considering these behaviours important to the risk of pest and disease spread, and engagement activities may increase awareness around the introduction pathway.

In the case of the Asian Longhorn Beetle outbreak in the South of England, there were many attempts to engage a wide range of local people with the eradication programme (public meetings, leaflets, websites) but many expressed frustration that these platforms allowed for information access but didn't allow 'open dialogue' to question or change management direction (Porth et al., 2015). In the case of eradication programmes, decisions often have to be made quickly and relationships with tree owners cannot always be built sufficiently and often the national impact is considered over the local impact (Mackenzie and Larson, 2010; Marzano et al., 2020). It was clear in this case that engaging local people in management decisions could have had a substantial effect on the resident perception of the programme but it could be argued by programme enforcers that in this instance engaging local tree owners in decisions most likely wouldn't have changed the outcome (Porth et al., 2015).

Mackenzie and Larson (2010) mirrored these findings in the rapid response programme against Emerald Ash Borer in Canada where residents and local woodland managers felt excluded from the management conversation and helpless to protect their land. It is important to note that if local people had felt more included perhaps this experience would have had an impact on their future responses to pest and disease outbreaks on their land (Marzano, Fuller and Quine, 2017; Marzano, Woodcock and Quine, 2019; Marzano et al., 2020; Urquhart et al., 2017). Ultimately, sometimes pests and diseases need to be eradicated quickly but without the consideration, cooperation and engagement of woodland managers and local residents, the nature of outbreaks mean part action could be a waste of time (Tomlinson, Potter and Bayliss, 2015).

4.3 Communication with pest and disease outbreaks

Marzano, Fuller and Quine (2017) suggest that sharing knowledge of pest and disease outbreaks, which are constantly in a state of change, needs to consider the attitudes of woodland managers and site-specific factors which would allow certain management measures to be adopted. Marzano, Fuller and Quine (2017) also highlighted that the scale of information shared with woodland managers

should be considered, whether it be focusing on individual threats or broader biosecurity measures. Considering information about biosecurity measures within management is important, but communicating a concept about the management of all threats may be overwhelming for woodland managers and may seem unfeasible, which could have the adverse effect and lead to no management being undertaken (Young et al., 2018).

Tomlinson, Potter and Bayliss (2015) suggest framing pest and disease outbreaks through a social lens, communicating to woodland managers the impacts of human health risks of pests or diseases, which could be influential in private woodland managers declaring tree health concerns to relevant bodies. This suggests that how information is communicated to woodland managers can have an impact on the management taken against pests and diseases, cooperation within eradication programmes and consideration of outbreaks in the future (Mackenzie and Lawrence, 2010; Marzano et al., 2020; Porth et al., 2015). Marzano et al., (2020) concluded that in the case of Emerald Ash Borer, large amounts of time and money were invested in communicating tree removal and replacement plans to woodland managers and the wider public. This occurred through outreach programmes, local media, and public meetings with forestry staff informing tree owners about treatments, and preemptive measures as well as discussing any objections (Marzano et al., 2020).

Porth et al., (2015) concluded that there were multiple layers of communication in the eradication of the Asian longhorn beetle involving: managers organising the eradication programme (e.g. Forestry Commission), contractors hired to do the work, those who had been directly impacted and the broader public. A series of meetings provided information to affected parties but when the outbreak buffer zone was extended woodland managers were affected without knowing what was happening (Porth et al., 2015). However, woodland managers and tree owners felt the communication about the eradication programme was inconsistent and contradictory and led to rumours about the work being undertaken and the managers of the sites being treated unfairly by other local residents (Porth et al., 2015). This again highlights the importance of including social impact considerations in tree health management (Marzano et al., 2020). Furthermore, Mackenzie and Lawrence (2010) concluded that even in eradication programmes of pests and diseases if there is no effort to build stakeholder trust, woodland managers and tree owners will lack trust in the information shared, how it is shared and who as well as hesitance with cooperating with the eradication programmes.

4.4 Information sources

Woodland management decisions can be affected by the information available, how it is shared, and where it comes from (Ambrose-Oji et al., 2020; Lawrence and Marzano, 2014; Marzano et al., 2016; Marzano, Fuller and Quine, 2017; Tomlinson, Potter and Bayliss, 2015; Urquhart et al., 2017; Young et al.,

2018). Marzano et al., (2016) identify that woodland managers are keen to learn more about the biology of pests and diseases as well as methods to prevent or control outbreaks from trusted sources. Concurrently, there was a strong feeling among woodland managers that more formal advice and guidance at the management level were required to respond to threats of pests and diseases effectively (Young et al., 2018). This suggests that woodland managers are keen to follow advice from trusted groups and potentially adapt behaviour, but feel suitable information is not currently available.

Furthermore, how managers access this information and who it is from is crucial to whether the methods suggested are considered for adoption (Ambrose-Oji et al., 2020). Marzano et al., (2016) indicate that there are several ways that woodland managers and other tree professionals gain knowledge about pests and diseases with the internet the single most popular choice although newspapers and government organisations were also used for information. Woodland managers also rated education and training as an important information source and would prefer to receive more information in the form of seminars first, and then online resources if that wasn't possible and would be open to receiving regular updates about threats through e-mail (Marzano et al., 2016). This suggests that woodland managers appear to want to improve their knowledge of pests and diseases and are willing to engage through several platforms.

Urquhart et al., (2017) suggest that media plays a significant role in influencing woodland managers' knowledge and perception of the severity of pest and disease outbreaks. However, the amount of media coverage available has begun resulting in woodland managers questioning whether the perceived impact and concern were in line with the actual impact and whether this information can be trusted (Tomlinson, Potter and Bayliss, 2015). Furthermore, the media often triggers a public reaction which collectively acts as a key driver for government response alongside other environmental lobbying resulting in more attention and resources which is not representative of what is really required (Urquhart et al., 2017).

Young et al., (2018) identified woodland managers also take advice from Forest Research and the UK plant health register and several multidisciplinary advisory forums. However, Ambrose-Oji et al., (2020) identify small woodland managers were highly distrusting of advice from main government and research organisations, with many looking to them for technical information but in the application, this information didn't reflect their values, objectives and site conditions so were not inclined to act on it. Mackenzie and Larson (2010) also supported these findings that woodland managers distrust in the government, particularly with regard to eradication programmes where they felt excluded from the conversation, with information not properly explained or justified. This lack of

trust could result in less engagement and cooperation with pest and disease management in the future so the balance between necessary action and social impact is key for future tree health management.

4.5 Networking

Marzano, Fuller and Quine (2017) suggest that social networks are highly influential in improving communication that leads to greater uptake of pest and disease management. Additionally, informal communication networks are useful in developing understanding, mutual trust and collaboration amongst managers and between people and government officials which is often identified as a barrier within tree health management (Marzano, Fuller and Quine, 2017). In the case of Oak Processionary Moth in London, the introduction of interdisciplinary networking groups showed some elements of success in the coordination response. However, Lawrence and Marzano (2014) identified that some woodland managers felt especially in the private sector there was a poor flow of information between woodland managers themselves. In the case of the outbreak of the Asian longhorn beetle, Porth et al., (2015) recognised that sharing of information across networks wasn't occurring, and as a result, managers' relationships within the community were detrimentally impacted. Overall, as demonstrated above, not only the information provided to woodland managers influences management action but also the way in which it is shared and by whom.

4.6 Government and policy tools

Nearly three-quarters of the British woodlands are in private ownership so the management action of private woodland owners is crucial to reach policy goals (Lawrence and Marzano, 2014). Woodland managers were aware of several policy tools: the Plant Biosecurity Strategy for Great Britain, the UK Forestry Standard, and at an international level, the International Plant Protection Convention which develops international standards to prevent the entry of pests and diseases but also facilitate trade (Young et al., 2018). Marzano, Fuller and Quine (2017) acknowledged that relatively few managers were undertaking measures advised by policy despite having awareness of them.

Tomlinson, Potter and Bayliss (2015) identified that in the case of Oak Processionary Moth legislation even compromised the response to the outbreak slowing down the reaction time by debating whether the pest should be managed as a public health or environmental risk despite it being both. Urquhart et al., (2017) suggest that the political agenda (short-term goals and upkeeping reputations) does not necessarily align with the long-term goals required to achieve resilient woodlands across the UK. Although, Ambrose-Oji et al., (2020) suggest some larger woodland managers felt relatively

well served by policy but there were acknowledged restrictions for commercial forests with strong financial objectives.

The main policy tools for encouraging woodland management in the case of tree health is provision of advice and grants with limited regulation (Lawrence and Marzano, 2014). The use of Statutory Plant Health Notices is one of the only legally binding processes that require the removal of trees from woodlands when faced with tree health issues. However, many woodland managers are either slow to act or are not acting at all about these notices because the Forestry Commission threaten legal action but it is becoming common knowledge among woodland managers that they do not have the time or resources to pursue legal action against managers (Tomlinson, Potter and Bayliss, 2015).

Although the use of eradication programmes, which are also mandatory, but the government usually bears the cost, were seen by some woodland managers as a political stunt rather than a programme based on scientific evidence (Mackenzie and Larson, 2010; Marzano et al., 2020). They believed that by the time the programmes are set up the introduction of the pest or disease could have happened many years ago leaving it already established and the programme mostly useless (Mackenzie and Larson, 2010; Marzano et al., 2020). However, Porth et al., (2015) acknowledge the success of the eradication programme of the Asian Longhorn Beetle but the woodland manager's memories of the event suggest that these programmes provide a positive experience for woodland managers.

4.7 Advice and grants

Young et al., (2018) suggested woodland managers were still heavily reliant on government intervention to reduce the impact of pest and disease threats, with the primary tool at the local scale being access to grants. Lawrence and Marzano (2014) acknowledge that grant mechanisms have been particularly useful in supporting woodland management on agricultural land which may have been completely neglected previously. On the other hand in some cases where there are incentives to plant species for pest and disease resilience but these species can also be intolerant to other threats like squirrels (Lawrence and Marzano, 2014). Marzano, Woodcock and Quine (2019) suggest that woodland managers think existing woodland creation grants would be sufficient to incorporate adaptive management including producing resistant material however any experimentation should be accompanied by sufficient funding and technical advice.

However, Lawrence and Marzano (2014) suggest that some woodland managers used concern about forest threats as a method to meet criteria for applications and were not always representative of actual concern. Lawrence and Marzano (2014) suggested that it is hard to distinguish between the effects of grants and advice as they are often supplied together. Lawrence and Marzano (2014)

concluded that advisory services fall into three main groups: commercial and/ or investment forest employing consultants, a small woodland using grants, and the accompanying advisory services and those who have no access. Lawrence and Marzano (2014) suggested that woodland managers were seen to be heavily reliant on external advice but some suggested this could be disconnected and confusing. The UK Forestry Standard was perceived largely as a regulatory guide but many small woodland managers considered the advice and information about grants overwhelming (Young et al., 2018). As a result, Lawrence and Marzano (2014) acknowledge many woodland managers rely on the use of agents who often help with specific issues but do not provide long-term management. There was a lot of scepticism about advice that will be discussed later in this review where woodland managers detailed many examples of advice that had been given but in practice was later proven unsuitable (Lawrence and Marzano, 2014). This could leave managers hesitant to take future advice and subsequently adopt future behaviours.

5. Management approaches

This review identifies that relatively little information is known about the actual action taken by individual woodland managers when faced with pest and disease outbreaks (Marzano, Fuller and Quine, 2017; Marzano, Woodcock and Quine, 2019). Decisions taken by woodland managers are most often based on perceptions of their relative cost and effectiveness and the specific ecological and economic contexts of different outbreak sites (Tomlinson, Potter and Bayliss, 2015). Young et al., (2018) suggest that woodland managers, for the most part, are aiming to create resilient forests through a broad range of approaches that can also be adapted over time to support their objectives and policy contexts. Ambrose-Oji et al., (2020) suggest small-scale woodland managers fell into three main groups when carrying out woodland management against threats: those who make no provision believing nature will adapt, those who were considering implementing adaption practices but relied on their own belief, and those who made active provision for environmental change using advice from organisations that were representative of their objectives and values. Ambrose-Oji et al., (2020) suggest that conservation managers fall into the active management against threats that would support the work and aims of many conservation organisations but in some cases goes against earlier comments that for the benefit of biodiversity some areas should be left unmanaged (Lawrence and Marzano, 2014; Tomlinson, Potter and Bayliss, 2015). This highlights that even within conservation organisations with similar objectives there may be observable differences in the management in practice against pests and diseases.

5.1 Management plans and risk analysis

There is a lack of understanding of woodland management behaviour as a whole across British woodlands. This is attributed in part to a lack of legal obligations to produce and implement management plans or pest and disease readiness plans (Lawrence and Marzano, 2014). Management plans are increasingly useful documents to guide current and future management actions of woodland managers and inform other stakeholders (e.g. scientists, and policymakers) about the site's conditions and management direction. Furthermore, the production of objective risk assessment for both current and future tree health outbreaks is becoming increasingly important but future uncertainty makes this also increasingly difficult (Urquhart et al., 2017). There was one paper (Urquhart et al., 2017) that mentioned risk assessments as part of pest and disease management strategies and one paper that used a risk committee in a rapid eradication programme (Mackenzie and Larson, 2010).

Despite this seeming lack of risk provision, the concern about the risk posed by pest and disease outbreaks was highlighted by woodland managers across several studies (Lawrence and Marzano, 2014; Marzano, Fuller and Quine, 2017; Marzano et al., 2020). Readiness plans are also suggested as key elements of planning for outbreaks and have been successfully implemented with Emerald Ash Borer in an American context (Marzano et al., 2020). There was no evidence found that these plans are currently being prepared in the UK where eradication programmes have been implemented and considered costs, responses and management required (Porth et al., 2015). This preparation of information and stakeholder logistics would be useful as woodland managers often have the highest concern in the early stages of outbreaks when information may be delayed (Mackenzie and Larson, 2010; Urquhart et al., 2017). Their lack of use could be attributed to the cost of producing such plans when tree health resources are limited and often fall to the responsibility of woodland owners (Marzano et al., 2020).

5.2 Monitoring, detection and reporting

Continuous monitoring is a useful tool for woodland managers and a key element of both resilience and pest and disease detection (Marzano, Fuller and Quine, 2017; Marzano et al., 2016; Porth et al., 2015; Young et al., 2018). Marzano, Fuller and Quine (2017) found managers identified the importance of monitoring for the early detection of pests and diseases but many were blocked from carrying out monitoring because of the cost and manpower, and in some cases are also restricted to small time frames when the pest or disease may be observed. In the case of the Oak Processionary Moth outbreak in London, the absence of an effective surveillance system meant that local authority

officers working outside of their remit of duties reported infestations (Tomlinson, Potter and Bayliss, 2015).

In most outbreaks early detection is critical and in the case of Emerald Ash Borer, which is notoriously difficult to detect and in America, significant investment has gone into monitoring programmes. Although to achieve rapid detection, this surveillance needs to be ongoing, which was identified by Marzano, Fuller and Quine (2017) as being financially unfeasible for woodland managers. In most cases, it wasn't possible for woodland managers to monitor just one pest or disease of particular concern let alone monitor all potential threats. Porth et al., (2015) concluded that in the case of the Asian Longhorn Beetle, where annual local monitoring was funded by the government and not that private woodland managers themselves a successful eradication programme was implemented. However, complete reliance on monitoring and detection through observable damage by pests and disease does pose limitations as irreversible damage can be caused long before trees show visible problems (Young et al., 2018).

Furthermore, in the case of the Asian Longhorn beetle, a beetle was found 3 years prior at a site in packaging, therefore, suggesting that potentially the pest could have been establishing for some time (Porth et al., 2015). This is where advancement in detection techniques through satellite imagery, and the sharing of scientific models about future projection and sufficient funding, would significantly benefit woodland managers' action against outbreaks (Lawrence and Marzano, 2014; Marzano, Fuller and Quine 2017). Also once the pest is detected it is important they are actually reported to the relevant bodies with most woodland managers reporting findings to governmental and local authorities as well as conservation groups in the first instance although some admitted they still might not report their findings to anyone (Marzano et al., 2016). This suggests that engaging with woodland managers about the importance of reporting pest and disease outbreaks so that outbreaks can also be dealt with at a landscape scale is a crucial element of a coordinated response to pest and disease outbreaks (Tomlinson, Potter and Bayliss, 2015).

5.3 Species choice

Species selection was the most prominent decision considered by woodland managers against pests and diseases (Lawrence and Marzano, 2014; Marzano, Fuller and Quine, 2017; Ambrose-Oji et al., 2020). Lawrence and Marzano (2014) demonstrated that altering species as a management choice against threats was demonstrated by three main selections: native diversity, Sitka Spruce or planting a wide new range of species. Marzano, Fuller and Quine (2017) highlight that whichever choice is made represents a major decision with long-lasting consequences for woodland managers. Marzano,

Woodcock and Quine (2019) conclude that land managers want to ensure that diversifying species mixtures and managing common pests be maintained over time.

Therefore, when faced with uncertainty, forest managers with commercial objectives tend to look to replant new exotics whilst smaller-scale owners with lower commercial objectives rely more on native genetic diversity (Lawrence and Marzano, 2014). However several factors (site conditions, availability of species and markets) contribute further to uncertainty in woodlands and despite woodland managers acknowledging criticisms of single species plantations, many have reverted to this, managing this species because currently it is less susceptible to current pests and diseases and more economically viable (Lawrence and Marzano, 2014; Marzano, Fuller and Quine, 2017).

Woodland managers feel that government policy, including the UK forestry standard, is encouraging the use of diverse tree species but this in practice isn't feasible due to the species available and the cost to plant them (Marzano et al., 2020; Marzano, Fuller and Quine, 2017; Marzano Woodcock and Quine, 2019). Marzano et al., (2020) found that replacing species has a high financial cost but allows woodland managers to have input into forest design. This resulted in woodland managers considering native broadleaves that provide multiple benefits as well as their suitability to plant in native woodland mixtures (Marzano, Woodcock and Quine, 2019). However, Marzano, Woodcock and Quine (2019) suggest that some managers felt that there was a decreasing number of broadleaf species and this governmental drive to diversify will leave increasing gaps in mixed forest stands with the current and future effects of acute oak decline, phytophthora and ash dieback.

In the case of ash dieback, woodland managers are planting other native broadleaf species or non-native broadleaves such as sycamore but there is less support for non-native ash alternatives (Marzano, Woodcock and Quine, 2019). This suggests that woodland managers are more likely to diversify with alternative species when faced with pest and disease threats than plant non-native versions of the same species which may not exhibit the same properties. Furthermore, Ambrose-Oji et al., (2020) suggest that woodland managers felt pressure from government guidelines to diversify but from several different perspectives: large-scale woodland managers argued that increasing diversity would reduce areas of commercial productivity and claimed that variation was being achieved at a genetic level across stands and small scale managers considered species diversification an appropriate adaptation response but conservation-focused management stress the importance of diversification as a natural process. Overall, managers are considering or changing species towards diversification as a result of pest and disease threats but not always in the same way based on objectives, resources and contextual factors and are hindered by species availability, costs

and markets (Ambrose-Oji et al., 2020; Lawrence and Marzano, 2014; Marzano, Woodcock and Quine, 2019).

5.4 Tree removal (thinning and felling)

The removal of trees as a management action is not taken lightly because of its social and biological impact (Mackenzie and Larson, 2010; Marzano et al., 2020; Porth et al., 2015). However, tree removal management is common practice in silviculture management and is particularly useful when dealing with pests and disease outbreaks (Ambrose-Oji et al., 2020; Marzano, Fuller and Quine, 2017; Marzano et al., 2020). Tree removal is used in a number of outbreak situations to slow the spread of pests and diseases by minimising the density of trees and increasing the distance the pest or disease has to travel to spread (Ambrose-Oji et al., 2020; Marzano, Fuller and Quine, 2017; Marzano et al., 2020). Ambrose-Oji et al., (2020) suggest that many woodland managers felt shorter rotations and improved thinning regimes should be used as a principal response to the threat of pests and diseases. Marzano, Fuller and Quine (2017) suggest that the selective removal of trees from pine stands is a vital measure to slow down the spread of Dothistroma Needle Blight with managers generally acknowledging the positives of thinning to slow the spread but highlighting the economic viability and feasibility of heavy thinning within challenging sites and conditions. This becomes a trade-off between the spread of pests and diseases through remote and therefore potentially unmanaged forests and the resources required to access these forests to thin the trees to slow the spread.

Marzano, Fuller and Quine (2017) suggest some woodland managers identified clear-felling as more suitable in terms of Dothistroma Needle Blight management but the felling observed was carried out for different purposes: saving some value of infected trees, halting the disease and preemptively due to proximity of their forest to the outbreak. This suggests that felling can provide managers with an option that can slow the spread/ eradicate the pest or disease and support multiple objectives (e.g. land managed for biodiversity, commercial plantations). Marzano et al., (2020) identify in the case of Emerald ash borer and Asian Longhorn beetle preemptive felling, provided short-term social impacts but the eradication of the pests prevent the long-term costs of infestation. Forest managers have shown some, or targeted, removal of trees has contributed to the slower spread or eradication of pests and diseases however engaging with individuals must consider the social impacts of removing trees (especially those not infected) if successful mobilisation of forest managers is to be achieved to tackle outbreaks in the future (Porth et al., 2015).

5.5 Disease and pest removal

There are a number of methods used by woodland managers to remove a pest or disease from trees within a woodland (Marzano, Fuller and Quine, 2017; Marzano et al., 2020; Tomlinson, Potter and Bayliss, 2015; Urquhart et al., 2017). The method taken can depend on several characteristics of both the infected site and the pest or disease itself (Tomlinson, Potter and Bayliss, 2015; Urquhart et al., 2017). Within two London sites (Royal Botanical Gardens Kew and Richmond Park) infected with Oak Processionary Moth tree managers initially began removing nests to minimise the spread of the pest (Tomlinson, Potter and Bayliss, 2015).

However in Royal Botanical Garden Kew, this wasn't sufficient to balance out the public health risk so was quickly abandoned for spraying (Tomlinson, Potter and Bayliss, 2015). Spraying was an effective method for removing Oak Processionary Moth in this case but there have long been concerns about the biodiversity impact of chemicals used particularly on aquatic organisms and bees (Urquhart et al., 2017). Consequently, this method was not adopted in Richmond Park because the site was heavily restricted by conservation legislation so a large-scale volunteer nest removal scheme was carried out by land managers instead (Tomlinson, Potter and Bayliss, 2015). This method was time-consuming, complex to coordinate and less effective than areas using spraying (Tomlinson, Potter and Bayliss, 2015; Urquhart et al., 2017). Therefore, following permission from Natural England, spraying of a biological control agent which required more applications but was considered less harmful to the environment was applied but this faced increasing criticism with some managers arguing that Richmond Park has contributed to the spread of the pest through its refusal to spray more intensely (Tomlinson, Potter and Bayliss, 2015). Again, this could be attributed to conservation woodland managers focusing on overall biodiversity objectives or allowing natural processes to occur with regard to forest structure rather than specifically managing pests and diseases (Ambrose-Oji et al., 2020). Moreover, it could just be that funding is often tied to conservation legislation and both cost of spraying and the damage of spraying breached the conservation protection on the site.

In the wider environment, there was little consensus around whether the Oak Processionary Moth presents a significant risk to tree health with impact going through manageable and expected peaks and troughs causing damage to areas of trees but not the species as a whole (Tomlinson, Potter and Bayliss, 2015). This suggests that woodland managers, in some cases consider, the impact of pest and disease damage at the species level and were less worried about removing groups of trees within one site. However, this is not always the case with many detrimental social and biological impacts of losing trees at one location highlighted across many papers reviewed (Lawrence and Mackenzie, 2010; Marzano et al., 2020; Porth et al., 2015; Tomlinson, Potter and Bayliss, 2015). Furthermore, Urquhart

et al., (2017) suggested managers felt that the risk from Oak Processionary Moth was low due to a range of active management but conservation organisations were more concerned with the impact of the control methods of Oak Processionary Moth than the pest itself.

Marzano, Fuller and Quine, (2017) suggest that spraying in the wider environment and British forests for Dothistroma Needle Blight is not a currently available option to woodland managers but many have already formed an opinion about this method of management on their land. Private sector managers were largely in favour of spraying to save high-value crops and argued this had been successful in other countries and such action was allowed to save agricultural crops (Marzano, Fuller and Quine, 2017). From an anthropocentric perspective, the use of spraying, which in some cases can pose human health risks as well as biological impacts, can be more dangerous to spray plants that are used for consumption than those used for timber and other commercial uses (Urquhart et al., 2017). On the other hand, public sector managers acknowledged the potential of infection-sensitive water courses and public access making the use of spraying for Dothistroma Needle Blight not feasible (Marzano, Fuller and Quine, 2017).

The interconnection of the wider environment would make it challenging to have different rules in public access and privately owned forests in this case even when the management method would be justified. In the case of Emerald ash borer in America, woodland managers found that chemical insecticides were a cost-effective way of keeping ash trees alive and reducing Emerald Ash Borer populations through extending the time frame available to complete ash tree removals and replant trees (Marzano et al., 2020). There are often concerns about the use of chemicals in natural areas but perhaps surprisingly many woodland managers and residents were willing to accept an insecticide injected into the stem of the tree but were unhappy about the cost and effectiveness of the treatment (Marzano, Fuller and Quine, 2017; Urquhart et al., 2017).

In another site infected with Emerald Ash Borer parasitic wasps were used as a biological control which may not save ash trees but may keep Emerald Ash Borer resurgence low enough to facilitate natural ash regeneration in forested areas (Marzano et al., 2020). Overall, it is suggested that management objectives play a large part in the method used to remove pests or diseases from woodlands with conservation-focused managers choosing slightly less effective methods such as biological controls and nest removal that have a lesser impact on the wider environment (Tomlinson, Potter and Bayliss, 2015; Marzano et al., 2020) compared with commercial and urban forests preferring spraying of chemicals when faced with protecting high-value crops of public health (Marzano, Fuller and Quine, 2017; Tomlinson, Potter and Bayliss, 2015).

5.6 Adaptive management strategies

There are also several overarching management approaches observed in British woodlands that can directly or indirectly affect pest and disease impact and spread (Ambrose-Oji et al., 2020; Lawrence and Marzano, 2014; Marzano, Fuller and Quine, 2017; Marzano Woodcock and Quine, 2019; Tomlinson, Potter and Bayliss, 2015). With increased pest and disease introductions, it is suggested that woodland managers should be more actively looking to integrate pest and disease considerations into their overall management (Tomlinson, Potter and Bayliss, 2015). Additionally, with increased uncertainty, the use of adaptive management which gives the ability for managers to review and adjust progress over time focusing on desired outcomes rather than individual management action is considered a significantly useful approach for dealing with ongoing threats and the long time frames associated in forestry (Young et al., 2018).

Adaptive management approaches are readily observed by woodland managers in London where the management of Oak Processionary Moth began with nest removal and then through to a range of different less harmful chemicals over time depending on site-specific effectiveness as well as a range of public health, biodiversity and financial factors (Tomlinson, Potter and Bayliss, 2015). Lawrence and Marzano (2014) found that woodland managers felt they were actively discouraged by the Forestry Commission from carrying out adaptive management because of the level of experimentation required although non-commercial forests do carry out a range of experimental techniques regardless. Several managers felt they were utilising adaptive management through continuous forest cover but overall, this wasn't particularly evident in practice (Lawrence and Marzano, 2014).

The lack of adaptive management observed in the field by Ambrose-Oji et al., (2020) was attributed partly to large woodland owners feeling less inclined to take risks and incur the costs associated with adaptive management towards more resilient practices. Lawrence and Marzano (2014) also acknowledged that whilst woodland managers wanted to actively adapt it was often disputed who should take the burden of trying new management techniques (public or private sector) and bare those additional risks. This doesn't mean adaptive management wasn't taking place with Ambrose-Oji et al., (2020) identified woodland managers who were introducing shortened rotation and improved thinning regimes as a response to the increasing incidence of pests and diseases. In cases of small woodlands with utilitarian worldviews, there was greater evidence of adaptive management and among those larger woodlands with ecological worldviews, there was evidence of wider adaptive management in practice (Ambrose-Oji et al., 2020). This again highlights the importance of understanding woodland managers' individual attitudes, and contextual and structural influences

(Ambrose-Oji et al., 2020; Lawrence and Marzano, 2014; Marzano, Fuller and Quine, 2016; Tomlinson, Potter and Bayliss, 2015; Marzano et al., 2016). Ambrose-Oji et al., (2020) acknowledged that small and medium woodland managers were more likely to adaptively manage if the information, advice and support measures were representative of the woodland managers' beliefs and operating contexts.

Although more tentative approaches to woodland management can be observed when faced with pest and disease outbreaks (Marzano, Fuller and Quine, 2017; Marzano, Woodcock and Quine, 2019). Marzano, Woodcock and Quine (2019) suggest in the case of Ash Dieback that managers are keen to avoid wholesale removal where outbreaks were not thought to be severe. This could be attributed to the social and biological effects of removing whole areas of tree species and in particular removing those trees that might not be infected (Porth et al., 2015; Marzano et al., 2020). Additionally, previous experience with similar diseases and management techniques like reactive felling meant which also allowed for monitoring for resistance managers were keen to take a wait-and-see management approach (Marzano, Woodcock and Quine, 2019). Some woodland managers argued for a land abandonment approach, in some cases concluding that largely inaccessible sites where costs outweigh the value of trees should be left to nature and not managed now or over time (Marzano, Fuller and Quine, 2017). Some even highlighted that this approach can be beneficial as if damaged trees are felled it is an obligation to replant them but there is no obligation if they die themselves however it was acknowledged that these sites contribute to the spread of pests and diseases (Marzano, Fuller and Quine, 2017). Overall, woodland managers acknowledge that integrating management into their overall approach is useful against the impact and spread of pests and diseases (Ambrose-Oji et al., 2020; Lawrence and Marzano, 2014; Marzano, Fuller and Quine, 2017; Marzano Woodcock and Quine, 2019; Tomlinson, Potter and Bayliss, 2015). It is a complicated mosaic of factors that translates this to management action that is able to adapt over time (Ambrose-Oji et al., 2020; Lawrence and Marzano, 2014; Tomlinson, Potter and Bayliss, 2015; Marzano et al., 2020).

6. Barriers to pest and disease management

There are a number of barriers identified from this review that can prevent woodland managers from adopting practices that mitigate the threat of pests and diseases (Marzano, Fuller and Quine, 2017; Marzano et al., 2016; Marzano et al., 2020; Marzano, Woodcock and Quine, 2019; Tomlinson, Potter and Bayliss, 2015; Urquhart et al., 2017; Young et al., 2018). Marzano et al., (2016) highlight that barriers faced by woodland managers include lack of financial resources, insufficient knowledge and information, management is often too labour intensive, perceptions of other people's behaviours, lack of coordination of agencies at the national and local level, lack of means and cooperation with agencies. Of the barriers listed above woodland managers conclude that at least one or more are

affecting the uptake of more resilient practices (Marzano, Fuller and Quine, 2017; Marzano et al., 2016; Marzano et al., 2020; Marzano, Woodcock and Quine, 2019; Tomlinson, Potter and Bayliss, 2015; Urquhart et al., 2017; Young et al., 2018). Providing feasible solutions to these barriers would be an important element in translating evident concern about pests and diseases to management action and engaging woodland managers with wider eradication programmes (Lawrence and Marzano, 2014; Mackenzie and Larson, 2010; Marzano et al., 2020; Young et al., 2018).

6.1 Cost and access to resources

Marzano, Fuller and Quine (2017) found managers highlighted there are many economic challenges facing the forestry sector limiting funds and resources available for tree health issues. Tomlinson, Potter and Bayliss (2015) conclude that even when the cost doesn't fall directly on the woodland itself but from public money, budgets are limited and affect the level of management taken. Therefore, it is suggested that regardless of who bears the cost it becomes a balancing act between the cost of managing the pest and diseases and the economic consequences if the threat spreads out of control (Marzano, Fuller and Quine, 2017). In both public and private woodlands there was concern about the lack of resources to deal with outbreaks at the necessary scale (Marzano, Fuller and Quine, 2017; Tomlinson, Potter and Bayliss, 2015). Marzano, Fuller and Quine (2017) suggest that woodland managers were doing what they could to deal with outbreaks, but if nurseries also became infected they had very limited management choices.

Tomlinson, Potter and Bayliss (2015) also identified that governmental bodies can be useful in response to pest and disease outbreaks in a planning or coordinating role but often don't have the legal powers to enforce management action response. Marzano, Fuller and Quine (2017) suggest that even if woodland managers are happy to adopt management changes it is unlikely they could fund ongoing costs as changing species may not be supported by the market and the cost of spraying to prevent the spread may not be recovered by the crop value. This suggests accessing sufficient resources and overcoming financial barriers should not only consider immediate outbreaks but how to deal with threats over time (Marzano, Woodcock and Quine, 2019).

6.2 Skepticism of expert advice

Marzano, Fuller and Quine (2017) suggested that managers were influenced by past recommendations made by government agencies that didn't work in practice or went against their observations and as a result affected their management approaches. This was particularly evident in eradication programmes where decisions were made quickly (Porth et al., 2015; Mackenzie and Larson, 2010; Marzano et al., 2020). In the case of Emerald Ash Borer, some woodland managers

questioned the scientific advice of eradication when many believe the pest to be already well established outside the designated tree removal zone (Mackenzie and Larson, 2010). The approaches taken to eradicate the Asian Longhorn beetle were also questioned when lessons to help local people identify the pest used images of the wrong pest and many trees ended up being removed from large woodland areas which didn't have any signs of the pest at all (Porth et al., 2015). This led to sceptical opinions about those who carried out the eradication programme and suggests that experience with bad advice could significantly affect the cooperation of woodland managers within eradication programmes and willingness to adopt new management practices in the future. Furthermore, woodland managers have demonstrated that a wait-and-see approach is much more favourable until this advice can be proven to work in practice (Marzano, Woodcock and Quine, 2019). This is useful to understand that the adoption of practices will need to be supplemented with financial support and advice or have clear communication strategies to engage woodland managers with previous examples of success (Lawrence and Marzano, 2014).

6.3 Scepticism of expert advice

A key barrier identified in preventing the adoption of effective responses to tree pests and disease outbreaks is the confusion over who is responsible for identifying and managing them (Marzano, Fuller and Quine, 2017; Tomlinson, Potter and Bayliss, 2015). Woodland managers felt, in the case of Dothistroma Needle Blight, that the industry had taken too long to react to the threat but it was also highlighted that it should not always fall to the sole responsibility of the woodland manager due to substantial non-timber benefits of forests that benefit that are non-market public goods (Marzano, Fuller and Quine, 2017). Tomlinson, Potter and Bayliss (2015) suggest that in the case of Oak Processionary Moth, the confusion about who was responsible for managing the disease across a complex urban landscape delayed effective control. However on the other hand some woodland managers argued that there shouldn't need to be confusion over who had responsibility for pest and disease management and that it should be a shared responsibility of both the government (inspections, regulation, awareness) and forest managers (monitoring, reporting) (Marzano, Fuller and Quine, 2019). This suggests that there are differing opinions as to who should be responsible for tree health management which becomes detrimental when the confusion slows down the response to outbreaks.

6.4 Risks, uncertainty and unknown outcomes

Potentially the largest barrier identified by this review to adopting more resilient management in British woodlands is risk, uncertainty and preparing to deal with unknown outcomes (Lawrence and Marzano, 2014; Marzano, Fuller and Quine, 2017; Tomlinson, Potter and Bayliss, 2015; Urquhart et al.,

2017). Lawrence and Marzano (2014) found that generally there is scepticism when woodland managers want to take high risks. Marzano, Fuller and Quine (2017) acknowledged, for instance, that there was awareness of the risks of single species plantations in terms of resilience but managers perceived there was less risk of spruce picking up diseases than planting unknown species which they did not know how it will perform and whether anyone will buy it. This was also supported by woodland managers dealing with ash dieback deemed the risk of planting unknown non-native species was too high as they had the potential to be invasive with those with a conservation focus unlikely to support this action (Marzano, Woodcock and Quine, 2019). Furthermore, Ambrose-Oji et al., (2020) suggested that particularly large woodland owners felt the risk and uncertainty of diversifying species without economic and ecological resilience was too great to make changes. This could be because managers of bigger woodland may perceive they have more investment in their woodland and therefore more to lose. A similar distinction was made by whether private or public forests had a greater ability to take risks with some woodland managers arguing that private woodland managers have more freedom to adopt new practices but public managers were more protected from the impact of risks (Lawrence and Marzano, 2014).

Marzano et al., (2020) found that risk perceptions influenced management actions and considered the impacts of multiple elements including insecticides on human health, biodiversity, and the wider environment; costs of management and who pays; and the perceived effectiveness of each approach. Tomlinson, Potter and Bayliss (2015) suggested that in the case of Oak Processionary Moth where the public health impact in some cases is considered over the tree health issue can lead to a disproportionate assessment of the risk which could result in the unnecessary loss of trees and their benefits. In addition, when considering anthropocentric frames there is the additional issue of balancing real risk with perceived risk whereby woodland managers perceive the risks of the same pest or disease differently (Urquhart et al., 2017). This could influence the perceived severity of certain outbreaks between different managers within the same area and may carry out different management actions as a result. In the case of the Oak Processionary Moth woodland managers constructed risk associated with the pest differently by a wide range of information sources (e.g. personal experience, other countries, public concern, government action and media). This suggests that perceived risk in terms of manager behaviour is complex but may be more informative when considering what managers actually do than the actual risk of an outbreak.

7. Research approach of the studies reviewed

This literature review had strict eligibility criteria for inclusion returning only 11 suitable results. However, it is important to analyse the study design, data collection and analysis of the studies included to

understand the context in which the literature has been generated. Furthermore, it allows for any analysis of outlying information that may be attributed to study limitations than a reflection on woodland manager attitudes, behaviours or influences. Mackenzie and Larson (2010), Marzano, Fuller and Quine (2017) and Tomlinson, Potter and Bayliss (2015) carried out qualitative semi-structured interviews with individuals directly involved in the management of the Emerald Ash Borer, Dothistroma Needle Blight and Oak Processionary Moth respectively. These papers consider in-depth interviews with woodland managers which can provide detailed information about the attitudes, influences and actual behaviour of woodland managers when faced with a particular disease or pest.

Ambrose-Oji et al., (2020) also carried out semi-structured interviews considering woodland managers' resilience management and any adoption of resilient practices. Marzano, Woodcock and Quine (2019) collected qualitative data through semi-structured interviews with forest advisors and managers from public private and non-governmental organisations who have experienced ash dieback either in their forests or in forests belonging to clients. This paper not only demonstrates the management of ash dieback but allows for any potential grouping of behaviours between public and private woodland managers. Two additional papers included, Marzano et al., (2016) and Urquhart et al., (2017) who consider woodland managers as a wider tree professional group, conducting semi-structured interviews about outbreaks risk and self-completed questionnaire surveys of tree professionals across nine European countries with knowledge and concern for tree pests and diseases. Due to the limited suitable literature available the above papers were supplemented by interviews with small samples of 'key informants' which give an overview of several different perspectives of woodland management threats through perceived behaviours. Lawrence and Marzano (2014), Marzano et al., (2020) and Young et al., (2018) recollect the perceived behaviour of woodland managers when reacting to threats generally.

Overall, it is clear that current literature supports semi-structured interviews as a strong study design for obtaining detailed information about attitudes, influences and the actual behaviour of woodland managers behaviour which also allows for some comparison between different experiences (Ambrose-Oji et al., 2020; Lawrence and Marzano, 2014; Mackenzie and Larson, 2010; Marzano et al., 2020; Marzano, Fuller and Quine, 2017; Marzano, Woodcock and Quine, 2019; Porth et al., 2015; Tomlinson, Potter and Bayliss, 2015; Urquhart et al., 2017; Young et al., 2018). There are also examples of focus groups (Young et al., 2018) which allow for high respondent involvement which is often highlighted as a barrier in pest and disease management decisions (Porth et al., 2015; Mackenzie and Larson, 2010; Marzano et al., 2020). The only paper (Marzano et al., 2016) that has no interview component uses a survey which gave quite a succinct overview of many aspects of tree health

among tree professionals. Perhaps a limitation of this review is that perceived and actual recollections of woodland managers' attitudes, behaviour and influences are compared with equal weight.

Some studies include wider tree professionals that might not specifically act as woodland managers but where this information is used in the review this is always detailed and considered necessary. Additionally, the scale and application of the studies included vary from local (Porth et al., 2015), to European level (Marzano et al., 2016) and overseas examples (Larson and Mackenzie, 2010; Marzano et al., 2020). However, this is considered in the analysis and the two overseas examples were specifically picked because the pest identified poses an immediate threat to British woodlands. Overall this review acknowledges having strict eligibility criteria and with additional time more papers containing different study designs, scales and applications may be found. However, these papers do demonstrate the lack of peer reviews literature available on this topic and indicate that the elements of attitudes, influences and behaviour had been reached by the end of the analysis (principle of saturation).

7.1 Participant recruitment

Lawrence and Marzano (2014) selected participants purposively and then used the 'snowballing approach' to further identify individuals with suitable experiences in forest management for interview. This was a common method identified in this review from papers that detailed participant recruitment methodology (Ambrose-Oji et al., 2020; Mackenzie and Larson, 2010; Marzano et al., 2020; Marzano, Woodcock and Quine, 2019; Porth et al., 2015; Tomlinson, Potter, Bayliss, 2015; Urquhart et al., 2017; Young et al., 2018). Selecting participants purposively is both a cost-effective and time-effective methodology that relies on the judgement of the researcher to assess the suitability of the participants selected for studies. This could have been utilised effectively involving woodland managers when researchers would purposely want to talk to managers with experience in pest and disease or managers of certain species. The use of 'snowballing' approach is used to accompany this methodology because it allows researchers to find more suitable participants through already established relationships through organisations and stakeholders involved with the study. The use of chain referral was completed by Tomlinson, Potter and Bayliss (2015) until the principle of saturation is reached and no new information was found. The only paper involved in this review that didn't take this approach was Marzano et al., (2016) who used opportunistic sampling to recruit survey respondents. The scope of sampling opportunistically is higher than purposive and may well be more representative of the general population. However, opportunistic sampling is equally convenient and effective for gaining large amounts of data in a relatively short time frame.

7.2 Data collection

Of the studies conducted, there were several different methods used to collect data. Marzano, Fuller and Quine, (2019) highlighted the importance of informed consent for both study participation and the recording of interviews before data collection. Interview length varied from 30 minutes to 2 hours (Ambrose-Oji et al., 2020; Lawrence and Marzano, 2014; Mackenzie and Larson, 2010; Marzano et al., 2020; Marzano, Fuller and Quine, 2017; Marzano, Woodcock and Quine, 2019; Porth et al., 2015; Tomlinson, Potter and Bayliss, 2015; Urquhart et al., 2017; Young et al., 2018). Of the papers that detail how many participants were interviewed the amount ranged between 9 and 37 respondents (Ambrose-Oji et al., 2020; Lawrence and Marzano, 2014; Marzano et al., 2020; Mackenzie and Larson, 2010; Porth et al., 2015; Tomlinson, Potter and Bayliss, 2015; Urquhart et al., 2017). The majority of papers carry out most of interviews over the phone (Lawrence and Marzano, 2014; Marzano, Fuller and Quine, 2017; Marzano, Woodcock and Quine, 2019).

There were far fewer studies carrying out interviews face to face (Mackenzie and Larson, 2010; Porth et al., 2015). Whilst there is disagreement among the studies aforementioned whether the information given through interviews is different in-situ or over the telephone. Porth et al., (2015) suggest that more vivid details are given in face-to-face interviews than over the telephone. However, face-to-face interviews are labour and time intensive and may be the reason whilst the majority of studies are carried out over the telephone. Marzano et al., (2016) distributed surveys by hand, email and through social networks with 1250 surveys distributed and a 30% response rate and Young et al., (2018) ran three focus groups of 7 people lasting 15–20 minutes. Both data collection methods provide utilisable information alongside interviews in this review and suggest that useful information from woodland managers can be collected through several platforms and over varying periods of time.

7.3 Data analysis

Marzano, Fuller and Quine (2017) recorded, transcribed and coded data collected through interviews coding information into associated categories and then into key themes. This data analysis was also demonstrated by Tomlinson, Potter and Bayliss (2015) and Mackenzie and Larson (2010). Furthermore, studies used NVivo a qualitative analysis computer software package that allows for thorough organisation, analysis and identifying insights into interview data collected (Ambrose-Oji et al., 2020, Lawrence and Marzano, 2014; Young et al., 2018; Urquhart et al., 2017). Most of the studies carried out the analysis process within their research team but Marzano, Woodcock and Quine, (2019), and Porth et al., (2015) transcribed interviews through professional services which is a useful way to save time but are quite a high cost to factor into research which is why it may not have been used in all the studies reviewed. Marzano et al., (2020) suggested that much of the information analysed didn't

produce direct comparisons but offered informative observations of inter-related examples of response to pest and disease outbreaks. Marzano et al., (2016) analysed the data collected through survey responses through descriptive statistics using the software SPSS which allowed more direct comparisons between woodland managers across Europe to be observed.

7.4 Study location

Marzano, Fuller and Quine (2017) highlight that the management of pest and disease outbreaks is site-specific. It is suggested, however, certain locations can provide useful information and insights into the behaviour of woodland managers (Porth et al., 2015; Tomlinson, Potter and Bayliss, 2015). Lawrence and Marzano (2014) suggest that North Wales is a good location for considering woodland manager behaviour because woodland ownership is representative of what could be found across the UK. Marzano et al., (2020) suggest sites can be opportunistic but valid in woodland management behaviour studies where there have been substantial pest and disease outbreaks. This review highlights that different locations outside of the UK may have an impact on the woodland management behaviour identified with threats being relatively limited in British woodlands compared to those in Canada or America (Lawrence and Marzano, 2014; Mackenzie and Larson, 2010 and Marzano et al., 2020). Therefore any conclusions drawn from other countries should be done with some consideration of differences but can also be useful to predict how woodland managers may deal with threats that are not yet present in the UK but pose a significant threat like Emerald Ash Borer (Mackenzie and Larson, 2010; Marzano et al., 2020). Furthermore, Marzano et al., (2016) highlight that awareness of pests and diseases does vary across locations and studies tend to focus on countries which have ready access to networks of woodland management and tree professionals.

7.5 Further research

This review highlights several areas where further research would allow progression in the understanding of woodland management behaviour. Lawrence and Marzano (2014) suggest that studies that were reliant on 'key informants' should consider supplementary studies that allow observations and interviews to detail actual woodland management behaviour which would develop robust evidence to support more effective adaption in the private and public forestry sectors across the UK. This is further supported by Marzano, Fuller and Quine (2017) who suggest that there is still little known about how individual managers respond to pest and disease threats. Marzano, Woodcock and Quine (2019) suggest future research should also look into woodland managers more directly about their preferred management options and what characteristics and external factors influence these opinions and decisions.

Marzano et al., (2020) suggest that the movement to document stakeholder response to different management approaches is an important element of progressing understanding of social aspects of pest and disease outbreaks. Tomlinson, Potter and Bayliss (2015) suggest the study of funding models and compensation are important for future tree pest outbreaks and enable a timely and effective response. Additionally exploring the logic of adopting new management approaches against threats should consider new science and policy development to create the most effective pathway forward into uncertain forest circumstances (Ambrose-Oji et al., 2020). Young et al., (2018) felt that there should also be a movement to address flaws in government policies and the relationships between different stakeholders and land use sectors need to be developed.

Conclusion: This review supports Potter and Urquhart, (2017) and Wingfield et al., (2015)

Findings that British woodlands have faced an observable increase in the introduction and spread of pests and diseases in recent decades with varying impact (Ambrose-Oji et al., 2020; Lawrence and Marzano, 2014; Marzano et al., 2016; Marzano, Fuller and Quine, 2016; Porth et al., 2015; Tomlinson, Potter and Bayliss, 2015; Urquhart et al., 2017; Young et al., 2018). There is limited support that pests and diseases occur naturally in woodlands and should be left to naturally establish (Lawrence and Marzano, 2014; Tomlinson, Potter and Bayliss, 2015). Furthermore, there was also limited support suggesting the majority of pests and diseases introduced to British woodlands spread at a relatively slow speed and can at present be managed by feasible woodland management (Marzano, Fuller and Quine, 2017). However, for the most part, the review supports concern for the detrimental impact of pests and diseases which threaten the health of trees, forestry ecosystems and several subsequent services they provide to society (Ambrose-Oji et al., 2020; Lawrence and Marzano, 2014; Marzano et al., 2016; Marzano, Fuller and Quine, 2016; Porth et al., 2015; Tomlinson, Potter and Bayliss, 2015; Urquhart et al., 2017; Young et al., 2018). Therefore implementing effective management strategies against tree pests and diseases was a common theme across the papers reviewed and was considered an important element of resilient woodlands (Lawrence and Marzano, 2014; Marzano et al., 2016; Marzano, Fuller and Quine, 2017; Porth et al., 2015; Young et al., 2018).

British woodlands are diverse in species composition and management providing varied resources and are used for a number of purposes (Ambrose-Oji et al., 2020; Porth et al., 2020). Therefore this review identifies that understanding what woodland managers already do to mitigate the impact of pests and diseases and what prevents them from adopting other resilience approaches is an important element of tree health management (Marzano, Fuller and Quine, 2017; Marzano et al., 2016; Marzano et al., 2020; Marzano, Woodcock and Quine, 2019; Tomlinson, Potter and Bayliss, 2015; Urquhart et al., 2017; Young et al., 2018). Multiple previous reviews have produced informative

'benchmark' strategies to manage pests and diseases and the policy available to support them (Ayres and Lombardero, 2018). However, this review identifies that whilst there is relatively little peer-review literature several informative conclusions can be drawn about woodland managers, their behaviour and their willingness to adopt resilient management approaches if feasible solutions to barriers could be provided.

Woodland management behaviour against tree pest and diseases support findings by Andersson, Keskitalo and Lawrence (2017) and Khanal et al., (2017) woodland manager behaviour is affected by attitudes, (Ambrose-Oji et al., 2020; Marzano et al., 2020; Marzano, Fuller and Quine, 2017; Tomlinson, Potter and Bayliss, 2015; Young et al., 2018) motivations (Ambrose-Oji et al., 2020; Lawrence and Marzano, 2014; Marzano et al., 2016; Marzano, Fuller and Quine, 2016; Porth et al., 2015; Tomlinson, Potter and Bayliss, 2015; Urquhart et al., 2017; Young et al., 2018) and management objectives (Ambrose-Oji et al., 2020; Lawrence and Marzano, 2014; Marzano, Fuller and Quine, 2016; Tomlinson, Potter and Bayliss, 2015) as well as contextual of structural factors such as forest size, wider policy support or markets (Ambrose-Oji et al., 2020; Lawrence and Marzano, 2014; Urquhart et al., 2017).

However, this review found that there was relatively little information about the management action of individual managers, particularly from the private forestry sector which is responsible for nearly 75% of all British woodland (Lawrence and Marzano, 2014). Furthermore, there was even less information regarding variation among these managers within the private forest sector, in which the landscape is complex and diverse (Ambrose-Oji et al., 2020). Marzano et al., (2020) suggested that much of the information analysed doesn't produce direct comparisons but informative observations of inter-related examples to outbreak responses can still be utilised in several ways to understand and predict future behaviour. Therefore it has become increasingly important to not only understand the action of woodland managers and the factors behind those decisions but to attempt to categorise any associated groups within woodland managers that could provide insight into behaviour represented at a larger scale or predict the adoption of management practices over time. Although any assumptions of other management based on collected data should consider the wide number of factors that influence behaviour and be met with caution, as outbreaks can be largely site-specific (Marzano, Fuller and Quine, 2017).

Furthermore, utilising influential tools (e.g. media, forestry networks, internet, grants) that influence woodland behaviour by encouraging and incentivising resilient behaviours and engage effectively to mobilise action when pest and disease outbreaks occur (Ambrose-Oji et al., 2020; Lawrence and Marzano, 2014; Marzano et al., 2016; Marzano, Fuller and Quine, 2017; Porth et al., 2015; Tomlinson, Potter and Bayliss, 2015; Urquhart et al., 2017; Young et al., 2018). For these tools to be effective, woodland

managers need to be willing to adapt and feasible solutions need to be provided at multiple scales to remove barriers that prevent resilient behaviours from being adopted. This review identified several woodland managers who demonstrated concern for pests and disease (Lawrence and Marzano, 2014) and a willingness to adapt proactively to more resilient behaviours (Young et al., 2018). However several barriers are preventing this management from taking place: cost and resources (Marzano, Fuller and Quine 2017; Tomlinson, Potter and Bayliss, 2015), scepticism of expert advice (Mackenzie and Larson, 2010; Marzano et al., 2020; Porth et al., 2015) and planning for unknown outcomes (Lawrence and Marzano, 2014; Marzano, Fuller and Quine, 2017; Tomlinson, Potter and Bayliss, 2015; Urquhart et al., 2017).

This literature review itself is not without limitation, supplementing information from actual woodland managers with perceived information, through key informants and comparing those responses with equal weight. The limited literature could be attributed to the fact pest and diseases are not an issue in woodland management, resilient management isn't being demonstrated or it has not been widely studied. This review suggests that for the most part, woodland managers do consider pests and diseases a threat (Lawrence and Marzano, 2014; Tomlinson, Potter and Bayliss, 2015) and want to take a proactive stance in mitigating their impact (Marzano, Fuller and Quine, 2016). Therefore, it supports Marzano, Fuller and Quine's (2017) conclusion that the lack of research in this area could be limiting the understanding of management behaviour when faced with pest and disease outbreaks over time. This call for further research was widely demonstrated throughout this review (Lawrence and Marzano, 2014; Marzano, Fuller and Quine, 2017; Marzano, Woodcock and Quine, 2019; Tomlinson, Potter and Bayliss, 2015; Young et al., 2018).

References

- Altieri, V., De Franco, S., Lombardi, F., Marziliano, P.A., Menguzzato, G. and Porto, P., 2018. The role of silvicultural systems and forest types in preventing soil erosion processes in mountain forests: a methodological approach using cesium-137 measurements. *Journal of Soils and Sediments*, 18(12), pp.3378–3387.
- Ambrose-Oji, B., Atkinson, M., Petrokofsky, G. and Hemery, G., 2020. Do Environmental Worldviews and Distrust Influence Action for Adaptation to Environmental Change Among Small-Scale Woodland Managers?. *Small-scale Forestry*, 19, pp.159–185.
- Anderson, P.K., Cunningham, A.A., Patel, N.G., Morales, F.J., Epstein, P.R. and Daszak, P., 2004. Emerging infectious diseases of plants: pathogen pollution, climate change and agrotechnology drivers. *Trends in ecology & evolution*, 19(10), pp.535–544.
- Andersson, E., Keskitalo, E.C.H. and Lawrence, A., 2017. Adaptation to climate change in forestry: A perspective on forest ownership and adaptation responses. *Forests*, 8(12), p.493.
- Asner, G.P., Knapp, D.E., Broadbent, E.N., Oliveira, P.J., Keller, M. and Silva, J.N., 2005. Selective logging in the Brazilian Amazon. *science*, 310(5747), pp.480–482.
- Aukema, J.E., McCullough, D.G., Von Holle, B., Liebhold, A.M., Britton, K. and Frankel, S.J., 2010. Historical accumulation of nonindigenous forest pests in the continental United States. *BioScience*, 60(11), pp.886–897.
- Axelsson, A.L., Östlund, L. and Hellberg, E., 2002. Changes in mixed deciduous forests of boreal Sweden 1866–1999 based on interpretation of historical records. *Landscape Ecology*, 17(5), pp.403–418.
- Ayres, M.P. and Lombardero, M.J., 2018. Forest pests and their management in the Anthropocene. *Canadian Journal of Forest Research*, 48(3), pp.292–301.
- Battisti, A., Avci, M., Avtzi, D., Ben Jamaa, M., Berardi, L., Berretima, W., Branco, M., Chakali, G., Alaoui El Fels, M., Frérot, B. and Hódar, J., 2015. Processionary moths and climate change: An update Chapter 2 Natural History of the Processionary Moths (*Thaumetopoea* spp.): New Insights in Relation to Climate Change. Roques A.(Ed.).
- Binner, A.R., Smith, G., Bateman, I.J., Day, B.H., Agarwala, M. and Harwood, A., 2017. Valuing the social and environmental contribution of woodlands and trees in England, Scotland and Wales. Forestry Commission.
- Blakesley, D. and Buckley, P., 2010. *Managing your woodland for wildlife*. Newbury: Woodlands.co.uk, pp.1–98.
- Bonan, G.B., 2008. Forests and climate change: forcings, feedbacks, and the climate benefits of forests. *science*, 320(5882), pp.1444–1449.
- Boyd, I.L., Freer-Smith, P.H., Gilligan, C.A. and Godfray, H.C.J., 2013. The consequence of tree pests and diseases for ecosystem services. *Science*, 342(6160).

- Branco, S., Faccoli, M., Brockerhoff, E.G., Roux, G., Jactel, H., Desneux, N., Gachet, E., Mouttet, R., Streito, J.C. and Branco, M., 2021. Preventing invasions of Asian longhorn beetle and citrus longhorn beetle: are we on the right track?. *Journal of Pest Science*, pp.1–26.
- Brasier, C.M., 2008. The biosecurity threat to the UK and global environment from international trade in plants. *Plant Pathology*, 57(5), pp.792–808.
- Brasier, C.M., Beales, P.A., Kirk, S.A., Denman, S. and Rose, J., 2005. *Phytophthora kernoviae* sp. nov., an invasive pathogen causing bleeding stem lesions on forest trees and foliar necrosis of ornamentals in the UK. *Mycological Research*, 109(8), pp.853–859.
- Brasier, C.M. and Gibbs, J.N., 1973. Origin of the Dutch elm disease epidemic in Britain. *Nature*, 242(5400), pp.607–609.
- Brockerhoff, E.G., Jactel, H., Parrotta, J.A., Quine, C.P. and Sayer, J., 2008. Plantation forests and biodiversity: oxymoron or opportunity?. *Biodiversity and Conservation*, 17(5), pp.925–951.
- Brown, A. and Webber, J., 2008. Red band needle blight of conifers in Britain. Forestry Commission.
- Bürgi, M., Gimmi, U. and Stuber, M., 2013. Assessing traditional knowledge on forest uses to understand forest ecosystem dynamics. *Forest Ecology and Management*, 289, pp.115–122.
- Bryman, A., 2016. Social research methods. Oxford university press.
- Canadell, J.G. and Raupach, M.R., 2008. Managing forests for climate change mitigation. *science*, 320(5882), pp.1456–1457.
- Chadès, I., Nicol, S., Rout, T.M., Péron, M., Dujardin, Y., Pichancourt, J.B., Hastings, A. and Hauser, C.E., 2017. Optimization methods to solve adaptive management problems. *Theoretical Ecology*, 10(1), pp.1–20.
- Chazdon, R.L., Brancalion, P.H., Laestadius, L., Bennett-Curry, A., Buckingham, K., Kumar, C., Moll-Rocek, J., Vieira, I.C.G. and Wilson, S.J., 2016. When is a forest a forest? Forest concepts and definitions in the era of forest and landscape restoration. *Ambio*, 45(5), pp.538–550.
- Ciesla, W.M., 2004. Forests and forest protection in Cyprus. *The Forestry Chronicle*, 80(1), pp.107–113.
- Curtis, P.G., Slay, C.M., Harris, N.L., Tyukavina, A. and Hansen, M.C., 2018. Classifying drivers of global forest loss. *Science*, 361(6407), pp.1108–1111.
- Dale, V.H., Joyce, L.A., McNulty, S. and Neilson, R.P., 2000. The interplay between climate change, forests, and disturbances. *Science of the total environment*, 262(3), pp.201–204.
- Dandy, N., Marzano, M., Porth, E.F., Urquhart, J. and Potter, C., 2017. Who has a stake in ash dieback? A conceptual framework for the identification and categorisation of tree health stakeholders. Dieback of European Ash (*Fraxinus* spp.)—consequences and guidelines for sustainable management. Swedish University of Agricultural Sciences, Uppsala, pp.15–26.
- Davis, R.A., Valentine, L.E., Craig, M.D., Wilson, B., Bancroft, W.J. and Mallie, M., 2014. Impact of *Phytophthora*-dieback on birds in Banksia woodlands in south west Western Australia. *Biological Conservation*, 171, pp.136–144.

DEFRA, 2014. *Protecting Plant Health A Plant Biosecurity Strategy for Great Britain*. London: DEFRA, pp.1-34.

Department of Agriculture, Environment and Rural Affairs, 2022. *Forestry and the environment / Department of Agriculture, Environment and Rural Affairs*. [online] DAERA. Available at: <<https://www.daera-ni.gov.uk/topics/forestry/forestry-and-environment>> [Accessed 27 January 2022].

Dyck, B., 2003, March. Benefits of planted forests: social, ecological and economic. In *UNFF Intersessional Experts Meeting on the Role of Planted Forests in Sustainable Forest Management* (pp. 24-30).

Eriksson, L., 2018. Effects of policy measures and moderating factors on climate change adaptation among private forest owners in Sweden. *Society & Natural Resources*, 31(4), pp.409-423.

Estay, S.A. ed., 2020. *Forest Pest and Disease Management in Latin America: Modern Perspectives in Natural Forests and Exotic Plantations*. Springer Nature.

Evans, M.R., 2019. Will natural resistance result in populations of ash trees remaining in British woodlands after a century of ash dieback disease?. *Royal Society open science*, 6(8), p.190908.

FAO, 2009. *Global review of forest pests and diseases*. Rome: FAO, pp.1-53.

FAO, 1997. *International Plant Protection Convention*. Rome: FAO, pp.1-18.

FAO, 2020. *The State of the World's Forests 2020*. Rome, pp.1-214.

Fisichelli, N.A., Abella, S.R., Peters, M. and Krist Jr, F.J., 2014. Climate, trees, pests, and weeds: Change, uncertainty, and biotic stressors in eastern US national park forests. *Forest Ecology and Management*, 327, pp.31-39.

Forestal, L., 1987. Public Law 15939.

Forestry Commission, 2020. *Forestry Statistics 2020*. Edinburgh: Forestry Commission, pp.1-307.

Forestry Commission, 2021. *Managing and maintaining woodlands: overview*. [online] GOV.UK. Available at: <<https://www.gov.uk/guidance/managing-and-maintaining-woodlands-overview>> [Accessed 27 January 2022].

Forest Research, 2020. *Provisional estimates of the ownership type and property type of woodlands in Britain*. Roslin: Forest Research, pp.1-26.

Forest Research. 2022. *Pests and diseases resources and advice - Forest Research*. [online] Available at: <<https://www.forestresearch.gov.uk/tools-and-resources/fthr/pest-and-disease-resources/>> [Accessed 19 January 2022].

Forest Research, 2017. *The UK Forestry Standard*. Edinburgh: Forest Research, pp.1-232.

Forest Research, 2016. *Woodland area in the UK by ownership - Forest Research*. [online] Forest Research. Available at: <<https://www.forestresearch.gov.uk/tools-and-resources/statistics/forestry-statistics/forestry-statistics-2016-introduction/woodland-areas-and-planting/woodland-area/woodland-area-in-the-uk-by-ownership/>> [Accessed 28 January 2022].

- Franco, L.S., Shanahan, D.F. and Fuller, R.A., 2017. A review of the benefits of nature experiences: more than meets the eye. *International journal of environmental research and public health*, 14(8), p.864.
- Frankel, S.J., 2008. Sudden oak death and *Phytophthora ramorum* in the USA: a management challenge. *Australasian Plant Pathology*, 37(1), pp.19–25.
- Freer-Smith, P.H. and Webber, J.F., 2017. Tree pests and diseases: the threat to biodiversity and the delivery of ecosystem services. *Biodiversity and Conservation*, 26(13), pp.3167–3181.
- Funk, J.M., Aguilar-Amuchastegui, N., Baldwin-Cantello, W., Busch, J., Chuvasov, E., Evans, T., Griffin, B., Harris, N., Ferreira, M.N., Petersen, K. and Phillips, O., 2019. Securing the climate benefits of stable forests. *Climate Policy*, 19(7), pp.845–860.
- García-Nieto, A.P., García-Llorente, M., Iniesta-Arandia, I. and Martín-López, B., 2013. Mapping forest ecosystem services: from providing units to beneficiaries. *Ecosystem Services*, 4, pp.126–138.
- Godefroid, M., Meurisse, N., Groenen, F., Kerdelhué, C. and Rossi, J.P., 2020. Current and future distribution of the invasive oak processionary moth. *Biological Invasions*, 22(2), pp.523–534.
- Graziosi, I., Tembo, M., Kuate, J. and Muchugi, A., 2020. Pests and diseases of trees in Africa: A growing continental emergency. *Plants, People, Planet*, 2(1), pp.14–28.
- Groenen, F. and Meurisse, N., 2012. Historical distribution of the oak processionary moth *Thaumetopoea processionea* in Europe suggests recolonization instead of expansion. *Agricultural and forest entomology*, 14(2), pp.147–155.
- Haack, R.A., Hérard, F., Sun, J. and Turgeon, J.J., 2010. Managing invasive populations of Asian longhorned beetle and citrus longhorned beetle: a worldwide perspective. *Annual review of entomology*, 55.
- Hall, C.M., James, M. and Baird, T., 2011. Forests and trees as charismatic mega-flora: implications for heritage tourism and conservation. *Journal of Heritage Tourism*, 6(4), pp.309–323.
- Heuch, J., 2014. What lessons need to be learnt from the outbreak of Ash Dieback disease, *Chalara fraxinea* in the United Kingdom? *Arboricultural Journal*, 36, 32–44.
- Harris, A.R. and Webber, J.F., 2016. Sporulation potential, symptom expression and detection of *Phytophthora ramorum* on larch needles and other foliar hosts. *Plant Pathology*, 65(9), pp.1441–1451.
- Hisano, M., Chen, H.Y., Searle, E.B. and Reich, P.B., 2019. Species-rich boreal forests grew more and suffered less mortality than species-poor forests under the environmental change of the past half-century. *Ecology letters*, 22(6), pp.999–1008.
- Hu, J., Angeli, S., Schuetz, S., Luo, Y. and Hajek, A.E., 2009. Ecology and management of exotic and endemic Asian longhorned beetle *Anoplophora glabripennis*. *Agricultural and Forest Entomology*, 11(4), pp.359–375.
- Hughes, F.M., del Tánago, M.G. and Mountford, J.O., 2012. Restoring floodplain forests in Europe. In *A goal-oriented approach to forest landscape restoration* (pp. 393–422). Springer, Dordrecht.
- Jactel, H., Koricheva, J. and Castagnèyrol, B., 2019. Responses of forest insect pests to climate change: not so simple. *Current opinion in insect science*, 35, pp.103–108.

- Jennings, L., Treasure, E., Myers, J.M., McNulty, S., Brogan, S. and Jones, D., 2012. North Carolina's Emerging Forest Threats: Management Options for Healthy Forests. *Information Pamphlet: North Carolina Forest Service, Raleigh, NC. 4p.*, pp.1-4.
- Johnston, M., Webber, S., O'Neill, G., Williamson, T. and Hirsch, K., 2009. Climate Change Impacts and Adaptation Strategies for the Forest Sector in Canada. In: *2nd Climate Change Technology Conference*. Hamilton, pp.1-13.
- Kaul, M., Dadhwal, V.K. and Mohren, G.M.J., 2009. Land use change and net C flux in Indian forests. *Forest Ecology and Management*, 258(2), pp.100-108.
- Khanal, P.N., Grebner, D.L., Munn, I.A., Grado, S.C., Grala, R.K. and Henderson, J.E., 2017. Typology of nonindustrial private forest landowners and forestry behavior: Implications for forest carbon sequestration in the southern US. *Small-Scale Forestry*, 16(3), pp.419-434.
- Kozak, J., Estreguil, C. and Troll, M., 2007. Forest cover changes in the northern Carpathians in the 20th century: a slow transition. *Journal of Land Use Science*, 2(2), pp.127-146.
- Laurance, W.F., 2007. Forests and floods. *Nature*, 449(7161), pp.409-410.
- Lawrence, A. and Dandy, N., 2014. Private landowners' approaches to planting and managing forests in the UK: What's the evidence?. *Land use policy*, 36, pp.351-360.
- Lawrence, A. and Marzano, M., 2014. Is the private forest sector adapting to climate change? A study of forest managers in north Wales. *Annals of forest science*, 71(2), pp.291-300.
- Lee, J., Li, Q., Tyrväinen, L., Tsunetsugu, Y., Park, B.J., Kagawa, T. and Miyazaki, Y., 2012. Nature therapy and preventive medicine. *Public Health-Social and Behavioral Health*, 16, pp.325-350.
- Lehmann, P., Ammunét, T., Barton, M., Battisti, A., Eigenbrode, S.D., Jepsen, J.U., Kalinkat, G., Neuvonen, S., Niemelä, P., Terblanche, J.S. and Økland, B., 2020. Complex responses of global insect pests to climate warming. *Frontiers in Ecology and the Environment*, 18(3), pp.141-150.
- Li, Y., Bao, W., Bongers, F., Chen, B., Chen, G., Guo, K., Jiang, M., Lai, J., Lin, D., Liu, C. and Liu, X., 2019. Drivers of tree carbon storage in subtropical forests. *Science of the total environment*, 654, pp.684-693.
- Liebhold, A.M., Bockerhoff, E.G., Kalisz, S., Nuñez, M.A., Wardle, D.A. and Wingfield, M.J., 2017. Biological invasions in forest ecosystems. *Biological Invasions*, 19(11), pp.3437-3458.
- Linnakoski, R., Kasanen, R., Dounavi, A. and Forbes, K.M., 2019. Forest health under climate change: effects on tree resilience, and pest and pathogen dynamics. *Frontiers in plant science*, 10, p.1157.
- Lugo, A.E., 2000. Effects and outcomes of Caribbean hurricanes in a climate change scenario. *Science of the Total Environment*, 262(3), pp.243-251.
- Lugo, A.E. and Scatena, F.N., 1996. Background and catastrophic tree mortality in tropical moist, wet, and rain forests. *Biotropica*, pp.585-599.
- MacFarlane, D.W. and Meyer, S.P., 2005. Characteristics and distribution of potential ash tree hosts for emerald ash borer. *Forest Ecology and Management*, 213(1-3), pp.15-24.

- Mackenzie, B.F. and Larson, B.M., 2010. Participation under time constraints: landowner perceptions of rapid response to the emerald ash borer. *Society and Natural Resources*, 23(10), pp.1013–1022.
- MacLeod, A., Evans, H.F. and Baker, R.H.A., 2002. An analysis of pest risk from an Asian longhorn beetle (*Anoplophora glabripennis*) to hardwood trees in the European community. *Crop Protection*, 21(8), pp.635–645.
- Mamun, A.A., 2010. Understanding the value of local ecological knowledge and practices for habitat restoration in human-altered floodplain systems: a case from Bangladesh. *Environmental management*, 45(5), pp.922–938.
- Martínez, M.L., Pérez-Maqueo, O., Vázquez, G., Castillo-Campos, G., García-Franco, J., Mehlreter, K., Equihua, M. and Landgrave, R., 2009. Effects of land use change on biodiversity and ecosystem services in tropical montane cloud forests of Mexico. *Forest ecology and management*, 258(9), pp.1856–1863.
- Marzano, M., Dandy, N., Papazova-Anakieva, I., Avtzi, D., Connolly, T., Eschen, R., Glavendekić, M., Hurley, B., Lindelöw, Å., Matošević, D. and Tomov, R., 2016. Assessing awareness of tree pests and pathogens amongst tree professionals: A pan-European perspective. *Forest policy and economics*, 70, pp.164–171.
- Marzano, M., Fuller, L. and Quine, C.P., 2017. Barriers to management of tree diseases: framing perspectives of pinewood managers around Dothistroma Needle Blight. *Journal of environmental management*, 188, pp.238–245.
- Marzano, M., Hall, C., Dandy, N., LeBlanc Fisher, C., Disston, A. and Haight, R., 2020. Lessons from the frontline: Exploring how stakeholders may respond to emerald ash borer management in Europe. *Forests*, 11(6), p.617.
- Marzano, M., Woodcock, P. and 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(5), pp.554–567.
- Meyerson, L.A. and Mooney, H.A., 2007. Invasive alien species in an era of globalization. *Frontiers in Ecology and the Environment*, 5(4), pp.199–208.
- Miller, D.C., Mansourian, S., Gabay, M., Hajjar, R., Jagger, P., Kamoto, J.F., Newton, P., Oldekop, J.A., Razafindratsima, O.H., Shyamsundar, P. and Sunderland, T., 2021. Forests, trees and poverty alleviation: Policy implications of current knowledge. *Forest Policy and Economics*, 131, p.102566.
- Mitchell, S., 2019. *The Differences in Woods, Forests & Jungles*. [online] Sciencing. Available at: <<https://sciencing.com/differences-woods-forests-jungles-8377449.html>> [Accessed 28 January 2022].
- Musolin, D.L., Selikhovkin, A.V., Shabunin, D.A., Zviagintsev, V.B. and Baranchikov, Y.N., 2017. Between ash dieback and emerald ash borer: two Asian invaders in Russia and the future of ash in Europe. *Baltic Forestry*, 23(1), pp.316–333.

Natural Resources Wales, 2021. *Natural Resources Wales / Forestry*. [online] Naturalresources.wales. Available at: <<https://naturalresources.wales/guidance-and-advice/business-sectors/forestry?lang=en>> [Accessed 27 January 2022].

Paini, D.R., Sheppard, A.W., Cook, D.C., De Barro, P.J., Worner, S.P. and Thomas, M.B., 2016. Global threat to agriculture from invasive species. *Proceedings of the National Academy of Sciences*, 113(27), pp.7575–7579.

Palmer, S., Martin, D., DeLauer, V. and Rogan, J., 2014. Vulnerability and adaptive capacity in response to the Asian longhorned beetle infestation in Worcester, Massachusetts. *Human Ecology*, 42(6), pp.965–977.

Pautasso, M., Aas, G., Quelo, V. and Holdenrieder, O., 2013. European ash (*Fraxinus excelsior*) dieback – A conservation biology challenge. *Biological conservation*, 158, pp.37–49.

Pautasso, M., Schlegel, M. and Holdenrieder, O., 2015. Forest health in a changing world. *Microbial Ecology*, 69(4), pp.826–842.

Polato, N.R., Gill, B.A., Shah, A.A., Gray, M.M., Casner, K.L., Barthelet, A., Messer, P.W., Simmons, M.P., Guayasamin, J.M., Encalada, A.C. and Kondratieff, B.C., 2018. Narrow thermal tolerance and low dispersal drive higher speciation in tropical mountains. *Proceedings of the National Academy of Sciences*, 115(49), pp.12471–12476.

Porth, E.F., Dandy, N. and Marzano, M., 2015. “My garden is the one with no trees:” Residential lived experiences of the 2012 Asian Longhorn Beetle eradication programme in Kent, England. *Human Ecology*, 43(5), pp.669–679.

Potter, C., Harwood, T., Knight, J. and 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(1573), pp.1966–1974.

Potter, C. and Urquhart, J., 2017. Tree disease and pest epidemics in the Anthropocene: A review of the drivers, impacts and policy responses in the UK. *Forest Policy and Economics*, 79, pp.61–68.

Potter, C., Harwood, T., Knight, J. and 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(1573), pp.1966–1974.

Ramsfield, T.D., Bentz, B.J., Faccoli, M., Jactel, H. and Brockerhoff, E.G., 2016. Forest health in a changing world: effects of globalization and climate change on forest insect and pathogen impacts. *Forestry*, 89(3), pp.245–252.

Randhir, T.O. and Erol, A., 2013. Emerging Threats to Forests: Resilience and Strategies at System Scale.

Ramsfield, T.D., Bentz, B.J., Faccoli, M., Jactel, H. and Brockerhoff, E.G., 2016. Forest health in a changing world: effects of globalization and climate change on forest insect and pathogen impacts. *Forestry*, 89(3), pp.245–252.

Riitters, K., Wickham, J., O'Neill, R., Jones, B. and Smith, E., 2000. Global-scale patterns of forest fragmentation. *Conservation ecology*, 4(2).

Roberge, J.M., Bengtsson, S.B., Wulff, S. and Snäll, T., 2011. Edge creation and tree dieback influence the patch-tracking metapopulation dynamics of a red-listed epiphytic bryophyte. *Journal of Applied Ecology*, 48(3), pp.650–658.

Roux, J. and Ham, H., 2020. INTRODUCTION: International Year of Plant Health: a Focus on Tree Health: Southern Forests: a Journal of Forest Science.

Santini, A., Ghelardini, L., De Pace, C., Desprez-Loustau, M.L., Capretti, P., Chandelier, A., Cech, T., Chira, D., Diamandis, S., Gaitniekis, T. and Hantula, J., 2013. Biogeographical patterns and determinants of invasion by forest pathogens in Europe. *New Phytologist*, 197(1), pp.238–250.

Scotland's Environment, 2019. *Woodland and forests | Scotland's environment web*. [online] Environment.gov.scot. Available at: <<https://www.environment.gov.scot/our-environment/habitats-and-species/woodland-and-forests/#:~:text=Woodlands%20and%20forests%20support%20a%20large%20part%20of%20Scotland's%20terrestrial,is%20equal%20to%20tree%20cover.>> [Accessed 29 January 2022].

Scottish Forestry, 2022. *Scottish Forestry - Home*. [online] Forestry.gov.scot. Available at: <<https://forestry.gov.scot/>> [Accessed 27 January 2022].

Shea, K., Possingham, H.P., Murdoch, W.W. and Roush, R., 2002. Active adaptive management in insect pest and weed control: intervention with a plan for learning. *Ecological Applications*, 12(3), pp.927–936.

Simler-Williamson, A.B., Rizzo, D.M. and Cobb, R.C., 2019. Interacting effects of global change on forest pest and pathogen dynamics. *Annual Review of Ecology, Evolution, and Systematics*, 50, pp.381–403.

Skovsgaard, J.P., Wilhelm, G.J., Thomsen, I.M., Metzler, B., Kirisits, T., Havrdová, L., Enderle, R., Dobrowolska, D., Cleary, M. and Clark, J., 2017. Silvicultural strategies for *Fraxinus excelsior* in response to dieback caused by *Hymenoscyphus fraxineus*. *Forestry: An International Journal of Forest Research*, 90(4), pp.455–472.

Song, C., Ikei, H., Park, B.J., Lee, J., Kagawa, T. and Miyazaki, Y., 2018. Psychological benefits of walking through forest areas. *International journal of environmental research and public health*, 15(12), p.2804.

Store, R., 2009. Sustainable locating of different forest uses. *Land use policy*, 26(3), pp.610–618.

Sutherland, I.J., Villamagna, A.M., Dallaire, C.O., Bennett, E.M., Chin, A.T., Yeung, A.C., Lamothe, K.A., Tomscha, S.A. and Cormier, R., 2018. Undervalued and under pressure: a plea for greater attention toward regulating ecosystem services. *Ecological Indicators*, 94, pp.23–32.

Szabó, P. and Hédli, R., 2011. Advancing the integration of history and ecology for conservation. *Conservation Biology*, 25(4), pp.680–687.

Taubert, F., Fischer, R., Groeneveld, J., Lehmann, S., Müller, M.S., Rödig, E., Wiegand, T. and Huth, A., 2018. Global patterns of tropical forest fragmentation. *Nature*, 554(7693), pp.519–522.

Teshome, D.T., Zharare, G.E. and Naidoo, S., 2020. The threat of the combined effect of biotic and abiotic stress factors in forestry under a changing climate. *Frontiers in plant science*, 11, p.1874.

Tomlinson, I. and Potter, C., 2010. 'Too little, too late'? Science, policy and Dutch Elm Disease in the UK. *Journal of Historical Geography*, 36(2), pp.121–131.

Tomlinson, I., Potter, C. and Bayliss, H., 2015. Managing tree pests and diseases in urban settings: the case of Oak Processionary Moth in London, 2006–2012. *Urban Forestry & Urban Greening*, 14(2), pp.286–292.

Tribe, G.D. and Cillie, J.J., 2004. The spread of *Sirex noctilio* Fabricius (Hymenoptera: Siricidae) in South African pine plantations and the introduction and establishment of its biological control agents. *African entomology*, 12(1), pp.9–17.

UK Government, 2022. *Plant Health Act 1967*. London: UK Government, pp.1–9.

United Nations, 2021. *FIRST DRAFT OF THE POST-2020 GLOBAL BIODIVERSITY FRAMEWORK*. Rome: United Nations, pp.1–12.

United Nations, 2017. *United Nations strategic plan for forests, 2017–2030*. Rome: United Nations, pp.1–16.

Urquhart, J., Potter, C., Barnett, J., Fellenor, J., Mumford, J. and Quine, C.P., 2017. Expert risk perceptions and the social amplification of risk: A case study in invasive tree pests and diseases. *Environmental science & policy*, 77, pp.172–178.

USDA APHIS, 2022. *USDA APHIS / PPQ Scientists Evaluate Wasp's Ability to Detect and Attack the Asian Longhorned Beetle*. [online] Aphis.usda.gov. Available at: <<https://www.aphis.usda.gov/aphis/ourfocus/planthealth/ppq-program-overview/plant-protection-today/articles/alb-biocontrol>> [Accessed 22 January 2022].

van Lierop, P., Lindquist, E., Sathyapala, S. and Franceschini, G., 2015. Global forest area disturbance from fire, insect pests, diseases and severe weather events. *Forest Ecology and Management*, 352, pp.78–88.

Vasaitis, R. and Enderle, R., 2017. Dieback of European ash (*Fraxinus* spp.)–consequences and guidelines for sustainable management. *Dieback of European ash (Fraxinus spp.)–consequences and guidelines for sustainable management*.

Wade, T.G., Riitters, K.H., Wickham, J.D. and Jones, K.B., 2003. Distribution and causes of global forest fragmentation. *Conservation Ecology*, 7(2).

Weber, P., Rigling, A. and Bugmann, H., 2008. Sensitivity of stand dynamics to grazing in mixed *Pinus sylvestris* and *Quercus pubescens* forests: a modelling study. *Ecological Modelling*, 210(3), pp.301–311.

Weir, J., 2017. Forests for the future: planting resilient woodlands. *Quarterly Journal of Forestry*, 111(2), pp.98–101.

Welsh Government, 2019. *Phytophthora ramorum: Strategy for Wales*. Cardiff: Welsh Government, pp.1–29.

Welsh Government, 2005. Public Law 2517

Welsh Government, 2016. Public Law 2016

Welsh Government, 2018b. Public Law 1064

Welsh Government, 2018a. The Welsh Government's Strategy for Woodlands and Trees. Cardiff: Welsh Government, pp.1-60.

Welsh Government, 2017. *What we do: Wales Tree Health Steering Group* | GOV.WALES. [online] GOV.WALES. Available at: <<https://gov.wales/wales-tree-health-steering-group/what-we-do>> [Accessed 22 January 2022].

Welsh Government, 2015. *Well-being of Future Generations (Wales) Act 2015*. Cardiff: Welsh Government, pp.1-14.

Welsh Parliament, 2021. *Forestry and Woodland in Wales Research Briefing*. Cardiff: Welsh Parliament, pp.1-26.

West, S., Beilin, R. and Wagenaar, H., 2019. Introducing a practice perspective on monitoring for adaptive management. *People and Nature*, 1(3), pp.387-405.

Wilcove, D.S., Rothstein, D., Dubow, J., Phillips, A. and Losos, E., 1998. Quantifying threats to imperiled species in the United States. *BioScience*, 48(8), pp.607-615.

Willoughby, I. and Peace, S., 2019. Delivering Resilient Forests.

Wingfield, M.J., Brouckhoff, E.G., Wingfield, B.D. and Slippers, B., 2015. Planted forest health: the need for a global strategy. *Science*, 349(6250), pp.832-836.

Wohlgemuth, T., Bürgi, M., Scheidegger, C. and Schütz, M., 2002. Dominance reduction of species through disturbance—a proposed management principle for central European forests. *Forest Ecology and Management*, 166(1-3), pp.1-15.

Woodcock, P., Cottrell, J.E., Buggs, R.J. and Quine, C.P., 2018. Mitigating pest and pathogen impacts using resistant trees: a framework and overview to inform development and deployment in Europe and North America. *Forestry: An International Journal of Forest Research*, 91(1), pp.1-16.

WTO, 1994. *AGREEMENT ESTABLISHING THE WORLD TRADE ORGANIZATION*. Marrakesh: World Trade Organisation, pp.1-11.

Yang, X., Li, D., McGrouther, K., Long, W., Li, Y., Chen, Y., Lv, X., Niazi, N.K., Song, Z. and Wang, H., 2017. Effect of Eucalyptus forests on understory vegetation and soil quality. *Journal of Soils and Sediments*, 17(9), pp.2383-2389.

Young, J.C., Marzano, M., Quine, C.P. and Ambrose-Oji, B., 2018. Working with decision-makers for resilient forests: A case study from the UK. *Forest Ecology and Management*, 417, pp.291-300.

Yuan, L., Bao, Z., Zhang, H., Zhang, Y. and Liang, X., 2017. Habitat monitoring to evaluate crop disease and pest distributions based on multi-source satellite remote sensing imagery. *Optik*, 145, pp.66-73.

Zhang, D. and Stenger, A., 2015. Value and valuation of forest ecosystem services. *Journal of Environmental Economics and Policy*, 4(2), pp.129-140.

Paper justification: The literature review provides a detailed account of the

current understanding of stakeholder responses to tree pest and disease outbreaks within the UK. Conclusions drawn from the review could direct several future research projects within a Welsh context as requested by Forest Research. Ambrose-Oji et al., (2020) suggest that woodland managers' objectives and subsequent action can be attributed to an interlinked combination of manager motives (e.g. beliefs, worldviews) and structural factors (e.g. woodland size) and contextual factors (e.g. market demands). Marzano, Fuller and Quine (2017) identify that there is still limited information in the UK about how woodland managers respond to tree pest and disease threats in practice as well as the factors that influence decisions. Therefore, Marzano, Woodcock and Quine (2019) suggest one potential direction for further research should incorporate conversations with woodland managers about their experience with tree threats including influences their opinions and decisions. The review identified there is limited information available about the actions of private woodland managers in a British context despite these managers being responsible for over two thirds of woodlands (Lawrence and Marzano, 2014). Therefore, manager behaviour within the private sector seemed an obvious direction for further focus.

The literature review identified that private managers are tasked with managing woodlands that are diverse in species composition and used for several different purposes (Ambrose-Oji et al., 2020; Porth et al., 2020). Lawrence and Marzano (2014) identified that non-commercial private woodlands (those with a conservation and/ or recreation focus) hereby referred to as conservation focused managers were considered to have more versatility to employ adaptive management and this was evident when faced with tree pests and diseases. Ambrose-Oji et al., (2020) suggest that conservation focused managers believe that diversifying is an appropriate response to threats but that it should occur as much as possible through natural processes facilitated by managers. However, management attitudes shift when public health in these woodlands become a greater factor and considered a higher priority particularly in urban areas. This led to the observation that perspectives of conservation focused managers were considered in less than 30% of the reviewed literature.

Overall, it is suggested that management objectives play a large part in the management choices used to remove pests or diseases from woodlands. Conservation focused managers are known to choose slightly less effective methods to mitigate threat impacts such as biological controls and nest removal that have a lesser impact on the wider environment (Tomlinson, Potter and Bayliss, 2015; Marzano et al., 2020). This is in contrast to their counterparts managing commercial and urban woodlands in the private sector where managers prefer the spraying of chemicals when faced with protecting high value crops and public health (Marzano, Fuller and Quine, 2017; Tomlinson, Potter and Bayliss, 2015). Management approaches were observed varying when conservation is a key consideration particularly guided by environmental legislation. This was observed by Tomlinson, Potter and Bayliss (2015) whereby mitigation methods were adapted to be less harmful to the surrounding environment when managing Oak Processionary Moth. In fact, Urquhart et al., (2017) suggested managers felt that risk from Oak Processionary Moth was low due to a range of active management but conservation focused managers were more concerned with the impact of the control methods than the pest itself.

However, the review highlights several cases where conservation focused managers may take different approaches when faced with similar tree threats. It is suggested that conservation focused managers views vary based on location and context. Whilst some provide active management against threats, in some cases for the benefit of biodiversity, other managers believe that areas should be left unmanaged (Ambrose-Oji et al., 2020; Lawrence and Marzano, 2014; Tomlinson, Potter and Bayliss, 2015). The literature review also identified that woodland managers with a conservation focus had contradictory views both about management approaches and practice despite having similar objectives (Ambrose-Oji et al., 2020; Lawrence and Marzano, 2014; Tomlinson, Potter and Bayliss, 2015). This reinforces the findings by Ambrose-Oji et al., (2020) that managers' objectives and subsequent action can be attributed to motives as well as structural and contextual factors. Therefore, further research considering conservation focused managers should consider differences in behaviour between managers in different contexts as well as when behaviour varies despite managers exhibiting similar attitudes, motivations and objectives.

The review supports future research considering private woodland managers particularly those managing woodlands for conservation and/or recreational purposes. In order to strategically direct focus towards these woodland managers additional research about Welsh woodland management structures was conducted. This identified that Marzano et al., (2015) categorises private woodland management into two further branches: woodland managed by private managers and those by non-governmental organisations (NGOs). The categorisation of woodland management into private woodland and NGOs identified a substantial gap in the literature considering the behaviour of NGOs particularly with a conservation focus when faced with tree threats (Marzano, Woodcock and Quine, 2019). To date, there is currently no known studies considering the role conservation organisation play in mitigating tree pest and diseases in Wales.

Conservation organisations (NGOs) own and manage large areas of woodland in Wales and predominately manage woodland from a conservation and/ or recreation perspective (North Wales Wildlife Trust, 2022). Conservation organisations (non-governmental organisations) are of particular interest in the role of mitigating the impact of ash dieback because ash has high cultural and biodiversity value but less economic value compared to other species (Marciulyniene et al., 2017). Organisations often prioritise conservation value and are not restricted entirely by commercial outcomes, therefore they could be more likely to take management approaches that maintain ash dieback in the landscape for longer (Bengtsson and Stenström, 2017). Maintaining ash in the landscape is beneficial for both biodiversity and aesthetics in the landscape (Marciulyniene et al., 2017; Pautasso et al., 2013). Organisations are also known to keep deadwood in the landscape which is highly beneficial to a number of deadwood invertebrates and other dependent organisms (Bače, Svoboda and Vítková, 2019). Therefore further research will consider conservation organisations in Wales and their experience with ash dieback and the influences that affect their management decisions.

However, it is not just the conservation objectives and subsequent management action of conservation organisations within their woodlands that makes understanding their management behaviour of interest. Conservation organisations have an unusual role in woodland management in Wales and as a result potentially also in mitigating the impact of

ash dieback. In addition to owning and managing large areas of woodland the sites of these organisations are regularly visited for wildlife spotting, walks and activities (Welsh Government 2018a). This gives organisations the opportunity to interact with many residents and tourists on site, through activities and to raise awareness about ash dieback. Moreover, conservation organisations are widely supported in Wales with high membership numbers (Cracknell, Miller and Williams, 2013). Through the literature review, Tomlinson, Potter and Bayliss (2015) identified that tree pest and disease management relies on engaging effectively with stakeholders with information shared through trustworthy and credible sources. It is proposed that support for conservation organisations in Wales and the engagement opportunities that arise through their woodlands could translate to greater awareness of ash dieback. With the added educational benefit of disseminating information about ash dieback that could be trusted and well received.

Conservation organisations are also known to offer advice through publicly or privately funded schemes directly to private landowners (North Wales Wildlife Trust, 2022). The literature identified that there is demand for external bodies to be used to coordinate pest and disease outbreaks which have sufficient resources and the ability to give unbiased advice (Tomlinson, Potter and Bayliss, 2015). Lawrence and Marzano (2014) suggested that woodland managers were seen to be heavily reliant on external advice but some suggested this could be disconnected and confusing. It is proposed that conservation organisations despite their conservation focus could be a vehicle for providing clear, engaging and unbiased advice. The review further supports this potential role of conservation organisations as woodland managers were keen to follow advice from trusted groups and potentially adapt their behaviour, but often feel suitable information is not currently available (Ambrose-Oji et al., 2020; Lawrence and Marzano, 2014; Marzano et al., 2016; Marzano, Fuller and Quine, 2017; Tomlinson, Potter and Bayliss, 2015; Urquhart et al., 2017; Young et al., 2018). Conservation organisations also offers a shift away from government advice which was associated with distrust, skepticism and reluctance to adopt suggested behaviours (Lawrence and Marzano, 2014; Mackenzie and Larson, 2010).

The review identified gaps in knowledge regarding tree pests and diseases which limit what managers do to tackle pest and disease outbreaks but it appears there would be willingness to learn (Marzano, Fuller and Quine, 2017; Urquhart et al., 2017). This suggests that conservation organisations could provide training that would be well received by woodland managers. The review identified that woodland managers are likely to report tree pest and disease outbreaks to conservation organisations (Marzano et al., 2016). This suggests that conservation organisations could engage with woodland managers and create a bridge to facilitate a 2-way dialogue about mitigating the impact of ash dieback in Wales. Moreover, Lawrence and Marzano (2014) identified that woodland managers felt that there was poor flow of information between woodland managers themselves. It is also suggested that woodland managers distrust in the government make them feel excluded in the conversation about tree pests and diseases (Mackenzie and Larson, 2010). Therefore, conservation organisations could be best placed for running training for woodland managers, collecting and transferring information between woodland managers and policy makers. while at the same time facilitating relationships between woodland managers themselves. Considering the need to deal with tree threats at the landscape scale, a coordinated response is required and conservation organisations could be a crucial element of this coordinated response (Tomlinson, Potter and Bayliss, 2015).

Overall, further research will consider the role of conservation organisations in mitigating the impact of ash dieback in Wales. The following potential impacts will be considered:

1. Conservation organisations manage ash dieback within woodlands they own and manage for others through a predominantly conservation and/ or recreation purpose
2. Woodlands managed by Conservation organisations tend to be open access and widely visited making opportunities to engage widely with the public about ash dieback
3. Conservation organisations are highly supported and respected in Wales and this could be translated to trust proving beneficial when giving advice about managing ash dieback in Wales
4. Conservation organisations can be used as a vehicle to transfer unbiased information about ash dieback between managers, policymakers and others stakeholders

5. Conservation organisations can provide bring together stakeholders to facilitate networks for ash dieback mitigation
6. Conservation organisations could facilitate participatory management processes that would make woodland managers feel more involved in tree pest and disease management in Wales

The research project that will follow will consider the experience of managers working for conservation organisations when faced with tree pests and diseases. The format of the research will also draw advice from the literature review conducted. It is clear that current literature supports semi-structured interviews as a strong study design for obtaining detailed information about attitudes, influences and actual behaviour of woodland managers. The results of which allows for some comparison between different experiences (Ambrose-Oji et al., 2020; Lawrence and Marzano, 2014; Mackenzie and Larson, 2010; Marzano et al., 2020; Marzano, Fuller and Quine, 2017; Marzano, Woodcock and Quine, 2019; Porth et al., 2015; Tomlinson, Potter and Bayliss, 2015; Urquhart et al., 2017; Young et al., 2018). Therefore, semi-structured interviews will be carried out with managers working with conservation organisations across Wales to understand their experience with ash dieback.

The participants will be selected in the same way as Lawrence and Marzano (2014) who selected participants purposively and then used the 'snowballing approach' to further identify individuals with suitable experiences in forest management for interview. This was a common method identified in this review from papers that detailed participant recruitment methodology (Ambrose-Oji et al., 2020; Mackenzie and Larson, 2010; Marzano et al., 2020; Marzano, Woodcock and Quine, 2019; Porth et al., 2015; Tomlinson, Potter, Bayliss, 2015; Urquhart et al., 2017; Young et al., 2018). Selecting participants purposively cost-effective and time-effective methodology that relies on the judgement of the researcher to assess the suitability of the participants selected for studies. This methodology will be utilised to approach woodland managers with experience of ash dieback. This is an appropriate methodology for the project proposed given the purpose, time and funding constraints.

The project will also utilise thematic analysis similarly implemented by Marzano, Fuller and Quine (2017) where data from the semi-structured interviews will be recorded, transcribed and coded into associated categories and then into key themes. This data analysis was also demonstrated within the literature review by Tomlinson, Potter and Bayliss (2015) and Mackenzie and Larson (2010). Furthermore studies used NVivo a qualitative analysis computer software package that allows for thorough organisation, analysis and identifying insights into interview data collected (Ambrose-Oji et al., 2020, Lawrence and Marzano, 2014; Young et al., 2018; Urquhart et al., 2017). The project will consider the use of similar software to complete the analysis of the data during thematic analysis.

The project will collate the information from the desk-based research and semi-structured interviews. The data collected will be collated into an academic research paper that considers the experience of woodland managers who work within conservation organisations when faced with ash dieback. It will consider conservation organisations across the entirety of Wales as ash dieback has spread nationwide and mitigation strategies need to be considered at the landscape scale. Exploring the experience of managers working within conservation organisations and the wider role they may play in the Welsh landscape in the mitigation of ash dieback will provide research that is topical, relevant and novel and contribute to the wider literature considering tree pest and disease management.

The role conservation organisations in mitigating the impact of ash dieback in Wales



MScRes Submission: Research paper

Highlights

- Conservation organisations exhibited high awareness and understanding of ash dieback and many roles have been established within organisations to mitigate its impact
- Conservation organisations aim to maintain ash trees in the Welsh landscape for biodiversity value and to build woodland resistance to ash dieback
- Conservation organisations are playing a potentially underestimated but influential role in the mitigation of ash dieback (*Hymenoscyphus fraxineus*) in Wales
- Conservation organisations have a wide role managing woodlands, increasing public awareness of ash dieback, offering advice and facilitating tree health networking
- Conservation organisations can utilise their influence, working with stakeholders to achieve common outcomes facilitating a cohesive response to the disease at the landscape scale

Abstract

Outbreaks of tree pests and diseases are continuing to increase globally, causing detrimental impacts to woodland habitats. Ash dieback (*Hymenoscyphus fraxineus*) is a disease which is causing significant damage to the common ash (*Fraxinus excelsior*). Ash is a native tree of significant cultural and biodiversity value and the Welsh landscape has been substantially impacted. Management of affected wooded areas where possible must aim to slow the spread of the disease whilst mitigating its impact through preventative and reactionary measures. Conservation organisations are proposed as a stakeholder that may be playing an overlooked but influential role in coordinating the management response to ash dieback within Wales. Organisations are directly responsible for managing ash dieback on their own land and the land they manage on behalf of others. However, this may be an underestimation of the influence organisations have on ash dieback mitigation. Conservation organisations are highly supported among the public in Wales with many woodlands managers providing the public and other managers about tree health. To date, there is no current studies that consider the role conservation organisations appear to play in the mitigation of ash dieback in Wales. Therefore, semi-structured interviews were carried out with 18 managers working on behalf of conservation organisations to understand their experiences. Thematic analysis identified conservation organisations were found to be readily experiencing ash dieback, adapting management over time and advising other stakeholders about management options. Their management approaches were found to largely follow recommendations by the Tree Health Council and Forest Research which are both derived from overarching Welsh governmental policy and widely considered 'best practice'. Findings revealed that conservation are mitigating the impact of ash dieback on both their own sites as those in the ownership of others. Management decisions were found to be predominantly influenced by health and safety, but their conservation focus and time frame of the disease was found to influence the management approach taken. Overall, conservation organisations are having a far reaching influence on ash dieback mitigation and further support should be provided to enhance this influence therefore recommendations are provided.

Key words

Ash dieback, tree disease, woodland management, conservation organisations, best practice, successful outcomes

Abbreviations:

NGOs – Non-Governmental Organisation

NNR – National Nature Reserve

NVC – Natural Vegetation Classification

PAWS – ancient woodland site where semi-natural woodland has been replaced with a plantation

SAC – Special Areas of Conservation

SSSI – Site of Special Scientific Interest

Introduction

The introduction and establishment of tree pests and diseases continue to increase impacting forest structure and services globally (Fisichelli et al., 2014; Graziosi et al., 2020). The trends observed can be facilitated and accelerated by climate change, extreme weather and globalisation (Ramsfield et al., 2016). Increased spreading of pests and diseases across commercial plantations as well as natural and semi-natural woodlands have widely impacted communities through biodiversity, economic and social implications (Graziosi et al., 2020; Wingfield et al., 2015). In parallel, forests themselves are dynamic, changing over time and often rely on management to predict, monitor, and manage these changes (Pautasso et al., 2015). However, exploitation, fragmentation and land use change within many wooded areas remain prevalent (Curtis et al., 2018; Kozak et al., 2018). This exposes trees to stress, making them more susceptible to the detrimental impacts of tree pests and diseases once introduced and established (Canadell and Raupach, 2008; Marzano, Fuller and Quine, 2017).

Those that advise or carry out woodland management must adapt their approaches to protect their trees from threats minimising environmental, economic, and logistical impacts (Lawrence and Marzano, 2014; Young et al., 2018). Concurrently their approaches directly influence mitigation strategies of tree threats at the landscape scale (Dandy et al., 2017; Marzano et al., 2020). Woodland managers are influential in pest and disease management as they often possess the skills and capabilities required to manage an outbreak (Dandy et al., 2017). The action they take on the ground act as the first line of defence against introduced and establish threats, monitoring, reporting, and carrying out activities that can minimise their impact (Marzano et al., 2020; Tomlinson, Potter and Bayliss, 2015). It is critical to understand the actions taken by managers and the factors that influence their decisions. Marzano et al., (2016) identify that information about woodland management decisions in response to tree health remains limited.

Ash dieback for instance caused by the invasive pathogenic fungus *Hymenoscyphus pseudoalbidus* (anamorph *Chalara fraxinea*) causes a significant impact to common ash, *Fraxinus excelsior* (McKinney et al., 2014). It has spread widely across Welsh landscapes, but the complex and fragmented ownership of Welsh woodlands makes mitigating its impact challenging (Welsh Government, 2021). There are a number of best practice guidance documents published by The Tree Health Council (2020) and Forest Research (2022a), as well as overarching policy (Welsh Government, 2016). Alongside this, there is a number of evidence-based recommendations predominately from experience in Europe as ash dieback has spread rapidly west from Poland since 1992 (Bengtsson and Stenström, 2017). However, there remains relatively little literature about how closely these strategies

are followed in practice and in which circumstances they may be adapted, substituted, or even omitted by woodland managers (Marzano, Fuller and Quine, 2017).

Marzano et al., (2015) categorize woodland management into public sector, private sector and non-governmental organisations (NGOs). There is limited evidence of stakeholders' attitudes and management approach to ash dieback in Wales particularly of NGOs (Marzano, Woodcock and Quine, 2019). Conservation organisations (non-governmental organisations) are of particular interest in the role of mitigating the impact of ash dieback because ash has high cultural and biodiversity value but less economic value compared to other species (Marciulyniene et al., 2017). Organisations often prioritize conservation value and are not restricted entirely by commercial outcomes therefore they could be more likely to take management approaches that maintain ash in the landscape for longer (Bengtsson and Stenström, 2017). Maintaining ash in the landscape is beneficial for both biodiversity and aesthetics in the landscape (Marciulyniene et al., 2017; Pautasso et al., 2013). Organisations are also known to keep deadwood in the landscape which is highly beneficial to a number of deadwood invertebrates and other dependent organisms (Bače, Svoboda and Vítková, 2019).

Furthermore, conservation organisations have an unusual role in woodland management in Wales and, as a result, potentially also in mitigating the impact of ash dieback. Conservation organisations own and manage large areas of woodland but are also known to offer advice through publicly or privately funded schemes to private landowners (North Wales Wildlife Trust, 2022). The sites of organisations are readily visited for wildlife spotting, walks and activities (Welsh Government 2018a). This gives organisations the opportunity to interact with local residents and tourists on their sites, through activities and to raise awareness about ash dieback. Moreover, conservation organisations are widely supported in Wales with high membership numbers (Cracknell, Miller and Williams, 2013). This potentially means that their advice and approach regarding ash dieback could be more trusted than other advice sources. Overall as an entity organisations own large areas of woodland in Wales, offer advice to land owners over the whole landscape as well as having access to the public who support them. This suggests that these organisations could be having a large impact on the management of ash dieback in Wales.

This paper will address the call by Tinsley-Marshall et al., (2022) to enhance the knowledge of how successfully best practise is implemented by management on the ground. This is because decisions on the ground are affected by a myriad of influencing factors including management objectives, outcomes and forest size (Ambrose-Oji et al., 2020). Furthermore to successfully manage ash dieback across Wales a coordinated response with similar desired outcomes will need to be ascertained

particularly among stakeholders with common purposes. However, management approaches are still largely motivated by individual site objectives and outcomes (Forest Research, 2022b). Therefore, discussing and understanding management approaches, the factors that influence those approaches and desired outcomes with individuals in roles within conservation organisations involved with mitigating ash dieback could be critical to coordinating the national response to the disease in Wales.

Methodology

The arrival, establishment and impact of ash dieback has been widely studied in the UK (Hill et al., 2019; Orton et al., 2018). Mitchell et al., (2014) demonstrated that the loss of ash trees could have a substantial ecological impact and proposed a number of potential management options. Natural England (2014) identified that UK woodlands managed for biodiversity conservation but infected with ash dieback should be a key issue and best management should be adopted. As a result there is guidance readily available about best practice for mitigating the impact of ash dieback (Forest Research, 2022b; Tree Health Council, 2020). There is less known about how successfully woodland managers with a conservation focus are able to follow this guidance in practice (Tinsley-Marshall et al., 2022). Consequently, this research focuses on woodland managers in Wales who are of particular interest as they are managing ash dieback across almost the entirety of woodland habitats. Currently, Wales has the second most expansive distribution of ash dieback within the wider environment in the UK (Forest Research, 2020). However, there remains limited knowledge about what management approaches woodland managers are taking and what they consider successful outcomes.

Moreover, this research considers the contribution of conservation organisations in mitigating the impact of ash dieback in the Welsh landscape. Conservation-focused organisations are of interest because they have an interest in protecting native species with a high cultural value when considering management approaches to mitigate the impact of ash dieback (Marciulyniene et al., 2017). Charitable organisations are widespread throughout Wales but the latest data shows they only own 2.9% of woodland cover in Wales in comparison to 40% of woodlands publicly owned (Welsh Parliament, 2021). However, it is contested that organisations influence much larger areas of woodland than this through undertaking management on behalf of others, providing advice to woodland owners and engaging with the public with their advice largely supported (Cracknell, Miller and Williams, 2013; North Wales Wildlife Trust, 2022; Welsh Government, 2018a).

This research aims to build on the work carried out by Marzano, Woodcock and Quine (2019) looking at management attitudes to ash dieback solutions in the UK. This paper aims to enhance the

understanding of specifically conservation organisations in Wales that have experienced ash dieback in the woodlands they own, manage or offer advice on. The role of woodland managers influencing or carrying out the practical management of ash dieback particularly within the NGO sector is not well understood and research is limited (Tinsley-Marshall et al., 2022). This paper collects qualitative data from semi-structured interviews with individuals within conservation organisations that play a role in mitigating the impact of ash dieback. The methodology used is well established to understand woodland management approaches and factors that influence those decisions when faced with tree health issues (Marzano, Fuller and Quine, 2017; Tomlinson, Potter and Bayliss, 2015).

Interviews were carried out with 18 respondents across 8 regional and national conservation organisations in Wales. Respondents included a number of roles who are all tasked with carrying out practical woodland management (see Table 1). As well as advisors and ecologists who are tasked with advising and overseeing mitigation work against ash dieback. Further detailed information on respondents can be found in Appendix A.

Table 1. Summary of respondents

Area	Number of sites	Access
<i>Anglesey (and Gwynedd)</i>	1	Public
<i>Carmarthenshire</i>	1	Public
<i>Conwy</i>	2	Public
<i>Denbighshire</i>	1	Public
<i>Flintshire</i>	1	Public
<i>Gwent</i>	1	Public
<i>Gwynedd</i>	5	Public
<i>Monmouthshire</i>	1	Public
<i>Pembrokeshire</i>	1	Public
<i>Powys</i>	3	Public + private farms
<i>Wrexham county</i>	1	Public

Conservation organisations across Wales, and roles within them that may be involved in the mitigation of ash dieback, were identified through detailed internet searches utilising websites of conservation organisations and available management plans. Furthermore, a snowballing approach (Bryman, 2016) was implemented to ensure that further management approaches and perspectives could be considered..

The result, 18 interviews at various woodland sites geographically dispersed across Wales, managed by 8 organisations and represented by 9 different job roles of varying tree composition and conservation designations that would provide, detailed information about management approaches and their influencing factors.

Interviews were carried out between September and November 2021 with 9 interviews carried out in person, 7 through Microsoft Teams, 1 through Zoom and 1 over the telephone. The interviews lasted an average of 42 minutes and topics included: the management approach when faced with ash dieback in their woodland, factors that influence the management approach and defining success when mitigating ash dieback (see appendix B for the interview guide). Informed consent was obtained from all 18 respondents, who agreed to have the interviews digitally recorded. The audio files were transcribed by a professional transcription service before being checked for accuracy. The Responses were coded to categorise different management approaches and to identify the prominent themes for factors influencing those management approaches (see table 2). Quotes in the results are anonymised but further information about respondents can be found in appendix A.

Table 2. Qualitative coding structure for key themes

Research aims	Themes	Subthemes	
Management approach to ash dieback	Management approach	Adaptive strategies	Biosecurity
		Evidence	Experience
		Experiment	Felling
		Identification	Machinery
		Management action	Management plan
		Monitoring	Policy
		Preventative measures	Recuperating cost
		Replanting	Rerouting
		Resistance	Season
		Management notices	Threats
		Time frame	Wait and see
Factors that affect management	Management factors	Conservation	Coordination
		Funding	Information
		Management team	Responsibility
		Risk	Site accessibility
		Site location	Site size
		Species composition	Time frame

Impact of ash dieback	Impact of ash dieback	Conservation	Dynamic systems
		Financial	Forest structure
		Planning	
Defining success	Successful outcomes	Absent	Health and safety
		Liability	Lost cause
		Retaining ash	Robust woodlands

Results

1. Role of conservation organisations in tree health

Conservation organisations are acquiring more land to manage from a conservation focus but are being more selective on which land they chose based on tree health, woodland structure and accessibility. They own and manage large areas of woodland themselves but are also tasked with managing some public woodlands through contracts and offering advice to private managers through grants and schemes. This means that they are influencing management beyond their woodland ownership and among multiple stakeholders. They have different priorities to other private woodland managers in Wales who manage trees commercially to sustain their livelihoods. For example, felling trees is [“the cheapest, it’s the easiest, the quickest way. If you’re looking to recoup some of those losses,” – respondent 13]. However, conservation organisations are [“leaving the valuable bits as standing deadwood because it’s valuable for wildlife. I’m not too worried about recuperating a little bit of money to cover the losses. I’m worried about public safety and doing something for wildlife.” – respondent 13]. However, one respondent highlighted that there are limitations to their role in tree health as some decisions about management should be for specialists [“professional foresters, we’re nature conservationists, it’s a bit of a stretch.” – respondent 12] for organisations to their make those decisions. Some organisations were relying on specialists to conduct management as there wasn’t the skills available in house.

2. Experience with tree pests and diseases

The most prominent issue experienced by conservation organisations is ash dieback (*Hymenoscyphus fraxineus*), with all respondents dealing with the disease in some capacity. Respondents thought that managing the disease was obvious [“obviously, ash dieback” – respondent 2] because its widespread impact is well known. Ramorum diseases (*Phytophthora ramorum*) we’re experienced to a lesser extent and predominately among conservation organisations responsible for plantations, commercial or private woodland. There were fewer but some notable experiences with

Dutch elm disease (*Ophiostoma novo-ulmi*) among respondents although management focused on specific mature trees within woodlands. However, experience with red needle blight (*Dothistroma septosporum*), acute oak decline, honey fungus (*Armillaria*) and Ganoderma was limited and were identified rarely on their sites. This was reflected in several roles identified within conservation organisations that are tasked with mitigating the impact of the disease. These include reserve managers and equivalent positions that are responsible for carrying out practical management, ecologists providing specialist advice and senior positions overseeing organisational ash dieback strategies. Moreover more roles within organisations are being introduced to cope with the increasing demand to mitigate the impact of ash dieback.

3. Concern for ash dieback

Conservation organisations were concerned about ash dieback to varying degrees but largely acknowledged it was requiring immediate management attention, particularly where it has become a health and safety concern. However, even where concern was low and the disease was associated with natural woodland, adaption management was still occurring and therefore ash dieback was consuming large amounts of their time. One respondent acknowledges that despite their organisation being aware of ash dieback four or five years ago it was only last year (2020) that they realised managing ash dieback would be an ongoing management priority and started to make action plans to mitigate its impact. Ash dieback was considered detrimental suggesting that trees were [“suffering” – respondent 11], [sick – respondent 10], and the disease was a cause for [“concern” – respondent 14]. It was considered that experience with ash dieback was obvious [“obviously, ash dieback” – respondent 2] because the widespread impact of the disease is well known. One respondent suggests the current concern around the disease is that [“it’s not really stopped any activities or anything like that. It’s obviously affected the budget because it costs a lot of money, and takes a lot of time. And, unfortunately, we’re losing trees.” – respondent 13]. This suggests that conservation organisations are coping with managing ash dieback but it is costly and time-consuming to manage.

4. Ash dieback impact

Conservation organisations are being impacted by ash dieback in several ways. Management approaches to mitigate the impact of ash dieback has resulted in organisations having less capacity to carry out other woodland management. Furthermore, one respondent suggests that ash dieback [“is an astronomical cost nationally which is not recuperable” – respondent 10]. Other respondents agreed, identifying tree removal, shutting roads and needing specialist equipment as key contributors

to this increase in cost. Another respondent also identified that the disease is unlike other tree pests and diseases because the processing costs are too high to sell the ash. [“But it’s the processing costs. By the time you actually process it, bag it up, sell it on and faff around, you’re thinking, well, we’re barely covering staff costs, and do I want my wardens doing conservation work, or do I want them selling firewood?” – respondent 12]. This is in contrast to felling other tree species where the wood can still be sold commercially to recuperate the losses and cover the felling costs. Where removing trees was to be avoided, closing footpaths had resulted in some conflict with local people but respondents were actively educating people about ash dieback and communities were receptive and understanding towards management approaches.

4.1 Ash dieback planning

Despite awareness of ash dieback and its detrimental impact, it wasn’t always evident in site management plans. Most management plans identified that managers [“should be vigilant” – respondent 2], [aware of external threats – respondent 14] and [“mentions dangerous trees – respondent 15]. It is suggested that if anything ash dieback has been [“extremely disruptive to the site management plan” – respondent 1]. Therefore the response to ash dieback has been mostly reactionary. In contrast, some respondents had ash dieback at the forefront of their management plan. This included aiming to [“know a little bit more about how ash is going to behave or how the ecology of ash is going to alter” – respondent 12]. As well as plans [“changing the structure of woodlands and what can be replanted – respondent 7]. Overall there is a shift to alter management plans to include ash dieback, although organizational-led policies are being implemented as an addition to site management plans.

4.2 Ash dieback monitoring

Monitoring for ash dieback is carried out annually or biannually predominately considering the health of trees and where they are located. Walk-through surveys look at leaf loss, black lesions and brittle limbs. There are a number of similar approaches to monitoring looking at the % leaf loss as a result of ash dieback, followed by splitting sites into zones based on footfall and risk. [“We definitely react on the ones that have lost, you know, 50% plus their leaf. So they’re our highest priority. And, you know, we have to prioritize the--you know, the location as well – respondent 5]. Other respondents use a traffic light system [“the red zones are located next to heavily visited areas or heavily accessed areas. And then the amber, of course, is not so heavily accessed.” – respondent 14]. During surveys, trees can be tagged based on decay and location. Photographs are identified as a usual tool for monitoring crown

changes. However, one respondent suggests whilst monitoring is good practice, managers know their sites intimately and if ["it's dangerous, it's dealt with pretty much straight away." – respondent 13].

4.3 Ash dieback identification

Ash dieback in wooded areas was expected and it was thought there was little that could be done to prevent it. ["Ash dieback, yes, we saw it coming, but again, sort of, we discussed it that it was here, but what could we do to stop it." – respondent 1]. Most identification of ash dieback was carried out by site managers although some organisations are training volunteers to assist with identification. Local people were aware of ash dieback on trees but were perhaps unaware of the extent that ash dieback was a problem across Wales. ["We do get emails and phone calls saying, "There's an ash tree with ash dieback." But they're usually people coming from quite a... Sorry, I don't want to sound patronizing, but they say things like, "I didn't realise it had arrived in Gwent now already, " you know, when, actually, we've got dead trees absolutely everywhere [laughs]." – respondent 8]. Respondents also reported that external stakeholders also regularly contact conservation organisations to ask about ash dieback, including the highway agency.

5. Management approaches

Conservation organisations are aiming to maintain ash trees in the Welsh landscape for biodiversity value and to build woodland resistance to ash dieback (see appendix C). However, management action considers individual trees within woodlands and takes a predominate site-specific approach. The management decision taken is influenced by a range of often conflicting factors including tree location, public access and conservation focus. Mitigating the impact of ash dieback for the purpose of protecting tree health and ensuring public safety is considered the highest priority. One respondent explains ["I feel like I am doing enough to keep people safe. Getting the balance between keeping people safe and doing as much as I can for wildlife" – respondent 13]. Similarities within management approaches taken were evident where organisational-led policies or best practice are cited. Respondents acknowledged that the factors that affected the management approach were often conflicting. One respondent shared their experience felling a tree with ash dieback, ["It did really pain me to do that cause I love to see trees to age and mature naturally and the benefit of wildlife of decaying trees. That's really vital and should be of paramount importance on a nature reserve. But this... and, again, it's the same sort of issue comes up with the ash dieback as well is felling in terms of public safety and potential liability versus leaving a tree to decay and die naturally." – respondent 3].

5.1 Location

The common consensus among respondents is that management of ash dieback is location dependent due to public safety and potential liability. Conservation organisations acknowledge that it is a balance when dealing with ash dieback, [“felling in terms of public safety and potential liability versus leaving a tree to decay and die naturally.” – respondent 3]. Therefore most organisations are following policies that detail best practice for retaining as many ash trees as possible whilst minimising the risk to people and property. Particularly in sites that have conservation designation [“a high-risk site, to take out some--and it's a SSSI, SAC, to take out some ash that was really, really bad, and then some other trees were retained as best practice.” – respondent 1]. It is not known whether the best practice referred to here was from organisational policy or derived from another set of guidelines. Most management of ash dieback is voluntary, proactively removing dangerous trees. This involves focusing management action on monitoring and removing ash trees from high-risk areas (e.g. trees immediately adjacent to footpaths, and roads). However, commonly conservation organisations are identifying ash dieback in the main woodland block and leaving it where it poses no health risk. [“With ash dieback, we try to leave it as long as possible for regeneration and resistance capacity and leave it as long as possible within the stand where it doesn't pose a risk” – respondent 16].

5.2 Time frame

The management of ash dieback is time-critical as tree limbs become increasingly brittle and can rapidly decay. Therefore, it is more challenging to fell the tree requiring more experienced tree surgeons and equipment. It is suggested for [“each six months, year that you leave it, it is dying from the top down. So you're reducing your options in terms of how to manage it in the end” – respondent 7]. The speed at which an ash tree can decline was often underestimated by higher management within organisations. [“I was pushing and pushing, trying to start the work. And, as I say, to be honest, it took a tree falling over and blocking a road before the managers kicked in and realised, oh, yeah, you- know, he's not being overdramatic – respondent 5]. Removing dangerous ash early with a straight fell or winch assist fell was one approach to achieve safe removal. However, a number of respondents across multiple organisations suggest that there is a need to [“wait and see” – respondent 2] and let [“nature do its thing” – respondent 3] before taking the hasty decision to fell a diseased ash especially if it is not posing a safety concern. One respondent suggests that the best practice is [“being aware of those tolerant trees and not being so hasty to fell it” – respondent 4].

5.3 Conservation focus

Organisations utilise management approaches that consider the conservation value of ash. They are keen to avoid felling ash trees and are [“leaving them, only cutting back if unsafe” – respondent 9]. Cutting back limbs, reducing the crown or pollarding to manage trees that are considered dangerous provide organisations with more favourable options. While there is concern that infection can spread even with mature coppice or pollarded trees there is also a concern about disturbing protected species such as dormice and bats therefore moving footpaths is also a preferred approach. The size and conservation features of a tree can alter the management approach taken [“I go for felling if they’re below a certain size because I find that the younger trees don’t tend to have much in the way of features, potential bat roost type features or anything of interest on them. And then we get the larger trees, which, you know, are big. Then we’ll go for pruning where we can.” – respondent 15]. Then if it needs further work [“take the height out of it, take the danger out of it and the risk out of it and then leave the tree to give it a chance.” – respondent 13].

Organisations manage aesthetic and cultural dimensions for visitors, [“ash trees in this area are quite distinctive in the landscape” – respondent 4]. Where there is limited risk organisations are aiming to leave as many dead ash trees as possible for wildlife. [“Depending on safety, visitor safety, and we’ll have a quick--as I say, we’ll have a quick look after, but you’ll see where we will leave whole dead trees just lying in the field because from a conservation point of view, that then ends up benefitting the SSSI status for the deadwood invertebrates”. – respondent 11]. It is still important to manage those dead trees to prevent spread of ash dieback across woodlands. This management approach has led to work with the public to change their perception surrounding deadwood [“we did get a lot of comments from the public, going, “Oh, you’re not managing this. It’s untidy,” et cetera. But as soon as you explain why, they get it, you know.” – respondent 11]. Organisations are considering the impact of losing ash trees from two ecological perspectives, the loss of habitat for species such as the Brown Hairstreak Butterfly and the opportunity for flora such as the Grass of Parnassus to recover. One respondent suggests [“it’s very subjective as to how good or bad it all is.” – respondent 3].

A long-term approach towards managing ash dieback is promoting species variety within woodlands. One respondent suggests that [“the conservation world is hung up on maintaining just a handful of species when they’re being affected by so many diseases, and I think that we should--there should be more exploration of the potential of other species.” – respondent 10]. Many organisations are currently relying on natural regeneration to improve the woodland structure and resilience. Considerations of soil quality, weather and climate are also important when dealing with the spread of ash dieback. Moreover, conservation legislation can provide additional work for

organisations when mitigating ash dieback in terms of the approval required and conflicting policies in terms of protected species and dangerous trees. This includes when protected species are identified in dangerous trees that needed to be felled and getting permission to move the species was and is challenging.

6. Adaptive strategies

Organisations are aware that tree diseases have been around for centuries but their impact is falling increasingly within their management remit. [“Certainly, you know, tree safety management has gone from being quite a small job to being a major undertaking.” – respondent 12]. Organisations are becoming more organised and structured in their approach to ash dieback. One respondent suggests [“I think when we first started dealing with the ash trees, we weren’t—you know, you don’t really know the risks involved” – respondent 17]. Monitoring has become more methodical and managers are reacting quicker to source funding and machinery to remove trees. Management has also changed as the disease has spread with more hesitance to fell ash. One respondent explains [“with ash that they’re not just going, “Right, take it out.” If it had been right at the beginning of the disease, then that would be the thing to have done: get rid of the affected trees, burn them, stop all imports of ash. You might have caught it, but it’s too late. It’s everywhere. You’re never going to stop it from spreading. So we just now have to manage it as best we can. – respondent 11]. Management has also changed with organisation direction [“but it’s also changed with the views of the site manager or the wardens, which is always the case. But I think what we’ve got at the moment seems to make a lot more sense than some of the things that we were doing a few years ago, which, quite frankly, you look back on and think, well, it was barking mad. – respondent 12]. Additionally, conservation organisations are learning from their successes [“if we’ve done something well and move it forward such as pollarding of the trees – respondent 13]. Conservation managers are largely following the policies of the organisation although it was clear that some managers preferred within budget constraints to work harder to save ash trees, particularly those that were significant in their woodland.

7. Defining success

Success when dealing with ash dieback appears to differ between and among organisations suggesting that variation occurs at the organisational and manager level. It appears success has largely not been discussed before, [“I don’t think that question’s been asked. It’s a really interesting question.– respondent 8]. Another respondent suggested success was interesting because [“people see things in different ways” – respondent 3]. This was demonstrated by a respondent who felt [“like there’s very little we can do to control tree pests and diseases. You know, if they’re not carried on the

wind, they're carried in droplets in the air or boots and machinery, and there's--it doesn't work. Any mitigation doesn't seem to work" – respondent 10]. Whereas another respondent suggested that success would be the absence of a disease but admitted that ["it's still quite early days, in terms of ash dieback especially. Once we fell a tree, then you think, right, okay, we've dealt with it, but it might still be in the ground, or it might still be in the roots as well." – respondent 14]. Respondents suggest that success is mitigating the risk of ash dieback whilst maintaining healthy ash trees for the purpose of ["developing resistance over time" – respondent 16] and for ["biodiversity and--mainly, predominantly and, hopefully, for the longevity of our ash within our landscape." – respondent 17]. Another respondent suggests that ["success is that we've reduced the risk and stopped anybody from getting hurt, and wherever possible, we've left standing deadwood." – respondent 13]. Furthermore, a respondent highlights success in terms of public liability ["I think reducing the risk to a level that our insurers is happy with whilst at the same time conserving what you can. Not felling healthy trees if at all possible" – respondent 15].

One direction of success is a shift to robust woodlands that can withstand and adapt to change. One respondent suggests that ["So I think that what we have to do--success is about accepting the change in woodland structure and composition and making sure that there is room for the woodland to change and that the woodland is robust enough to adapt." – respondent 10]. This thought was supported by another respondent ["best situation you've got is that you find the tree pest early enough. You go in and remove a tree, and that's it, job done, and you don't have the problem anymore. Reality is not like that. The reality is that you can see it appearing in the wider landscape, and then, you know, it's only a matter of time until it finds its way onto the reserve, and at that point, it's at the door. And a lot of these landscapes' initiatives to remove vast amounts of trees don't seem to be working. And I'm not sure it's possible. And I think probably it would be good to get the woodland management in place where the woods themselves are robust enough to cope" – respondent 12].

8. Achieving success

Most conservation organisations felt like they have adequate knowledge and understood how to manage ash dieback, although some organisations were keen to pursue more on-site training, particularly to be more confident in identifying the disease. More time, resources, and people on the ground would also aid their management approaches. Additional funding would allow more management of ash trees to take place that would prevent path and site closures allowing woodlands to remain accessible to the public. With more resources, one respondent suggests they would be able to alter management to restart ["coppicing" – respondent 15] to gain additional benefits. With more capacity, several respondents suggested that more monitoring could be carried

out earlier in the year enhancing safety and increasing management options. One respondent suggests that more support to find contractors to do the work would be useful as [“I think probably sometimes we get ripped off” – interview 12]. Furthermore, if trees do have to be removed organisations were keen to gain more evidence and support for replanting including potential species adaptations better suited to climate change. One respondent suggested that [“I think the thing that would be very useful is making the markets for small-scale timber production easier” – respondent 12] which would allow woodland managers to recuperate some costs from ash dieback but also support the local industry. It was believed that if trees needed to be felled and woodland managers had to bear the costs then investment in the local industry should occur to support woodland managers to recuperate costs.

Conservation organisations were keen for Natural Resources Wales to focus on a long-term national coordination approach. Particularly providing guidance about how to keep people safe when dealing with ash dieback. One respondent felt like a direct contact at Natural Resources Wales would be beneficial to access help rather than having to hunt for the information themselves. [“It would be good for me to have that direct communication channel with somebody at the NRW or Forestry Commission – respondent 4]. Another respondent also felt that if ash dieback was a big issue there should be someone at Natural Resources Wales providing support to private landowners. [“Well, I mean, it’s such a widespread, big issue. Why aren’t NRW employing somebody to come out and help us do it, you know, deal with it, and then deal with it right? It’s... I feel it’s a national problem” – respondent 2]. There is also a keenness for a general quarterly newsletter that disseminates current threats, research and recommendations and a greater understanding of what other organisations and authorities are doing. Moreover, because conservation organisations rely on support, a move towards educating the public about tree disease and the need to fell trees was considered important. Research into the practical implications of ash dieback management was widely supported.

Discussion

1. Relevance of ash dieback

Ash dieback has been substantially impacting the Welsh landscape causing detrimental ecological impact in the wider environment since 2013 (Hill et al., 2019; Mitchell et al., 2014). Therefore it is perhaps not surprising that all respondents were dealing with ash dieback in some capacity. However, it would appear that conservation organisations are predominantly managing ash dieback reactively when trees have been found to be infected. Respondents identify that ash dieback is a prominent and

current problem within conservation organisations. Moreover, some organisations have been only actively been managing ash dieback since 2020 and that management has largely been hindered by the Covid-19 pandemic. Therefore whilst conservation organisations were largely aware of ash dieback approaching (Woodward and Boa, 2013) understanding what approaches have been taken and how successful they have been in mitigating ash dieback remains recent and highly relevant.

2. Awareness and understanding of ash dieback

Conservation organisations exhibited high awareness and understanding of the disease and many roles have been established to mitigate its impact. Marzano et al., (2015) suggests this level of awareness should be expected given the impact the disease could have on trees for which they are responsible. Whilst most management was reactionary, organisations did attempt varied levels of ongoing monitoring. Dandy et al., (2013) suggest, that organisations are likely to possess the skills to engage in preventative measures, monitoring and dealing with an outbreak once it occurs. Organisations for the most part did possess the skills to be proactive but reactionary management took priority due to limited time, funding and resources. However, in cases where the disease had become too advanced and the trees had become too brittle outsourcing help was required leading to further costs and additional resources. Although, this is largely to be expected as organisations are largely constrained by funding streams that are dynamic and often unpredictable and preventative measures need to be in place over long periods of time (Meir, Andelman and Possingham, 2004).

3. Ash dieback management

Conservation organisations consider conservation and/ or recreation their primary management focus. Ash dieback affects trees of all ages where the chances of mortality are high placing the species as well as many organisms who depend on the species under threat (Marzano, Woodcock and Quine, 2019; Pautasso et al., 2013). However, unlike commercial woodlands, organisations do not necessarily have to recuperate all the cost and so can prioritise additional management, particularly of veteran trees. As a result, most managers are engaging in low-level management that ensures ash remains part of the Welsh landscape. Appendix C outlines the decisions taken by conservation managers in Wales when faced with ash dieback utilising monitoring, pruning, pollarding and felling which leads to resistant trees in the landscape, deadwood in the forest or wood removed to be sold.

Pollarding, one method used by organisations, is more expensive than felling but can preserve an ash tree safely for a time until it succumbs to the disease (Bengtsson and Stenström, 2017). Mitchell et al., (2014) consider pollarding the best option from a conservation perspective providing habitat for highly associated species like the Brown Hairstreak Butterfly (*Thecla betulae*) a species which

conservation organisations are concerned about. On the other hand, Ahlberg (2014) suggests selective thinning of infected ash trees can also allow other species to recover. Conservation organisations suggest this method has allows light to enter stands and other species to recover such as Grass of Parnassus (*Parnassia palustris*). Whilst Marzano, Fuller and Quine (2017) identify woodland managers are concerned about funding challenges that management brings, it is clear that woodland managers within conservation organisations are still prioritising conservation outcomes.

The longer the ash species stay in the woodland there is a higher chance of identifying resistant species which McKinney et al., (2014) suggest could be the long term solution to ash dieback. This suggests that the actions of woodland managers in conservation could be directly contributing to the resilience of ash species within the Welsh landscape. However, despite this evidence organisations were uncertain about whether ash trees could recover from infection so this doesn't appear to be the main motivation for their management approaches. Even if the tree dies many organisations are leaving deadwood within the woodland which is important for invertebrates (Bače, Svoboda and Vítková, 2019). This is supported by Pautasso et al., (2013) who detail that dead and dying ash trees should be left for biodiversity conservation.

Some organisations are aiming to create diverse woodlands which was identified by Forest Research (2022b) as the best approach to mitigate the impact of ash dieback with mixed-species stands making woodlands less vulnerable to disease. Although Guo et al., (2019) suggest that whilst tree diversity can minimise the hosts available for threats encouraging high species diversity might provide more niches for the threat to take hold. This was described as a particular concern for organisations that feared their oak trees getting a similar disease and more research should look into this as increasing tree diversity is highly recommended for ash dieback.

4. Best practice for managing ash dieback

Many of the roles established within organisations for the mitigation of ash dieback have a direct management impact on Welsh woodlands. Tinsley-Marshall et al., (2022) explain that there is often an expectation, particularly in policy, that management is based on sound evidence and best practice. Stanley, Clouston and Binney (2005) identify however that there is a myriad of factors that influence land management decisions that could cause organisations to divert from best practice. The management approaches adopted by conservation organisations were strongly influenced by the location of trees on sites, the stage of the disease on a tree and conservation management objectives. Limited information is currently available about whether conservation organisations follow what is nationally considered best practice to mitigate ash dieback therefore the research findings

have been considered against some suggested best practice in Wales. There are a number of documents that advise on best practice management approaches to mitigate ash dieback. The Ash dieback response for Wales (Welsh Government, 2016), the Tree Councils' guide to ash dieback (The tree council, 2020) and Forest Research's ash dieback manual (Forest Research, 2022b). This guidance is also supported by wider literature from Pautasso et al., (2013) and Mitchell et al., (2014) which provides evidence-based management recommendations for managers.

It is useful to consider how conservation organisation's management of ash dieback compares to national and evidence-led examples of best practice. The Ash dieback response for Wales identifies five key priorities for mitigating the impact of ash dieback: research, monitoring, prophylactic measures, reactive measures and communication (Welsh Government, 2016). Most relevant to conservation organisations it highly encouraged the voluntary felling of younger ash trees and the planting of alternative species. Conservation organisations showed some signs of removing younger trees but predominately alongside roads where safety was a concern. However, they were reluctant to replant with alternative species relying mostly on natural regeneration. This was because either there wasn't significant tree cover lost or organisations were restricted to what to plant because of site designation. Additionally, the Welsh Government discouraged the automatic felling of symptomatic trees (Welsh Government, 2016). This was also supported by Mitchell et al., (2014) that not removing infected ash is better for biodiversity and is the most cost effective in terms of management. Being more hesitant to fell ash was an approach that conservation organisations had said they had adopted over time but were still concerned first and foremost with the public danger posed by infected trees. However, Pautasso et al., (2013) recommend that if the ash does deteriorate the deadwood should be left in the forest for conservation purposes and organisations shared many examples of where they were doing this.

Forest Research provides a more practical tool, developing management guidance for ash dieback for all stakeholders with ash trees (Forest Research, 2022b). This provides an opportunity to look at how closely conservation organisations follow best practices. The overarching approach is to slow the spread of the disease whilst preserving as many tolerant ash trees as possible. This approach was evident throughout the organisations where public safety would allow. The guidance suggests monitoring should be enhanced around highly accessed areas looking at the trunk and felling or pruning the trees if posing a hazard. Organisations monitored high footfall areas as a priority but were more focused on leaf loss. Forest research recommends that management should consider the age and features of ash trees. Organisations, as recommended, are removing younger trees with less features prone to rapid decline but are reducing the crown or pollarding veteran trees despite it being more expensive and management intensive. Conservation organisations are also following best

practice from a conservation perspective carrying out low-level management retaining ash for habitat and resistance as well as increasing woodland diversity. This suggests that not only are organisations having a wider impact on ash dieback mitigation than first thought, they are also predominately following best practice and that should be recognised and acknowledged.

5. Measuring success

It is clear that conservation organisations are adapting to deal with ash dieback from a more methodical and structural approach as the disease progresses. This can be attributed to experience and increased knowledge facilitating a more successful approach. Organisations are using similar management approaches but don't consider the same management outcomes successful. Tucker (2010) highlights that in order for woodland governance to be successful goals and outcomes should be agreed upon by all stakeholders. There was no correlation between success, either across organisations or within the same organisation. It was also apparent that successful outcomes had not been widely discussed within organisations. Padney (2010) suggests this could be attributed to successful management outcomes being context-specific and perhaps current management utilising their own experience and judgement to which outcomes their site can achieve. For instance, one respondent suggested that successful management of the disease was eradication but another suggested that nothing could be done about ash dieback but best practice suggests something in the middle with a low management approach (Forest Research, 2022b). Therefore, it could be suggested that working with stakeholders to achieve common outcomes from ash dieback management would produce a more cohesive response to the disease at the landscape scale.

6. Influence of conservation organisations

Conservation organisations have a wider role in mitigating the impact of ash dieback appears to have been largely underestimated and overlooked. Marzano et al., (2015) categorise environmental NGOs (including conservation organisations) as a distinct woodland stakeholder. The Welsh Government (2018b) does not distinguish conservation organisations from the private sector, even though their role in the management of ash dieback is substantially different. The latest available data of NGO's ownership in Wales dates back to 1967 demonstrating a 2.9% share of woodland cover included most recently in a report by the Forestry Commission, (2002). The results from this research support the wider literature that their influence over the management of woodlands in Wales is far greater. They manage land on behalf of others, give advice to other landowners and readily engage with the public about ash dieback as previously outlined by North Wales Wildlife Trust, (2022). The approaches taken collectively by these organisations and those that follow their advice are directly

influencing ash dieback mitigation strategies at a landscape scale, findings consistent with those of several other studies (Dandy et al., 2017; Marzano et al., 2020; Marzano, Fuller and Quine, 2017).

6.1 Public Engagement

Conservation organisations differ from large parts of the private sector encouraging visitors to their sites. In 2018 nature reserves were identified as the 2nd most visited destination for tourism in Wales (Welsh Government, 2018a). The sites of organisations are readily visited for wildlife spotting, walks and activities (Welsh Government 2018a). This gives organisations the opportunity to interact with many local residents and tourists on their sites, through activities and to raise awareness about ash dieback. Conservation organisations confirmed they readily engage with the public about tree health and were working to change the perception of management approaches needed.

McFarlane et al., (2006) found that local residents had a basic knowledge of tree health issues and supported management to mitigate their impact. Tourists on the other hand had little awareness of invasive species generally (García-Llorente et al., 2008). Organisations acknowledge that local people did identify ash dieback but ultimately were not aware to the extent that ash dieback had already spread across Wales, leaving much of the identification up to the managers. Organisations felt that their biggest challenge is tree planting projects, as described by Brancalion and Holl, (2020), which have caused the public to see tree removal negatively. Organisations highlight their role allows them to educate the benefits of tree management. This suggests that organisations are engaging and educating the wider community about ash dieback management.

This research suggests that conservation organisations are engaging readily with the public and successfully communicating information about ash dieback. Furthermore, it demonstrates that explaining the purpose of management approaches to mitigate ash dieback has caused changes in public behaviour with support maintained even when locals or visitors might have to have their accessibility restricted. The understanding relating to ash dieback and the desire to support mitigation management is potentially not surprising as the media, public and political response to ash dieback was unprecedented (Tomlinson, 2016). However, this research highlights the potential for conservation organisations to engage with the public and explain appropriate management approaches even when trees need to be removed which may be negatively perceived.

6.2 Public support

Moreover, conservation organisations are widely supported in Wales with high membership numbers (Cracknell, Miller and Williams, 2013). This was evident through the interviews as managers recollected

that whilst removing trees and closing footpaths had caused some conflict with local people managers were actively educating people about ash dieback and communities were receptive and understanding of the management approaches used. One in ten UK residents are members of an environmental organisation with 34.8% of their income coming from individual donations, membership fees and sales of associated products (Cracknell, Miller and Williams, 2013). Therefore, organisations are positively supported and can be influential on the public perception of woodland management. Concurrently, organisations need to maintain that support from the public which in turn influences their management approaches. Veteran ash trees have high cultural value within the landscape and Marciulyniene et al., (2017) recommends pruning ash trees to maintain their aesthetic value. The Tree Council (2020) highlights that ash dieback can cause dying branches to become brittle and under both criminal and civil law conservation organisations are potentially liable if trees fall. Conservation organisations where possible try to avoid this conflict and move permissive paths but ultimately dangerous ash trees are removed. Therefore, conservation organisations can provide a vehicle for information exchange between local people, woodland managers and policymakers regarding tree health, management approaches and associated legislation.

6.3 Advice

Conservation organisations are known to offer advice through publicly or privately funded schemes directly to private landowners. The literature identified that there is a demand for external bodies to be used to coordinate pest and disease outbreaks which have sufficient resources and the ability to give unbiased advice (Tomlinson, Potter and Bayliss, 2015). Respondents recollected that they had experienced this demand for advice with stakeholders regularly contacting them to ask about ash dieback, including bigger organisations such as the highway agency. Lawrence and Marzano (2014) suggested that woodland managers were seen to be heavily reliant on external advice but some suggested this could be disconnected and confusing. It was evident that conservation organisations despite their conservation focus were providing clear, engaging and unbiased advice. Furthermore, this role is particularly well suited to conservation organisations as woodland managers are keen to follow advice from trusted groups and potentially adapt behaviour (Ambrose-Oji et al., 2020; Lawrence and Marzano, 2014; Marzano et al., 2016; Marzano, Fuller and Quine, 2017; Tomlinson, Potter and Bayliss, 2015; Urquhart et al., 2017; Young et al., 2018). Conservation organisations also offer a shift away from government advice which was associated with distrust, scepticism and a reluctance to adopt suggested behaviours (Lawrence and Marzano, 2014; Mackenzie and Larson, 2010).

6.4 Facilitate networks

It has been identified that there is a willingness by woodland managers to learn about tree pests and diseases (Marzano, Fuller and Quine, 2017; Urquhart et al., 2017). However, Lawrence and Marzano (2014) identified that woodland managers felt that there was a poor flow of information between woodland managers. It is also suggested that woodland manager's distrust of the government make them feel excluded in the conversation about tree pests and diseases (Mackenzie and Larson, 2010). Conservation organisations were keen to collaborate working with organisations, the authorities and the public to tackle ash dieback. Therefore, conservation organisations considering their support and engagement capabilities could be best placed to deliver training for woodland managers, collecting and transferring information between woodland managers and policymakers, as well as facilitating relationships between woodland managers themselves. Considering the need to deal with tree threats at the landscape scale, a coordinated response is required and conservation organisations could be a crucial element of this coordinated response (Tomlinson, Potter and Bayliss, 2015). Therefore the influence of conservation organisations across the woodland landscape in Wales suggests that the government should look to collaborate, support and utilise conservation organisations for achieving desired national outcomes with ash dieback.

Recommendations

The influence of conservation organisations is varied and hard to quantify but their current and potential widespread impact on the mitigation of ash dieback in Wales should be an area of interest. Therefore, this research recommends eight specific recommendations that could support and/ or enhance the role of conservation organisations play in mitigating the impact of ash dieback.

1. Facilitate the development of a network of professional foresters who can be readily available for woodland managers when felling particularly dangerous trees need to be outsourced
2. Improve the coordination and process for shutting roads for the purpose of specialist equipment and tree removal which is a key cost for woodland managers
3. Investing in local industry to make small-scale tree production more accessible to conservation organisations felling trees because of ash dieback
4. Ensuring that conservation legislation and tree health policy are complimentary and do not provide conflicting instruction when conservation organisations are faced with ash dieback
5. The provision of on-site training to allow conservation organisations to increase the confidence of woodland managers identifying ash dieback

6. Additional funding would allow more management of ash trees to take place that would prevent path and site closures allowing woodlands to remain accessible to the public
7. Conduct research to gain more evidence regarding replanting potential alternative species when woodland managers are faced with ash dieback
8. The provision of a national contact at Natural Resources Wales that can provide advice and support would be highly beneficial to implementing their management approaches.

The support through these recommendations is best placed to come from varied sources but would benefit from being overseen by Natural Resources Wales to provide a central coordination point.

Conclusions

Overall, as tree pests and diseases continue to be introduced and establish globally woodland managers will have to adapt regardless of sector to mitigate their impacts (Fisichelli et al., 2014; Young et al., 2018). It is suggested that a successful response to ash dieback should be coordinated at the national scale across multiple landscapes involving varied stakeholders. However, the complex ownership and fragmented nature of woodland areas found in Wales make this challenging (Welsh Government, 2021). Conservation organisations are identified in this paper as a stakeholder with influence across multiple sectors widely impacting the mitigation of ash dieback. Particularly through their conservation focus which alters management approaches to maintain ash in the landscape for longer than their commercial counterparts. This increases the habitat for biodiversity and the opportunity to identify resistance. Furthermore, conservation organisations exhibit a high awareness of the disease and possess the capabilities to mitigate its impact exhibiting strong association with best practice where funding allows. Conservation organisations can have a wide-ranging role in mitigating the impact of ash dieback beyond their own chosen management strategies by engaging with the public and other private woodland owners about tree health issues. Through their established standing in the community, generate support so advice about mitigating the impact of ash dieback is well-received and trusted. Working alongside a network of established woodland stakeholders the organisations can help influence and facilitate a common management approach to ash dieback with agreed success criteria with aim of establishing a more cohesive response to the disease at the landscape scale. It is therefore the reports feeling that support should be provided centrally by Natural Resources Wales and also from varied sources to support and/ or enhance the role that conservation organisations play in mitigating the impact of ash dieback. Limited research of their involvement with ash dieback (Marzano, Woodcock and Quine, 2019) and lack of consideration in policy (Welsh

Government, 2021) suggest this involvement could be being overlooked and potentially underestimated.

Declaration of competing interest

The author declares that they have no financial or personal interest that could have appeared to influence the work reported in this paper.

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Appendices

Supplementary material is attached.

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References

- Ahlberg, A., 2014. The influence of thinning intensity on stands of European ash (*Fraxinus excelsior* L.) affected by ash dieback—how should they be managed?.
- Ambrose-Oji, B., Atkinson, M., Petrokofsky, G. and Hemery, G., 2020. Do Environmental Worldviews and Distrust Influence Action for Adaptation to Environmental Change Among Small-Scale Woodland Managers?. *Small-scale Forestry*, 19, pp.159–185.
- Bače, R., Svoboda, M. and Vítková, L., 2019. Deadwood management in production forests. *Management guidelines for forest managers in Central European temperate forests*, (s 31).
- Bengtsson, V. and Stenström, A.N.N.A., 2017. Ash dieback—A continuing threat to veteran ash trees. *Dieback of European Ash (Fraxinus spp.): Consequences and Guidelines for Sustainable Management*, pp.262–272.
- Brancalion, P.H. and Holl, K.D., 2020. Guidance for successful tree planting initiatives. *Journal of Applied Ecology*, 57(12), pp.2349–2361.
- Bryman, A., 2016. *Social research methods*. Oxford university press.
- Canadell, J.G. and Raupach, M.R., 2008. Managing forests for climate change mitigation. *science*, 320(5882), pp.1456–1457.
- Cracknell, J., Miller, F. and Williams, H., 2013. *Passionate collaboration*. London: Green Funders, pp.1–64.
- Curtis, P.G., Slay, C.M., Harris, N.L., Tyukavina, A. and Hansen, M.C., 2018. Classifying drivers of global forest loss. *Science*, 361(6407), pp.1108–1111.
- Dandy, N., Marzano, M., Porth, E.F., Urquhart, J. and Potter, C., 2017. Who has a stake in ash dieback? A conceptual framework for the identification and categorisation of tree health stakeholders. *Dieback of European Ash (Fraxinus spp.)—consequences and guidelines for sustainable management*. Swedish University of Agricultural Sciences, Uppsala, pp.15–26.
- Dandy N, Porth EF, Marzano M, Potter C, Bayliss H, Maye D 2013 Working paper 2: tree health stakeholder analysis—identification and categorisation. Project report for Defra Projects TH0104 & TH0107 Mapping, analysis and improved understanding of stakeholders and the public to help protect tree health
- Dufour, S. and Piégay, H., 2008. Geomorphological controls of *Fraxinus excelsior* growth and regeneration in floodplain forests. *Ecology*, 89(1), pp.205–215.

Fisichelli, N.A., Abella, S.R., Peters, M. and Krist Jr, F.J., 2014. Climate, trees, pests, and weeds: Change, uncertainty, and biotic stressors in eastern US national park forests. *Forest Ecology and Management*, 327, pp.31-39.

Forestry Commission, 2002. *National Inventory of Woodlands in Wales*. Cardiff: Forest Research.

Forest Research, 2022a. *Ash dieback (Hymenoscyphus fraxineus) - Forest Research*. [online] Forest Research. Available at: <<https://www.forestresearch.gov.uk/tools-and-resources/fthr/pest-and-disease-resources/ash-dieback-hymenoscyphus-fraxineus/>> [Accessed 19 May 2022].

Forest Research, 2022b. *Chalara manual - 2. Managing ash trees and woodland, including logs and firewood - Forest Research*. [online] Forest Research. Available at: <<https://www.forestresearch.gov.uk/tools-and-resources/fthr/pest-and-disease-resources/ash-dieback-hymenoscyphus-fraxineus/chalara-manual-2-managing-ash-trees-and-woodland-including-logs-and-firewood/>> [Accessed 20 May 2022].

Forest Research, 2020. *SITUATION REPORT – HYMENOSCYPHUS FRAXINEUS*. London: Forest Research.

García-Llorente, M., Martín-López, B., González, J.A., Alcorlo, P. and Montes, C., 2008. Social perceptions of the impacts and benefits of invasive alien species: implications for management. *Biological Conservation*, 141(12), pp.2969-2983.

Graziosi, I., Tembo, M., Kuate, J. and Muchugi, A., 2020. Pests and diseases of trees in Africa: A growing continental emergency. *Plants, People, Planet*, 2(1), pp.14-28.

Guo, Q., Fei, S., Potter, K.M., Liebhold, A.M. and Wen, J., 2019. Tree diversity regulates forest pest invasion. *Proceedings of the National Academy of Sciences*, 116(15), pp.7382-7386.

Harmon, M.E., Franklin, J.F., Swanson, F.J., Sollins, P., Gregory, S.V., Lattin, J.D., Anderson, N.H., Cline, S.P., Aumen, N.G., Sedell, J.R. and Lienkaemper, G.W., 1986. Ecology of coarse woody debris in temperate ecosystems. *Advances in ecological research*, 15, pp.133-302.

Hill, L., Jones, G., Atkinson, N., Hector, A., Hemery, G. and Brown, N., 2019. The £15 billion cost of ash dieback in Britain. *Current Biology*, 29(9), pp.R315-R316.

Kozak, J., Ziółkowska, E., Vogt, P., Dobosz, M., Kaim, D., Kolečka, N. and Ostafin, K., 2018. Forest-cover increase does not trigger forest-fragmentation decrease: Case Study from the Polish Carpathians. *Sustainability*, 10(5), p.1472.

Lawrence, A. and Dandy, N., 2014. Private landowners' approaches to planting and managing forests in the UK: What's the evidence?. *Land use policy*, 36, pp.351-360.

- Marciulyniene, D., Davydenko, K., Stenlid, J. and Cleary, M., 2017. Can pruning help maintain vitality of ash trees affected by ash dieback in urban landscapes?. *Urban Forestry & Urban Greening*, 27, pp.69–75.
- Marzano, M., Dandy, N., Bayliss, H.R., Porth, E. and Potter, C., 2015. Part of the solution? Stakeholder awareness, information and engagement in tree health issues. *Biological Invasions*, 17(7), pp.1961–1977.
- Marzano, M., Fuller, L. and Quine, C.P., 2017. Barriers to management of tree diseases: framing perspectives of pinewood managers around Dothistroma Needle Blight. *Journal of environmental management*, 188, pp.238–245.
- Marzano, M., Hall, C., Dandy, N., LeBlanc Fisher, C., Disstorrance, A. and Haight, R., 2020. Lessons from the frontline: Exploring how stakeholders may respond to emerald ash borer management in Europe. *Forests*, 11(6), p.617.
- Marzano, M., Woodcock, P. and 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(5), pp.554–567.
- McFarlane, B.L., Stumpf-Allen, R.C.G. and Watson, D.O., 2006. Public perceptions of natural disturbance in Canada's national parks: the case of the mountain pine beetle (*Dendroctonus ponderosae* Hopkins). *Biological conservation*, 130(3), pp.340–348.
- McKinney, L.V., Nielsen, L.R., Collinge, D.B., Thomsen, I.M., Hansen, J.K. and Kjær, E.D., 2014. The ash dieback crisis: genetic variation in resistance can prove a long-term solution. *Plant Pathology*, 63(3), pp.485–499.
- McMullan, M., Rafiqi, M., Kaithakottil, G., Clavijo, B.J., Bilham, L., Orton, E., Percival-Alwyn, L., Ward, B.J., Edwards, A., Saunders, D.G. and Garcia Accinelli, G., 2018. The ash dieback invasion of Europe was founded by two genetically divergent individuals. *Nature Ecology & Evolution*, 2(6), pp.1000–1008.
- Meir, E., Andelman, S. and Possingham, H.P., 2004. Does conservation planning matter in a dynamic and uncertain world?. *Ecology Letters*, 7(8), pp.615–622.
- 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. and Hewison, R.L., 2014. Ash dieback in the UK: a review of the ecological and conservation implications and potential management options. *Biological conservation*, 175, pp.95–109.

Mitchell, R.J., Hewison, R.L., Hester, A.J., Broome, A. and 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(1), pp.2-15.

Natural England, 2014. *Assessing and addressing the impacts of ash dieback on UK woodlands and trees of conservation importance (Phase 2)*. London: Natural England.

North Wales Wildlife Trust, 2022. *Support for landowners | North Wales Wildlife Trust*. [online] Northwaleswildlifetrust.org.uk. Available at: <<https://www.northwaleswildlifetrust.org.uk/support-landowners>> [Accessed 20 May 2022].

Orton, E.S., Brasier, C.M., Bilham, L.J., Bansal, A., Webber, J.F. and Brown, J.K., 2018. Population structure of the ash dieback pathogen, *Hymenoscyphus fraxineus*, in relation to its mode of arrival in the UK. *Plant pathology*, 67(2), pp.255-264.

Pandey, D.N., 2010. Critical necessity of local monitoring and enforcement for sustainable governance of forests. *Indian Forester*, 136(9), pp.1155-1163.

Pautasso, M., Aas, G., Queloz, V. and Holdenrieder, O., 2013. European ash (*Fraxinus excelsior*) dieback – A conservation biology challenge. *Biological conservation*, 158, pp.37-49.

Ramsfield, T.D., Bentz, B.J., Faccoli, M., Jactel, H. and Brockerhoff, E.G., 2016. Forest health in a changing world: effects of globalization and climate change on forest insect and pathogen impacts. *Forestry*, 89(3), pp.245-252.

Scherrer, D., Bader, M.K.F. and Körner, C., 2011. Drought-sensitivity ranking of deciduous tree species based on thermal imaging of forest canopies. *Agricultural and Forest Meteorology*, 151(12), pp.1632-1640.

Stanley, J., Clouston, B. and Binney, J., 2005. *Understanding social and economic influences on natural resource management decisions*. Department of Natural Resources and Mines.

The Tree Council, 2020. *Ash dieback: A Guide for tree owners*. The Tree Council, pp.1-24.

Tinsley-Marshall, P., Downey, H., Adum, G., Al-Fulaij, N., Bourn, N.A., Brotherton, P.N., Frick, W.F., Hancock, M.H., Hellon, J., Hudson, M.A. and Kortland, K., 2022. Funding and delivering the routine testing of management interventions to improve conservation effectiveness. *Journal for Nature Conservation*, 67, p.126184.

- Tomlinson, I., Potter, C. and Bayliss, H., 2015. Managing tree pests and diseases in urban settings: the case of Oak Processionary Moth in London, 2006–2012. *Urban Forestry & Urban Greening*, 14(2), pp.286–292.
- Tomlinson, I., 2016. The discovery of ash dieback in the UK: The making of a focusing event. *Environmental Politics*, 25(4), pp.709–728.
- Tucker, C., 2010. Learning on governance in forest ecosystems: Lessons from recent research. *International Journal of the Commons*, 4(2).
- Welsh Government, 2016. *Chalara Dieback of Ash – Response for Wales (2016)*. Cardiff: Welsh Government, pp.1–13.
- Welsh Government, 2021. *Forestry and Woodland in Wales Research Briefing*. Cardiff Bay: Welsh Government, pp.1–26.
- Welsh Government, 2018a. *Visits to Tourist Attractions in Wales 2018 Report for Visit Wales*. Cardiff: Welsh Government, pp.1–65.
- Welsh Government, 2018b. *Woodlands for Wales: The Welsh Government's Strategy for Woodlands and Trees*. Cardiff: Welsh Government, pp.1–60.
- Welsh Parliament, 2021. *Forestry and Woodland in Wales Research Briefing. rep.* Cardiff: Welsh Parliament, pp. 1–26.
- Wingfield, M.J., Brockerhoff, E.G., Wingfield, B.D. and Slippers, B., 2015. Planted forest health: the need for a global strategy. *Science*, 349(6250), pp.832–836.
- Woodward, S. and Boa, E., 2013. Ash dieback in the UK: a wake-up call. *Molecular plant pathology*, 14(9), p.856.
- Young, J.C., Marzano, M., Quine, C.P. and Ambrose-Oji, B., 2018. Working with decision-makers for resilient forests: A case study from the UK. *Forest Ecology and Management*, 417, pp.291–300.

Key findings document:

An accessible two page document was produced to present the findings of the KESS 2 East funded MScRes project which aims to further the understanding of stakeholder responses to tree pest and disease outbreaks across Wales. The document summarises:

1. Findings from a systematic literature review that aimed to further the understanding of private stakeholders and their experience with tree pests and diseases
2. Empirical research directed from the literature review is also summarised. The research considers role conservation organisations play in mitigating the impact of ash dieback
3. It provides eight specific recommendations that will provide support to encourage and/ or enhance the role conservation organisations may play at the landscape scale

These recommendations are largely targeted around support that can be provided by Natural Resources Wales towards conservation organisation to continue and/ or enhance the role they play in mitigating ash dieback at the landscape scale in Wales. However, support should be obtained from several sources to provide the greatest level of support.



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Support for conservation organisations when dealing with ash dieback in Welsh woodlands

Summary: Ash dieback (*Hymenoscyphus fraxineus*) is widely distributed throughout the Welsh landscape but complex and fragmented ownership of woodlands makes mitigating its impact challenging (Welsh Government, 2021). Management must aim to slow the spread of the disease whilst minimising its impact through preventative and reactionary measures (Forest Research, 2022). Guidance is readily available about best practice at national, regional and organisational level supported by overarching policy (Forestresearch, 2022a; Tree Health Council, 2020; Welsh Government, 2016). However, there is limited information about how closely these recommended approaches are followed (Tinsley-Marshall et al., 2022). As a result, semi-structured interviews were carried out with woodland managers tasked with mitigating the impact of ash dieback in Wales. The research focused on individuals managing woodland on behalf of conservation organisations which are of interest not only because of their behaviour is understudied but it is also proposed that their influence across the Welsh landscape is widely underestimated.

Conservation organisations have high knowledge and awareness of ash dieback and exhibit the skills to manage the disease where safety allows. Predominately organisations follow best practice guidance utilising management approaches to maintain ash species within woodlands where finance isn't a constraint. Conservation organisations are identified as having a far reaching influence on ash dieback management in Wales not only managing their own land or land on behalf of other but also providing advice to private landowners and playing an active part in educating the public about ash dieback management (Cracknell, Miller and Williams, 2013; North Wales Wildlife Trust, 2022; Welsh Government, 2018).



Therefore, acknowledging and facilitating the positive role that conservation organisations play in the national coordination of ash dieback requires further attention.

Background: Ash dieback is causing significant impact to common ash (*Fraxinus excelsior*) a native species of high biodiversity and cultural value (McKinney et al., 2014). The action managers take act as the first line of defense, monitoring and carrying out activities that can minimise impact of threats (Marzano et al., 2020). Management approaches taken by conservation organisations are of interest as they manage large areas of woodland in Wales, offer advice to private landowners and educate the public about tree health (North Wales Wildlife Trust, 2022). They also have strong conservation objectives. Combined these attributes suggests that they could be influential in the national response to ash dieback in Wales.

Methodology: In September and November 2021, 18 interviews were carried out across Wales with individuals from 8 conservation organisations, carrying out 9 different roles involving sites which had varying tree composition and conservation designation. Individuals provided detailed information about management approaches and their influencing



Findings: Conservation organisations exhibited high awareness and understanding of ash dieback and many roles have been established within organisations to mitigate its impact. Conservation organisations aim to maintain ash trees in the Welsh landscape for biodiversity value and to build woodland resistance to ash dieback (appendix C.). Conservation organisations are playing a potentially underestimated but influential role in the mitigation of ash dieback in Wales. Conservation organisations have a wide role managing woodlands, increasing public awareness of ash dieback, offering advice and facilitating tree health networking. Conservation organisations can utilise their influence, working with stakeholders to achieve common outcomes facilitating a cohesive response to the disease at the landscape scale.

Recommendations: The influence of conservation organisations is hard to quantify but their current and potential widespread impact on the mitigation of ash dieback in Wales should be an area of interest. Therefore, this research recommends eight specific recommendations that could support and/ or enhance the role of conservation organisations play in mitigating the impact of ash dieback.

1. Facilitate the development of a network of professional foresters who can be readily available for woodland managers when felling particularly dangerous trees need to be outsourced
2. Improve the coordination and process for shutting roads for the purpose of specialist equipment and tree removal which is a key cost for woodland managers
3. Investing in local industry to make small-scale tree production more accessible to conservation organisations felling trees because of ash dieback
4. Ensuring that conservation legislation and tree health policy are complimentary and do not provide conflicting instruction when conservation organisations are faced with ash dieback
5. The provision of on-site training to allow conservation organisations to increase the confidence of woodland managers identifying ash dieback
6. Additional funding would allow more management of ash trees to take place that would prevent path and site closures allowing woodlands to remain accessible to the public
7. Conduct research to gain more evidence regarding replanting potential alternative species when woodland managers are faced with ash dieback
8. The provision of a national contact at Natural Resources Wales that can provide advice and support would be highly beneficial to implementing their management approaches.

The support through these recommendations are best placed to come from varied sources but would benefit from being overseen by Natural Resources Wales to provide a central coordination point.

Conclusions: Conservation organisations have a wide role in mitigating the impact of ash dieback. They are engaging with the public and other woodland owners about tree health issues. Their advice is well received and trusted often facilitating information sharing within networks of woodland stakeholders. Conservation organisations can utilise their influence, working with stakeholders to achieve common outcomes from ash dieback management which would produce a more cohesive response to the disease at the landscape scale. Therefore, support should be provided centrally by Natural Resources Wales but also from varied sources to support and/ or enhance the role conservation organisations play in mitigating the impact of ash dieback. Limited research about their involvement with ash dieback (Marzano, Woodcock and Quine, 2019) and lack of consideration in policy (Welsh Government, 2021) suggest their involvement could be being overlooked and potentially underestimated.

References:

- Cracknell, J., Miller, F. and Williams, H., 2013. *Passionate collaboration*. London: Green Funders, pp.1–64.
- Forest Research, 2022. *Ash dieback (Hymenoscyphus fraxineus) – Forest Research*. [online] Forest Research. Available at: <<https://www.forestresearch.gov.uk/tools-and-resources/fthr/pest-and-disease-resources/ash-dieback-hymenoscyphus-fraxineus/>> [Accessed 19 May 2022].
- Marzano, M., Hall, C., Dandy, N., LeBlanc Fisher, C., Disstorrance, A. and Haight, R., 2020. Lessons from the frontline: Exploring how stakeholders may respond to emerald ash borer management in Europe. *Forests*, 11(6), p.617.
- Marzano, M., Woodcock, P. and 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(5), pp.554–567.
- McKinney, L.V., Nielsen, L.R., Collinge, D.B., Thomsen, I.M., Hansen, J.K. and Kjær, E.D., 2014. The ash dieback crisis: genetic variation in resistance can prove a long-term solution. *Plant Pathology*, 63(3), pp.485–499.
- North Wales Wildlife Trust, 2022. *Support for landowners | North Wales Wildlife Trust*. [online] Northwaleswildlifetrust.org.uk. Available at: <<https://www.northwaleswildlifetrust.org.uk/support-landowners>> [Accessed 20 May 2022].
- The Tree Council, 2020. *Ash dieback: A Guide for tree owners*. The Tree Council, pp.1–24.
- Tinsley-Marshall, P., Downey, H., Adum, G., Al-Fulaij, N., Bourn, N.A., Brotherton, P.N., Frick, W.F., Hancock, M.H., Hellon, J., Hudson, M.A. and Kortland, K., 2022. Funding and delivering the routine testing of management interventions to improve conservation effectiveness. *Journal for Nature Conservation*, 67, p.126184.
- Welsh Government, 2016. *Chalara Dieback of Ash – Response for Wales (2016)*. Cardiff: Welsh Government, pp.1–13.
- Welsh Government, 2021. *Forestry and Woodland in Wales Research Briefing*. Cardiff Bay: Welsh Government, pp.1–26.
- Welsh Government, 2018. *Visits to Tourist Attractions in Wales 2018 Report for Visit Wales*. Cardiff: Welsh Government, pp.1–65.

Conclusions: The following document evaluates the overall findings from the project conducted as part of the KESS 2 East funded MScRes project which aims to further the understanding of stakeholder responses to tree pest and disease outbreaks across Wales. It also considers the research process in order to provide future direction for this timely and relevant research topic.

Overall conclusions, reflections and future direction



MScRes Submission: Overall conclusion

Conclusions

The introduction and establishment tree pests and disease continue to increase globally (Fisichelli et al., 2014). The action taken by woodland managers act as the first line of defence against introduced and established threats through monitoring, reporting and carrying out activities that minimise their impact (Marzano et al., 2020; Tomlinson, Potter and Bayliss, 2015). Therefore this project took an interest in the role private woodland managers play in mitigating the impact of tree pests and diseases. Initially a detailed review of current literature about private woodland management approaches was undertaken. The review identified that there was a number of 'benchmark strategies' for dealing with tree pests and diseases (Ayres and Lombardero, 2018). However, there remains limited information about how closely these strategies are followed in practice and in which circumstances they may be adapted, substituted, or even omitted by woodland managers (Marzano, Fuller and Quine, 2016). The review concluded that for the most part managers consider tree pests and diseases a threat and want to take a proactive stance in mitigating their impact (Lawrence and Marzano, 2014; Marzano, Fuller and Quine, 2016). The review identified understanding the role conservation focused managers play in mitigating tree pest and disease impact was understudied. Whilst not the majority, a substantial number of British woodlands are managed by conservation focused managers but were only mentioned in 3 reviewed papers but often detailed different management approaches (Ambrose-Oji et al., 2020, Lawrence and Marzano, 2014; Tomlinson, Potter and Bayliss, 2015). The review supports Marzano, Fuller and Quine (2017) conclusion that the lack of research of private managers could be limiting the understanding of management behaviour when faced with pest and disease outbreaks overtime.

Research looked into the role conservation focused woodlands managers play in Wales where a substantial gap in the literature was identified. Conservation organisations are responsible for 2.9% of woodland, a relatively small area of woodland but this information may be outdated in policy documentation and their overall management impact underestimated (Welsh Government, 2021). Therefore, a 12 month project was undertaken in Wales to identify the role conservation organisations play in mitigating the impact of ash dieback. Ash dieback has spread widely throughout Wales and its mitigating its impact will need to be achieved at the national scale coordinated across multiple landscapes involving varied landscapes. However, the complex ownership and fragmented woodland areas found in Wales make this challenging (Welsh Government, 2021). Woodland managers will have to readily adapt to mitigate the impact of ash dieback (Fisichelli et al., 2014; Young et al., 2018). The research paper identified that conservation organisations have influence across multiple sectors with the potential to widely impact the management of ash dieback. Conservation

organisations were also observed altering management approaches to maintain ash in the landscape for longer than their commercial counterparts increasing habitat for biodiversity creating the opportunity to build resistance.

Conservation organisations exhibit a high awareness of the disease and possess the capabilities to mitigate its impact exhibiting strong association with best practice where funding allows. Conservation organisations have a wide role in mitigating the impact of ash dieback through engaging with the public and other private woodland owners about tree health issues, generating support so advice is well received and trusted, providing advice about mitigating the impact of ash dieback, and through facilitating networks of woodland stakeholders. Conservation organisations can utilise their influence, working with stakeholders to achieve common outcomes from ash dieback management would produce a more cohesive response to the disease at the landscape scale. Limited research in their involvement with ash dieback (Marzano, Woodcock and Quine, 2019) and lack of consideration in policy (Welsh Government, 2021) suggest this involvement could be being overlooked and potentially underestimated.

1. Future direction

The influence of conservation organisations is hard to quantify but their current and potential widespread impact on the mitigation of ash dieback in Wales should be an area of interest. Therefore, support should be provided centrally by Natural Resources Wales but also from varied sources suggest research and local regulators to support and/ or enhance the role of conservation organisations play in mitigating the impact of ash dieback.

1.1 Policy makers:

This research recommends policy makers should acknowledge the standard to which conservation organisations appear to manage ash dieback and the information they pass onto others in the wider landscape closely following national guidance. Organisations being largely trusted by the public and involved in various management advice schemes suggests that organisations have a larger influence on wooded areas in Wales than just the land they own. Therefore, providing targeted funding, support and training for conservation organisations will in turn support the role of conservation organisations play in the Welsh landscape and contribute to the national mitigation approach to mitigating to ash dieback. Conservation organisations believed that this support was essential as currently there isn't sufficient support available to take more expensive conservation friendly management approaches and others to do the same. Therefore this research was able to

make a number of recommendations to maximize the potential of conservation organisations positively influencing the national response to ash dieback in Wales.

1. Facilitate the development of a network of professional foresters who can be readily available for woodland managers when felling particularly dangerous trees need to be outsourced
2. Improve the coordination and process for shutting roads for the purpose of specialist equipment and tree removal which is a key cost for woodland managers
3. Investing in local industry to make small-scale tree production more accessible to conservation organisations felling trees because of ash dieback
4. Ensuring that conservation legislation and tree health policy are complimentary and do not provide conflicting instruction when conservation organisations are faced with ash dieback
5. The provision of on-site training to allow conservation organisations to increase the confidence of woodland managers identifying ash dieback
6. Additional funding would allow more management of ash trees to take place that would prevent path and site closures allowing woodlands to remain accessible to the public
7. Conduct research to gain more evidence regarding replanting potential alternative species when woodland managers are faced with ash dieback
8. The provision of a national contact at Natural Resources Wales that can provide advice and support would be highly beneficial to implementing their management approaches.

1.2 Research

This research identifies that the understanding of woodland management behaviour and the factors that influence that behaviour remains limited. Managers that were interviewed for this research were keen for more research into practical management outcomes of ash dieback and analysing their success. This would allow them to learn from others experiences as well as their own leading to more informed choices. This in turn would be shared through their various stakeholder channels influencing management across the Welsh landscape. Research considering other woodland managers within the private sector where motivations might deviate from a commercial and conservation focus would also be of interest including the increasing emergence of community woodlands.

1.3 Collaboration

Furthermore, this research reinforces the importance of a collaborative approach to ash dieback and tree health more broadly within Wales. It should be a priority for cross sector communication about management approaches to tree threats which should involve common goals that support woodland management objectives. Conservation organisations appear best placed to facilitate and support a network of woodland stakeholders promoting a multidirectional dialogue about best practices, support and solutions to management issues. Moreover, organisations can be pivotal in the coordination of responses across the complex and fragmented Welsh woodland landscape for both ash dieback and other arising tree health threats.

2. Reflections

This project provides a detailed review of the current literature available about management approaches to tree pests and diseases in the UK. It also identifies a myriad of factors that can influence those decisions. It provided both the justification for a research paper and empirical data from woodland managers in Wales which will be submitted for publication. Recommendations for further supports alongside key findings will be disseminated back to ForestResearch. This project had several strength that will make it suitable for having impact at these multiple scales. Woodland managers were interviewed from all regions of Wales making the findings representative of the Welsh woodland landscape. Interviews were carried out in a number of formats making the project highly accessible to respondents therefore encouraging participation. Although there were some limitations including covid-19 regulations which prevented some interviews being taking place in person but was overcome by moving interviews to Teams. As with all projects if there had been more time and resources more interviews could have been undertaken but the information collected showed saturation after 18 interviews. Overall the research undertaken information of management undertaken by conservation organisations when faced with ash dieback was recorded highlighting a policy, research and management interest. It will be useful for bodies to understand the impact of conservation organisation when managing ash dieback and provide further support where appropriate.

References:

Ambrose-Oji, B., Atkinson, M., Petrokofsky, G. and Hemery, G., 2020. Do Environmental Worldviews and Distrust Influence Action for Adaptation to Environmental Change Among Small-Scale Woodland Managers?. *Small-scale Forestry*, 19, pp.159-185.

Ayres, M.P. and Lombardero, M.J., 2018. Forest pests and their management in the Anthropocene. *Canadian Journal of Forest Research*, 48(3), pp.292-301.

Fisichelli, N.A., Abella, S.R., Peters, M. and Krist Jr, F.J., 2014. Climate, trees, pests, and weeds: Change, uncertainty, and biotic stressors in eastern US national park forests. *Forest Ecology and Management*, 327, pp.31-39.

Lawrence, A. and Marzano, M., 2014. Is the private forest sector adapting to climate change? A study of forest managers in north Wales. *Annals of forest science*, 71(2), pp.291-300.

Marzano, M., Dandy, N., Papazova-Anakieva, I., Avtzi, D., Connolly, T., Eschen, R., Glavendekić, M., Hurley, B., Lindelöw, Å., Matošević, D. and Tomov, R., 2016. Assessing awareness of tree pests and pathogens amongst tree professionals: A pan-European perspective. *Forest policy and economics*, 70, pp.164-171.

Marzano, M., Fuller, L. and Quine, C.P., 2017. Barriers to management of tree diseases: framing perspectives of pinewood managers around *Dothistroma* Needle Blight. *Journal of environmental management*, 188, pp.238-245.

Marzano, M., Hall, C., Dandy, N., LeBlanc Fisher, C., Disstorrance, A. and Haight, R., 2020. Lessons from the frontline: Exploring how stakeholders may respond to emerald ash borer management in Europe. *Forests*, 11(6), p.617.

Marzano, M., Woodcock, P. and 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(5), pp.554-567.

Tomlinson, I., Potter, C. and Bayliss, H., 2015. Managing tree pests and diseases in urban settings: the case of Oak Processionary Moth in London, 2006-2012. *Urban Forestry & Urban Greening*, 14(2), pp.286-292.

Tinsley-Marshall, P., Downey, H., Adum, G., Al-Fulaij, N., Bourn, N.A., Brotherton, P.N., Frick, W.F., Hancock, M.H., Hellon, J., Hudson, M.A. and Kortland, K., 2022. Funding and delivering the routine testing of

management interventions to improve conservation effectiveness. *Journal for Nature Conservation*, 67, p.126184.

Welsh Government, 2021. *Forestry and Woodland in Wales Research Briefing*. Cardiff Bay: Welsh Government, pp.1-26.

Young, J.C., Marzano, M., Quine, C.P. and Ambrose-Oji, B., 2018. Working with decision-makers for resilient forests: A case study from the UK. *Forest Ecology and Management*, 417, pp.291-300.