ABSTRACT
The health and sustainability of trees are increasingly under threat from biotic and abiotic sources, including rising incidences of non-native invasive plant pests and pathogens. The island of Ireland (Ireland and Northern Ireland) is generally understood to have a high plant health status, due to its island status and because of the national and international regulations aimed at protecting plant health. To establish a baseline of the current pest and pathogen threats to tree health for the island of Ireland, the literature and unpublished sources were reviewed to produce a dataset of pests and pathogens of trees on the island of Ireland. The dataset contains 396 records—the majority of pests and pathogens being arthropods and fungi—and indicates potentially more than 44 non-native pest and pathogen introductions. The reliability of many (378) of the records was judged to be high, therefore the dataset provides a robust assessment of the state of pests and pathogens of trees recorded on the island of Ireland. We analyse this dataset and review the history of plant pest and pathogen invasions; in doing so, we discuss (i) notable native and non-native pests and pathogens of trees, (ii) interceptions at borders and (iii) pests, pathogens and climate change. The dataset establishes an important baseline for the knowledge of plant pests and pathogens on the island of Ireland, and will be a valuable resource for future plant health research and policy making.

INTRODUCTION
The incidences of non-native pests and pathogens of plants are increasing globally, and these pests threaten important ecosystem services (Boyd et al. 2013; Crous et al. 2016), with this increase mainly attributed to increased globalisation (Desprez-Loustau et al. 2010; Liebhold et al. 2012; Santini et al. 2013) and climate change (Desprez-Loustau et al. 2007; Bebber 2015; Ramsfield et al. 2016). Reviews in the USA (Aukema et al. 2010), New Zealand (Sikes et al. 2018) and the UK (Freer-Smith and Webber 2015) have shown an increase in the records of highly damaging non-native pests and pathogens of woody plants since the late twentieth century. One such insect pest causing significant economic and environmental damage is the emerald ash borer (Agrilus planipennis Fairmaire), which has been spreading across North America since its introduction there during the 1990s (Herms and McCullagh
This pest is considered a very serious threat to ash (*Fraxinus excelsior*) in Europe (EPPO 2013), where another non-native fungal pathogen (*Hymenoscyphus fraxineus* Baral *et al*.) is causing widespread decline and mortality in the form of ash dieback disease (Kowalski 2006; Gross *et al*. 2014). Ash dieback is estimated to cost many billions of euros in economic damage, with estimates from the UK alone reaching £15 billion (Hill *et al*. 2019). Eradication of these pathogens is difficult (Liebhold and Kean 2019), and bioeconomic modelling indicates that resources are best allocated to activities preventing these invasive species introductions rather than those trying to eradicate or control invasive species (Leung *et al*. 2002). Liebhold *et al*. (2016) identify the need for improved surveillance systems to help eradicate pests through early detection.

Forests provide vital ecosystem services (FAO 2018), but these are under threat from non-native pests and pathogens (Boyd *et al*. 2013). Ireland is one of the least forested countries in the EU (FRA 2015), with forests covering 770,020ha or around 11% of the land area (Anon 2018). Northern Ireland has over 112,000ha of forestry (Department of Agriculture, Environment and Rural Affairs (DAERA) 2018), equating to roughly 8% of the land area. Historic forest clearance across the island of Ireland (i.e. Ireland and Northern Ireland) led to almost complete deforestation, with estimates of just 1% remaining forest cover in the late eighteenth century (Cross 1998). The forest area in Ireland has increased in recent years, being composed primarily of the exotic species *Picea sitchensis* (Bong.) Carr. (51% of forest area), *Pinus contorta* Douglas (10%), *Picea abies* (L.) H. Karst. (4%) and *Larix kaempferi* (Lamb.) Carr. (Anon 2018). In Northern Ireland, almost 62% of the forest area is composed of conifer or conifer mixtures (DAERA 2018). Outside of forests, there are also a large number of trees scattered across the island, with estimates from Northern Ireland indicating that there are more than five million trees in hedgerows (Spaans *et al*. 2018). The low cover of forest across the island of Ireland probably had a significant impact on the numbers of known forest-associated species, such as forest-associated fungi (O’Hanlon and Harrington 2011) and insects (Morris 1993; Reilly 2008), compared to that in similar regions such as England or Scotland. The historically low level of forest cover (as low as 1% in the early 1900s (Rackham 1997 as cited in Cross 2006)) probably also contributed to the development of a depauperate community of forest-associated pests and pathogens, with the forests of the island of Ireland generally known to have less diseases due to pests and pathogens than similarly sized European regions (Grégoire and Evans 2004; McCracken 2013).

The newness of Ireland’s forest estate as well as the country’s island status confer a strong natural advantage in terms of forest health (Department of Agriculture, Food and the Marine (DAFM) 2014)); and at a European level, Ireland’s forests are recognised as being relatively healthy. However, during the 1970s, de Brit and McAree (1977) flagged how such plantations were potentially susceptible to introduced pests and pathogens, due to the structure and composition of Ireland’s spruce plantations. In recent years there has been a growing concern over the threat that non-native pests and pathogens pose to tree and forest health on the island of Ireland (McCracken 2013; O’Hanlon 2015) (Figure 1a,b,c,d,e,f). Many of the recently introduced pathogens and pests arrived with trade consignments, such as *Phytophthora ramorum* Werres, De Cock and Man in ’t Veld 2001 and the eucalyptus psyllid *Ctenarytaina eucalypti* Maskell on plants for planting (Purvis *et al*. 2002; O’Hanlon *et al*. 2016a). Plants for planting, and wood packaging material such as pallets and crates are
known pathways for introducing non-native pests and pathogens worldwide (Kenis et al. 2007; Brasier 2008; Humble 2010; Liebhold et al. 2012; Eyre et al. 2018), and thus are regulated under the plant health regulation (EU 2016/2031) and the related official controls regulation (EU 2017/625) in the EU.

The aim of this article is to provide a list of occurrences of pests of trees on the island of Ireland. Despite having a strong history of plant pathology expertise (Muskett 1976; Kavanagh and Brennan 1993), the island of Ireland has in recent years seen a reduction in the number of practicing forest pathologists, mycologists and entomologists (Copeland and Dowley 2010; Skilling and Batzer 1995; Battisti and Faccoli 2004; Dahlberg et al. 2009; O’Hanlon 2016; O’Hanlon et al. 2016b). Data from the Tree CD project found that just 2% of forest researchers’ time in Ireland was devoted to forest protection compared to 13, 17 and 11% in Austria, Switzerland and the UK, respectively (Bystriakova and Schuck 1999). This is in line with similar recent declines in tree and forest health specialists in Britain (Jones and Baker 2007; Anon 2013c) and more widely in Europe (EPPO 2004). The information and results from years of work in the disciplines of forest pathology and entomology on the island of Ireland is scattered across many sources, both published and unpublished. Collating this type of historic data is important because it offers the opportunity to assess if trends are evident in new pest invasions, or if climate change may be influencing the distribution of pests and pathogens (Jeger and Pautasso 2008).

PLANT DISEASE, PHYTOSANITARY MEASURES AND THE INTERNATIONAL YEAR OF PLANT HEALTH

The United Nations General Assembly declared 2020 as the International Year of Plant Health (http://www.fao.org/plant-health-2020/home/en/). Governments and organisations across the world have seized on the opportunity to raise global awareness on how protecting plant health can help end hunger, reduce poverty, protect the environment and boost economic development. Plant diseases are caused by biotic and abiotic factors, and in recent years the threat from plant diseases to global food security and environmental sustainability had come to prominence (Boyd et al. 2013; MacLeod et al. 2016). Protection of plant health worldwide is enshrined in the agreements of the International Plant Protection Convention (IPPC; www.ippc.int). This convention aims to protect the world's plant resources from the spread and introduction of pests and pathogens, while also promoting safe trade. Within the EU the measures to calculate and reduce the risk to plant health are contained in the EU plant health regulation (EU 2016/2031), which replaces the previous Plant Health Directive (2000/29/EC).

Under the IPPC, plant health legislation mainly follows a list-based system of regulation. Pests are assessed using pest risk assessment (PRA), and listed in terms of threat and regulated accordingly. A prerequisite of the listing of any pest or pathogen, is that the organism must be identifiable, and able to spread and cause consistent damage in a plant (FAO 2007). The identifiable requirement is usually fulfilled by the pest being a formally described species. This can pose a difficulty to the rapid regulation of new pests and pathogens, given that some recent epidemics (sudden oak death, ash dieback) in Europe were caused by organisms unknown to science at the time the epidemic started. The sudden oak death pathogen Phytophthora ramorum caused a major epidemic in oak forests in California from 1995 onwards (Rizzo et al. 2002), but was only formally described as a species in 2001
Similarly, ash dieback was first noted in Poland in 1996, but the causal organism *Chalara fraxinea* (syn. *Hymenoscyphus fraxineus*) was only formally described in 2006 (Kowalski 2006). Further evidence for the practical issues with needing a formal species description before an organism can be regulated can be seen in some of the sentinel planting research in China and Russia, where many of the disease-causing organisms were undescribed taxa (Eschen *et al.* 2018). Eschen *et al.* (2018) suggest that risk assessments should focus on the commodity (commodity risk assessment) rather than on individual PRA in order to prevent threats, at least until formal species description and pest risk assessment can take place.

There are three types of regulated pests (including pathogens) in the EU plant health regulation: (i) priority pests, (ii) quarantine pests and (iii) regulated non-quarantine pests (RNQP). For the 20 priority pests, EU member states must carry out annual surveys and monitoring as well as put in place contingency plans and information/outreach activities in order to prevent these pests and pathogens establishing in their jurisdiction. Quarantine pests are those whose presence would have an unacceptable economic, social or environmental impact within the EU. These pests include union quarantine pests (n=173) and protected zone (PZ) pests (n=31). Member states are required to conduct one survey every five years for each union quarantine pest, if that pest has the potential to establish in their jurisdiction. Ireland and Northern Ireland enjoy PZ status for many harmful forest pests and pathogens. A PZ is essentially an area in the EU where a pest or pathogen of quarantine significance, established in other parts of the EU, is not present despite favourable conditions for it to establish. Annual surveys for PZ pests must be conducted to prove freedom from the pest, in order to maintain a PZ status. Regulated non-quarantine pests are those pests and pathogens that are spread on plants for planting or planting material, and can cause unacceptable yield or quality losses on those plants. They differ from quarantine pests in being present within the region already.

The EU Plant Health Regulation is administered and implemented by the National Plant Protection Organisations (NPPO), which in Ireland is the Department of Agriculture, Food and the Marine (DAFM). In the UK, plant health is a devolved matter, with the Department of Agriculture, Environment and Rural Affairs (DAERA) being responsible for plant health matters in Northern Ireland. DAERA work closely with the Department of the Environment, Food and Rural Affairs, who act as the NPPO for the UK. The island of Ireland is treated as a single epidemiological unit in the context of plant or animal health. Due to the harmonised approach to plant health on the island (DAFM 2019a) and the EU plant health regulation, there are limited physical checks on plants or plant products moving between Ireland and Northern Ireland, or vice-versa. However, the EU plant health regulation does require that conifer wood that is not bark-free must be accompanied by a plant passport to prove it has been inspected by a professional operator authorised by the NPPO of the exporting country. The UK left the EU in 2020; however, at present the specific plant health rules that the UK will implement are as of yet unclear and will be agreed during the transition period (Spence 2020).
DEVELOPING A DATASET OF PEST DETECTIONS ON THE ISLAND OF IRELAND

This research provides a dataset containing a range of important details of pests and pathogens detected on the island of Ireland (Supplementary Table 1). Pests in this article and dataset are taken to be arthropods, while pathogens include fungi, oomycetes and bacteria. Although viruses and nematodes are also important pests and pathogens of woody plants, the literature on the diseases of woody plants on the island of Ireland caused by these groups is limited (NBDC 2010). For example, in a published dataset of nematode abundances from around the world, no data was available for nematodes of forest sites from the island of Ireland (van Hoogen et al. 2020). A number of literature sources were examined for reports of diseases of trees. Some reports of disease on other woody plants, though not generally considered trees, were also included. Many pests that cause disease on woody shrubs can also cause disease on trees, and therefore pose a risk to tree health. In this case a disease is any damage or ill health, which may or may not have been caused by a pest or pathogen. This literature examined included published literature (e.g. Irish Naturalists Journal), grey literature (e.g. the annual reports of the respective Departments of Agriculture in Ireland, and Northern Ireland; Table 1), and the private records of the authors and colleagues. A search of the literature was conducted in Google Scholar using the search terms ‘pathogen OR pest AND forest OR tree AND Ireland’. The results were reviewed, and relevant literature examined. The Trees of Great Britain and Ireland (Elwes and Henry 1906) was also searched for the terms ‘pest’, ‘parasite’, ‘pathogen’, ‘insect’, ‘fungus’ and ‘disease’.

While developing the dataset for the island of Ireland, other sources were also consulted to compare the detections of pests and pathogens with those in Britain (i.e. England, Scotland and Wales) and Europe. These sources provided information on pest and pathogen detections, risk rating and native status for pathogens (Kloet and Hincks 1945; Moore 1959; Jones and Baker 2007; Freer-Smith and Weber 2015; FRDBI 2020; CABI 2020a; DAERA 2020) and arthropod pests (Browne 1968; BRC 2018; CABI 2020a) in Britain, and for pathogens (Santini et al. 2013) and arthropod pests (Day and Leather 1997) in Europe. Pests and pathogens not found in either Britain or the island of Ireland, but with a risk rating >80 on the Northern Ireland health risk register (DAERA 2020) were also included. Information on the behaviour and ecology of a pest or pathogen in its native range is useful in designing control strategies in areas where it has potential to invade (Webber et al. 2012). However, assigning native or non-native status to pests or pathogens—especially microbial pathogens—is not straightforward (Regan et al. 2010; Jung et al. 2016); therefore this information should be taken as evidence of putative native status. Synonyms were resolved for fungi by means of the Index Fungorum (www.indexfungorum.org), and for arthropod pests using a number of websites (e.g. NBN Atlas 2020). The taxonomic position of the pest or pathogen was also listed from the European and Mediterranean Plant Protection Organisation (EPPO) (2020a), along with the binomial authority for the species. In cases where the year of first detection was not specified, the date of the publication was taken as the date of the detection. There were many relevant pest records reported in Browne (1968), which unfortunately does not assign a year of detection. Therefore, the dataset reflects that many pest records were reported in 1968, though this does not mean these pests were first recorded in 1968. The pest and pathogen detections in surveys and monitoring conducted in Ireland (by, or on behalf of the DAFM and its precursor departments) and Northern Ireland (by, or on behalf of the DAERA and its precursor departments) were split by year of...
publication in order to provide a measure of a pests’ frequency of occurrence. Where available, the host on which the pest or pathogen was detected was also noted.

The records of pest and pathogen detections on the island of Ireland were scored on their reliability, based on the guidelines listed in ISPM 8 (FAO 2017). For reports published by the NPPO, or in peer reviewed scientific journals within the last 20 years, a rank of 1 (the most reliable source) was given. The EPPO reporting service (EPPO 2020b) was the primary source for NPPO reports of pests and pathogens, although the official websites of the NPPO in Ireland also provided several pest and pathogen reports. For reports that were either an official historical record (>20 years old) or published in a non-peer-reviewed scientific journal or a technical journal, a rank of 2 was given. Reports in specialist amateur publications, or in unpublished scientific or technical documents, were categorised as rank 3. Rank 4 (the least reliable source) was applied to reports in non-technical media (e.g. periodicals, newspapers), or to personal communications or unpublished records. Ranking the reliability of records is important to allow readers attach a degree of uncertainty to any analysis that uses these records. The economic consequences of a pest or pathogen presence in a country can be significant, therefore great care should be taken in interpreting these reports. Direct contact with the NPPO via their respective websites in Ireland (https://www.agriculture.gov.ie/farmingsectors/planthealthtrade/) and Northern Ireland (https://www.daera-ni.gov.uk/topics/plant-and-tree-health) is the most reliable way of finding information about the official status of a pest or pathogen in that jurisdiction.

SOURCES OF NOTABLE PESTS AND PATHOGENS OF TREES ON THE ISLAND OF IRELAND

There is speculative evidence from pollen core and tree-ring radiocarbon dating of a pathogen that contributed to the decline of elm trees in Ireland and the UK around 5,000 years ago (Parker et al. 2002; Mitchell 2006). Until the early 1900s, there were few records found of tree pests or pathogens, and these were scattered in periodicals such as Gardeners Chronicle and its successor titles. Some of these reports were included in reviews of pests and pathogens of plants and trees in Ireland and the UK (Johnson and Halbert 1902; Massee 1913; Adams and Pethybridge 1910; Brooks 1928; McKay 1952; Musckett 1976; Moore 1959; Peace 1962; Browne 1968; Musckett and Malone 1978, 1980a, 1980b, 1983, 1984, 1985; Phillips and Burdekin 1982; Mangan 2008), while other records appeared sporadically in the more nationally important journals Irish Naturalists Journal (previously known as Irish Naturalist) and Irish Forestry. The first published reports from the government departments responsible for forest health (the name of which changed several times; O’Carroll and Joyce 2004) started in Ireland in 1933, and in Northern Ireland in 1952 (Table 1). These reports continued almost annually and are considered here up until 2015, although the level of detail on the pests and pathogens reported varies widely across the years. The research reports from the horticulture, horticulture and forestry, plant sciences and crop husbandry, and soils divisions of An Foras Taluntais (now known as Teagasc) between 1962 and 2002 were also examined for information about the official status of a pest or pathogen of woody plants.

Monitoring for forest pests and pathogens during the period from 1938 to 1956 was commissioned by the Department of Agriculture Ireland and carried out by scientists from University College Dublin (Forest and Wildlife Service 1938; 1943). Between 1986 and 2006 a European forest health monitoring scheme known as the International Co-operative Programme (ICP) was established as part of an EU-wide programme to monitor forest conditions in response to concerns over increasing atmospheric pollution. These plots were
established across Ireland, with results reported sporadically (Keane et al. 1989; McCarthy 1993; Ward and Keane 1993; Anon 2006a, 2007a, 2008a). Recording focussed on disease symptoms rather than causal organisms (i.e. pests and pathogens), limiting the use of the data for the purposes of this pest and pathogen list. There were no ICP plots established in Northern Ireland (Brown et al. 2019). The National Forest Inventory of Ireland recorded the presence of forest damage in the assessment plots during its three previous cycles (Anon 2007, 2013, 2018). In the most recent inventory, 24% of the forests had obvious damage due to biotic causes, including over 6,000ha of damage due to pests and pathogens. The methodology for recording damage from pests and pathogens was based on the presence of symptoms of the pests and pathogens *Heterobasidion annosum*, *Armillaria* spp., *Rhizina undulata* Fr., *H. fraxineus*, *P. ramorum*, *Phytophthora alni* Brasier and S.A. Kirk, *Dothistroma* sp., *Hylobius abietis* (L.), *Elatobium abietinum* (Walker), *Rhyacionia buoliana* (Denis and Schiffermüller).

Figure 1, a-f. Symptoms of pests and pathogens of woody plants and trees recorded on the island of Ireland. Figure 1a, *Phytophthora lateralis* dieback in Lawson cypress (*Chamaecyparis lawsoniana*) in Co. Antrim, Northern Ireland. The trees with the sparse crowns and foliage in the centre of the figure are affected by *P. lateralis* trunk canker and root rot. Figure 1b, Ash dieback disease on European ash (*Fraxinus excelsior*) in Co. Fermanagh, Northern Ireland. The diamond shaped lesion (marked with a red arrow) emanating from the small side shoot in the centre of the figure is characteristic of ash dieback disease caused by *Hymenoscyphus fraxineus*. Figure 1c, aerial view of roadside Sitka spruce (*Picea sitchensis*) damage caused by green spruce aphid (*Elatobium abietinum*) in Co. Antrim, Northern Ireland. The grey coniferous trees in the centre of the figure are diseased due to *E. abietinum* (copyright DAERA). Figure 1d, *Heterobasidion annosum* on a Sitka spruce root. Figure 1e, Ash sawfly (*Tomostethus nigritus*) caterpillar feeding on a European ash tree. Figure 1f, *Ips typographus* galleries on Norway spruce (*Picea abies*) in Kent, England.

There have been several initiatives nationally and internationally to increase plant health expertise and knowledge sharing. The Society of Irish Plant Pathologists (SIPP) was founded in 1968, and organised seminars on plant health almost every year since its inception. Reports of forest pathology activities can be found in several SIPP newsletters, including details of the involvement of SIPP members in the informal Forest Pathology group, which included experts from Ireland and the UK. The group met regularly from 1960 to 1996 (SIPP 1970, 1975, 1982, 1987), and even hosted a joint meeting with members of the British Mycological Society in 1969 (SIPP 1970). A herbarium for forest disease and mycorrhizal fungi was set up in 1981 in an attempt to establish a forest health resource for future research and diagnostics (Forest and Wildlife Service 1982). This herbarium was maintained and expanded in 1985 and 1987 (Anon 1986b, 1988). Other large forest pathology initiatives included the development of an All-island Plant Health and Research Strategy in 2005 (Anon 2006a), and the All-Ireland Chalara Control Strategy in 2013 (Anon 2013a). Close cooperation between the NPPO in Ireland and Northern Ireland is fostered through the North South Ministerial Council (https://www.northsouthministerialcouncil.org/).
Table 1 Details of the annual plant health survey information published by the responsible government department in Ireland and Northern Ireland and included in this review. The data from these reports are included in the dataset (Supplementary table 1).

| Region          | Years    | Reference                              |
|-----------------|----------|----------------------------------------|
| Ireland         | 1933–75  | Report of the Minister for Lands on Forestry |
|                 | 1971–85  | Forest and wildlife service reports     |
|                 | 1986–88  | Forest service reports                 |
|                 | 1991–2011| DAFF annual report                     |
|                 | 2012–15  | DAFM annual report                     |
| Northern Ireland| 1952–67  | Record of agricultural research        |
|                 | 1963–69  | Annual progress report on research and technical work |
|                 | 1963     | Ministry of Agriculture NI             |
|                 | 1970–87  | Annual report NI                       |
|                 | 1995–2017| AFBI records                           |

THE DATASET OF PESTS AND PATHOGENS OF TREES ON THE ISLAND OF IRELAND

A total of 396 pests and pathogens were recorded on trees on the island of Ireland. Also included in the dataset are 49 cases from the island of Ireland where the pest or pathogen could not be identified, and are indicated in the dataset by ‘?’ preceding the name. The dataset also includes a further 57 pests and pathogens that have not been detected on the island of Ireland but were judged to pose a high threat. These were included either because they were recorded in Britain or have a risk rating of 80 or above on the Northern Ireland Plant Health Risk Register. There is evidence that 45 of the pests and pathogens recorded on the island of Ireland are potentially native, with a further 129 of the pests and pathogens being native to at least some parts of Europe. The literature suggests that 12 pests and pathogens are non-native to the island of Ireland, while 31 are non-native to Europe. A further twelve pests or pathogens have a cryptic biology and so their native status is not easy to determine. No information could be found on the native status of the remaining 216 pests and pathogens. A total of 294 of the pests and pathogens recorded on the island of Ireland have a host associated with them. The hosts most frequently recorded (i.e. more than 20 pests or pathogens associated with them) were species of *Larix*, *Populus*, *Quercus*, *Alnus*, *Betula*, *Picea*, *Pinus* and *Salix*. Of the 396 pests and pathogens detected in Ireland, 378 have a reliability rating of 1 or 2, indicating a high degree of certainty in their detection.

A total of 33 of the pests and pathogens listed in the dataset are regulated under the EU Plant Health Regulation, of which 23 have been recorded on the island of Ireland, with 5 of these as interceptions at ports and 12 being RNQP. None of the priority pests have ever been recorded on the island of Ireland. Of the 123 pathogens listed as threatening to forests in
Europe (Santini et al. 2013), 41 have been recorded in Ireland. A total of 63 of the 99 pests listed by Day and Leather (1997) as major forest pests in Europe have been recorded on the island of Ireland.

The 396 recorded pests and pathogens included 11 bacteria, 20 oomycetes, 150 fungi and 215 arthropods. It is likely that all of these groups have been under-recorded in Ireland and Northern Ireland. A dearth of scientific expertise—and consequently a lack of surveys—for certain groups of pests and pathogens including insects and bacteria (NBDC 2010; Regan et al. 2010), fungi (Dahlberg et al. 2009; O’Hanlon and Harrington 2011; O’Hanlon 2016) and oomycetes (O’Hanlon et al. 2016b) is evident in Ireland and Northern Ireland. Between 1970 and 2004, Jones and Baker (2007) examined records from several sectors (including horticulture, agriculture and forestry) and recorded 234 pathogens in Britain, while only 42 were recorded during the same period on the island of Ireland. It is also likely that the number of microbial (bacteria, fungal and oomycete) pathogens are under-recorded because of inherent difficulties in detecting and identifying these (Brasier 2008; Morales et al. 2019), and their ability to infect plants asymptomatically (e.g. Migliorini et al. 2015). Recent studies by O’Hanlon et al. (2016a) and McEvoy et al. (2016) used molecular analysis to identify thirteen new records of plant pathogenic microorganisms for Ireland. Similarly, analysis of *P. sitchensis* needle endophytes in four sites in Scotland identified thirteen taxa of fungi (Stewart et al. 2018), of which none have been recorded from conifers on the island of Ireland. This lack of understanding of the fungal and bacterial communities of plants in Ireland is worrying as these are some of the most threatening pathogens to tree and plant health globally (Wingfield et al. 2001; Crous et al. 2016).

The Irish forest estate was relatively free from serious diseases caused by pests and pathogens during the twentieth century, as evidenced by the low number of publications dealing with plant health in the primary technical journal for Irish foresters, *Irish forestry* (Quirke 1946; Clear 1951; McKay and Clear 1953, 1957; de Brit 1967; McAree 1975, 1987; de Brit and McAree 1977; Keane 1986). Indeed, several other sources highlight the relatively low impact of disease in Irish forests during the twentieth century (Anon 1920; Quirke 1946; McCarthy 1993). In recent years, pest and pathogen reports have continued to increase at a relatively steady rate (Fig. 2). This is in line with records of new non-native pathogens (Jones and Baker 2007) and arthropod pests (Smith et al. 2007) in Britain. The large spike (71 new arthropod pests) in records in the year 1968 (Fig 2) in the dataset is due to the publication of a large number of reports in Browne (1968). Given that Browne (1968) did not provide the source of the records, the date of publication of the book (i.e. 1968) is used as the first report. During the five decades starting in the 1970s, the number of new pest and pathogen reports was 26, 27, 16, 37 and 28 up to 2017. Similar trends have been seen in the number of new pest and pathogens in recent years in other regions, including Britain (Freer-Smith and Webber 2015), New Zealand (Sikes et al. 2018) and the USA (Aukema et al. 2010).
Figure 2 Species accumulation curve for the pests and pathogens reported from trees on the island of Ireland.

The dataset includes records from many print-only publications. For example, 127 official reports of the respective Departments of Agriculture in Ireland and Northern Ireland were reviewed (Table 1), most of which are only available in print format. These valuable data sources should be digitised into searchable formats and shared online to enable researchers gain access to this data. The data could also then be added to online pest list sources, such as the EPPO global database (EPPO 2020a) and the CABI plantwise knowledge bank (CABI 2020b).

IMPORTANT DISEASES CAUSED BY NATIVE PESTS AND PATHOGENS

Native plants develop mechanisms to reduce the amount of disease from native pests and pathogens through co-evolution. However, in certain circumstances native pests and pathogens gain an advantage over native plants, allowing them to cause increased disease. Several examples of this are reviewed in Riggins and Londo (2009), including an increased amount of damage caused by the oak pinhole borer, *Platypus cylindrus* (Fabricius) in Britain following several years of favourable breeding conditions for the pest. In southwest Western Australia, the native fungal pathogen *Quambalaria coyrecup* has been causing increasing amounts of disease to native marri trees (*Corymbia calophylla*) in response to anthropogenic disturbance and other predisposing factors (Paap *et al.* 2017). Diseases caused by native pests and pathogens on non-native hosts are probably more threatening, as there is probably a lack of co-evolution in the host (Wingfield *et al.* 2010). Liebhold (2012) identified non-native forest plantations as high risk and prone to catastrophic damage from both native and non-native pests. More than 60% of the forest estate in Ireland is composed of two non-native tree species (*P. sitchensis* and *P. contorta*), therefore pests and pathogens pose a major threat to the Irish forest industry. Species diversification and the use of alternative silvicultural systems (e.g. uneven aged silviculture) have been identified as ways to buffer against large
scale pest and pathogen epidemics in forests (Ennos 2015; Jactel et al. 2017, 2020; Roberts et al. 2020).

The dataset contains reports of 77 native pests and pathogens associated with native genera of trees and woody plants, and 51 native pests and pathogens associated with non-native genera of trees and woody plants. Reports of large-scale disease caused by native pests and pathogens on native trees are generally rare. Quirke (1946) noted the pathogenic fungi Armillaria mellea (Vahl) P. Kumm. to be damaging to various native broadleaf trees, and Neonectria ditissima (Tul. and C. Tul.) Samuels and Rossman causing disease on native Betula and Fraxinus. Large native bracket forming fungi such as Ganoderma, Inonotus and Porodaedalea (previously Phellinus) are probably a factor in the death of many mature native trees, however they are generally known as secondary or destabilising pathogens and are not suited to causing large epidemics in native trees (Hansen and Goheen 2000). Disease caused by native pests and pathogens on non-native trees are more frequently reported. Damage caused by the gall adelgid (Adelges cooleyi [Gillette]) pest in 1930s and 1940s led to Douglas fir (Pseudotsuga menzeisii [Mirbel] Franco) falling out of favour with many Irish foresters (Clear 1951). The pest R. buoliana has been an issue for Irish forestry for many years. Regular surveys were carried out, using pheromones traps in Northern Ireland in the early 1980s (Department of Agriculture for Northern Ireland 1982; Forest and Wildlife Service 1983).

Group dying of conifers (especially P. sitchensis) caused by the fungal pathogen Rhizina undulata (Schaeff.) Sacc. was first noted (under the synonym Rhizina inflata) in Ireland in 1952 (McKay and Clear 1953, 1955), after similar reports in Britain in 1936 (Murray 1953). The pathogen that causes the disease was noted to fruit prolifically on fire sites, and restrictions on burning fires in forest sites has led to the disease being controlled (Joyce and O’Carroll 2002). Quirke (1946) listed several pests and pathogens of importance to Irish forestry, including those of broadleaves (N. ditissima, and Prays fraxinella Bjerkander) and conifers (R. buoliana, E. abietinum, A. mellea, and H. annosum). The fungal pathogen H. annosum causes annosus root disease in many trees, and is listed as the most significant pathogen for forestry in Ireland (Joyce and O’Carroll 2002). Records of this fungus go back as far as 1836, while records of A. mellea go back 1843 (Muskett and Malone 1980), indicating that both are probably native. Reviews by de Brit (1968), McAree (1975) and de Brit and McAree (1977) discussed several of these pathogens and their significance on the island of Ireland. These pathogens have also affected forestry practices on the island of Ireland, with the forest service in Northern Ireland stopping the use of chemical thinning in coniferous forests over concerns that this encouraged H. annosum (Department of Agriculture for Northern Ireland 1992). Ever since the establishment of plantation forestry in Europe, the large pine weevil (Hylobius abietis L.) has been a major pest (Munro, 1927). In newly clear-felled stands adult female weevils are attracted by the volatiles and oviposit just under the bark of the stumps. Weevil larvae subsequently develop in the protected environment under the bark for one to three years depending on temperature (Leather et al. 1999; Inward et al. 2012). Following emergence, adults feed on the bark of young trees and replanted sites can suffer up to 100% mortality of newly planted trees if no control measures are taken. Pine weevil was estimated to cost the UK economy £2 million per annum (Weslien 1998; Leather et al. 1999). Current
control measures include the synthetic chemicals alpha cypermethrin or cypermethrin, which are administered in nursery pre-treatment either via electrodyne application or dipping of young trees prior to planting and/or through on-site post-planting spray. However, with concerns over potential environmental impacts, cypermethrin is being phased out across Europe (E.C. 2012). Under Forest Stewardship Council (FSC) guidelines, alpha cypermethrin and cypermethrin are considered ‘highly hazardous chemicals’ applied only under derogation, so there is an obligation on FSC-certified companies to find alternatives to chemical control. Furthermore, current pesticides have a repellent effect on the pine weevil and, while this protects young plants, it does little to impact on the local populations of the pest (Torr et al. 2005; Leather et al. 1999).

In Ireland there has been much work on the use of biological control agents to help mitigate the pine weevil problem. There have been many studies assessing the efficacy of entomopathogenic nematodes (EPN) in the control of pine weevil (Brixey et al. 2006; Dillon et al. 2007; Dillon et al. 2008; Torr et al. 2007). Williams et al. (2013a) in a meta-analysis of EPN efficacy found, for two EPN species, Steinernema carpocapsae (Weiser) and Heterorhabditis downesi Stock, Griffin and Burnell, that efficacy was greater on sites with a peaty substrate than sites with a mineral substrate. The species of the tree stump did not affect efficacy and there was no density-dependence. A more recent study by Kapranas et al. (2017) found site specific differences were more important than substrate type. More recently there has been a focus on entomopathogenic fungi (EPF) with Beauveria bassiana (Bals.-Criv.) Vuill., Metarhizium anisopliae (Metchnikoff) Sorokin and Beauveria caledonica Bissett and Widden being used in combination with EPNs (Williams et al. 2013b and McNamara et al. 2018).

IMPORTANCE DISEASES CAUSED BY NON-NATIVE PESTS AND PATHOGENS
The first reported outbreak in the dataset of a non-native pest or pathogen of trees in Ireland was that of Dutch elm disease. This disease is caused by fungi from the genus Ophiostoma (namely Ophiostoma ulmi (Buisman) Melin and Nannf. and Ophiostoma novo-ulmi Brasier), which are vectored by bark beetles of the genus Scolytus. The first outbreak in Ireland was caused by the relatively less pathogenic O. ulmi in 1958 (Mangan and Walsh 1980), after a similar outbreak in Britain in 1927 (Moore 1959). Following further reports of widespread elm decline in Britain in the late 1960s, the more aggressive pathogen Ophiostoma novo-ulmi Brasier was detected in Britain in 1965 (Potter et al. 2011) and in Ireland in 1977 (Walsh and Mangan 1977). The pathogen was recorded as causing large amounts of mortality to Ulmus in Northern Ireland throughout the 1970s. The vectors of O. ulmi and O. novo-ulmi on the island of Ireland are the non-native elm bark beetles (Scolytus multistriatus Marsham and Scolytus scolytus Fabricius), which were first reported in Ireland in 1980 and 1943, respectively (O’Callaghan 1982; Quirke 1943).

The link between pest and pathogen findings in Britain and Ireland has been indicated previously (O’Hanlon 2015; O’Hanlon et al. 2016b). The pests Cameraria ohridella, Cinara kochiana, Cinara cupressi and Pulvinaria regalis; and pathogens Blumeriella jaapii, Chondrolea populea, Cylindrocladium buxicola, Gymnosporangium asiaticum, Hymenoscyphus fraxineus, Kabatina juniperia, O. novo-ulmi, Pseudomonas syringae pv. aesculi, P. ramorum, Phytophthora kernoviae, Phytophthora lateralis and Seiridium cardinal and are all non-native organisms established in Britain after 1960 and have since become established on the island of Ireland. The average delay in these pests and pathogens being
recorded on the island of Ireland after their detection in Britain is ten years. Pests and pathogens that have established in Britain pose a higher risk to plant health on the island of Ireland due to the similar conditions (suitable environment, similar hosts), close geographic proximity, and the high amounts of movement of consignments and travellers between the two regions. In 2018 an estimated 30,000 tonnes of conifer roundwood from Scotland was moved into Northern Ireland for processing (Smith 2019).

The fungal pathogen that causes larch canker (*Lachnellula willkommii* (Hartig) Dennis) has been noted as native to parts of Europe (Yde Anderson 1979; Santini *et al.* 2013) and was first recorded in Ireland in 1840 (Muskett and Malone 1983), having been recorded in Britain since 1800 (Oppermann 1923 as cited in Yde Anderson 1979). *Lachnellula willkommii* is specific to *Larix* and *Pseudolarix* (Yde Anderson 1979; CABI 2020a; FRDBI 2020). During the 1970s and 80s investigations into *Pinus contorta* shoot dieback identified a causal relationship with the fungal pathogens *Sydowia polyspora* (Bref. and Tavel) E. Müll. (syn. *Sclerophoma pithyophilla* V. Hohn.) and *Ramichloridium pini* de Hoog and Rhaman. Further testing and assessments during the 1980s confirmed *Ramichloridium pini* was the main cause of the shoot dieback of lodgepole pine (Anon 1986b). Whether *S. polyspora* and *R. pini* are native is unclear. Santini *et al.* (2013) noted that the cryptic lifestyle of *R. pini* made it difficult to say if it was native to Europe. *Sydowia polyspora* has been detected on healthy pine plants and seeds in the USA (Ridout and Newcombe 2018), possibly identifying the trade in seed as a pathway for this pathogen into Ireland, if indeed the pathogen is not native.

The next major outbreak of a non-native pathogen of trees and woody plants was that of the bacterium *Erwinia amylovora* (Burrill) Winslow *et al.* in 1986 (Hume and Conway 1993), which causes a disease of woody plants called fireblight. The pathogen had previously been detected in Northern Ireland on plants (*Stranvaesia* sp. and *Crataegus* sp.) imported from the Netherlands in 1985 (Department of Agriculture for Northern Ireland 1985). This outbreak led to a strict eradication programme being instigated, with a fireblight prevention programme launched in 1986 (Anon 1990). In 1992, both Ireland and Northern Ireland were granted PZ status for *E. amylovora*, with Northern Ireland relinquishing this in 2016 in favour of restricted buffer zone status due to the increased spread of the pest in the wider environment (DAERA 2016). Most of Ireland, except Galway city, retains a PZ for *E. amylovora* to mid-2020. Efforts to eradicate the pathogen in the Galway city area between 2005 and 2013 were not successful. The pathogen is regulated as an RNQP under the EU Plant Health Regulation. Genotypic analysis of the *E. amylovora* isolates detected in Ireland showed no clear genetic structuring in relation to host or location (Brennan *et al.* 2002), possibly indicating that multiple genotypes had been introduced into Ireland. Indeed, *E. amylovora* infected plants have been intercepted at the Irish border on several occasions (EUROPHYT 2016).

McAree and MacKenzie (1993) listed eight forest pests and pathogens (*Bupalus piniaria* [L.], *Cephalcia lariciphila* Wachtl, *Dendroctonus micans* (Kugelann), *Gilpinia hercyniae* (Htg.), *Ips cembrae* (Heer), *Ips sexdentatus* (Börner), *Pristiphora abietina* (Christ), and *G. abietina* (Lagerberg) Morelet) that were present in Britain, but absent from the island of Ireland. *Bupalis piniaria*, *P. abietina* and *G. abietina* have since been recorded on the island of Ireland. *Gremmeniella abietina* is a threat to several coniferous trees, especially
Pinus (Jeeger et al. 2017a), and up until recently, both Ireland and Northern Ireland have PZ for G. abietina. This history of detections of G. abietina in Northern Ireland provides a useful insight into the process for official detections of plant health pests. Official detections of pests should follow international legislation and should work according to international or regional guidance. For many regulated pests and pathogens, official diagnostic standards exist, either published by international (i.e. International Standards for Phytosanitary Measures, ISPM; FAO 2020) or regional (EPPO) organisations. For G. abietina, the EPPO standard (EPPO 2009) relies on morphological detection of the pathogen, and although molecular identification methods did exist when the standard was agreed, these were not deemed suitable due to confusion over the taxonomy of the pest. In 2008 in Northern Ireland, samples from three sites indicated the presence of the pathogen using a nested PCR method (Zeng et al. 2005), however no morphological structures of the fungus were observed. In 2009, DNA sequencing of extracts of fungal DNA from symptomatic Pinus samples indicated a match to the type culture of G. abietina. The records in 2008 and 2009 did not satisfy the EPPO standard and so were not officially recognised. Apothecia (i.e. fruiting structures) of the pathogen were first visually observed on Pinus in Northern Ireland in the 2012, and hence count as the first valid official record of the pest. Isolation of the fungus into pure culture, which is another acceptable identification method, was achieved in Northern Ireland in 2015. These findings of G. abietina in Northern Ireland have led to removal of the PZ in that jurisdiction, while the pathogen has not been confirmed in Ireland and the PZ status is maintained. Findings of the RNQP needle blight pathogen Lecanosticta acicola () in Ireland (Mullett et al. 2018) in recent years warrant further surveys to delimit the distribution of this pathogen on the island of Ireland. The case of G. abietina, L. acicola and P. kernoviae represent detections of pathogens in one jurisdiction, but not in the other. The case of the distribution of the phylogenetic lineages of P. ramorum on the island of Ireland is another example of a clear difference between Ireland and Northern Ireland. In Ireland, only the EU1 lineage has been detected, while in Northern Ireland both the EU1 and EU2 lineages have been detected, though the EU1 has never been detected in the wider environment (O’Hanlon et al. 2016b). Ireland has 15 PZ and Northern Ireland has 14 PZ in place for pests and pathogens of woody plants and trees (Table 2).

Table 2 Protected zone status of pests and pathogens of woody plants and trees in Ireland and Northern Ireland as per Commission Implementing Regulation (EU) 2019/2072

| Pest or pathogen                  | Ireland PZ | Northern Ireland PZ |
|-----------------------------------|------------|---------------------|
| Erwinia amylovora                 | Yes        |                     |
| Xanthomonas arboricola pv. pruni  | Yes        |                     |
| Cryphonectria parasitica          | Yes        | Yes                 |
| Entoleuca mammata                 | Yes        | Yes                 |
Gremmeniella abietina | Yes |
---|---
Cephalcia lariciphila | Yes | Yes |
Dendroctonus micans | Yes | Yes |
Dryocosmus kuriphilus | Yes | Yes |
Gilpinia hercyniae | Yes | Yes |
Ips amitinus | Yes | Yes |
Ips cembrae | Yes | Yes |
Ips duplicatus | Yes | Yes |
Ips sexdentatus | Yes | Yes |
Ips typographus | Yes | Yes |
Thaumetopoea pityocampa | Yes | Yes |
Thaumetopoea processionea | Yes | Yes |

Since the beginning of the twenty-first century, there have been a number of pest and pathogen epidemics of trees and forestry. One particular group of plant pathogens—the genus *Phytophthora*—is a serious risk to plant health globally (Martin et al. 2012; Jung et al. 2018) and has been reasonably well studied in agricultural settings on the island of Ireland (O’Hanlon et al. 2016b). The outbreak of *P. ramorum* in 2002 initially started as a pathogen of the horticulture and ornamental plant industries (EPPO 2020b), which was followed by findings in invasive rhododendron in forests. The pathogen became a major threat to the forest estate in 2010 when found causing disease on Japanese larch (*Larix kaempferi*) (EPPO 2020b). Since the original detection on imported *Rhododendron* spp. and *Viburnum* spp. in Ireland in 2002 (EPPO 2020b), the pest has caused disease on 30 different hosts in both horticultural and forest environments (O’Hanlon et al. 2016a). Current disease control actions in forest outbreaks concentrates on removal of infected and susceptible hosts, a control method that has been shown to be effective, at least at a local scale (O’Hanlon et al. 2018).

The introduction of *P. ramorum* was followed by the detection of other non-native *Phytophthora* species, including *Phytophthora kernoviae* Brasier in 2008 (not detected in Northern Ireland) and *P. lateralis* Tucker and Milbrath in 2011 (O’Hanlon et al. 2016a). Detected on *Larix* and *Nothofagus* in Ireland, *Phytophthora pseudosyringae* has also been found in the last decade in the course of DAFM official surveys. This pathogen is also damaging to *Nothofagus* species in the UK (Scanu et al. 2012). The pathogen *Phytophthora cinnamomi* is one of the ten most threatening oomycetes globally (Kamoun et al. 2014), causing significant disease in Mediterranean type climates (Burgess et al. 2017). This pathogen has caused minor issues to woody plants and trees on the island of Ireland, mainly in the plant nursery industry (Department of Agriculture for Northern Ireland 1969, 1975; Shafizadeh and Kavanagh 2005). *Phytophthora* disease of alder (caused by several different *Phytophthora* species) is causing many issues across Europe (Bjelke et al. 2016), and this
was confirmed in Ireland in 2001 (Clancy and Hamilton 2001), while evidence of the disease was noted as far back as 1995 (McCracken 1996). In 2019, alder disease caused by *Phytophthora plurivora* was recorded along the river Lagan in Belfast, Northern Ireland (O’Hanlon *et al.* 2019). It is likely that there are many *Phytophthora* species present but have not yet been recorded, as O’Hanlon *et al.* (2016b) suggested that based on the species richness in Britain, at least eleven more species of *Phytophthora* are potentially to be discovered on the island of Ireland.

More recently, the ash dieback fungal pathogen *Hymenoscyphus fraxineus* (T. Kowalski) Baral, Queloz and Hosoya has spread across Europe from Poland in the 1990s (Gross *et al.* 2014) finally being confirmed in Ireland and Northern Ireland in 2012 (EPPO 2020b; DAERA 2017). Notable attempts to eradicate the pathogen from the island of Ireland were made early in the invasion, with clear efforts at cooperation established via the All-Ireland Chalara control strategy (Anon 2013a). The pathogen causes dieback of European ash (*Fraxinus excelsior*) and is now recorded in every county in Northern Ireland and Ireland (DAERA 2017; Ryan 2018). The pathogen has the potential to cause major negative economic, environmental and social consequences on the island of Ireland. The economic consequences are likely to cost many millions of euro, with over 13,000ha of ash grant-aided by government in Ireland between 1992 and 2012 (McCracken *et al.* 2017). The negative environmental consequences of ash dieback are also major, with estimates of more than 2.9 million ash trees in Northern Irish hedgerows (Spaans *et al.* 2019) now under serious threat from by *H. fraxineus*. As well as the large economic losses incurred because of ash dieback in Britain (Hill *et al.* 2019), the disease also threatens biodiversity associated with ash trees, with over 1,000 species thought to be associated with ash trees in the UK (Mitchell *et al.* 2014). Ash dieback disease causes high levels of mortality in European ash in forests (Gross *et al.* 2014), though recent evidence suggests that survival of solitary trees and those isolated from other ash trees may be better than previously expected (Grosdidier *et al.* 2020).

Another recent non-native pest (though only locally important) on trees has been the outbreak of horse chestnut leaf miner *Cameraria ohridella* Deschka and Dimić on horse chestnut (*Aesculus hippocastanum* L.) in Dublin in 2013 (Moths Ireland 2020). Symptoms of the pest have now been reported from several counties along the east of Ireland and Northern Ireland. The damage due to *C. ohridella*, combined with other present threats to horse chestnut, namely bacterial canker of horse chestnut (caused by *Pseudomonas syringae aesculi*) and Guignardia leaf blotch (caused by the fungus *Guignardia aesculi*), mean that the health of horse chestnut is under increasing threat. Horse chestnut is a commonly planted tree in urban environments, with 684 present within the Belfast city area, of which 171 are in poor health (Belfast Trees 2020). The ash sawfly (*Tomostethus nigritus* [Fabricius]), which was first detected in Northern Ireland in 2016 (Jess *et al.* 2017), led to defoliation of hundreds of trees in 2017 in urban areas in south Belfast (Ian Rea unpublished data). Recent work has highlighted the threat to these and other urban trees from disease (biotic and abiotic), with a need to diversify urban tree species (Stevenson *et al.* 2020)

**PEST AND PATHOGEN INTERCEPTIONS AT BORDERS**

The two most recognised pathways for introduction of exotic plant pests are (i) wood packaging material (Eyre *et al.* 2018; Meurisse *et al.* 2019) and (ii) plants for planting (Liebhold *et al.* 2012), while pathogens are primarily understood to be introduced on plants
for planting. Although phytosanitary treatments are in place for both pathways, there are a number of examples where pests have been transported on commodities despite controls. Haack (2006) reviewed 25 new beetle (Coleoptera) pest records in the USA and found that most were associated with wood packaging material. Similarly, Brockerhoff et al. (2006) examined interception data from the USA and New Zealand and found that 82% of the most frequently intercepted pests have become established as invasive plant pests worldwide. Inward (2019) highlighted potential shortcomings in debarking of roundwood as an effective treatment for regulation of plant pests in the ambrosia beetles group, and concluded that appropriate heat treatment, fumigation or irradiation are more effective measures than debarking alone. Freedom from bark (not to be confused with debarking) is also used as a phytosanitary measure for controlling pests and pathogens, such as the bark beetle *I. typographus* and fungal pathogen *Cryphonectria parasitica*. For example, wood of conifers needs to be either bark-free, from a pest free area or kiln dried to below 20% moisture content before it can be imported into Ireland or the UK (EU 2019/2072) from other EU member states.

It is the remit of the NPPO of each country to survey for and apply controls for quarantine pests and pathogens. These pests and pathogens are usually identified using a risk-based approach, such as the Northern Irish Plant Health Risk Register (DAERA 2020) in Northern Ireland. In the EU, the importation of commodities that have threatening pests or pathogens present are reported to the country of export via the Europhyt reporting system (EUROPHYT 2016). Europhyt records information on consignments received by EU member states that violate any of the EU’s plant health requirements. Reports of pests and pathogens found in Northern Ireland are included in the overall UK reports. Based on the Europhyt data between the dates February 2006 and November 2016, inspections of imports into the UK and Ireland intercepted numerous pests and pathogens, including the following: *Anoplophora chinensis* (Forster) (in 2006, 2007, 2008, 2010), *Anoplophora glabripennis* (Motschulsky) (2016), *H. fraxineus* (2012), *Ips typographus* (L.) (2009), *Oemonia hirta* Fabricius (2010), *Opogona sacchari* (Bojer) (2010), *Monochamus alternatus* Hope (2013, 2015), *Phytophthora ramorum* (2006–2016), and *Thaumetopoea processionea* (L.) (2016)(EUROPHYT 2016). *Anoplophora chinensis* was also intercepted in Britain in 2005 (EPPO 2020b). There are potentially many more pests and pathogens going undetected, as a recent analysis by Eyre et al. (2018) indicated that the surveillance systems in place in most EU countries are not sufficient to detect all of the potential pests on wood packaging material. Brockerhoff et al. (2003) also highlight the threat of wood and wood packaging material for transferring pests, listing 1,468 records of interceptions of at least 98 plant pest beetles into New Zealand between 1952 and 2000. While it would be extremely difficult to inspect all wood packaging imported, in recent years an EU-wide monitoring programme has focussed on wood packaging associated with imports of high-risk commodities such as stone from China (EU Commission decision 2013/92/EU). Under the new EU plant health regulation, member states are required to implement a risk-based surveillance regime on wood packaging imports.

Ashe et al. (2002) published findings of beetles imported into Ireland on commodities from China, finding *M. alternatus* and *Cryptorhynchus rufescens* Roelofs. The former is very threatening due to its ability to vector the Pine wood nematode *Bursaphelenchus xylophilus* (Steiner and Buhrer) Nickle, currently causing a large epidemic in Portugal and Spain (Futai 2013). There is no evidence to indicate that *Monochamus* spp. are native to the island of
Ireland, though Kloet and Hincks (1945) judged *Monochamus sutor* to be at least native to parts of Europe. Interestingly, one adult of *M. sutor* was detected in a furniture shop in Northern Ireland in 2017, presumably emerging as an adult having pupated for several years inside a wooden piece of imported furniture (A.K. Murchie unpublished data). Further detections of arthropods pests present on imported wood and wood packaging into Ireland included *Dendroctonus rufipennis* Kirby, *Dryocoetes affaber* (Mannerheim), *Ips acuminatus* (Gyllenhal) and *Ips typographus* as part of the ‘Insects imported into Ireland’ series of articles (O’Connor and Nash 1979, 1982, 1983). There is no evidence that any of the latter insect pests have become established in Ireland or Northern Ireland. O’Connor et al. (1991) identified insect pests (specifically Scolytids) that had been found in Britain, but which were not present on the island of Ireland; these included *Dendroctonus micans*, *Ips amitinus* (Eichhoff), *Ips cembrae* and *Ips sexdentatus*. These pests are the subject of longstanding annual PZ surveys. Furthermore, phytosanitary checks and monitoring are carried out on imports of unprocessed conifer wood (a high risk for transporting bark beetles) from Scotland. These imports are only allowed if the wood has come from an officially designated area that has been surveyed by the NPPO and shown to be free from the pest *D. micans*. It is likely, however, that great spruce bark beetle, *D. micans*, is the most imminent insect pest threat to Northern Irish forestry since it is present in Dumfries and Galloway, approximately 70km from Northern Ireland, and is expanding its range in Scotland (Jeger et al. 2017b; Forest Commission Scotland 2019). To counter this, a contingency plan is currently being drawn up by DAERA. In addition to plant health biosecurity measures, the contingency plan also considers the release of the predatory beetle *Rhizofagus grandis* Gyllenhal, which has been used successfully to control *D. micans* in Great Britain (Fielding and Evans 1997; Jeger et al. 2017b).

To prevent the establishment of high-risk pests, early detection and eradication is vital. There have been two major eradication campaigns against insect pests in England in the last ten years: the first was the Asian longhorn beetle (*Anoplophora glabripennis*) in 2012, and the second *Ips typographus* in 2018. The eradication operation for the *A. glabripennis* was recently concluded in England (Anon 2019a), successfully eradicating the outbreak in 2019 (EPPO 2020b). Detailed research at the site has indicated that the beetle probably arrived at the site around 2000, and from there colonised the surrounding trees. In total, the cost of monitoring and eradication actions for *A. glabripennis* was estimated at £2 million (Straw et al. 2016). This pest has often been intercepted in the UK associated with *Acer* plants for planting (EPPO 2020b) and wood packaging material from China (EPPO 2020b). This pest was first found in Europe in 2001, after which it has since been detected in ten EU countries. Genetic testing of the European populations indicates that there were most likely several introductions of this pest into Europe, probably originally on wood and/or wood packaging material before moving within Europe by similar pathways (Javal et al. 2019). The related Citrus longhorn beetle *Anoplophora chinensis* has never been intercepted on the island of Ireland, but there have been several interceptions in England. This pest has also been discovered causing infestations in several countries in Europe, notably on 36 occasions in Italy (Hérard and Maspero 2019).

A population of the eight-toothed spruce bark beetle *Ips typographus*, a PZ pest, was discovered in Kent, England in November 2018. A demarcated area was set up and intensive
monitoring and eradication actions are ongoing (Forestry Commission 2019). This being the first established population of *I. typographus* in the British Isles, it represents an increased threat from this damaging pest to spruce forests on the island of Ireland and has prompted increased risk-based surveys and monitoring to bolster existing surveys for the beetle. Considered as the most damaging insect pest of spruce, *I. typographus* has a widespread distribution throughout continental Europe and northern Asia. The summers of 2018 and 2019 were hot and dry, which stressed trees and led to *I. typographus* outbreaks across much of the spruce-growing parts of Europe (Jonsson 2020); for example, the Czech Republic witnessed an increase in salvaged timber from bark beetle outbreaks from 5.3 million m$^3$ in 2017 to 18 million in 2018 (Hlásny *et al.* 2019). Although not conclusive, it is thought that the incursion into Kent was from windborne migratory beetle flight and may have occurred several years earlier, with beetle populations only becoming detectable following a second generation during the hot summer of 2018 (Forest Research, pers. comm.). For the island of Ireland, importation of timber and bark remain the most likely pathway for introduction of *I. typographus*. In February 2004, 9,000 m$^3$ of wood bark from Estonia were detained at Belfast Port following a routine examination for quarantine pests. Despite having the necessary documentation indicating evidence of fumigation by methyl bromide, living invertebrates (larval Diptera, Coleoptera, mites and rhabditid nematodes) were found, along with galleries typical of *I. typographus*. The consignment was reloaded onto the ship and fumigated at sea, at a cost exceeding €170,000. Subsequently, two live adult *I. typographus* were reared from incubated bark samples (S. Clawson, pers. comm.).

While wood and wood packaging material are known as the main vectors for insect pests (Humble 2010), plants for planting is the commodity most often associated with the transfer of non-native plant pathogens (Jones and Baker 2007; Liebhold *et al.* 2012). Migliorini *et al.* (2015) tested plants from two large nurseries in Italy and found that 70% of the asymptomatic plants contained a plant pathogenic *Phytophthora* species. The records from the island of Ireland for harmful pathogens being intercepted during border inspections are less frequent than those of arthropod pests, probably because pathogens often have cryptic life stages that make them difficult to detect. The pathogen *Gymnosporangium haraerum* was reported on Japanese bonsai juniper plants imported into Northern Ireland in 1974 (Department of Agriculture for Northern Ireland 1974), while the pathogen *Discula destructiva* (Fr.) Munk ex H. Kern was reported on dogwood (*Cornus* sp.) in Northern Ireland in 1995 (McCracken 1996). Apart from the already noted cases of *E. amylovora*, *P. ramorum* and *H. fraxineus* on imported plants for planting to the island of Ireland, the low level of reports of pathogens on imported consignments is most likely due to pathogens often having cryptic lifecycles (see Migliorini *et al.* 2015), and the difficulty in surveying for plant pathogenic microorganisms in general (Morales *et al.* 2019). Furthermore, the use of pesticides on plants for planting can often mask symptoms of disease caused by pathogens, leading to the pathogen not being detected during border surveillance (Brasier 2008). Tjosvold *et al.* (2008) found that fungicides reduced the symptoms of *P. ramorum* blight on rhododendron, but that the pathogen could still be isolated from the infected leaf material. They caution that the use of these fungicides would confound visual inspection attempts. New technologies, such as those based using high throughput sequencing offer the potential to identify the presence of even latent microbial pests in plants (Tedersoo *et al.* 2018), though
the application of these techniques for phytosanitary and biosecurity purposes is not straightforward (e.g. McTaggart et al. 2016; Holdaway et al. 2017).

The global trade in tree seed has recently been identified as a plant health risk (Cleary et al. 2019; Franic et al. 2019). The latter two references sampled seed of three conifer and one broadleaf tree genera and detected potential pests of the genus Megastigmus and pathogens from the genera, Diaporthe, Fusarium, Gibberella, Pestalotiopsis, Neonectria, and Diplodia. The hymenopteran genus Megastigmus is a known plant pest with potential to be spread by seed trade, with 11 of the 21 seed wasp species in the genus Megastigmus being introduced to Europe (Roques and Skrzypczyńska 2003). Seeds of trees are regulated under the same rules as all other plant material in the EU. At present, seeds of the trees in the genus Pinus and Pseudotsuga menziesii can be imported into and moved within the EU only if they have official certification to show that they are free of the pitch canker pathogen of pine Fusarium circinatum Nirenberg and O'Donnell. Franic et al. (2019) concluded that seeds of trees represented a large threat to plant health in the EU.

The regulation of plant health at the international level has been criticised by many plant health scientists as being unsuitable for preventing pest and pathogen movements in traded commodities (Brasier 2008; Liebhold et al. 2012; Santini et al. 2012; Eschen et al. 2015; Jung et al. 2016; Meurisse et al. 2019). Many of the issues with the legislation have been discussed already above, and include (i) a reliance on visual inspections on plants and plant products which can miss asymptomatic infections, (ii) limited resources in NPPOs meaning that only a proportion of commodities can be inspected, (iii) the use of fungicides which mask pathogen symptoms in plants for planting, (iv) pest list-based regulation that overlooks undescribed organisms and (v) variation in the implementation of phytosanitary procedures. Until these issues are addressed it is likely further increases in the numbers of non-native pests and pathogens of trees will increase.

PESTS AND PATHOGENS AND CLIMATE CHANGE

The island of Ireland is expected to have fewer frost days, more rain in winter, increased chance of drought in summer and increased average annual temperatures by up to 2°C by the mid-twenty-first century (Sweeney and Fealy 2002). These changes are likely to affect the amounts of damage caused by pests and pathogens in trees, through a combination of effects related to range shifts in pests and pathogens and their natural enemies, adapted physiological or behavioural responses in pests and pathogens and phenological changes in host (Zvereva and Kozlov 2006; Cornelissen 2011). Across Europe, Neumann et al. (2017) found that recent variations in climate have led to large scale tree mortality. Research has shown that recent outbreaks of bark beetles such as Ips typographus in continental Europe and defoliating insects could be linked to climate change (Heliovaara Peltonen 1999; Pureswaran et al. 2018). Similarly, outbreaks of the weevil Hylastes ater Paykull (Leahy et al. 2007) and green spruce aphid E. abietinum (Westgarth-Smith et al. 2007) may increase under warming conditions. This could be due to milder winter temperatures that can result in reduced arthropod mortality and decreased diapause, thus directly affecting arthropod abundance (Ramsfield et al. 2016). Indirectly, more frequent weather extremes (e.g. drought) could lead to compromised tree host defences and increased frequency of arthropod damage. Secondary pests such as E. abietinum are likely to become primary pests causing mortality of trees when the tree is suffering from drought conditions as is predicted for future summer months in Ireland with climate change (Sweeney and Fealy 2002).
The threat from pathogens of plants may also change under different climate scenarios, including bacterial (Wainhouse et al. 2016), oomycete (Jung et al. 2018) and fungal pathogens (La porta et al. 2008; Pautasso et al. 2012). Jung et al. (2018) suggest that disease in oaks (Quercus spp.) in Europe due to Phytophthora will increase under future climate scenarios. Several pathogens may become more of a threat to the forest health in Ireland under future climate scenarios, including the low temperature sensitive pathogens Phytophthora kernoviae and Phytophthora cinnamomi. The dataset should be useful in tracking the effects of climate change on damage caused by pests and pathogens. For example, the fungus Neonectria fuckeliana (C. Booth) Castl. and Rossman is currently associated with widespread damage to Sitka spruce forests in Northern Ireland (O’Hanlon and Fleming 2018). Whether this is a new or re-emerging disease is not clear, as records of other similar Nectria/Neonectria taxa (the genus has been through several taxonomic changes) causing frequent damage on conifers in Wicklow in 1984 (Forest and Wildlife Service 1985).

The tree species planted in forests on the island of Ireland in the coming years will need to be resilient against the pressures of future climate and pest and pathogen threats. Building resilience through greater species and structural diversity would seem to be a useful strategy (Ennos 2015). DAFM currently supports the grant-aided forest planting of over thirty species of conifers and broadleaves (DAFM 2016), yet from 2012 to 2018 Sitka spruce dominated the species mix being planted under DAFM grant-aided afforestation schemes and its proportion increased significantly (DAFM 2019b). This is likely linked with the removal of ash (Fraxinus) and larch (Larix) from the list of grant-aided species but increasing reliance on Sitka spruce should consider the biotic threats to that species (Cameron 2015; Tuffen and Grogan 2019). Tree suitability modelling in Ireland has shown that some conifers from the pacific northwest of America have potential to replace larch in future planned Sitka spruce forest mixtures (Walsh et al. 2017).

CONCLUSIONS

The forests of Ireland have generally suffered less damage from pests and pathogens than mainland European countries, but this trend is changing with increased damage occurring in recent years. Until quite recently pest and pathogen management in Irish forestry focused largely on control of H. abietis and Heterobasidion annosum. In the last decade however, the greatest risk to trees and forests on the island of Ireland is the introduction of non-native pests. Evidence indicates that eradication efforts against non-native tree pests globally are rarely successful unless the eradication is attempted soon after the pest has arrived (Pluess et al. 2012; Liebhold et al. 2016). The resilience of a forest to pest outbreaks is also important in protecting forest estates. Good silviculture has always been about planting the right trees in the right places but today foresters are faced with increasingly complex planting decisions due to the uncertainties surrounding climate change and threats from pests over the lifetime of a forest crop.

This dataset of pests of trees on the island of Ireland sets an important baseline for pest frequency; such datasets provide a valuable resource for future research and policy making in plant health (Shivas et al. 2006). As is the case with pest lists from other countries (Kenis 2005; Jones and Baker 2007; Smith et al. 2007; Martinez and Malaua, 2000 as cited in Smith et al. 2007), this list can be taken as a starting point for developing regular
assessments of the threat to tree and forest health on the island of Ireland. These regular assessments need to be underpinned by scientific capacity in specialisms such as mycology, entomology, plant pathology and in broader areas including plant health diagnostics, taxonomy and risk-based surveillance. An educational resource for equipping graduates with plant health training is needed in order to produce the plant health experts of the future (Anon 2019b). For effective protection of plant health on the island of Ireland, continued cross-border work in partnership with all stakeholders (government, industry, academia, NGOs and the public) is vital to safeguarding Ireland’s trees.

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REFERENCES

Adams, I.P., Fox, A., Boonham, N., Massart, S. and De Jonghe, K. 2018 The impact of high throughput sequencing on plant health diagnostics. *European Journal of Plant Pathology* **152**, 909–19.

Adams, J. and Pethybridge, G.H. 1910 A census catalogue of Irish fungi. *Proceedings of the Royal Irish Academy* **28**, 120–66.

Alcock, N.L. and Maxwell, I. 1925 Successional diseases on willow. *Transactions of the Royal Scottish Arboricultural Society* **39**, 34–7.

Alexander, K.N. 2007 Goat Moth *Cossus cossus* L. (Lepidoptera: Cossidae) in Co Galway. *The Irish Naturalists’ Journal* **28**, 420.

Anderson Stewart, C.R., Doilom, M. and Taylor, J.E. 2019 Analysis of fungal endophytes in Scottish Sitka spruce plantations shows extensive infections, novel host partners and gives insights into origins. *Forest Pathology* **49**(1), e12471.

Anon 1879 Scientific committee. *Journal of the Royal Horticultural Society* **5**, 119.

Anon 1884 *Transactions of Scottish Arboriculture* 253. As cited in Elwes and Henry 1909; *Trees of Great Britain and Ireland*. Vol 4. Edinburgh, Self-published.

Anon 1903 A Conifer disease. *Journal of the Board of Agriculture Ireland*.

Anon 1951 *FAO report on forestry mission to Ireland*. Dublin. The stationary office.

Anon 1956 *Record of agricultural research*. Belfast. Ministry of Agriculture.

Anon 1971 *Report of the Minister for lands on the forest and wildlife service*. Dublin. The Stationery Office.

Anon 1972 *Report of the Minister for lands on the forest and wildlife service*. Dublin. The
Anon 1975a *Report of the Minister for Lands in Forestry*. Dublin. The Stationery Office.

Anon 1975b *Report of the Minister for lands on the forest and wildlife service*. Dublin: The Stationery Office.

Anon 1976a *Report of the Minister for Lands in Forestry*. Dublin. The Stationery Office.

Anon 1976b *Report of the Minister for lands on the forest and wildlife service*. Dublin. The Stationery Office.

Anon 1981 *Annual report on research and development*. Department of Agriculture for Northern Ireland.

Anon 1986 *Forest Service Report*. Dublin. Stationery office.

Anon 1987a *Forest Service Report*. Dublin. Stationary office.

Anon 1987b *Report of the Minister for Energy on the forest and wildlife service 1986*. Dublin. Stationary Office.

Anon 1988 *Forest service report*. Dublin. Stationary office.

Anon 1990 *Annual report of the minister of Agriculture and Food*. Dublin. Stationary office.

Anon 1993 *Annual report of the Minister for Agriculture and Food*. Dublin. Stationary office.

Anon 1994 *Annual report of the Minister for Agriculture and Food*. Dublin. Stationary office.

Anon 1995 *Results of pest and pathogen surveys and monitoring*. DARD science service unpublished records.

Anon 1996a *Annual report of the Minister for Agriculture and Food*. Dublin. Stationary office.

Anon 1996b Results of pest and pathogen surveys and monitoring. DARD science service unpublished records.

Anon 1997 Results of pest and pathogen surveys and monitoring. DARD science service unpublished records.

Anon 1998a *Annual report of the Minister for Agriculture and Food*. Dublin. Stationary office.

Anon 1998b Results of pest and pathogen surveys and monitoring. DARD science service unpublished records.

Anon 1999a *Annual report of the Minister for Agriculture and Food*. Dublin. Stationary
Anon 1999b Results of pest and pathogen surveys and monitoring. DARD science service unpublished records.

Anon 2000a Annual report of the Minister for Agriculture and Food. Dublin. Stationary office.

Anon 2000b Results of pest and pathogen surveys and monitoring. DARD science service unpublished records.

Anon 2001 Results of pest and pathogen surveys and monitoring. DARD science service unpublished records.

Anon 2002 EU-forest health survey for Ireland. Department of Agriculture and Food, Ireland. Unpublished report.

Anon 2002 Results of pest and pathogen surveys and monitoring. DARD science service unpublished records.

Anon 2003 EU-forest health survey for Ireland. Department of Agriculture and Food, Ireland. Unpublished report.

Anon 2003 Results of pest and pathogen surveys and monitoring. DARD science service unpublished records.

Anon 2004a Annual report of the Minister for Agriculture and Food. Dublin. Stationary office.

Anon 2004b Results of pest and pathogen surveys and monitoring. DARD science service unpublished records.

Anon 2005a Annual report of the Minister for Agriculture and Food. https://www.agriculture.gov.ie/publications/2005 (26 March 2021).

Anon 2005b Results of pest and pathogen surveys and monitoring. DARD science service unpublished records.

Anon 2006a Annual report of the Minister for Agriculture and Food. https://www.agriculture.gov.ie/publications/2006 (26 March 2021).

Anon 2006b Results of pest and pathogen surveys and monitoring. DARD science service unpublished records.

Anon 2007 National forestry inventory of Ireland. https://www.agriculture.gov.ie/nfi/nfifirstcycle2006/nationalforestinventoryresultsdata2006 (26 March 2021).

Anon 2007a Annual report of the Minister for Agriculture and Food. https://www.agriculture.gov.ie/publications/2007 (26 March 2021).
Anon 2007b Results of pest and pathogen surveys and monitoring. DARD science service unpublished records.

Anon 2008a *Annual report of the Minister of Agriculture, Fisheries and Food.*
https://www.agriculture.gov.ie/publications/2008 (36 March 2021).

Anon 2008b Results of pest and pathogen surveys and monitoring. AFBI unpublished records.

Anon 2009a *Annual report of the Minister of Agriculture, Fisheries and Food.*
https://www.agriculture.gov.ie/publications/2008 (26 March 2021).

Anon 2009b Results of pest and pathogen surveys and monitoring. AFBI unpublished records.

Anon 2010a *Annual report of the Minister of Agriculture, Fisheries and Food.*
https://www.agriculture.gov.ie/publications/2008 (26 March 2021).

Anon 2010b Results of pest and pathogen surveys and monitoring. AFBI unpublished records.

Anon 2011a *Annual report of the Minister of Agriculture, Fisheries and Food.*
https://www.agriculture.gov.ie/publications/2008 (26 March 2021).

Anon 2011b Results of pest and pathogen surveys and monitoring. AFBI unpublished records.

Anon 2012a *Annual report of the Minister of Agriculture, Food and the Marine.*
https://www.agriculture.gov.ie/publications/2012

Anon 2012b Results of pest and pathogen surveys and monitoring. AFBI unpublished records.

Anon 2013 National forestry inventory of Ireland.
https://www.agriculture.gov.ie/nfi/nfisecondcycle2012/nationalforestinventoryresultsdata2012/ (26 March 2021)

Anon 2013a *All-Ireland Chalara control strategy.* https://www.daera-ni.gov.uk/sites/default/files/publications/dard/ireland-control-strategy_0.ppt (29 March 2021).

Anon 2013b *Annual report of the Minister of Agriculture, Food and the Marine.*
https://www.agriculture.gov.ie/publications/2013 (29 March 2021).

Anon 2013c Results of pest and pathogen surveys and monitoring. AFBI unpublished records.

Anon 2013d *Tree health and plant biosecurity expert taskforce.*
https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_d
Anon 2014a Annual report of the Minister of Agriculture, Food and the Marine. https://www.agriculture.gov.ie/publications/2014

Anon 2014b Protecting plant health: a plant biosecurity strategy for Great Britain. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/307355/pb14168-plant-health-strategy.pdf (29 March 2021).

Anon 2014c Results of pest and pathogen surveys and monitoring. AFBI unpublished records.

Anon 2015a Annual report of the Minister of Agriculture, Food and the Marine. https://www.agriculture.gov.ie/publications/2015 (29 March 2021).

Anon 2015b Results of pest and pathogen surveys and monitoring. AFBI unpublished records.

Anon 2016 Results of pest and pathogen surveys and monitoring. AFBI unpublished records.

Anon 2017 Results of pest and pathogen surveys and monitoring. AFBI unpublished records.

Anon 2018 National forestry inventory of Ireland. https://www.agriculture.gov.ie/nfi/nfithirdcycle2017/nationalforestinventoryresultsdata2017/ (29 March 2021).

Anon 2019a Asian Longhorn Beetle eradicated in the UK. https://www.gov.uk/government/news/asian-longhorn-beetle-eradicated-in-the-uk (29 March 2021).

Anon 2019b Growing the future. https://www.rsb.org.uk/images/UKPSF_Growing_the_future.pdf (29 March 2021).

Anon 2019c Large r eight-toothed European spruce bark beetle (Ips typographus). https://www.gov.uk/guidance/eight-toothed-european-spruce-bark-beetle-ips-typographus (29 March 2021).

Anon 2020a Biological records centre. www.brc.ac.uk (29 March 2021).

Anon 2020b The Butterflies and Moths of Northern Ireland. http://www.habitas.org.uk/moths/frameset.html (29 March 2021).

Ashe, P., Cahalane, G. and O'Connor, J.P. 2002 Chinese beetles (Coleoptera) imported into Ireland. The Irish Naturalists' Journal 27, 140–42.

Aukema et al. 2010 Historical accumulation of nonindigenous forest pests in the continental United States. BioScience 60, 886–97.
Battisti, A. and Faccoli, M. 2004 The directory of European experts. In Lieutier et al. (eds), *Bark and wood boring insects in living trees in Europe: a synthesis*, 569. Dordrecht, The Netherlands. Kluwer Academic Publishers.

Baynes, E.S. A. 1964 A revised catalogue of Irish Lepidoptera. Classey, Middlesex.

Beirne, B. 1938 New Irish microlepidoptera. *The Irish Naturalists' Journal*, 7(1) 12–15.

Bebber, D.P. 2015 Range-expanding pests and pathogens in a warming world. *Annual review of phytopathology* 53, 335–56.

Belfast Trees 2020 https://data.gov.uk/dataset/a334b6bc-a8cf-438c-be05–827fd265c672/belfast-street-trees (25 March 2021)

Bevan, D. 1987 Forest insects. A guide to insects feeding on trees in Britain. Forestry Commission, Handbook No. 1. HMSO, London, UK.

Billany, D.J. and Brown, R.M. 1977 The geographical distribution of *Gilpinia hercyniae* Hymenoptera: Diprionidae in the United Kingdom. *Forestry* 50(2), 155–60.

Bjelke et al. 2016 Dieback of riparian alder caused by the *Phytophthora alni* complex: projected consequences for stream ecosystems. *Freshwater Biology* 61(5), 565–79.

Blackith, R. and Blackith, R. 1986 *Pygostolus sticticus* Fab. (Hymenoptera: Braconidae) parasitic on *Otiorrhynchus singularis* (L.)(Coleoptera: Curculionidae) in an Irish pine forest. *The Irish Naturalists' Journal* 22, 69–71.

Bond, K.G.M. and O'Connor, J.P. 2012 Additions, deletions and corrections to an annotated checklist of the Irish butterflies and moths (Lepidoptera) with a concise checklist of Irish species and *Elachista biatomella* (Stainton, 1848) new to Ireland. *Bulletin of the Irish Biogeographical Society* 36, 60–120.

Bond, K.G.M., Nash R. and O’Connor J.P. 2006 *An annotated checklist of the Irish butterflies and moths (Lepidoptera)*. Dublin. Irish Biogeographical Society.

Boyd et al. 2013 The consequence of tree pests and diseases for ecosystem services. *Science* 342, 1235773.

Brasier, C.M. 2008 The biosecurity threat to the UK and global environment from international trade in plants. *Plant Pathology* 57, 792–808.

Brasier et al. 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, 853–59.

Brennan et al. 2010 *Phytophthora ramorum* and *Phytophthora kernoviae* in Ireland: the current situation. *Phytopathology* 100, S17.

Brennan et al. 2002 Characterization and differentiation of Irish *Erwinia amylovora*
isolates. *Journal of Phytopathology* **150**(8–9), 414–22.

Brixey, J.M., Moore, R. and Milner, A.D. 2006 Effect of entomopathogenic nematode (*Steinernema carpocapsae* Weiser) application technique on the efficacy and distribution of infection of the large pine weevil (*Hylobius abietis* L.) in stumps of Sitka spruce (*Picea sitchensis* Carr.) created at different times. *Forest Ecology and Management* **226**, 161–72.

Brockerhoff *et al*. 2006 Interception frequency of exotic bark and ambrosia beetles (Coleoptera: Scolytinae) and relationship with establishment in New Zealand and worldwide. *Canadian Journal of Forest Research* **36**, 289–98.

Brockerhoff, E.G., Knížek, M. and Bain, J. 2003 Checklist of indigenous and adventive bark and ambrosia beetles (Curculionidae: Scolytinae and Platypodinae) of New Zealand and interceptions of exotic species (1952–2000). *New Zealand Entomologist* **26**, 29–44.

Brooks, F.T. 1928 *Plant diseases*. Oxford University Press, Oxford.

Brown *et al*. 2019 Monitoring Oak health. In Quine *et al*. (eds) *Action Oak Knowledge Review*. [http://www.actionoak.org/downloads/1-knowledge-review-12–06–2019/file](http://www.actionoak.org/downloads/1-knowledge-review-12–06–2019/file)

Browne, F.G. 1968 *Pests and diseases of forest plantation trees: an annotated list of the principal species occurring in the British Commonwealth*. Oxford. Clarendon Press.

Bullock, E. 1914 Coleoptera from the south west of Ireland. *The Irish Naturalist* **23**(5), 105–12.

Bullock, E. 1930 Some new records of Coleoptera from Ireland. *Entomologist's Monthly Magazine* **66**, 140–41.

Burdon, E.R. 1908 The spruce-gall and Larch-blight diseases caused by *Chermes* and suggestions for their prevention. *Journal of Economic Biology* **2**, 1–13, 63–67.

Burgess *et al*. 2017 Current and projected global distribution of *Phytophthora cinnamomi*, one of the world's worst plant pathogens. *Global Change Biology* **23**(4), 1661–74.

Bystriakova, N. and Schuck, A. 1999 *Forest research capacities in 18 European countries*. Office for Official Publications of the European Community.

CABI 2020a *Distribution maps of plant diseases*. [https://www.cabi.org/dmpdCMI](https://www.cabi.org/dmpdCMI)

CABI 2020b Plantwise. [https://www.cabi.org/projects/plantwise/](https://www.cabi.org/projects/plantwise/) (29 March 2021).

Cairns, H. and Muskett, A.E. 1933 *Phytophthora megasperma* causing pink rot of the potato. *Nature* **131**, 277.

Cameron, A.D. 2015 Building resilience into Sitka spruce (*Picea sitchensis* (Bong.) Carr.) forests in Scotland in response to the threat of climate change. *Forests* **6**, 398–415.

Carpenter, G.H. 1902 Injurious insects observed in Ireland during the year 1901. *Economic Proceedings of the Royal Dublin Society* **1**, 132–60.
Carpenter, G.H. 1902 The animals of Ireland. In W.P. Coyne (ed.) *Ireland; industrial and agricultural*. Dublin. Browne and Nolan.

Carpenter, G.H. 1903 Injurious insects and other animals observed in Ireland during the year 1902. *Economic Proceedings of the Royal Dublin Society* 1, 195–222.

Carpenter, G.H. 1904 Injurious insects and other animals observed in Ireland during the year 1903. *Economic Proceedings of the Royal Dublin Society* 1, 249–66.

Carpenter, G.H. 1905 Injurious insects and other animals observed in Ireland during the year 1904. *Economic Proceedings of the Royal Dublin Society* 1, 281–305.

Carpenter, G.H. 1906 Injurious insects and other animals observed in Ireland during the year 1905. *Economic Proceedings of the Royal Dublin Society* 1, 321–44.

Carpenter, G.H. 1907 Injurious insects and other animals observed in Ireland during the year 1906. *Economic Proceedings of the Royal Dublin Society* 1, 421–52.

Carpenter, G.H. 1908 Injurious insects and other animals observed in Ireland during the year 1907. *Economic Proceedings of the Royal Dublin Society* 1, 559–88.

Carpenter, G.H. 1909 Injurious insects and other animals observed in Ireland during the year 1908. *Economic Proceedings of the Royal Dublin Society* 1, 589–611.

Carter, C. and Winter, T. 1998 *Christmas tree pests*. Dublin. Stationery Office.

Carter, C.I., Wood-Baker, C.S. and Polaszek, A. 1987 Species, host plants and distribution of aphids occurring in Ireland. *Irish Naturalists’ Journal* 22, 266–84.

Carter, D.J. 1984 *Pest Lepidoptera of Europe, with special reference to the British Isles*. Series Entomologica, Volume 31. The Netherlands. Springer.

Clancy, K.J. 1986 Plant disease. Research report of the faculty of Agriculture, University College Dublin.

Clancy, K.J. and Hamilton, A. 2001 *Phytophthora* of Alder. *SIPP Newsletter* 28, 25–6.

Clawson, S. and Anderson, R. 2006 The banded pine weevils *Pissodes pini* (Linnaeus, 1758) and *P. castaneus* (DeGeer, 1775) (Coleoptera: Curculionidae) established in Ireland. *Entomologists Gazette* 57, 269.

Clear, T. 1951 Douglas Fir in Co. Wicklow. *Irish Forestry*, 8–18.

Cleary et al. 2019 Cryptic risks to forest biosecurity associated with the global movement of commercial seed. *Forests* 10, 459.

Coillte 1996b *Coillte annual report*. Dublin.

Coillte 1997a *Coillte annual report*. Dublin.
Copeland, R. and Dowley, L. 2010 *SIPP Newsletter* **31**.

Cornelissen, T. 2011 Climate change and its effects on terrestrial insects and herbivory patterns. *Neotropical Entomology* **40**(2), 155–63.

Cotton, A.D. 1917 The occurrence of oak mildew on beech in Britain. *Transactions of the British Mycological Society* **6**, 198–200.

Cornelissen, T. 2011 Climate change and its effects on terrestrial insects and herbivory patterns. *Neotropical Entomology* **40**, 155–63.

Cross, J.R. 1998 An outline and map of the potential natural vegetation of Ireland. *Applied Vegetation Science* **1**, 241–52.

Cross, J.R. 2006 The potential natural vegetation of Ireland. *Biology and Environment: Proceedings of the Royal Irish Academy* **106B**(2), 65–116.

Crous *et al.* 2016 Global food and fibre security threatened by current inefficiencies in fungal identification. *Philosophical Transactions of the Royal Society B* **371**: 20160024. [http://dx.doi.org/10.1098/rstb.2016.0024](http://dx.doi.org/10.1098/rstb.2016.0024)

**DAERA** 2016 A proposal to remove Protected Zone Status in Northern Ireland for Fireblight (*Erwinia amylovora*) and implement buffer zone arrangements [https://www.daera-ni.gov.uk/consultations/proposal-remove-protected-zone-status-northern-ireland-fireblight-erwinia-amylovora-and-implement](https://www.daera-ni.gov.uk/consultations/proposal-remove-protected-zone-status-northern-ireland-fireblight-erwinia-amylovora-and-implement) (27 October 2018)

**DAERA** 2017 Ash dieback/Chalara dieback of ash. [https://www.daera-ni.gov.uk/articles/chalara-dieback-ash](https://www.daera-ni.gov.uk/articles/chalara-dieback-ash) (26 March 2021).

**DAERA** 2020 Northern Irish Plant Health Risk Register. Online: [https://www.daera-ni.gov.uk/topics/plant-and-tree-health/northern-ireland-plant-health-risk-register](https://www.daera-ni.gov.uk/topics/plant-and-tree-health/northern-ireland-plant-health-risk-register) (26 March 2021).

**DAERA** 2018 Woodland register. [https://www.daera-ni.gov.uk/sites/default/files/publications/daera/Woodland%20register%20categorised%20by%20Forestry%20Planning%20Area.xlsx](https://www.daera-ni.gov.uk/sites/default/files/publications/daera/Woodland%20register%20categorised%20by%20Forestry%20Planning%20Area.xlsx) (26 March 2021).

**DAFM** 2014 *Forests, products and people Ireland’s forest policy – a renewed vision*.

**DAFM** 2016 Accepted tree species and provenances. [https://www.agriculture.gov.ie/media/migration/forestry/grantandpremiumschemes/schemecirculars/2016/Cir52016040416.pdf](https://www.agriculture.gov.ie/media/migration/forestry/grantandpremiumschemes/schemecirculars/2016/Cir52016040416.pdf)

**DAFM** 2019a Plant Health and Biosecurity Strategy 2020–2025. [https://www.agriculture.gov.ie/media/migration/farmingsectors/planthealthandtrade/dontriskit/planthealthbio-securitystrategy/DAFMPlantHealthandBiosecurityStrategy070220.pdf](https://www.agriculture.gov.ie/media/migration/farmingsectors/planthealthandtrade/dontriskit/planthealthbio-securitystrategy/DAFMPlantHealthandBiosecurityStrategy070220.pdf)

**DAFM** 2019b *Forest statistics Ireland 2019*.
Dahlberg, A., Genney, D.R. and Heilmann-Clausen, J. 2010 Developing a comprehensive strategy for fungal conservation in Europe: current status and future needs. *Fungal Ecology* 3(2), 50–64.

Day, K.R. and Leather, S.R. 1997 Threats to forestry by insect pests in Europe. In Allan D. Watt, Nigel E. Stork and Mark D. Hunter (eds) *Forests and insects*, 177–205. London. Chapman and Hall.

Day, K.R. and Watt, A.D. 1989 Population studies of the beech leaf mining weevil (*Rhynchaenus fagi*) in Ireland and Scotland. *Ecological Entomology* 14(1), 23–30.

de Brit, G. 1967 Forest protection. In Anon (ed) *Forest Research Review 1957–1964*. Dublin. Stationary Office.

de Brit, G. 1972 Forest protection. In Anon (ed) *Forest Research Review 1964–1970*. Dublin. Stationary Office

de Brit, G., and MCAree, D. 1977 Pests and diseases of Sitka spruce. *Irish Forestry* 34 22–30.

De Courcy Williams, M. 1986 Odinia bolentina (Zetterstedt) (Diptera: Odiniidae) New to Ireland. *The Irish Naturalists' Journal* 22(3), 117–18.

DEFRA 2020 Pest and disease factsheet. [https://planthealthportal.defra.gov.uk/pests-and-diseases/pest-and-disease-factsheets/](https://planthealthportal.defra.gov.uk/pests-and-diseases/pest-and-disease-factsheets/) (26 March 2021)

Denman *et al.* 2012 *Brenneria goodwinii* sp. nov., associated with acute oak decline in the UK. *International Journal of Systematic and Evolutionary Microbiology* 62, 2451.

Denman *et al.* 2016 Isolation studies reveal a shift in the cultivable microbiome of oak affected with Acute Oak Decline. *Systematic and Applied Microbiology* 39, 484–90.

Department of Agriculture 1963 *Annual report on research, development and technical work of the Department of Agriculture for Northern Ireland*. Belfast.

Department of Agriculture 1964 *Annual report on research, development and technical work of the Department of Agriculture for Northern Ireland*. Belfast.

Department of Agriculture 1965 *Annual report on research, development and technical work of the Department of Agriculture for Northern Ireland*. Belfast.

Department of Agriculture 1966 *Annual report on research, development and technical work of the Department of Agriculture for Northern Ireland*. Belfast.

Department of Agriculture 1967 *Annual report on research, development and technical work of the Department of Agriculture for Northern Ireland*. Belfast.

Department of Agriculture 1968 *Annual report on research, development and technical work of the Department of Agriculture for Northern Ireland*. Belfast.
Department of Agriculture  1969  *Annual report on research, development and technical work of the Department of Agriculture for Northern Ireland*. Belfast.

Department of Agriculture and Food, Ireland  2000  EU-forest health survey for Ireland. Unpublished report.

Department of Agriculture and Food, Ireland  2001  EU-forest health survey for Ireland. Unpublished report.

Department of Agriculture for Northern Ireland  1970  *Annual report on research and development*.

Department of Agriculture for Northern Ireland  1971  *Annual report on research and development*.

Department of Agriculture for Northern Ireland  1972  *Annual report on research and development*.

Department of Agriculture for Northern Ireland  1973  *Annual report on research and development*.

Department of Agriculture for Northern Ireland  1974  *Annual report on research and development*.

Department of Agriculture for Northern Ireland  1975  *Annual report on research and development*.

Department of Agriculture for Northern Ireland  1976  *Annual report on research and development*.

Department of Agriculture for Northern Ireland  1977  *Annual report on research and development*.

Department of Agriculture for Northern Ireland  1978  *Annual report on research and development*.

Department of Agriculture for Northern Ireland  1979  *Annual report on research and development*.

Department of Agriculture for Northern Ireland  1980  *Annual report on research and development*.

Department of Agriculture for Northern Ireland  1982  *Northern Ireland Forest Service annual report*. Belfast.

Department of Agriculture for Northern Ireland  1982  *Annual report on research and development*.

Department of Agriculture for Northern Ireland  1983  *Annual report on research and development*. 
Department of Agriculture for Northern Ireland 1983 *Northern Ireland Forest Service annual report*. Belfast.

Department of Agriculture for Northern Ireland 1984 *Annual report on research and development.*

Department of Agriculture for Northern Ireland 1985 *Annual report on research and development.*

Department of Agriculture for Northern Ireland 1986 *Annual report on research and development.*

Department of Agriculture for Northern Ireland 1987 *Annual report on research and development.*

Department of Agriculture for Northern Ireland 1992 *Northern Ireland Forest Service annual report*. Belfast.

Desprez-Loustau *et al*. 2010 Species diversity and drivers of spread of alien fungi (sensu lato) in Europe with a particular focus on France. *Biological Invasions* **12**(1), 157.

Desprez-Loustau *et al*. 2007 Simulating the effects of a climate-change scenario on the geographical range and activity of forest-pathogenic fungi. *Canadian Journal of Plant Pathology* **29**(2), 101–20.

Dillon *et al*. 2007 Optimizing application of entomopathogenic nematodes to manage large pine weevil, *Hylobius abietis* L. (Coleoptera: Curculionidae) populations developing in pine stumps, *Pinus sylvestris*. *Biological Control* **40**, 253–63.

Dillon *et al*. 2008 Establishment, persistence, and introgression of entomopathogenic nematodes in a forest ecosystem. *Ecological Applications* **18**, 735–47.

Dillon *et al*. 2006 Suppression of the large pine weevil *Hylobius abietis* (L.) (Coleoptera: Curculionidae) in pine stumps by entomopathogenic nematodes with different foraging strategies. *Biological Control* **38**, 217–26.

Doncaster, J.P. 1961 *Francis Walker's aphids*, 11–13. London. British Museum (Natural History).

Dowson, W.J. 1957 *Plant diseases due to bacteria*. Cambridge. Cambridge University Press.

Drenkhan *et al*. 2016 Global geographic distribution and host range of Dothistroma species: a comprehensive review. *Forest Pathology* **46**, 408–42.

E.C. 2012 Proposal for a revised directive of the European Parliament and of the Council on Priority Substances in the field of water quality. MEMO 12/59.

EFSA Panel on Plant Health (PLH) 2013 Scientific opinion on the risk to plant health posed
by *Dothistroma septosporum* (Dorog.) M. Morelet (*Mycosphaerella pini* E. Rostrup, syn. *Scirrhia pini*) and *Dothistroma pini* Hulbary to the EU territory with the identification and evaluation of risk reduction options. *EFSA Journal* **11**(1), 3026.

Elliot, C. 1951 *Manual of bacterial plant pathogens*. New York. Stechert-Hafner Inc.

Elwes, H.J. and Henry, A. 1906 *Trees of Great Britain and Ireland, volume 1*. Edinburgh. Private printing.

Elwes, H.J. and Henry, A. 1909 *Trees of Great Britain and Ireland, volume 4*. Edinburgh. Private printing.

Ennos, R.A. 2015 Resilience of forests to pathogens: an evolutionary ecology perspective. *Forestry* **88**, 41–52.

EPPO 2004 Plant health endangered - state of emergency. [https://www.eppo.int/RESOURCES/position_papers/council_madeira_declaration (27 October 2018)](https://www.eppo.int/RESOURCES/position_papers/council_madeira_declaration).

EPPO 2009 PM 7/92(1) *Gremmeniella abietina*. *EPPO Bulletin* **39**, 310–17.

EPPO 2013 Pest risk analysis for *Agrilus planipennis*. [https://gd.eppo.int/download/doc/292_pra_full_AGRLPL.pdf](https://gd.eppo.int/download/doc/292_pra_full_AGRLPL.pdf).

EPPO 2020a Global database. [https://gd.eppo.int/](https://gd.eppo.int/).

EPPO 2020b EPPO reporting service. [https://gd.eppo.int/reporting/](https://gd.eppo.int/reporting/).

Eschen et al. 2015 International variation in phytosanitary legislation and regulations governing importation of plants for planting. *Environmental Science and Policy* **51**, 228–37.

EU 2017 Harmful organisms in the European Union member states' reporting 2015–2016. [https://ec.europa.eu/food/sites/food/files/plant/docs/phb_ho_annual_report_2015–6_en.pdf](https://ec.europa.eu/food/sites/food/files/plant/docs/phb_ho_annual_report_2015–6_en.pdf).

EU 2018 Emergency control measures by species: *Xylella fastidiosa*. [https://ec.europa.eu/food/plant/plant_health_biosecurity/legislation/emergency_measures/xylella-fastidiosa_en](https://ec.europa.eu/food/plant/plant_health_biosecurity/legislation/emergency_measures/xylella-fastidiosa_en).

EUROPHYT 2016 Interception data. EU Unpublished data.

Eyre et al. 2013 Insect pests of trees arriving and spreading in Europe. *Outlooks on Pest Management* **24**, 176–80.

Eyre et al. 2018 Variation in inspection efficacy by member states of wood packaging material entering the European Union. *Journal of economic entomology* **111**(2), 707–15.

Fanning, P.D. and Baars, J.R. 2014 Biology of the Eucalyptus leaf beetle *Paropsisterna selmani* (Chrysomelidae: Paropsini): a new pest of Eucalyptus species (Myrtaceae) in
Ireland. *Agricultural and Forest Entomology* **16**(1), 45–53.

FAO 2007 International standard for phytosanitary management 2.  
https://www.ippc.int/static/media/files/publication/en/2019/05/ISPM_02_2007_En_Framework_PRA_2019–04–30_PostCPM14_InkAm.pdf. (29 March 2021).

FAO 2017 International standard for phytosanitary management 8.  
https://www.ippc.int/static/media/files/publication/en/2017/06/ISPM_08_1998_En_2017–05–23_PostCPM12_InkAm.pdf (29 March 2021).

FAO 2018 The state of the world’s forests 2018 - Forest pathways to sustainable development. Rome.

FAO 2015 Global forest resources assessment 2015. www.fao.org (29 March 2021).

FAO 2020 Adopted standards- ISPMs. https://www.ippc.int/en/core-activities/standards-setting/ispms/ (29 March 2021).

Fennessy, J. 2012 Common alder (*Alnus glutinosa*) as a forest tree in Ireland.  
http://www.coford.ie/media/coford/content/publications/projectreports/cofordconnects/Alder-reprod.pdf (29 March 2021).

Fielding, N.J. and Evans, H.F. 1997 Biological control of *Dendroctonus micans* (Scolytidae) in Great Britain. *Biocontrol News and Information* **18**, 51N–60N.

Fischer, E. 1902 Silver fir witch’s broom. *Journal of the Royal Horticultural Society* **27**, 272.

Fitzpatrick, H.M. 1965 *The forests of Ireland*. The Society of Irish Foresters. Bray. The Record Press Ltd.

Foley, S. and McCormack, S. 2013 *Leptoglossus occidentalis* Heidemann (Hemiptera, Coreidae) new to Ireland. *The Irish Naturalists' Journal* **33**(1), 66–7.

Forbes, A.C. 1910 The economic importance of Scolytidae in Irish forestry. *The Irish Naturalist* **19**, 89–91.

Forestry Commission 1920 Survey of forest insect conditions in the British Isles.  
https://www.forestreresearch.gov.uk/documents/6464/FCBU002.pdf (25 March 2021).

Forestry Commission 1953 Annual report.  
file:///C:/Users/2339608/Downloads/FCAR_1952%20(1).pdf

Forestry Commission 2019 *Larger eight-toothed European spruce bark beetle (Ips typographus)*.  
https://www.gov.uk/guidance/eight-toothed-european-spruce-bark-beetle-ips-typographus (29 March 2021).

Forest Service 1976 *Annual report, Forest Service DARD*. Belfast.

Forest Service 1979 *Annual report, Forest Service DARD*. Belfast.
Forest Service 1983 Annual report, Forest Service DARD, Belfast.

Forest Service NI 1990 As cited in Thompson, R. and Nelson, B. 2006. The butterflies and moths of Northern Ireland. Newtownards. Blackstaff Press.

Forest and Wildlife Service 1938 Report of the Minister for Lands in Forestry. Dublin. The Stationery Office.

Forest and Wildlife Service 1943 Report of the Minister for Lands in Forestry. Dublin. The Stationery Office.

Forest and Wildlife Service 1950 Report of the Minister for Lands in Forestry. Dublin. The Stationery Office.

Forest and Wildlife Service 1953 Report of the Minister for Lands in Forestry. Dublin. The Stationery Office.

Forest and Wildlife Service 1957 Report of the Minister for Lands in Forestry. Dublin. The Stationery Office.

Forest and Wildlife Service 1958 Report of the Minister for Lands in Forestry. Dublin. The Stationery Office.

Forest and Wildlife Service 1959 Report of the Minister for Lands in Forestry. Dublin. The Stationery Office.

Forest and Wildlife Service 1960 Report of the Minister for Lands in Forestry. Dublin. The Stationery Office.

Forest and Wildlife Service 1961 Report of the Minister for Lands in Forestry. Dublin. The Stationery Office.

Forest and Wildlife Service 1962 Report of the Minister for Lands in Forestry. Dublin. The Stationery Office.

Forest and Wildlife Service 1963 Report of the Minister for Lands in Forestry. Dublin. The Stationery Office.

Forest and Wildlife Service 1964 Report of the Minister for Lands in Forestry. Dublin. The Stationery Office.

Forest and Wildlife Service 1966 Report of the Minister for Lands in Forestry. Dublin. The Stationery Office.

Forest and Wildlife Service 1967 Report of the Minister for Lands in Forestry. Dublin. The Stationery Office.

Forest and Wildlife Service 1969 Report of the Minister for Lands in Forestry. Dublin. The Stationery Office.
Forest and Wildlife Service  1970  *Forest and Wildlife Service research report*. Dublin.

Forest and Wildlife Service  1970  *Report of the Minister for Lands in Forestry*. Dublin. The Stationery Office.

Forest and Wildlife Service  1971  *Forest and Wildlife Service research report*. Dublin.

Forest and Wildlife Service  1971  *Report of the Minister for Lands in Forestry*. Dublin. The Stationery Office.

Forest and Wildlife Service  1972  *Report of the Minister for Lands in Forestry*. Dublin. The Stationery Office.

Forest and Wildlife Service  1973  *Forest and Wildlife Service research report*. Dublin.

Forest and Wildlife Service  1975  *Forest and Wildlife Service research report*. Dublin.

Forest and Wildlife Service  1976  *Forest and Wildlife Service research report*. Dublin.

Forest and Wildlife Service  1977  *Forest and Wildlife Service research report*. Dublin.

Forest and Wildlife Service  1978  *Forest and Wildlife Service research report*. Dublin.

Forest and Wildlife Service  1979  *Forest and Wildlife Service research report*. Dublin.

Forest and Wildlife Service  1980  *Forest and Wildlife Service research report*. Dublin.

Forest and Wildlife Service  1981  *Forest and Wildlife Service research report*. Dublin.

Forest and Wildlife Service  1982  *Forest and Wildlife Service research report*. Dublin.

Forest and Wildlife Service  1983  *Forest and Wildlife Service research report*. Dublin.

Forest and Wildlife Service  1984  *Forest and Wildlife Service research report*. Dublin.

Forest and Wildlife Service  1985  *Forest and Wildlife Service research report*. Dublin.

Franić et al.  2019  Are traded forest tree seeds a potential source of non-native pests? *Ecological Applications* **29**(7), e01971.

FRDBI (2020) The fungal records database of Britain and Ireland. [http://www.frdbi.info/](http://www.frdbi.info/) (29 March 2021).

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), 3167–81.

Futai, K.  2013  Pine wood nematode, *Bursaphelenchus xylophilus*. *Annual Review of Phytopathology* **51**, 61–83.

Gillanders, A.T.  1908  *Forest entomology*. London. W. Blackwood and Sons.

Good, J.A. and Hume, H.  1991  *Silvanus bidentatus* (F.)(Coleoptera: Silvanidae) imported
into Ireland in bark of timber pallets. *The Irish Naturalists' Journal* 23(11), 463–4.

Good, J.A. and McAree, D. 1991 *Chlorophorus fainanensis* Pic (Coleoptera: Cerambycidae), a wood-boring beetle imported in the wood of a pepper pot. *The Irish Naturalists' Journal* 23(10), 423.

Graham, M.W.R. 1948 *Harpiphorus lepidus* Klug (Hym., Tenthredinidae) in Ireland. *Entomologist' monthly Magazine* 84, 264

Green *et al.* 2013 The destructive invasive pathogen *Phytophthora lateralis* found on *Chamaecyparis lawsoniana* across the UK. *Forest Pathology* 43(1), 19–28.

Grégoire, J. and Evans, H. 2004 Damage and control of BAWBILT organisms, an overview. 19–37. *Bark and wood boring insects in living trees in Europe, a synthesis*. Dordercht, The Netherlands. Kluwer Academic Publishers.

Grosdidier *et al.*, 2020 Landscape epidemiology of ash dieback. *Journal of Ecology*. https://doi.org/10.1111/1365-2745.13383.

Gross *et al.* 2014 *Hymenoscyphus pseudoalbidus*, the causal agent of European ash dieback. *Molecular Plant Pathology* 15(1), 5–21.

Grove, W.B. 1937 *British stem- and leaf-fungi (Coelomycetes), volume 2*. Cambridge. Cambridge University Press.

Haack, R.A. 2006 Exotic bark-and wood-boring Coleoptera in the United States: recent establishments and interceptions. *Canadian Journal of Forest Research* 36(2), 269–88.

Hahn, G.G. 1957 A new species of Phacidiella causing the so-called Phomopsis disease of conifers. *Mycologia* 49(2), 226–39.

Halbert, J.N. 1898 Beetles collected at Mote Park, Mount Talbot, and Clonbrock. *The Irish Naturalist* 7(4), 90–5.

Halbert, J.N. 1922 *Magdalis carbonaria* and other insects at Powerscourt. *The Irish Naturalist* 31(1), 8–10.

Haliday, A.H. 1833 Catalogue of Diptera occurring about Holywood in Downshire. *Entomolgists' Monthly Magazine* 1, 147–80.

D’Arcy-Burt, S. and Chandler, P.J. 1987 Irish Bibionidae and Scatopsidae (Diptera: Nematocera). *The Irish Naturalists' Journal* 22(6), 224–31.

Hansen, E.M. and Goheen, E.M. 2000 *Phellinus weirii* and other native root pathogens as determinants of forest structure and process in Western North America. *Annual Review of Phytopathology* 38, 515–39.

Heliovaara, K. and Peltonen, M. 1999 Bark beetles in a changing environment. *Ecological Bulletins* 47, 48–53.
Henricot, B., Sierra, A.P. and Prior, C. 2000 A new blight disease on Buxus in the UK caused by the fungus Cylindrocladium. Plant Pathology 49(6), 805.

Hérard, F. and Maspero, M. 2019 History of discoveries and management of the citrus longhorned beetle, *Anoplophora chinensis*, in Europe. Journal of pest science 92(1), 117–30.

Herms, D.A. and McCullough, D.G. 2014 Emerald ash borer invasion of North America: history, biology, ecology, impacts, and management. Annual review of entomology 59, 13–30.

Hill *et al.* 2019 The £15 billion cost of ash dieback in Britain. Current Biology 29(9), R315–R316.

Hlášny *et al.* 2019 *Living with bark beetles: impacts, outlook and management options.* European Forest Institute.

Holdaway *et al.* 2017 Using DNA metabarcoding to assess New Zealand’s terrestrial biodiversity. New Zealand Journal of Ecology 41(2), 251–62.

Horgan *et al.* 2003 *A guide to forest tree species selection and silviculture in Ireland.* Dublin. COFORD.

Humble, L. 2010 Pest risk analysis and invasion pathways-insects and wood packing revisited: What have we learned. New Zealand Journal of Forestry Science 40(Suppl).

Hume, H. and Conway, T. 1993 Recent introductions of alien pests and disease into Ireland. In J. Kavanagh, and P. Brennan (eds) *Plant health and 1992*. Dublin. Royal Irish Academy.

Inward, D.J.G. 2019 Three new species of ambrosia beetles established in Great Britain illustrate unresolved risks from imported wood. Journal of Pest Science 93, 117–26.

Inward, D.J.G., Wainhouse, D. and Peace, A. 2012 The effect of temperature on the development and life cycle regulation of the pine weevil *Hylobius abietis* and the potential impacts of climate change. Agricultural and Forest Entomology 14, 348–57.

Jactel *et al.* 2017 Tree diversity drives forest stand resistance to natural disturbances. Current Forestry Reports 3, 223–43. DOI 10.1007/s40725–017–0064–1

Jactel, H., Moreira, X. and Castagneryol, B. 2020 Tree diversity and forest resistance to insect pests: patterns, mechanisms and prospects. Annual Review of Entomology 66, 277–96.

Jactel, H., Brockerhoff, E. 2007 Tree diversity reduces herbivory by forest insects. Ecology Letters 10, 835–48.

Janson, O.E. 1924 Coleoptera at Lough Neagh (Co. Antrim) and Newcastle (Co. Down). The Irish Naturalist 33(7), 69–72.
Javal et al. 2019 Complex invasion history of the Asian long-horned beetle: fifteen years after first detection in Europe. *Journal of Pest Science* **92**(1), 173–87.

Jeger et al. 2017a Pest categorisation of Gremmeniella abietina. *EFSA Journal* **15**(11).

Jeger et al. 2017b Pest categorisation of Ips typographus. *EFSA Journal* **15**(7).

Jeger, M.J. and Pautasso, M. 2008 Plant disease and global change—the importance of long-term data sets. *New Phytologist* **177**(1), 8–11.

Jess, et al. 2014 European Union policy on pesticides: implications for agriculture in Ireland. *Pest Management Science* **70**(11), 1646–54.

Jess et al. 2017 First observation of Tomostethus nigritus (Fabricius) (Hymenoptera: Tenthredinidae) on urban ash trees in Ireland. *Irish Naturalists' Journal* **35**, 134–36.

Johnson, W.F. 1922 Insects at Carlingford, Co. Louth. *The Irish Naturalist* **31**(2), 13–17. www.jstor.org/stable/25525118 (29 March 2021).

Johnson, W.F., and Halbert, J.N. 1902 A list of the beetles of Ireland. *Proceedings of the Royal Irish Academy* **6**, 535–827.

Johnson, W.F. 1893 Coleoptera at Ardara, Co. Donegal. *The Irish Naturalist* **2**(2), 53–5.

Johnson, W.F. 1895 Report on insects collected at Coolmore, Co. Donegal, for the Royal Irish Academy Flora and Fauna Committee, July, 1894. *The Irish Naturalist* **4**(4), 95–9.

Jones, D.R. and Baker, R.H.A. 2007 Introductions of non-native plant pathogens into Great Britain, 1970–2004. *Plant Pathology* **56**(5), 891–910.

Jonsson P. 2020 The bark-beetle invades Europe. https://www.forestry.com/editorial/bark-beetle-invades-europe/ (28 April 2020).

Joyce, P.M. and O'Carroll, N. 2002 *Sitka spruce in Ireland*. National Council for Forest Research and Development (COFORD).

Jung et al. 2016 Widespread Phytophthora infestations in European nurseries put forest, semi-natural and horticultural ecosystems at high risk of Phytophthora diseases. *Forest Pathology* **46**, 134–63.

Jung et al. 2018 Canker and decline diseases caused by soil-and airborne Phytophthora species in forests and woodlands. *Persoonia: Molecular Phylogeny and Evolution of Fungi* **40**, 182.

Kamoun et al. 2015 The Top 10 oomycete pathogens in molecular plant pathology. *Molecular plant pathology* **16**(4), 413–34.

Kapranas et al. 2017 Efficacy of entomopathogenic nematodes for control of large pine weevil, Hylobius abietis: effects of soil type and pest density and spatial distribution. *Journal of Pest Science* **90**, 495–505.
Kavanagh, J. 1993  A strategy for improving plant health. In J. Kavanagh and P. Brennan *Plant health and 1992*. Dublin. Royal Irish Academy.

Kavanagh, J. and Brennan, P. 1993 *Plant health and 1992*. Dublin. Royal Irish Academy.

Kavanagh, J.A., O'Malley, M. and Simmonds, A. 1969 Some observations on the rotting of apple fruits by *Phytophthora syringae* Kleb. *Irish Journal of Agricultural Research* 8(3), 439–41.

Kavanagh, T. and Rath, N. 1982 Influence of fungicide applications for Botrytis control in strawberries on the incidence of leather rot (*Phytophthora cactorum*) and on the control of lesions on petioles and flower stalks. *Irish Journal of Agricultural Research* 21(1), 95–9.

Keane, M. 1986 Lawson cypress in danger? *Irish Forestry* 43, 144.

Keane et al. 1989 Forest health surveys in Ireland: 1987 and 1988 results. *Irish Forestry* 46, 59–62.

Kenis, M. 2005 Insects – Insecta. In R. Wittenberg (ed.) *An inventory of alien species and their threat to biodiversity and economy in Switzerland*, report to the Swiss Agency for Environment, Forests and Landscape, 131–46. Switzerland. CABI Bioscience Switzerland Centre.

Kenis et al. 2007 How can alien species inventories and interception data help us prevent insect invasions? *Bulletin of entomological research* 97(5), 489–502.

Kloet, G.S. and Hincks, W.D. 1945 A check list of British insects. London. Royal Entomological Society.

Kowalski, T. 2006 Chalara fraxinea sp. nov. associated with dieback of ash (*Fraxinus excelsior*) in Poland. *Forest Pathology* 36(4), 264–70.

La Porta et al. 2008 Forest pathogens with higher damage potential due to climate change in Europe. *Canadian Journal of Plant Pathology* 30(2), 177–95.

Laing, F. 1922 Rhinocola eucalypti, Mask., in England. *Entomologist's Monthly Magazine*, 58(697).

Leahy, M.J.A., Oliver, T.H. and Leather, S.R. 2007 Feeding behaviour of the black pine beetle, *Hylastes ater* (Coleoptera: Scolytidae) *Agricultural and Forest Entomology* 9, 115–24.

Leather, S.R., Day, K.R. and Salisbury, A.N.J. 1999 The biology and ecology of the large pine weevil, *Hylobius abietis* (Coleoptera: Curculionidae): a problem of dispersal? *Bulletin of Entomological Research* 89, 3–16.

Lee, U. 1988 Forest pathology group meeting. *SIPP Newsletter*.

Lett, H.W. 1883 First fungus foray in Ireland 18.11.83, by B.F.N.C. Grevillea 12.
Leung et al. 2002 An ounce of prevention or a pound of cure: bioeconomic risk analysis of invasive species. Proceedings of the Royal Society of London. Series B: Biological Sciences 269(1508), 2407–13.

Liebhold, A.M. and Kean, J.M. 2019 Eradication and containment of non-native forest insects: successes and failures. Journal of Pest Science 92(1), 83–91.

Liebhold, A.M. 2012 Forest pest management in a changing world. International Journal of Pest Management 58(3), 289–95.

Liebhold et al. 2016 Eradication of invading insect populations: from concepts to applications. Annual Review of Entomology 61, 335–52.

Liebhold et al. 2012 Live plant imports: the major pathway for forest insect and pathogen invasions of the US. Frontiers in Ecology and the Environment 10(3), 135–43.

Liston, A.D. and Sheppard, D.A. 2008 Checklist of British and Irish hymenoptera symphyta. Version: 18.11.2008 http://www.record-lrc.co.uk/Downloads/UK_sawfly_checklist_18_Nov_2008[14032009].pdf (29 March 2021).

Liston, A.D. 1988 Noteworthy Symphyta (Hymenoptera) from afforested areas in Northern Ireland. The Irish Naturalists' Journal 22(10), 445–7.

Liston et al. 2014 Checklist of British and Irish Hymenoptera-Sawflies, ‘Symphyta’. Biodiversity Data Journal 2: e1168.

Lovett et al. 2016 Non-native forest insects and pathogens in the United States: impacts and policy options. Ecological Applications 26(5), 1437–55.

MacDougall, R. 1900 The biology and forest importance of Scolytus multistriatus. Proceedings of the Royal Society of Edinburgh 23, 359–64.

MacDougall, R. 1906a The large larch sawfly. Journal of the Board of Agriculture 13, 385–94.

MacDougall, R.S. 1906b Megastigmus spermotrophus Wachtl, as an enemy of Douglas Fir (Pseudotsuga douglasii). Trans. R. Scott. Arboricult Soc.

MacLeod et al. 2016 Plant health and food security, linking science, economics, policy and industry. Food security 8(1), 17–25.

Mangan, A. 2008 A bibliography of mycology and plant pathology in Ireland, 1976 to 2000. Glasra 4, 119–88.

Mangan, A. and Walsh, P.F. 1980 Some observations on the spread of Dutch Elm Disease in Ireland, 1978–79. Irish Journal of Agricultural Research 19(2/3), 133–40.

Martin et al. 2012 Identification and detection of Phytophthora: reviewing our progress,
identifying our needs. *Plant Disease* 96(8), 1080–103.

Massee, G. 1913 *Diseases of cultivated plants and trees*. London. Duckworth.

McArdle, D. and Lafferty, H.A. 1922 *Didymosphaeria populina* and *Phytophthora syringae*. *Irish Naturalist* 31, 137.

McAree, D. 1972 *P. contorta* shoot dieback. *SIPP Newsletter*.

McAree, D. 1987 Some forestry aspects, of the EEC plant health directive. *SIPP Newsletter* No 17.

McAree, D.T. and MacKenzie, R.F. 1993 Guarding against potential threats to Irish forests. In J. Kavanagh and P. Brennan (eds) *Plant health and 1992*. Dublin. Royal Irish Academy.

McAree, D.T. 1975 *Fomes annosus*-a forest pathogen. *Irish Forestry* 32(2), 118–28.

McCarthy, R. 1993 Monitoring forest condition in Ireland (1988–1991). *Irish Forestry* 50(1), 21–34.

McCacken, A. 1996 Two new diseases of dogwood and Alder. *SIPP Newsletter* 26, 4–5.

McCacken, A. 2013 Current and emerging threats to Ireland’s trees from diseases and pests. *Irish Forestry* 70(1&2), 18–35.

McCacken et al. 2017 *Ash dieback on the island of Ireland*. Swedish University of Agricultural Sciences. [https://www.slu.se/globalassets/ew/org/inst/mykopat/forskning/stenlid/dieback-of-european-ash.pdf (19 March 2021)].

McEvoy et al. 2016 Bleeding canker of horse chestnut (*Aesculus hippocastanum*) in Ireland: incidence, severity and characterization using DNA sequences and real-time PCR. *Plant Pathology*, 65(9), 1419–29.

McKay, R. 1952 Pioneer workers in the field of plant pathology in Ireland. *Journal of the Department of Agriculture Ireland*, 48.

McKay, R. and Clear, T. 1953 Association of *Rhizina inflata* with group dying of Sitka spruce. *Irish Forestry* 10(2), 58–9.

McKay, R. and Clear, T. 1955 A further note on group dying of Sitka spruce and *Rhizina inflata*. *Irish Forestry* 12(2), 58–63.

McKay, R. and Clear, T. 1957 Violet root rot on Douglas fir and *Pinus contorta*. *Irish Forestry* 14, 90–7.

McNamara et al. 2018 Efficacy of entomopathogenic fungi against large pine weevil, *Hylobius abietis*, and their additive effects when combined with entomopathogenic nematodes. *Journal of Pest Science* 91(4), 1407–19.
McTaggart et al. 2016 Fungal genomics challenges the dogma of name-based biosecurity. *PLoS Pathogens*, 12(5), e1005475.

Mergaert et al. 1999 Reclassification of non-pigmented *Erwinia herbicola* strains from trees as *Erwinia billingiae* sp. nov. *International Journal of Systematic and Evolutionary Microbiology*, 49(2), 377–83.

Meurisse et al. 2019 Common pathways by which non-native forest insects move internationally and domestically. *Journal of Pest Science* 92(1), 13–27.

Migliorini et al. 2015 The potential of symptomless potted plants for carrying invasive soilborne plant pathogens. *Diversity and Distributions* 21(10), 1218–29.

Ministry of Agriculture 1952 *Record of agricultural research*. Belfast.

Ministry of Agriculture 1957 *Record of agricultural research*. Belfast.

Ministry of Agriculture 1958 *Record of agricultural research*. Belfast.

Ministry of Agriculture 1959 *Record of agricultural research*. Belfast.

Ministry of Agriculture 1960 *Record of agricultural research*. Belfast.

Ministry of Agriculture 1961 *Record of agricultural research*. Belfast.

Ministry of Agriculture 1962 *Record of agricultural research*. Belfast.

Ministry of Agriculture 1967 *Record of Agricultural Research*. Belfast.

Mitchel et al. 2002 New or interesting records of Irish fungi. *The Irish Naturalists' Journal*, 27(1), 38–43.

Mitchell, F.J.G. 2006 Where did Ireland's trees come from? *Biology and Environment: Proceedings of the Royal Irish Academy* 106(3), 251–59.

Mitchell et al. 2014 Ash dieback in the UK: a review of the ecological and conservation implications and potential management options. *Biological Conservation* 175, 95–109.

Moffat, C.B. 1897 *Bupalus piniaria*, L., in Ireland. *The Irish Naturalist* 6(10), 283.

Moller, G.J. 1975 A list of Irish sawflies (Hymenoptera: Symphyta) in the Ulster Museum: Including a new Irish record and a note on a teratological specimen of *Hemichroa* Steph. *The Irish Naturalists' Journal* 18(5), 133–36.

Moore, W.C. 1959 *British Parasitic Fungi*. Cambridge. Cambridge University Press.

Morales-Rodríguez et al. 2019 Forewarned is forearmed: harmonized approaches for early detection of potentially invasive pests and pathogens in sentinel plantings. *NeoBiota* 47, 95–123.

Morris 2002 *True Weevils (Part I): Family Curculionidae, subfamilies Raymondionyminae*
to Smicronychinae. London. Royal Entomological Society.

Morris, M.G. 1966 Records of weevils (Coleoptera Curculionoidea) from counties Galway, Offaly and Roscommon. *Irish Naturalist Journal* 15(7), 208–9.

Morris, M.G. 1968 Recent records of weevils (Coleoptera, Curculionoidea) from Ireland. *The Irish Naturalists' Journal* 16(2), 42–7.

Morris, M.G. 1993 A critical review of the weevils (Coleoptera, Curculionoidea) of Ireland and their distribution. *Biology and Environment: Proceedings of the Royal Irish Academy* 93B(2), 69–84. https://www.jstor.org/stable/20499880

Moths Ireland 2020 Moths Ireland, mapping Ireland’s moths. www.mothsireland.com (29 March 2021).

Mowat, D.J. and Clawson, S. 1996 The need for pest control in Northern Ireland Bramley apple orchards. *Crop Protection in Northern Britain* 2, 225–30.

Mullett et al. 2018 New country and regional records of the pine needle blight pathogens *Lecanosticta acicola, Dothistroma septosporum* and *Dothistroma pini*. *Forest pathology*, 48(5), e12440.

Munro, J.W. 1917 The genus Hylastes and its importance in forestry: a study in scolytid structure and biology. *Proceedings of the Royal Physical Society of Edinburgh* 20(3), 123–58.

Munro, J.W. 1920 Survey of forest insect conditions in the British Isles. *Bulletin of the Forestry Commission* 2, 35.

Munro, J.W. 1926 British bark beetles. *Forestry Commission bulletin* No. 8. London, HMSO.

Munro, J.W. 1927 The present position of forest entomology in Great Britain. *Forestry* 1, 44–6.

Murray, J.S. 1954 Two diseases of spruce under investigation in Great Britain. *Forestry: An International Journal of Forest Research* 27(1), 54–62.

Muskett, A.E. and Malone, J.P. 1978 Catalogue of Irish Fungi: I. Gasteromycetes. *Proceedings of the Royal Irish Academy. Section B: Biological, Geological, and Chemical Science* 78B, 1–11.

Muskett, A.E. and Malone, J.P. 1980 Catalogue of Irish Fungi: III. Teliomycetes. *Proceedings of the Royal Irish Academy. Section B: Biological, Geological, and Chemical Science* 80B, 343–66.

Muskett, A.E. and Malone, J.P. 1983 Catalogue of Irish Fungi: IV. Ascomycotina. *Proceedings of the Royal Irish Academy. Section B: Biological, Geological, and Chemical Science* 83B, 151–213.
Muskett, A.E. and Malone, J.P. 1984 Catalogue of Irish Fungi: V. Mastigomycotina and Zygomycotina. *Proceedings of the Royal Irish Academy. Section B: Biological, Geological, and Chemical Science* **84B**, 83–102.

Muskett, A.E. and Malone, J.P. 1985 Catalogue of Irish Fungi: VI. Deuteromycotina. *Proceedings of the Royal Irish Academy. Section B: Biological, Geological, and Chemical Science* **85B**, 133–200.

Muskett, A.E. 1976 Mycology and plant pathology in Ireland. *Proceedings of the Royal Irish Academy. Section B: Biological, Geological, and Chemical Science* **76B**, 393–472.

Muskett, A.E., Carrothers, E.N. and Cairns, H. 1931 Contributions to the fungus flora of Ulster. *Proceedings of the Royal Irish Academy. Section B: Biological, Geological, and Chemical Science* **40B**, 37–55.

Muskett, A.E., Malone, J.P. and Nixon, C.J.W. 1980 Catalogue of Irish Fungi: II. Hymenomycetes. *Proceedings of the Royal Irish Academy. Section B: Biological, Geological, and Chemical Science* **80B**, 197–276.

NBDC 2010 Ireland’s biodiversity in 2010. https://www.biodiversityireland.ie/wordpress/wp-content/uploads/Irelands-Biodiversity-2010.pdf (29 March 2021).

NBN Atlas 2020 NBN Atlas. https://nbnatlas.org/ (29 March 2021).

Nechwatal et al. 2013 The morphology, behaviour and molecular phylogeny of Phytophthora taxon Salixsoil and its redesignation as *Phytophthora lacustris* sp. nov. *Plant Pathology* **62**(2), 355–69.

Neumann et al. 2017 Climate variability drives recent tree mortality in Europe. *Global Change Biology* **23**(11), 4788–97.

Newstead, R. 1900 Felted beech coccus. *Journal of the Royal Horticulture Society* **23**, 249.

Nicholson, G.W. 1914 Coleoptera from Cavan and Meath. *The Irish Naturalist* **23**(3), 68–72.

Norfolk Moths 2020 Norfolk moths. www.norfolkmoths.co.uk (29 March 2021).

*Northern Ireland agriculture* 1963b *General report of the Ministry of Agriculture*. Belfast, Ministry of Agriculture.

O’Callaghan, D.P. 1982 Occurrence of the small elm bark beetle, *Scolytus multistriatus*, in Ireland. *Irish Naturalist Journal* **20**, 384–85.

O’Connor, J.P., O’Connor, M.A. and Wistow, S. 1993 Some records of Irish Cynipidae (Hymenoptera) including ten species new to Ireland. *The Irish Naturalists' Journal*, **24**(8), 321–25.
O'Connor, J.P. and Nash, R. 2000 Notes on the Irish Megastigmus (Hymenoptera: Torymidae) including two species new to Ireland. British Journal of Entomology and Natural History 13(4).

O'Connor, J.P., Nash, R. and Bouček, Z. 2000 A catalogue of the Irish Chalcidoidea (Hymenoptera). Dublin. Irish Biogeographical Society.

O'Connor, J.P. and Fox, H. 2000 The Horse Chestnut Scale Pulvinaria regalis Canard (Hemiptera: Coccidae) new to Ireland. Entomologist's Gazette 51(2), 145–46.

O'Connor, J.P. and Nash, R. 1979 Record of six insect species (Coleoptera: Orthopetra) recently imported into Ireland. The Irish Naturalists' Journal 19, 433–4.

O'Connor, J.P. and Nash, R. 1980 Notes on five species of insect (Hemiptera: Coleoptera) imported into Ireland. The Irish Naturalists' Journal 20, 299–300.

O'Connor, J.P. and Nash, R. 1982 Further records of insects (Dictyoptera, Lepidoptera, Coleoptera, Diptera) imported into Ireland. The Irish Naturalists' Journal 20, 393–5.

O'Connor, J.P. and Nash, R. 1983 Insects imported into Ireland. 5. Records of Orthoptera, Hemiptera, Hymenoptera and Coleoptera. The Irish Naturalists' Journal 21, 114–17.

O'Connor, J.P. 2000 Notes on Megastigmus dorsalis (Fabricius) and M. suspectus Borries (Hymenoptera: Torymidae) in Ireland. The Irish Naturalists' Journal 27(7), 279–80.

O'Connor, J.P., Gertsson, C.A. and Malumphy, C. 2013 A review of the Irish scale insects (Hemiptera: Coccoidea). Irish Naturalists' Journal, 32–44.

O'Connor, J.P., Winter, T.G. and Good, G.A. 1991 A review of the Irish Scolytidae (Insecta: Coleoptera). The Irish Naturalists' Journal 23(10), 403–9.

O'Connor, P. 1936 A contribution to knowledge of the Irish fungi. Scientific Proceedings of the Dublin Society 21, 381.

O'Farrell, A.F. 1947 Lepidoptera in Northern Ireland, 1943–5. The Irish Naturalists' Journal 9, 76–7.

O'Hanlon, R. 2015 Two further threats to Ireland’s tree’s from non-native invasive Phytophthoras. Irish Forestry 72(1&2), 87–100.

O'Hanlon, R. 2016 Options to protect forest and plant health in Ireland. Irish Forestry 73(1&2), 324–26.

O'Hanlon, R. and Fleming, C. 2018 Neonectria fuckeliana as a pathogen of Sitka spruce in Northern Ireland, 27. https://nibio.brage.unit.no/nibio-xmli/bitstream/handle/11250/2487247/NIBIO_BOK_2018_4_4.pdf?sequence=1andisAllowed=y (29 March 2021).

O'Hanlon, R. and Harrington, T.J. 2011 Diversity and distribution of mushroom-forming
fungi (Agaricomycetes) in Ireland. *Biology and Environment: Proceedings of the Royal Irish Academy* **111B**(2), 117–33.

O’Hanlon, R., Wilson, J. and Cox, D. 2019 Investigations into the declining health of alder (*Alnus glutinosa*) along the river Lagan in Belfast, including the first report of *Phytophthora lacustris* causing disease of Alnus in Northern Ireland. BioRXiv. [https://www.biorxiv.org/content/10.1101/2019.12.13.875229v1.full (29 March 2021)].

O’Hanlon *et al.* 2016a Diversity and detections of Phytophthora species from trade and non-trade environments in Ireland. *EPPO Bulletin*, **46**(3), 594–602.

O’Hanlon, R., McCracken, A.R. and Cooke, L.R. 2016b Diversity and ecology of Phytophthora species on the island of Ireland. *Biology and Environment: Proceedings of the Royal Irish Academy* **116B**(1), 27–51.

O’Hanlon *et al.* 2018 Assessment of the eradication measures applied to *Phytophthora ramorum* in Irish *Larix kaempferi* forests. *Forest Pathology* **48**(1), e12389.

O’Carroll, N., and Joyce, P.M. 2004 A forestry centenary. *Irish Forestry* **61**, 6–19.

Paap *et al.* 2017 Importance of climate, anthropogenic disturbance and pathogens (*Quambalaria coyrecup* and Phytophthora spp.) on marri (*Corymbia calophylla*) tree health in southwest Western Australia. *Annals of Forest Science* **74**(3), 62.

Parker *et al.* 2002 A review of the mid-Holocene elm decline in the British Isles. *Progress in Physical Geography* **26**(1), 1–45.

Paulson, R. 1900 An inquiry into the causes of death of birch trees in Epping Forest and elsewhere. *Essex Naturalist* **11**, 273–84.

Pautasso *et al.* 2012 Impacts of climate change on plant diseases—opinions and trends. *European Journal of Plant Pathology* **133**(1), 295–313.

Peace, T.R. 1962 *Pathology of trees and shrubs with special reference to Britain*. Oxford. Clarendon press.

Pethybridge, G.H. 1918 *Chrysomyxa abietis* in Ireland. *The Irish Naturalist* **27**(8/9), 130.

Phillips, D.H. and Burdekin D.A. 1982 *Diseases of forest and ornamental trees*. London. MacMillan.

Pluess *et al.* 2012 When are eradication campaigns successful? A test of common assumptions. *Biological Invasions* **14**(7), 1365–78.

Potter *et al.* 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), 1966–74.

Pureswaran, D.S., Roques, A. and Battisti, A. 2018 Forest insects and climate
change. *Current Forestry Reports* 4(2), 35–50.

Purvis *et al.*. 2002  Life history and phenology of the eucalyptus psyllid, *Ctenarytaina eucalypti* (Homoptera: Psylloidea) in Ireland. *Annals of Applied Biology*, 141(3), 283–92.

Quirke, D.A. 1943  *Eccoptogaster scolytus* F. (CoL, Ipidae) in Ireland. *Entomologists Monthly Magazine* 79, 198.

Quirke, D.A. 1947  *Insect pests of Irish woodlands*. Unpublished PhD Thesis, University College Dublin.

Quirke, D.A. 1946  Forest pathology. *Irish Forestry* 3(1), 10–25.

Ramsfield *et al.*. 2016  Forest health in a changing world: effects of globalization and climate change on forest insect and pathogen impacts. *Forestry* 89(3), 245–52.

Regan *et al.*. 2010  Countdown to 2010: Can we assess Ireland’s insect species diversity and loss? *Biology and Environment: Proceedings of the Royal Irish Academy*, 110B(2): 109–17.

Reilly, E. 2008  An ever-closing gap? Modern ecological and palaeoecological contributions towards understanding the Irish post-glacial insect fauna. *The Irish Naturalists’ Journal*, 29, 63–71.

Reynolds, S.C. and Reynolds, J.D. 2008  Knopper Gall *Andricus quercuscalicis* (Burgsdorf) records on oaks in Co. Limerick, with observations on the Artichoke Gall *Andricus fecundator* (Hartig). *The Irish Naturalists’ Journal* 29(1), 13–17.

Ridout, M. and Newcombe, G. 2018  *Sydowia polyspora* is both a foliar endophyte and a preemergent seed pathogen in *Pinus ponderosa*. *Plant Disease* 102, 640–4.

Riggins, J.J. and Londo, A.J. 2009  Wolves in sheep’s clothing: outbreaks of previously obscure native forest insects. *Forest Wisdom* 13, 6–7.

Rizzo *et al.*. 2002  *Phytophthora ramorum* as the cause of extensive mortality of Quercus spp. and *Lithocarpus densiflorus* in California. *Plant Disease* 86, 205–14.

Roberts *et al.*. 2020  The effect of forest management options on forest resilience to pathogens. *Frontiers in Forests and Global Change* 3, 7. doi: 10.3389/ffgc.2020.00007.

Roques, A. and Skrzypczyńska, M. 2003  Seed-infesting chalcids of the genus Megastigmus Dalman (Hymenoptera: Torymidae) native and introduced to Europe: taxonomy, host specificity and distribution. *Journal of Natural History* 37(2), 127–238. doi: 10.1080/713834569

Ryan, C. 2018  *Hymenoscyphus fraxineus* in Ireland

April 2018.

[https://www.agriculture.gov.ie/media/migration/forestry/publicconsultation/submissionsreceived2018/DAFMChalaraCR130418.ppt accessed 03/11/18](https://www.agriculture.gov.ie/media/migration/forestry/publicconsultation/submissionsreceived2018/DAFMChalaraCR130418.ppt).
Santini et al. 2013 Biogeographical patterns and determinants of invasion by forest pathogens in Europe. *New Phytologist* **197**(1), 238–50.

Scannell, M. 1972 Ovulina azaelaea. SIPP Newsletter No. 3.

Scanu, B., Jones, B. and Webber, J.F. 2012 A new disease of Nothofagus in Britain caused by *Phytophthora pseudosyringae*. *New Disease Reports* **25**(1), 27.

Shafizadeh, S. and Kavanagh, J.A. 2005 Pathogenicity of *Phytophthora* species and *Pythium undulatum* isolated from *Abies procera* Christmas trees in Ireland. *Forest Pathology* **35**(6), 444–50.

Shivas et al. 2006 Specimen-based databases of Australian plant pathogens: past, present and future. *Australasian Plant Pathology* **35**(2), 195–8.

Sikes et al. 2018 Import volumes and biosecurity interventions shape the arrival rate of fungal pathogens. *PLOS Biology* **16**(5), e2006025.

SIPP 1970 *SIPP Newsletter* 1.

SIPP 1975 *SIPP Newsletter* 6.

SIPP 1982 *SIPP Newsletter* 12.

SIPP 1987 *SIPP Newsletter* 17.

Skilling, D., and Batzer, H. 1995 *World directory of forest pathologists and entomologists*. International Union of Forest Research Organizations.

Smith A. 2019 Overview, tree health technical support inspection. Forest Operations Plant Health Seminar, 23/05/19, Greenmount College.

Smith et al. 2007 Recent non-native invertebrate plant pest establishments in Great Britain: origins, pathways, and trends. *Agricultural and Forest Entomology* **9**(4), 307–26.

Spaans, F., Caruso, T. and Montgomery, I. 2018 The abundance and condition of hedgerow tree standards in Northern Ireland. In *Biology and Environment: Proceedings of the Royal Irish Academy* **118B**(3), 1–17.

Speight, M.C. 1985 The extinction of indigenous *Pinus sylvestris* in Ireland: relevant faunal data. *The Irish Naturalists' Journal* **21**(10), 449–53.

Speight, M.C.D. and Moller, G.J. 1979 *Amauronematus mundus, Hemichroa australis* and *Nematus brevivalvis*: sawflies new to Ireland, with notes on some other Irish sawflies (Hymenoptera: Symphyta). *The Irish Naturalists' Journal* **19**(12), 443–45.

Spence, N. 2020 Implementation of the GB Plant Health and Biosecurity Strategy 2014–2019 with foresight on a new strategy for 2020. *Outlook on Agriculture* **49**(1). doi: https://doi.org/10.1177/0030727020906831.
Speyer, E.R. 1914 A contribution to the life-history of the larch chermes (Cnaphalodes strobilobius, kalt.) 1. Annals of Applied Biology 6, 171–82.

Stendall, J.A.S. 1922 Felted beech coccus in Ireland. Irish Naturalist 31.

Straw et al. 2016 History and development of an isolated outbreak of Asian longhorn beetle Anoplophora glabripennis (Coleoptera: Cerambycidae) in southern England. Agricultural and Forest Entomology, 18(3), 280–93.

Stevenson et al. 2020 The state of the world’s urban ecosystems: What can we learn from trees, fungi, and bees? Plants, People, Planet 2(5), 482–98.

Sweeney, J. and Fealy, R. 2002 A preliminary investigation of future climate scenarios for Ireland. Biology and Environment: Proceedings of the Royal Irish Academy 102B(3), 121–28.

Tedersoo et al. 2019 High-throughput identification and diagnostics of pathogens and pests: overview and practical recommendations. Molecular ecology resources 19(1), 47–76.

Theobald, F. 1904 The larch Coleophora or leaf miner (Coleophora laricella Hubner). Gardeners Chronicle 36, 181–82.

Torr, P., Heritage, S. and Wilson, M.J. 2007. Steinernema kraussei, an indigenous nematode found in coniferous forests: efficacy and field persistence against Hylolobius abietis. Agricultural and Forest Entomology 9, 181–88.

Torr, P.S., Wilson, M.J. and Heritage, S. 2005 Forestry applications. In P.S. Grewal, R.U. Ehlers and D.I. Shapiro-Ilan (eds) Nematodes as biocontrol agents. Oxfordshire. CABI Publishing.

Tuffen, M.G. and Grogan, H.M. 2019 Current, emerging and potential pest threats to Sitka spruce plantations and the role of pest risk analysis in preventing new pest introductions to Ireland. Forestry 92(1), 26–41.

Turok, J., Eriksson, G. and Russel, K. 2002 Noble hardwoods network: Report of the fourth meeting, 4–6 September 1999, Gmunden, Austria and the fifth meeting, 17–19 May 2001, Blessington, Ireland. Biodiversity International.

van den Hoogen et al. 2020 A global database of soil nematode abundance and functional group composition. Scientific Data 7, 1–8.

Wainhouse et al. 2016 Agriculture and forestry climate change impacts summary report, living with environmental change. 10.13140/RG.2.2.17378.73929.

Walsh et al. 2013 Report on migrant and notable Lepidoptera in Ireland, 2009. Irish Naturalists' Journal 32(2), 89–98.

Walsh, P.F. and Mangan, A. 1977 Dutch elm disease survey, 1977. Journal of the Department of Agriculture, Ireland, 74, 40–3.
Walsh et al. 2017 The potential of alternative conifers to replace larch species in Ireland, in response to the threat of *Phytophthora ramorum*. *Irish Forestry* **74**, 149–67.

Ward, D. and Keane, M. 1993 Harmful organisms in forestry production. In J. Kavanagh and P. Brennan (eds) *Plant Health*. Dublin. Royal Irish Academy.

Webber et al. 2012 Isolation of Phytophthora lateralis from Chamaecyparis foliage in Taiwan. *Forest Pathology* **42**(2), 136–43.

Werres et al. 2001 *Phytophthora ramorum* sp. nov., a new pathogen on Rhododendron and Viburnum. *Mycological Research* **105**(10), 1155–65.

Weslien, J. 1998 How much does the pine weevil damage cost? (Vad kostar snytbaggeskadorna?) *Kunglige Skogs-och Lantbruksakademins Tidskrift* **137**, 19–22.

Westgarth-Smith et al. 2007 Temporal variations in English populations of a forest insect pest, the green spruce aphid (*Elatobium abietinum*), associated with the North Atlantic Oscillation and global warming. *Quaternary International* **173–174**, 153–60.

Williams et al. 2013a Organic soils promote the efficacy of entomopathogenic nematodes, with different foraging strategies, in the control of a major forest pest: a meta-analysis of studies to date. *Biological Control* **65**, 357–64.

Williams et al. 2013b Control of a major pest of forestry, *Hylobius abietis*, with entomopathogenic nematodes and fungi using eradicant and prophylactic strategies. *Forest Ecology and Management* **305**, 212–22.

Wingfield, M.J., Slippers, B. and Wingfield, B.D. 2010 Novel associations between pathogens, insects and tree species threaten world forests. *New Zealand Journal of Forestry Science* **40** suppl., s95–s103.

Wingfield et al. 2001 Worldwide movement of exotic forest fungi, especially in the tropics and the southern hemisphere. *Bioscience* **51**, 134–40.

Wormald, H. 1931 Bacterial diseases of stone fruit trees in Britain. III The symptoms of bacterial canker in plum trees. *Journal of Pomology and Horticultural Science* **9**(4), 239–56.

Yde-Andersen, A. 1979 Host spectrum, host morphology and geographic distribution of larch canker, *Lachnellula willkommii*. A literature review. *European Journal of Forest Pathology* **9**, 211–19.

Zeng, Q.Y., Hansson, P. and Wang, X.R. 2005 Specific and sensitive detection of the conifer pathogen *Gremmeniella abietina* by nested PCR. *BMC Microbiology* **5**(1), 65.

Zvereva, E.L. and Kozlov, M.V. 2006 Consequences of simultaneous elevation of carbon dioxide and temperature for plant–herbivore interactions: a metaanalysis. *Global Change Biology* **12**(1), 27–41.