

Review

Alien Invasive Pathogens and Pests Harming Trees, Forests, and Plantations: Pathways, Global Consequences and Management

Tiziana Panzavolta *, Matteo Bracalini, Alessandra Benigno and Salvatore Moricca

Department of Agricultural, Food, Environmental and Forest Sciences and Technologies, University of Florence, Piazzale delle Cascine 28, 50144 Firenze, Italy; matteo.bracalini@unifi.it (M.B.); alessandra.benigno@unifi.it (A.B.); salvatore.moricca@unifi.it (S.M.)

* Correspondence: tiziana.panzavolta@unifi.it; Tel.: +39-0552755552

Abstract: Forest health worldwide is impacted by many invasive alien pathogens and pests (IAPPs) that cause significant harm, with severe economic losses and environmental alterations. Destructive tree pathogens and pests have in the past devastated our forests, natural landscapes and cityscapes and still continue to represent a serious threat. The main driver of pathogen and pest invasions is human activities, above all global trade, which allows these invasive species to overstep their natural distribution ranges. While natural transport occurs according to a regular, expected colonization pattern (based on the dispersive capacity of the organism), human-mediated transport takes place on a larger, unpredictable scale. In order for a pathogen or pest species to become invasive in a new territory it must overcome distinct stages (barriers) that strongly affect the outcome of the invasion. Early detection is crucial to enabling successful eradication and containment. Although sophisticated diagnostic techniques are now available for disease and pest surveillance and monitoring, few control and mitigation options are usable in forestry; of these, biological control is one of the most frequently adopted. Since invasion by pathogens and pests is an economic and ecological problem of supranational relevance, governments should endorse all necessary preventive and corrective actions. To this end, establishing and harmonizing measures among countries is essential, both for preventing new introductions and for diminishing the eventual range expansion of IAPPs present at a local scale. Research is fundamental for: (i) developing effective and rapid diagnostic tools; (ii) investigating the epidemiology and ecology of IAPPs in newly introduced areas; and (iii) supporting policymakers in the implementation of quarantine regulations.

Citation: Panzavolta, T.; Bracalini, M.; Benigno, A.; Moricca, S. Alien Invasive Pathogens and Pests Harming Trees, Forests, and Plantations: Pathways, Global Consequences and Management. *Forests* **2021**, *12*, 1364. <https://doi.org/10.3390/f12101364>

Academic Editor: Angus Carnegie

Received: 19 August 2021

Accepted: 7 October 2021

Published: 8 October 2021

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Keywords: forest insects; forest diseases; diagnostics; mitigation options; citizen science

1. Introduction

Forests are of primary importance, being a source of both income and well-being for human populations worldwide; however, biological invasions pose a serious threat to their economic and ecological sustainability globally. The damage caused by biological invasions is estimated to be second only to that resulting from habitat destruction/fragmentation [1]. In fact, every year a substantial part of the world's forests is destroyed or seriously damaged by invasive alien pathogens and pests (IAPPs) [2].

The exponential increase in introduction of IAPPs to new habitats is a complex phenomenon with multiple factors. Currently, the foremost cause is the increase in trade, especially that of plants, on a global scale [3]. The economic and social transformations that have taken place in recent decades have had, and continue to have, a direct effect on the introduction of harmful organisms. In particular, the evolution in transportation vehicles has favoured an ever greater and faster handling of plants, foodstuffs, and plant materials [4]. Another leading factor is the dramatic increase in human mobility, whether for work

or tourism; it is not uncommon for alien organisms to be transported from one country to another this way, both inadvertently (for example, through contaminated seeds or dirt stuck to footwear or clothing) and intentionally (e.g., seeds, bulbs, fruits, souvenirs made with plant materials) [5,6].

Once the IAPPs have reached a new territory, other factors, such as anthropogenic disturbance, can favour their establishment. The alteration of habitats and changes to natural ecosystems—via the construction of roads, dams, power lines, buildings, or due to crop conversions, deforestation, changes in land use, etc.—create favourable conditions for their invasion [7,8]. Specifically, all these modifications: induce a release of resources; influence the interactions between species; alter the substrates; and modify the physical environment [9]. It is no coincidence that the habitats most disturbed by urbanization and tourism, such as those in coastal and island areas, lakes, rivers, and periurban forests, are where most alien species are found [10].

Another factor involved in IAPP invasions is climate change. The current climate trend towards global warming acts directly on IAPPs by creating favourable conditions for their establishment in formerly unsuitable areas [11]. In addition, higher temperatures enhance the fitness of the more thermophilic IAPPs, favouring their reproductive and dispersive biology; furthermore, milder climates increase the number of yearly reproductive cycles and of individuals surviving the winter season [12]. Changes in climate additionally bolster IAPPs indirectly by making plants more susceptible, since adverse climatic factors, such as extended drought and extreme weather events (e.g., rainstorms, windstorms, hail, and severe flooding), impact plant health, reducing plant growth and vigour, altering phenology, impairing physiological processes, and creating wounds that favour IAPP attacks [13,14].

Some of the major impacts of forest IAPPs are: reduction of primary production; alterations of evolutionary processes, both in host populations and in organisms taxonomically related to the invaders; changes in ecological relationships within tree communities (for example, alteration of symbiotic relationships, either mutualistic or antagonistic, between the tree species and their animal or microbial symbionts); decrease or loss of ecosystem services (water filtration and supply, climate mitigation, erosion prevention, nutrient cycling, carbon storage, and habitat provision); and demise of native species (extinction) [12,15].

The governments of various countries are paying great attention to the problem of the introduction of organisms harmful to agriculture and forestry; hence, phytosanitary protection has become an important component of their agricultural and forestry policies [16]. In an attempt to counter this growing phenomenon, many countries have started adopting increasingly stringent measures aimed at ensuring the early detection of banned pathogens and pests, as well as at eradicating harmful quarantine organisms present locally [17]. Furthermore, intergovernmental regional plant protection organizations try to tackle the problem on a regional scale, aiming to ensure adequate levels of plant protection through a coordinated series of phytosanitary actions [18].

2. IAPP Pathways

The movement of IAPPs to novel locations can occur naturally or through human-mediated processes. Natural movement, even over long distances, always occurs along a trajectory that follows a regular, expected colonization pattern [10]. The populations that colonize a new environment normally originate from nearby areas, such as neighbouring islands or the adjacent mainland, and, in any case, they follow a path that can be predicted according to existing knowledge about their biology, the biology of their vectors, the prevailing winds and water currents (in particular for oomycetes), as well as their dispersal capabilities (migratory capacity) [10]. Human-mediated transport, on the other hand, takes place on a much larger scale [19], since a given species can be taken from one point on the planet and released on the opposite side of the globe. Such transportation both breaks up natural biogeographic barriers and disrupts natural evolutionary processes,

constituting a concrete threat to the planet's biodiversity [20]. Such anthropogenic conveyance of agricultural and forest pests has increased immensely in terms of frequency, geographical breadth, and number of species involved.

Among the human-dependent causes of the introduction of forest IAPPs, postal traffic, tourist activities, and, of course, global trade play a leading role [6]. The movement of people in general, either international or domestically, influences the amount of interception. Liebhold et al. [21] has quantified this and showed how the number of insect pests intercepted in baggage was positively correlated to the number of travellers entering the U.S. As regards trade-related transport, the main pathways are germplasm (tree seeds, cuttings, and plants for planting) and wood (logs, firewood, processed wood, as well as packaging material, etc.). According to Meurisse et al. [6], live plants and wood packaging material are the main source for movement of forest IAPPs beyond their range limits into new, uncontaminated forest areas, based on the data collected in the ports of entry in the U.S. and New Zealand.

Live plants and wood packaging material have also been confirmed as the main pathways for IAPPs in Europe based on interceptions at ports of entry during the last 5 years (Figure 1). The European Union Notification System for Plant Health Interceptions (Europhyt) (https://ec.europa.eu/food/plants/plant-health-and-biosecurity/europhyt/interceptions_en, accessed on 1, June, 2021) records interceptions of new pests and diseases made by EU Member States [22]. Among the main intercepted commodities in this database, there are the following categories: "plants", which includes plants for planting, scions, cuttings, leaves, flowers, branches with foliage; "wood-packaging material", such as wooden crates, wood pallets, wooden packaging material, dunnage; "wood and bark", including roundwood, bark, and processed wood; "produce", such as fruits, vegetables, seeds; "soil", including soil and growing media. "Plants", in particular those coming from Asia and Africa, constitute the most important pathway of forest IAPPs into Europe. The "plants" pathway is followed by the "wood-packaging material", again mainly coming from Asia. Although wood has historically been one of the most common introduction pathways, Europhyt data relating to the 2016–2020 period show that interceptions of harmful organisms on this commodity have reduced significantly, while "wood-packaging material" has moved up to second place. In Europe, there is a third major pathway: "produce", which is an important entry route mainly for agricultural IAPPs (Figure 1). One feature of imports which is overlooked is "soil". The scarce or absent interception of alien organisms in the "soil" (Figure 1) is to be attributed to the very nature of this material, which hampers detection. This is because harmful IAPPs present in the soil remain hidden inside this matrix [5]. Asia was found to be the main source of alien plant insects, followed by Africa and, to a lesser extent, South America (Figure 1). On the other hand, fungal pathogens were intercepted on commodities coming mainly from South America, and secondly, from Asia. However, it should also be considered that EU phytosanitary rules impose a ban on different commodities imported to EU, a restriction that could impact the rate of interceptions on imports from different continents.

A fact that immediately stands out, according to McCullough et al. [23], is that insect interceptions largely prevail over fungal interceptions. This essentially depends on the fact that many fungal pathogens possess a latent phase during which they are not visible on plant surfaces [24,25]. Figure 1 shows how fungal infections become more frequent on fresh plant produce. This is because the herbaceous (fleshy) consistency of fresh plant produce makes this commodity more easily colonizable and, as a consequence, disease symptoms and/or signs become noticeable in a shorter time [23].

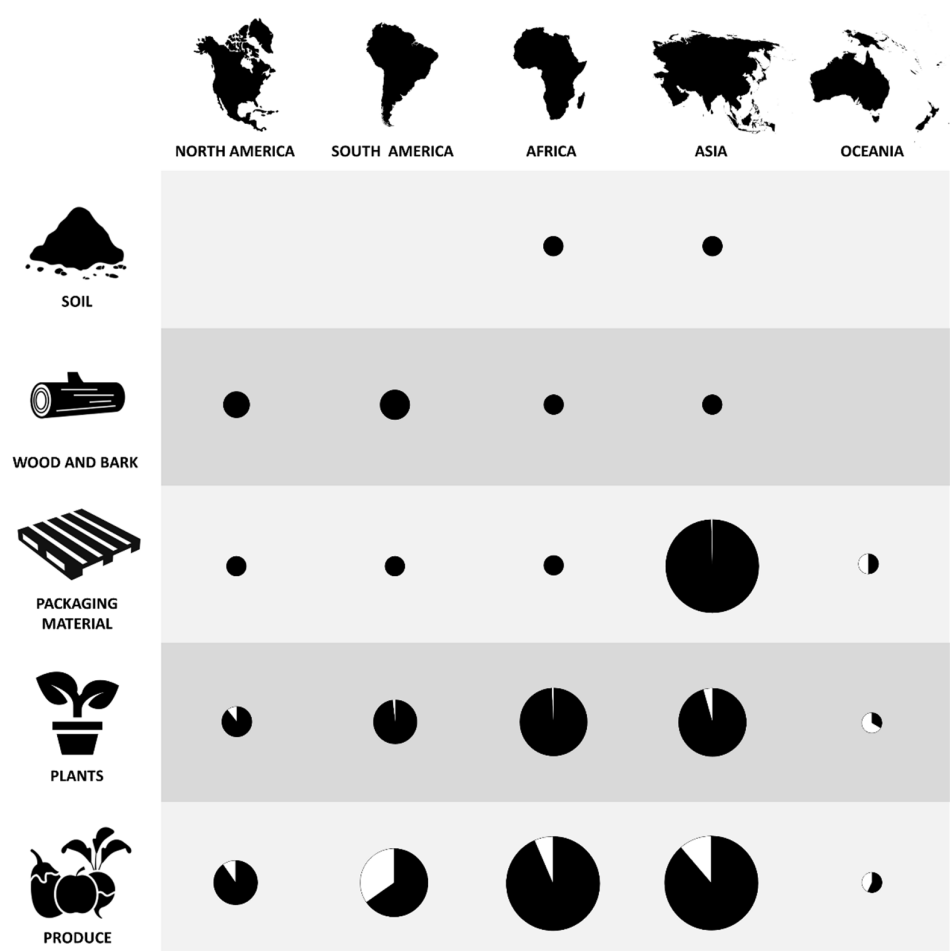


Figure 1. The frequency of fungus and insect interceptions at ports of entry in Europe in the 2016–2020 period (data obtained from reports of Europhyt). Circle sizes indicate the relative amount of interceptions of IAPPs (fungi and insects) within each transport pathway according to their continents of origin. The black sector of the circle denotes the relative frequency of insect interceptions; the white indicates fungi interceptions. Legend: soil = soil and growing media; wood and bark = roundwood, bark, and processed wood; packaging material = wooden crates, wood pallets, wooden packaging material, dunnage; plants = plants for planting, scions, cuttings, leaves, flowers, branches with foliage; produce = fruits, vegetables, seeds.

The higher frequency of insect interceptions at ports of entry compared to fungal pathogens, corresponds also to a higher number of insects established in new areas (Figure 2). This is because fungi, as microorganisms, are generally not visible (the fungal fruiting bodies are not always present), thus they remain less noticeable and less detected. However, even considering only the species with a high impact, whose effects have been tangible in terms of damage, insects continue to be reported in the highest numbers, as results from the European Alien Species Information Network indicate (EASIN; <http://easin.jrc.ec.europa.eu>, accessed on 10, June, 2021).

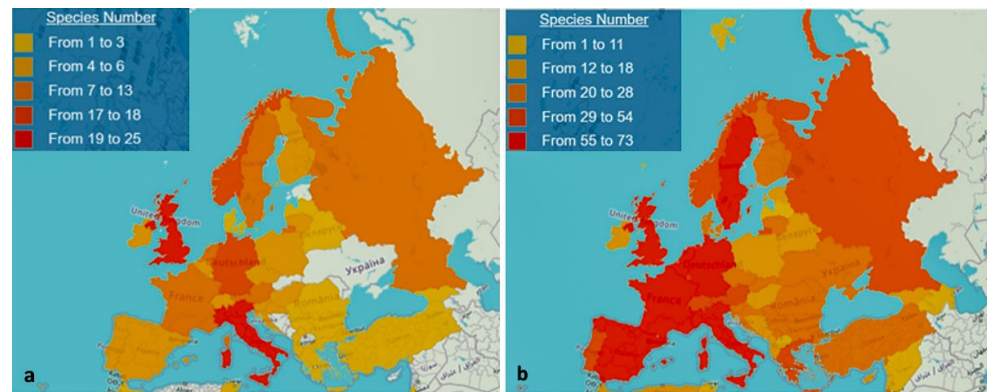


Figure 2. EU geographical distribution of invasive alien species of fungi (a) and insects (b) introduced into terrestrial and fresh-water environments from 1999 to 2021 (source: EASIN—European Alien Species Information Network). Fresh-water environments were also surveyed to include water moulds (Oomycetes).

The European climate turns out not to be a key factor in determining the abundance of IAPPs introduced. In fact, high numbers of new reported infestations are found in countries from both southern and northern Europe (Figure 2). Instead, other factors, such as trade volume, the presence of roads, and human population density are all correlated with the introduction of alien species to Europe [26].

3. Factors Driving the Invasion Process

The chance of newly introduced harmful organisms becoming invasive in new geographic areas is always uncertain [10]. Indeed, few of these survive either the chronic or occasional forces they encounter in the new environment. Only a very small percentage of them ever become naturalized, and even a smaller fraction ends up becoming invasive [27]. In fact, all non-native species must survive three distinct phases, not always clearly distinguishable, before being able to inflict ecological and economic damage: (1) transport: individuals are taken from their area of origin, transported to a new area, and released into the recipient environment; (2) establishment: the newcomers settle in the non-native environment and implant a reproductive population—among the set of the transported individuals, only a few are capable of this; (3) spread: colonizers grow in abundance and expand their geographical range. These phases are mandatory steps in the invasion process, and the advancement from one to the next one involves overcoming hefty ecological barriers [28]. These hindrances, in fact, allow only a small percentage of the introduced species to advance to the next phase (generally between 5% and 20%, with an average of roughly 10%). Based on this assumption, Williamson [29] introduced the so-called “10 rule”, according to which only one out of 10 new introductions would be successful in overcoming any single barrier. This approach has made it possible to analyse the various opportunities IAPPs have to successfully establish into new areas. Invasions, for example, always start with a limited number of individuals being transported and released into a novel location; here, they must be able to survive and give rise to an initial population capable of persisting in this new area. Only when the newcomer species becomes numerically abundant and begins to spread rapidly may “an outbreak” be generated, causing damage to agriculture, the environment, and the local economy, and being perceived as “invasive”. If, on the contrary, the population is not able to grow and expand, it remains small in number and is only local (an “endemic occurrence”) [30,31]. However, there is an ongoing debate within the scientific community regarding the reliability of the “10 rule”, since it can lead to underestimating the impact the introduced organisms can have in new introduction areas [32].

An alien species may have different outcomes in distinct sites of a same region [33]. The first arrivals may survive, reproduce, and spread to become invasive at some locations, while they may succumb at others, even if all individuals of that species share the same traits: e.g., aggressiveness, competitiveness, frugality, polyphagy, tolerance to adverse environmental conditions [34]. In fact, the physical and biological external forces, collectively known as “environmental resistance”, which the alien species has to face, vary from site to site, ultimately determining their fate [35]. Among the most common physical forces the alien species has to withstand are: the availability of nutrients, water, oxygen, light, space, shelter, or protection (e.g., the inner tissues of a plant for a fungal endophyte). Biological forces that can effectively hinder the invasion, instead, are: competition, predation, parasitism, and diseases, as well as other interactions with the resident community, including anthropogenic perturbation [36].

Evidence exists that IAPPs perform better than native pathogens and pests in the invaded community, and this can be attributed to various factors. One key reason for their successful infiltration is a higher host susceptibility in the new non-native range, due to the absence of coevolution with the indigenous hosts, the newcomer IAPPs can grow very rapidly and inflict greater damage, in some instances generating overwhelming outbreaks [37]. Another cause is that in the new environment the IAPP may also jump onto new host(s), which may even be taxonomically unrelated to its native hosts [38]. This is a fairly common phenomenon, whose frequency probably depends on the presence in the introduction area of native plants taxonomically close to the original host plant [39]. Another factor favouring IAPP outbreaks is the scarcity of natural enemies in the new range compared with their native range. According to this “enemy release hypothesis”, IAPPs leave behind all those natural enemies that would naturally keep their population under control in the area of origin. In the new environment, moreover, it encounters very few natural enemies able to use it as a trophic resource [40,41]. All these factors enable the IAPPs to exploit their enormous reproductive potential and to spread rapidly on a large scale, even displacing native species [42].

4. Invasive Alien Pathogens and Pests Harming Forests

The harm caused by the introduction of alien forest pathogens and pests is often difficult to fully quantify due to the multiple ecosystem services forests offer, and because each invasion event must be analysed within the specific context (forest, nursery, district, country, region) in which it occurs [43,44]. The damage may not only be significant at the economic, ecological and landscape level, but it might also generate negative repercussions in related sectors, such as in marketing and tourism [45].

4.1. A Retrospective Look

The forest and rural landscapes of various areas of the planet were transformed in the last century by the introduction of dangerous non-native forest pathogens [46]. Between the 1920s and 1940s, the agent behind Dutch elm disease (DED), *Ophiostoma ulmi* (Buisman) Nannf, spread pervasively throughout Europe and North America on native elm species [47]. The invasion by this vascular pathogen, native to Asia, soon turned into a true pandemic [48]. Moreover, the several variants the fungus spawned over time, including the more aggressive subspecies *americana* of *Ophiostoma novo-ulmi* Brasier, were introduced to Europe from North America via infected logs [49]. As clear evidence of the fungus’ high evolutionary potential and destructiveness, it eventually led to the almost total disappearance of the European field elm (*Ulmus minor* Mill.) from many countryside and urban districts of Europe [50].

Similarly, iconic tree species of the genus *Castanea*, such as the American chestnut *Castanea dentata* (Marsh.) Borkh. and the sweet chestnut *Castanea sativa* Mill., were, in the last two centuries, wiped out from forest ecosystems and orchards due to the combined, sometimes synchronous, attack of the two fearsome oomycete pathogens, *Phytophthora*

cambivora (Petri) Buisman and *Phytophthora cinnamomi* Rands [51], as well as of the ascomycete chestnut blight agent *Cryphonectria parasitica* (Murrill) M.E. Barr [52]. In many European countries, the epidemic spread of chestnut blight led to a severe loss of chestnut cultivation. The disease devastated coppices and orchards, with tragic effects on the already poor economy of many farming communities, for which the edible chestnut fruit was a primary source of food, causing famine and emigration [12].

Around the 1930s, another harmful pathogen, *Ceratocystis platani* (J.M. Walter) Engelbr. and T.C. Harr., the agent behind blue stain canker in plane trees or sycamores (*Platanus occidentalis* L.), spread epidemically first in the suburbs of Philadelphia, and then in many cities in the south-eastern U.S. [53]. Subsequently introduced into the Mediterranean basin either during World War II or soon after, in just a few decades this vascular pathogen gradually killed a multitude of monumental *P. occidentalis* and *Platanus orientalis* L., and their hybrid *Platanus x acerifolia* (Aiton) Willd., trees in city parks, squares, and boulevards [54]. The high genetic uniformity of host populations (most urban trees were clones) and the lack of knowledge about the high infectivity of fungus propagules, which can remain viable at length on pruning tools, favoured the outbreaks of blue stain canker [55].

Seiridium cardinale (W.W. Wagener) B. Sutton and I.A.S. Gibson, the agent behind cypress blight, is an anamorphic fungus native to the west coast of the U.S. (California), where it was first recorded on Monterey cypress (*Cupressus macrocarpa* Hartw. ex Gordon) in 1927 [56]. Despite lacking sexual reproduction, the pathogen was able to spread worldwide epidemically in a short time [57]. Accidentally introduced into Mediterranean Europe during the mid-1900s [58,59], in a few decades it killed planted and ornamental cypress trees (*Cupressus sempervirens* L.) in stands, windbreaks, parks, villas, cemeteries, and treelines. The destructive cypress blight outbreaks deeply altered the Mediterranean landscape, causing a true ecological disaster [60]. Cypress is, in fact, an iconic part of the Mediterranean countryside, so its disappearance also impacted local economies and tourism [57].

Alien insects can pose a direct danger to plants, but they can also act as vectors for phytopathogenic microorganisms [61]. In addition, native insects sometimes also play an important role in the spread of exotic diseases. For example, the bark beetle, *Phloeosinus aubei* (Perris), native to the Caucasus, Asia Minor, and the Mediterranean area, contributed to the increase in damage caused by the exotic *S. cardinale* by carrying its fungal spores; thus the beetle facilitated the fungus' colonization of host trees. In addition, over the last few decades, this bark beetle has continued to spread into Central Europe, where it is considered an alien pest [62]. Similarly, *Scolytus multistriatus* (Marsham) (Coleoptera: Curculionidae), with a Palearctic native range (from western Europe to Russia and northeast Africa) [63], is the main vector of D.E.D., not only in its native range but also in introduced areas, such as North America, where, before the 1930s, 50%–75% of the elm population in the north-eastern part of the continent were killed by this vascular pathogen [64].

Insects harmful to forest trees are also included among the world's worst 100 IASs [65]; those of forest concern include the gypsy moth, *Lymantria dispar* L. (Lepidoptera, Lymantriidae), and the cypress aphid, *Cinara cupressi* (Buckton) (Hemiptera, Aphididae). The gypsy moth, native to Europe and Asia, was introduced near Boston, Maine, in the late 1860s, and currently is listed as one of the most destructive invasive pests, ranking third among the costliest IASs in the world [66]. Its larvae cause serious defoliation of many tree and shrub species, which may ultimately die or become susceptible to subsequent infestation by secondary pests. From 1924 to 2013, in the north-eastern and mid-western U.S., over 37 million hectares were defoliated [67], with a high impact on timber, costs and losses to urban and suburban forests, as well as damage to the recreational sector [68,69]. In addition, gypsy moth outbreaks have contributed to the decline of oak forests in eastern North America [70]. The cypress aphid is also a highly invasive insect; probably native to North America and Syria, since the 1960s it has become newly established in parts of Europe, Africa, South America, and the Middle East [71]. The cypress aphid,

which sucks sap from twigs, causes yellowing to browning of the foliage. Depending on the severity and duration of the infestation, trees may suffer more or less severe damage, or even death in the worst cases [72]. In recent decades, sudden and explosive outbreaks of the cypress aphid have occurred in many countries (some African countries, Italy, Jordan, Yemen, Mauritius, and Colombia). As a consequence, populations of the host trees (*Cupressus*, *Juniperus*, *Widdringtonia*, and other Cupressaceae) have been decimated, both in commercial and ornamental plantings or native stands [73].

4.2. Emerging Invaders

Among the many currently emerging threats to forest ecosystems, oomycete *Phytophthora* species are at the pinnacle. For example, *Phytophthora ramorum* Werres, De Cock et Man in 't Veld, a polyphagous, invasive pathogen originally from the laurosilva forests of eastern Indochina and Japan [74], attacks a multitude of shrub ornamentals and tree species. After causing extensive tree mortality in oak (*Quercus* spp.) and tanoak *Notholithocarpus densiflorus* (Hook. & Arn.) Manos, Cannon and S. H. Oh) forests in California (for this it was called the agent of “sudden oak death”) [75], this destructive oomycete has been more recently killing off plantations of Japanese larch [*Larix kaempferi* (Lamb.) Carr.] in the UK, where it was renamed the agent behind “sudden larch death” [76]. Furthermore, the infamous *P. cinnamomi*, the causal agent of ink disease in chestnuts, already mentioned above, continues to destroy woody plants in natural environments, plantations and urban forests, as well as in parks, horticultural nurseries, and urban ornamental plantings around the world, to the point of earning the nickname of “biological bulldozer” [77]. *P. lateralis* Tucker and Milbrath is considered to be of Asian origin, such as the several *Chamaecyparis* species that, due to the similar native range, exhibit some tolerance or resistance to infection. It is also a harmful pathogen, responsible for serious root and aerial infections [78]. This oomycete shows considerable host specificity, with Port-Orford cedar (*Chamaecyparis lawsoniana* (Murray) Parl.) its main host, but it has also caused epidemic damage to *Taxus brevifolia*, *Thuja*, and other *Chamaecyparis* species growing in proximity to infected *C. lawsoniana* in forests, plantations and in the landscape [79].

Rust fungi also pose a constant threat to many forest ecosystems, mainly because of their high dispersal ability over long distances. It is therefore no coincidence that rust fungi are the largest group of pathogenic fungi in the EPPO (European and Mediterranean Plant Protection Organization) A1 List of Pests Recommended for Regulation as Quarantine Pests (EPPO, https://www.eppo.int/ACTIVITIES/plant_quarantine/A1_list, accessed on 30, June, 2021). One invasive rust that has been spreading pervasively throughout Europe in recent years is the fungus *Melampsoridium hiratsukanum* S. Ito ex Hirats. f., of Asian origin [80]. This rust is currently causing heavy defoliation, stunted growth and death to riparian *Alnus incana* (L.) Moench trees in the eastern Alps, threatening the stability of some riverbanks. In this mountain range the fungus has also found *Larix europea* L. to be a suitable alternate host on which to complete its life cycle [81].

Moreover, a highly destructive fungal disease of ash trees (*Fraxinus* spp.) is at present causing significant damage to ash populations throughout the European continent. The causative agent, *Hymenoscyphus fraxineus* (T. Kowalski) Baral, Queloz and Hosoya (anamorph: *Chalara fraxinea* T. Kowalski), kills young and coppiced ash trees in a very short time, whereas older trees can resist its irritative action for some time, until they are exposed to high inoculation pressure [82]. The resultant ash dieback is seriously impacting woodland biodiversity and ecology, reducing landscape aesthetics and gravely damaging hardwood industries, with heavy economic losses [83].

Yet another tree staple, pine stands, are currently being impacted worldwide by the destructive “Pine Pitch canker”, caused by *Fusarium circinatum* Nirenberg and O'Donnell, (teleomorph: *Gibberella circinata*) [84,85], as well as by some highly damaging foliar pathogens, such as *Lecanosticta acicola* (Thümen) H. Sydow [86], agent of *Lecanosticta* needle blight (LNB) and the related fungi, agents of *Dothistroma* needle blight (DNB) or of “red band needle blight”, *Dothistroma septosporum* (Dorog.) Morelet (syn. *Scirrhia pini* Funk and

Parker, teleomorph: *Mycosphaerella pini* Rostr.) and *Dothistroma pini* Hulbary (teleomorph: unknown) [87–89]. *F. circinatum*, considered native to Mexico, has spread in the last half century to many pine growing areas, causing severe damage to artificial plantations in the Americas, the Far East (Japan and the Republic of Korea), and in southern Africa [90]. DNB causes premature needle abscission, stunted growth, and, in some cases, tree mortality [91]. The disease represents a serious threat to both natural forest ecosystems and exotic pine plantations on all continents (it occurs everywhere except Antarctica) [92]. The disease has been primarily associated with exotic plantations of Monterey pine (*Pinus radiata* D. Don) but, starting from the 1990s, it has caused serious damage in stands of both planted and native pine species, e.g., in *Pinus contorta* subsp. *latifolia* stands in Canada and in *P. nigra* subsp. *laricio* stands in the Mediterranean region [8,93].

Some invasive pests involve symbiotic relationships between insects and fungi; in this case, the whole complex (the insect and its fungal symbiont) is introduced into the new environment. For example, the complex of *Geosmithia morbida* Kolařík (Ascomycota, Hypocreales, Bionectriaceae) and its vector, the bark beetle *Pityophthorus juglandis* Blackman (Coleoptera, Curculionidae, Scolytinae) is responsible for Thousand Cankers Disease (TCD) in walnut trees. First described in North America, TCD causes progressive crown decline, with the fungus colonizing the copious feeding and reproductive galleries made by its symbiont, the phloem-boring bark beetle. This results in numerous, coalescent cankers that girdle branches and trunks, ultimately leading to the tree's death [94]. This insect–fungus complex has been recorded in Italy, where in northern and central regions several plantations were found to be being attacked [95,96]. Another example is the polyphagous shot hole borer, *Euwallacea fornicatus* (Eichhoff) (Coleoptera: Curculionidae), an ambrosia beetle native to Asia that was accidentally introduced into Central and North America, Israel, and South Africa. This emerging tree pest carries the spores of three ambrosial fungi within specific body structures (mycangia), which are the only trophic source for insect adults and larvae. One of these fungi, *Neocosmospora* (= *Fusarium*) *euwallaceae* (S. Freeman, Z. Mendel, T. Aoki and O'Donnell) Sand.-Den., L. Lombard and Crous, a moderately virulent pathogen, is responsible for causing dieback in a range of susceptible host trees, or even mortality, depending on the level of infestation. This insect–fungus complex has caused significant damage to orchards and ecosystems around the world, even attacking important forest species [97].

Other insect species of great impact are the Asian long-horned beetle, *Anoplophora glabripennis* (Motschulsky) (Coleoptera: Cerambycidae), and the citrus long-horned beetle, *A. chinensis* Forster (Coleoptera: Cerambycidae). These are xylophagous insects native to Asia, whose big larvae can kill healthy broadleaf trees. The first record of an established population of *A. glabripennis* outside its native range was in 1996 [98], while that of *A. chinensis* was in 1999; both occurred in North America [99]. In Europe, eradication was successful at the sites where *A. chinensis* was discovered shortly after its introduction, proving how early detection is key to prevent the lasting establishment of the pest and to implement effective control measures [100]. Furthermore, the importance of citizen involvement in early detection was highlighted in 2008, when every new outbreak was first reported by members of the public [101].

However, when an IAPP species is not considered a major pest in its native range, it is unlikely to be included on IAS watch lists. Consequently, specific early detection surveys for that pest are not in place. Furthermore, it is difficult to predict the invasiveness of a non-native species in a new environment. Such was the case not only for pathogenic fungi, such as the ash dieback agent *H. fraxineus*, but also for several insect species, such as, for example, the emerald ash borer, *Agrilus planipennis* (Fairmaire) (Coleoptera: Buprestidae), a phloem-feeding beetle native to Asia, where it was only marginally studied as a minor pest. Once accidentally introduced (in 2002) in the United States, however, it became the most destructive forest pest ever recorded in North America [102]. Millions of ash trees have already died because of *A. planipennis*; the infestations have spread over 35 US States and two Canadian Provinces, as of 2020 [103]. The emerald ash borer has also

reached European Russia, being first recorded in Moscow in 2003; it is now already present in nine Russian regions [104]. In 2019, it was also confirmed for the first time in Ukraine, revealing how the beetle is continuing to expand its range towards Europe [105]. Because of what already happened in North America, the beetle is being addressed in Europe with more groundwork, trying to develop all the necessary measures to contain the problem [106]. However, it has yet to be determined whether the European ash (*Fraxinus excelsior* L.) is going to be susceptible to severe damage; in fact, most of the infested trees in Russia are in artificial urban settings of *F. pennsylvanica* Marshall [104].

5. Mitigating Threats to Forest Health: Possible Solutions and Action Strategies

In natural forests, the better approach is to actively maintain ecological integrity to ensure forest resilience, whereas in forest plantations the restoration of increasing levels of biodiversity should be favoured as the first line of defence against invasive pests and pathogens [107]. In this last case, the careful choice of appropriate plant material is always fundamental, specifically, avoiding the use of species unsuited to site conditions, as well as limiting the number of exotic plant species [108], since in the last century, non-native tree species, widely used as ornamentals or in afforestation programmes, acted as “Trojan horses” for many harmful diseases and pests [8]. Clear examples are the accidental introductions of *P. ramorum* into North America with nursery plant material [75], of *Teratosphaeria* (*Mycosphaerella*) *nubilosa* (Cooke) Crous and U. Braun, a causal agent of *Mycosphaerella* leaf disease of eucalypt, into South America (Uruguay) with propagation material of this exotic tree species [109], of *Rhynchophorus ferrugineus* (Olivier), harmful to palm trees widely diffused in South Europe [110], and of *Ophelimus maskelli* (Ashmead) (Hymenoptera: Eulophidae), which damages eucalypt plants in the Mediterranean Basin [111]. Furthermore, in forestry it is always advisable to avoid genetic uniformity, such as clonal plantations, as in poplar cultivation. Mixed forests, instead, are generally less prone to diseases and pests than monotypic stands, with nonhost trees creating effective physical and chemical barriers to the spread of pathogens’ inoculum, as well as hindering host searches by pests. In addition, higher biodiversity favours natural enemies and competitors which, interacting with IAPPs, contribute to keeping the invaders’ population densities low [107].

Preventing the introduction of dangerous IAPPs into new areas is the first step in their management, so this has become an important priority in many countries. Preventing introductions is carried out through effective surveillance activities, namely phytosanitary inspections at ports of entry (ports, airports, and custom barriers), as well as at vulnerable sites, i.e., those places where the plant material is in transit or processed, such as nurseries, loading and sorting stations, and wood processing companies [112,113]. Considering the enormous volume of commerce at present, and the incessant mobility of humans for work, tourism, etc., many IAPPs elude preventative measures, it being practically impossible to intercept all the species that transit on all commodities [114,115].

Careful prediction of potential invasiveness of harmful pests and diseases can aid interceptions [116]. Important predictive tools are those provided by international organizations such as the CABI (Commonwealth Agricultural Bureaux International) and the EFSA (European Food Safety Authority), as well as various Regional Plant Protection Organizations such as the EPPO, the NAPPO (North American Plant Protection Organization) and the APPPC (Asia and Pacific Plant Protection Commission), which were created to develop international strategies to fight the introduction and spread of harmful pests and diseases and to promote safe and effective pest control methods. In fact, they provide constantly updated lists of organisms considered as threats to agriculture, forestry, and the environment and that are most likely to be introduced into Europe and North America. These agencies’ published assessments of invasion risks are important tools since they focus the efforts of inspection services, plant health scientists, and all the stakeholders affected by imported pests and pathogens [117]. Another important early warning system of new and emerging pest and pathogen risks is sentinel plants [118]. These can be: (a)

plantings made with young, frequently exported native plants which are used to identify pests and diseases that may be introduced to import countries through the trade in live plants; and (b) plantings made of non-indigenous young or mature plants in import countries whose monitoring could give useful information about the potential damage of non-native pathogens and pests if they were to arrive and become established [119].

A primary obstacle to managing and mitigating alien forest pests is correctly identifying the agents of damage [117]. Traditional identification methods, essentially based on the analysis of macro- and/or micro-morphological characters, have inherent limitations. Considerable experience is necessary to induce the formation of fungal distinguishing structures *in vitro* and substantial expertise is needed for their microscopic observation and identification; moreover, special growth media (i.e., differential or selective substrates) may not be available for certain, fastidious microorganisms. In any case, these procedures are not applicable for unculturable microbes such as biotrophic fungi [120]. The above difficulties involve the fact that some taxa, for example, are not easily identified through morphological characters, so this entails inspectors with specific expertise [114]. In addition, some insects have juvenile stages that are indistinguishable by classical diagnostic methods. Furthermore, phytosanitary inspectors may face plant material that has been attacked, but which has already been abandoned by its phytophages; therefore, they have to track the pest only on the basis of the traces left behind, which becomes a more difficult task. It is also true, on the other hand, that the reproductive structures of many forest pathogens can be observed on infected plant material, and these are of a great diagnostic value [81]. Furthermore, when the reproductive structures (e.g., fruiting bodies) are not present on the host surface, they can still be obtained in the laboratory by using a moist chamber; alternatively, the isolation from infected plant material into pure culture can permit the growth and identification of the causal agent.

Many of the difficulties inherent in traditional morphological identification can nowadays be overcome by employing molecular techniques. Furthermore, for an effective inspection system which can cover the ever-increasing volume of import–export material, simple, timely, and repeatable methods have to be developed. Modern molecular diagnostic tools, which detect DNA polymorphisms, ensure high accuracy and diagnostic sensitivity, allowing the detection of even minimal traces of nucleic acids, such as those remaining in the frass of xylophagous insects [113]. Some of these methods have the advantage of being able to process a large number of samples in a short time [121]. For example, loop-mediated isothermal amplification (LAMP) is a nucleic acid amplification method that offers rapid, accurate, and cost-effective diagnosis of diseases and pests [122–124]. The simplicity and the portability of the equipment also make it a tool of choice for carrying out tests *in situ*, making inspection greatly easier [8]. Molecular methods are therefore of great help when it is necessary to focus attention on clearly defined species, for example for delimiting surveys at vulnerable sites known or suspected to harbour a given pathogen or pest, while conventional (e.g., morphology-based) methods continue to retain their high validity for the control of the territory for the occurrence of unknown IAPPs. In other words, morphological and molecular methods should go hand-in-hand and complement each other, with DNA-based techniques representing versatile tools to support and extend more classical species identification and taxonomy [125].

Novel diagnostic methods are also useful in monitoring the dynamics and ecology of a given IAPP after its introduction. These techniques are in fact also highly effective in: detecting early disease and insect foci; tracing and quantifying pathogens' inoculum (especially airborne inoculum) and insect populations; and locating infection and infestation reservoirs (e.g. storage facilities) that sustain invasion events [126]. National and local inspection services also make use of innovative strategies, including remote sensing technology (GIS and unmanned aerial vehicles like drones) [127,128] and detection dogs, whose keen smell can locate biological targets [129]. This last method was used for the first time for gypsy moths and later for other alien and invasive insect species [130].

The mobilisation of citizens as additional observers and reporters (citizen science) has become increasingly utilized for the early detection of unwanted IAPPs. Active monitoring by citizens, when extensively distributed throughout the territory, has in fact become an important part of biosecurity efforts to prevent IAPPs' establishment and spread [131]. However, to obtain the consent and collaboration of citizens, they must be properly informed about the risks and dangers associated with non-native pathogens and pests for native plants, also because citizens have sometimes opposed management interventions aimed at containing and eradicating harmful alien organisms [132]. Well-informed citizens, besides supporting the accurate monitoring of the territory by inspecting sites and trees, are also a fundamental resource for collecting, categorizing, transcribing, and analysing data [133]. Citizen science is possible today due to a growing number of citizens with ecological awareness and knowledge eager to contribute as volunteers [134]. Some examples of citizen science projects include Observatree (<https://www.observatree.org.uk>, accessed on 31, July, 2021) in the UK and LIFE ARTEMIS (<https://www.tujerodneviste.info/en/>, accessed on 31, July, 2021) in Slovenia; in addition there are several citizen science networks, such as the EASIN (<https://easin.jrc.ec.europa.eu/easin/Citizen-Science/BecomeACitizen>, accessed on 31, July, 2021), which is an initiative of the European Commission that aims to connect citizens, scientists and policymakers in an effort to manage harmful alien invasive species.

Once an IAPP has been detected within an area of concern, the next move is to try to eradicate invasion foci [135,136]. Quick action while IAPP populations are still small is the most efficient way to prevent ecological or economic harm. With forest IAPPs the only control options are mechanical approaches (such as sanitation cutting) [137], biological control, and the use of semiochemicals (e.g., mass trapping) [10]. While eradication of alien forest insects has been effective in some cases [138], the eradication of forest pathogens has always been incredibly challenging, with most of the successful interventions taking place in controlled environments (greenhouses and tree nurseries) or in urban green spaces (e.g., parks, trees, and gardens) [139].

After an IAPP population has newly established in a forest, biological control is one of the main measures to achieve self-sustaining long-term control [140]. In some cases, biological control has managed to restore more sustainable pest population dynamics, succeeding in keeping the population density of the invasive species below the damage thresholds [141–143]. For instance, the parasitoid *Torymus sinensis* Kamijo (Hymenoptera: Torymidae) proved to be a good control agent of the Asian chestnut gall wasp *D. kuriphilus* in several areas of the world, significantly reducing the pest populations with a self-sustaining effect [144]. Similarly, in North European conifer forests, the fungus *Phlebiopsis gigantea* (Fr.) Jul. has been successfully employed in the biological control of the root and butt rot pathogen *Heterobasidion annosum* (Fr.) Bref. [145,146]. Commercial formulations based on this biocontrol agent have even since been developed and are commercially available under the names of 'PG suspensionTM' in the UK, 'Rotstop[®]' in Finland, and PG IBL in Poland [146,147].

Biological control is not, however, a universal remedy; it is not always effective and several negative effects may occur. This variability in the efficacy of biological control in forest ecosystems is a frequent drawback, mainly due to the complex and multi-partite interactions between the tree, the IAPP, the biocontrol agent, and the other biotic factors [148], all of which are, in turn, impacted by the physical environment and human interference. Biological control in heterogeneous forest ecosystems, therefore, in order to be successful, should take into consideration the multiple biological factors involved: including the environmental conditions (e.g., soil properties, microclimate, etc.), type of forest stand, and silvicultural management [149]. Controlling IAPPs by introducing their natural enemies, many of which are exotic themselves, is a controversial issue whose effects may be viewed as "deliberate ecological invasions". Retrospective analyses of several biological control programs around the globe are now available, thus providing quantitative data on negative effects: parasitism/predation on non-targets; competition with native natural

enemies; intraguild predation; vectoring of pathogens [150]; and risk of hybridization with related native species [151]. Due to the increasing awareness of the related environmental and economic risks, many countries have implemented regulations for the release of biological control agents [152].

For the management of IAPP invasions, more stringent rules and policies are needed to protect plant health and to ensure a safer trade [153]. The need for such measures has long been recognised: at a regional level Plant Protection Organizations are trying to enforce phytosanitary policies, regulations and technical recommendations [154]. For example, the defence of the European territory and its plants has been recently tackled with the adoption of new rules (Regulation (EU) 2016/2031), which improve the European phytosanitary regime through more effective measures. A global effort is also required, involving all the countries and policymakers that in various ways may contribute to counteracting the problem. Specifically, international politics should work towards: consolidating phytosanitary coordination among the countries; harmonizing phytosanitary measures; eliminating the gaps between international and national laws; filling legislative gaps by implementing preventive and/or corrective legal actions; promoting more incisive and restrictive actions at national, regional, and international levels; and establishing legal responsibility frameworks to sanction countries that do not respect international regulations [117].

6. Role of Research

The introduction of IAPPs into new territories is a current environmental issue and a dominant theme of scientific research. Phytosanitary protection has become one of the priorities of many nations, as proven by the numerous funded research projects on this subject [155]. Information about the taxonomy, biology, and ecology of IAPPs during the onset of an invasion process is often lacking, especially as regards their reproduction and dispersal abilities into areas where they have been newly introduced; this knowledge gap may favour their establishment and uncontrolled spread [156]. Plant health scientists, besides being involved in the diagnosis of IAPPs, which, often being new, are sometimes little known, are also concerned with their taxonomic positioning, as well as with the characterization of those subspecific entities that are difficult to determine by traditional approaches [157]. The development of diagnostic methods is especially important for those IAPPs endowed with a latent phase, because latency increases the risk of their spreading undetected. However, research also needs to be performed in other, fundamental aspects of the IAPPs' life history strategies: their demographic history (gene flow, migration); mode of reproduction (i.e., sexual vs. asexual); recombinational events outside the sexual cycle, such as parasexuality and horizontal gene transfer, affecting pathogen virulence [158]; occurrence of hybridization events between related taxa [159]; microbial/pest virulence/aggressiveness versus host resistance. A constant threat is posed to forests by the possible arrival and co-occurrence of new mating types and haplotypes. While the coexistence of different mating types increases the chances for sexual recombination between genetically divergent lineages, continual haplotype introgression can give rise to the emergence of new pathotypes with heightened virulence. These natural events, which have become more frequent as a result of international trade and climate change, are strongly feared in many pest–plant interactions. The evolutionary and pathogenetic potential of *P. ramorum*, *H. fraxineus*, as well as of the walnut twig beetle *P. juglandis*, vector of TCD, to cite but a few examples, strongly depend on these mechanisms [78,137,160]. Research can thus dramatically advance our understanding of the evolution of pathogenesis and aggressiveness of pathogens and pests and of the epidemic risks associated with these phenomena.

This knowledge is crucial for enabling stakeholders (landowners, foresters, phytosanitary inspection services, and policymakers) to implement adequate management strategies. In addition, accurate information from the research community would also per-

mit valid, standardized phytosanitary certification, which could be adopted in participating countries and support inspections of feared IAPP introduction, including in the exporting country. On an open market, which allows the free movement of plant material, the certification of propagation material is of primary importance to avoid the spread of diseases and pests into new areas [161].

7. Conclusions

The problem of invasions by forest IAPPs is enormous and complex. It concerns countries, international organizations, and agencies; it affects economic interests, involving a multitude of activities from local to global scales [155,162]. At a local level, the problem must be tackled by concentrating efforts both on preventing new introductions and on eradicating early invasion foci [136]. Since trade-related transport is the main source of forest IAPPs, particularly that involving germplasm and wood-packaging material, this is where immediate action should be taken [6]. Implementing surveillance campaigns on these pathways would therefore help prevent, or at least minimize, the risks of introducing forest IAPPs.

In addition, forest health monitoring has now become of crucial importance. It is, however, challenging, due not only to the vast expanse of many forested areas, but also to the complexity of forest ecosystems, whose various compartments (soil, water, live plants, snags and logs) must be inspected by well-trained personnel [129]. Furthermore, due to the increasing rate of introduction of IAPPs, monitoring should be continual, and articulated across several activities: extensive monitoring of vast areas; intensive monitoring of vulnerable sites (loading stations, nurseries, import–export material checking points) [112]; the use of sentinel plants [118]; early warnings assisted by both conventional and innovative molecular diagnostic tools [123]; and involving volunteers in early detection (citizen science) [131].

Research has always played a key role in pest management and it continues to do so even more nowadays when dealing with IAPPs. As we have pointed out in this paper, the scientific community is looking into a multitude of issues related to IAPPs, from correct taxonomic positioning [157] to diagnosis [126], from the analysis of recombinational events between non-native and native species [159] to investigations into IAPPs' adaptation to new environments [137]. This scientific support will also be crucial to government agencies' setting up of effective control strategies [100], as well as to lawmakers tasked with enacting laws and regulations [117], who should be routinely notified of scientific advancements in this field.

Author Contributions: Conceptualization, T.P. and S.M.; data curation, T.P., S.M., M.B. and A.B.; writing—original draft preparation, T.P., S.M. and M.B.; writing—review and editing, T.P., S.M., M.B. and A.B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Publicly available datasets were analysed in this study. These data can be found here: [https://ec.europa.eu/food/plants/plant-health-and-biosecurity/europhyt/interceptions_en; <http://easin.jrc.ec.europa.eu>, accessed on 10, June, 2021].

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Wilcove, D.S.; Rothstein, D.; Dubow, J.; Phillips, A.; Losos, E. Quantifying threats to imperiled species in the United States. *BioScience* **1998**, *48*, 607–615. <https://doi.org/10.2307/1313420>.
2. Roy, B.A.; Alexander, H.M.; Davidson, J.; Campbell, F.T.; Burdon, J.J.; Sniezko, R.; Brasier, C. Increasing forest loss worldwide from invasive pests requires new trade regulations. *Front. Ecol. Environ.* **2014**, *12*, 457–465. <https://doi.org/10.1890/130240>.

3. Chapman, D.; Purse, B.V.; Roy, H.E.; Bullock, J.M. Global trade networks determine the distribution of invasive non-native species. *Glob. Ecol. Biogeogr.* **2017**, *26*, 907–917, <https://doi.org/10.1111/geb.12599>.
4. Ascensão, F.; Capinha, C. Aliens on the move: Transportation networks and non-native species. In *Railway Ecology*; Borda-de-Água, L., Barrientos, R., Beja, P., Pereira, H.M., Eds.; Springer: Cham, Switzerland, 2017, pp. 293–297, ISBN 978-3-319-57496-7, <https://doi.org/10.1007/978-3-319-57496-7>.
5. McNeill, M.; Phillips, C.; Young, S.; Shah, F.; Aalders, L.; Bell, N.; Gerard, E.; Littlejohn, R. Transportation of nonindigenous species via soil on international aircraft passengers' footwear. *Biol. Invasions* **2011**, *13*, 2799–2815, <https://doi.org/10.1007/s10530-011-9964-3>.
6. Meurisse, N.; Rassati, D.; Hurley, B.P.; Brockerhoff, E.G.; Haack, R.A. Common pathways by which non-native forest insects move internationally and domestically. *J. Pest. Sci.* **2019**, *92*, 13–27, <https://doi.org/10.1007/s10340-018-0990-0>.
7. Ginetti, B.; Moricca, S.; Squires, J.N.; Cooke, D.E.L.; Ragazzi, A.; Jung, T. *Phytophthora acerina* sp. nov., a new species causing bleeding cankers and dieback of *Acer pseudoplatanus* trees in planted forests in Northern Italy. *Plant Pathol.* **2014**, *63*, 858–876. <https://doi.org/10.1111/ppa.12153>.
8. Aglietti, C.; Benigno, A.; Scali, E.; Capretti, P.; Ghelardini, L.; Moricca, S. Molecular-based reappraisal of a historical record of *Dothistroma* needle blight in the centre of the Mediterranean region. *Forests* **2021**, *12*, 983, <https://doi.org/10.3390/f12080983>.
9. Hobbs, R.J.; Huenneke, L.F. Disturbance, diversity and invasion: Implications for conservation. *Conserv. Biol.* **1992**, *6*, 324–337.
10. Lockwood, J.L.; Hoopes, M.F.; Marchetti, M.P. *Invasion Ecology*; Blackwell Publishing: Oxford, UK, 2007; 304pp.
11. Jeschke, J.M.; Strayer, D.L. Invasion success of vertebrates in Europe and North America. *Proc. Natl. Acad. Sci. USA* **2005**, *102*, 7198–7202, <https://doi.org/10.1073/pnas.0501271102>.
12. Moricca, S.; Bracalini, M.; Croci, F.; Corsinovi, S.; Tiberi, R.; Ragazzi, A.; Panzavolta, T. Biotic factors affecting ecosystem services in urban and peri-urban forests in Italy: The role of introduced and impending pathogens and pests. *Forests* **2018**, *9*, 65, <https://doi.org/10.3390/f9020065>.
13. Panzavolta, T.; Panichi, A.; Bracalini, M.; Croci, F.; Ginetti, B.; Ragazzi, A.; Tiberi, R.; Moricca, S. Dispersal and propagule pressure of Botryosphaeriaceae species in a declining oak stand is affected by insect vectors. *Forests* **2017**, *8*, 228, <https://doi.org/10.3390/f8070228>.
14. Jactel, H.; Koricheva, J.; Castagneyrol, B. Responses of forest insect pests to climate change: Not so simple. *Curr. Opin. Insect Sci.* **2019**, *35*, 103–108, <https://doi.org/10.1016/j.cois.2019.07.010>.
15. Freer-Smith, P.H.; Webber, J.F. Tree pests and diseases: The threat to biodiversity and the delivery of ecosystem services. *Biodivers. Conserv.* **2015**, *26*, 3167–3181, doi:10.1007/s10531-015-1019-0.
16. Shine, C.; Williams, N.; Gundling, L. *A Guide to Designing Legal and Institutional Frameworks on Alien Invasive Species*; IUCN: Gland, Switzerland, 2000; 152pp.
17. Hurley, B.P.; Garnas, J.; Wingfield, M.J.; Branco, M.; Richardson, D.M.; Slippers, B. Increasing numbers and intercontinental spread of invasive insects on eucalypts. *Biol. Invasions* **2016**, *18*, 921–933, <https://doi.org/10.1007/s10530-016-1081-x>.
18. Petter, F.; Suffert, M.; McMullen, M.; Griessinger, D.; Roy, A.S. Seed-borne pests and phytosanitary issues: The role of EPPO. In *Global Perspectives on the Health of Seeds and Plant Propagation Material*; Gullino, M., Munkvold, G., Eds.; Springer: Dordrecht, the Netherlands, 2014; https://doi.org/10.1007/978-94-017-9389-6_3.
19. Banks, N.C.; Paini, D.R.; Bayliss, K.L.; Hodda, M. The role of global trade and transport network topology in the human-mediated dispersal of alien species. *Ecol. Lett.* **2015**, *18*, 188–199, <https://doi.org/10.1111/ele.12397>.
20. Eldredge, N. *Life on Earth: An Encyclopedia of Biodiversity, Ecology, and Evolution*; ABC-CLIO Inc.: Santa Barbara, CA, USA, 2002; 800pp.
21. Liebhold, A.M.; Work, T.T.; McCullough, D.G.; Cavey, J.F. Airline baggage as a pathway for alien insect species entering the United States. *Am. Entomol.* **2006**, *52*, 48–54, <http://dx.doi.org/10.1093/ae/52.1.48>.
22. Europhyt. Interceptions of Harmful Organisms in Imported Plants and Other Objects, Annual and Monthly Interception. Available online: https://ec.europa.eu/food/plants/plant-health-and-biosecurity/european-union-notification-system-plant-health-interceptions-2_en (accessed on 26 July 2021).
23. McCullough, D.G.; Work, T.T.; Cavey, J.F.; Liebhold, A.M.; Marshall, D. Interceptions of nonindigenous plant pests at US ports of entry and border crossings over a 17-year period. *Biol. Invasions* **2006**, *8*, 611–630, <https://doi.org/10.1007/s10530-005-1798-4>.
24. Boddy, L.; Griffith, G.S. Role of endophytes and latent invasion in the development of decay communities in sapwood of angiospermous trees. *Sydowia* **1989**, *41*, 41–73.
25. Précigout, P.A.; Claessen, D.; Makowski, D.; Robert, C. Does the latent period of leaf fungal pathogens reflect their trophic type? A meta-analysis of biotrophs, hemibiotrophs, and necrotrophs. *Phytopathology* **2020**, *110*, 345–361, <https://doi.org/10.1094/PHYTO-04-19-0144-R>.
26. Roques, A. Alien forest insects in a warmer world and a globalised economy: Impacts of changes in trade, tourism, and climate on forest biosecurity. *N. Zeal. J. For. Sci.* **2010**, *40*, 77–94.
27. Mack, R.N.; Simberloff, D.; Lonsdale, W.M.; Evans, H.; Clout, M.; Bazzaz, F.A. Biotic invasions: Causes, epidemiology, global consequences, and control. *Ecol. Applic.* **2000**, *10*, 689–710, [https://doi.org/10.1890/1051-0761\(2000\)010\[0689:BICEGC\]2.0.CO;2](https://doi.org/10.1890/1051-0761(2000)010[0689:BICEGC]2.0.CO;2).
28. Williamson, M.; Fitter, A. The varying success of invaders. *Ecology* **1996**, *77*, 1661–1665, <https://doi.org/10.2307/2265769>.
29. Williamson, M. *Biological Invasions*; Chapman & Hall: London, UK, 1996; 244pp.
30. Liebhold, A.M.; MacDonald, W.L.; Bergdahl, D.; Mastro, V.C. Invasion by Exotic Forest Pests: A Threat to Forest Ecosystems. *For. Sci.* **1995**, *41*, a0001–z0001, <https://doi.org/10.1093/forestscience/41.s1.a0001>.

31. Moricca, S.; Linaldeddu, B.T.; Ginetti, B.; Scanu, B.; Franceschini, A.; Ragazzi, A. Endemic and emerging pathogens threatening cork oak trees: Management options for conserving a unique forest ecosystem. *Plant Dis.* **2016**, *100*, 2184–2193, <https://doi.org/10.1094/PDIS-03-16-0408-FE>.
32. Jarić, I.; Cvijanović, G. The Tens Rule in invasion biology: Measure of a true impact or our lack of knowledge and understanding? *Enviro. Manag.* **2012**, *50*, 979–981, <https://doi.org/10.1007/s00267-012-9951-1>.
33. Lovell, R.S.L.; Blackburn, T.M.; Dyer, E.E.; Pigot, A.L. Environmental resistance predicts the spread of alien species. *Nat. Ecol. Evol.* **2021**, *5*, 322–329, <https://doi.org/10.1038/s41559-020-01376-x>.
34. Philibert, A.; Desprez-Loustau, M.L.; Fabre, B.; Frey, P.; Halkett, F.; Husson, C.; Lung-Escarment, B.; Marçais, B.; Robin, C.; Vacher, C.; et al. Predicting invasion success of forest pathogenic fungi from species traits. *J. Appl. Ecol.* **2011**, *48*, 1381–1390, <https://doi.org/10.1111/j.1365-2664.2011.02039.x>.
35. Warren, R.J.; Candeias, M.; Lafferty, A.; Chick, L.D. Regional-scale environmental resistance to non-native ant invasion. *Biol. Invasions* **2020**, *22*, 813–825, <https://doi.org/10.1007/s10530-019-02133-3>.
36. Zenni, R.D.; Nuñez, M.A. The elephant in the room: The role of failed invasions in understanding invasion biology. *Oikos* **2013**, *122*, 801–815, <https://doi.org/10.1111/j.1600-0706.2012.00254.x>.
37. Morrison, W.E.; Hay, M.E. Herbivore preference for native vs. exotic plants: Generalist herbivores from multiple continents prefer exotic plants that are evolutionarily naïve. *PLoS ONE* **2011**, *6*, e17227, <https://doi.org/10.1371/journal.pone.0017227>.
38. Gladieux, P.; Feurtey, A.; Hood, M.E.; Snirc, A.; Clavels, J.; Dutech, C.; Roy, M.; Giraud, T. The population biology of fungal invasions. *Mol. Ecol.* **2015**, *24*, 1969–1986, <https://doi.org/10.1111/mec.13028>.
39. Roques, A.; Shi, J.; Auger-Rozenberg, M.-A.; Ren, L.; Augustin, S.; Luo, Y. Are invasive patterns of non-native insects related to woody plants differing between Europe and China? *Front. For. Glob. Chang.* **2020**, *2*, 91, <https://doi.org/10.3389/ffgc.2019.00091>.
40. Keane, R.M.; Crawley, M.J. Exotic plant invasions and the enemy release hypothesis. *Trends Ecol. Evol.* **2010**, *17*, 164–170, [https://doi.org/10.1016/S0169-5347\(02\)02499-0](https://doi.org/10.1016/S0169-5347(02)02499-0).
41. Wolfe, L.M. Why alien invaders succeed: Support for the escape-from-enemy hypothesis. *Am. Nat.* **2002**, *160*, 705–711, <https://doi.org/10.1086/343872>.
42. Kenis, M.; Auger-Rozenberg, M.A.; Roques, A.; Timms, L.; Péré, C.; Cock, M.J.W.; Settele, J.; Augustin, S.; Lopez-Vaamonde, C. Ecological effects of invasive alien insects. *Biol. Invasions* **2009**, *11*, 21–45, <https://doi.org/10.1007/s10530-008-9318-y>.
43. Sache, I.; Roy, A.S.; Suffert, F.; Desprez-Loustau, M.L. Invasive plant pathogens in Europe. In *Biological Invasions: Economic and Environmental Costs of Alien Plant, Animal, and Microbe Species*, 2nd ed.; Pimentel, D., Ed.; CRC Press-Taylor and Francis Group: Boca Raton, FL, USA, 2011; <https://doi.org/10.1201/b10938>.
44. Lovett, G.M.; Weiss, M.; Liebhold, A.M.; Holmes, T.P.; Leung, B.; Lambert, K.F.; Orwig, D.A.; Campbell, F.T.; Rosenth, J.; McCullough, D.G.; et al. Nonnative forest insects and pathogens in the United States: Impacts and policy options. *Ecol. Appl.* **2016**, *26*, 1437–1455, <https://doi.org/10.1890/15-1176>.
45. Hulme, P.E.; Bacher, S.; Kenis, M.; Klotz, S.; Kühn, I.; Minchin, D.; Nentwig, W.; Olenin, S.; Panov, V.; Pergl, J.; et al. Grasping at the routes of biological invasions: A framework for integrating pathways into policy. *J. Appl. Ecol.* **2008**, *45*, 323–341; <https://doi.org/10.1111/j.1365-2664.2007.01442.x>.
46. Moore, B.A. *Alien Invasive Species: Impacts on Forests and Forestry. A Review*; Forest Health and Biosecurity Working Paper 8. Forest Resources Development Service Working Paper FBS/8E; Forest Resources Division FAO: Rome, Italy, 2005.
47. Brasier, C.M. China and the origins of Dutch elm disease: An appraisal. *Plant Pathol.* **1990**, *39*, 5–16, <https://doi.org/10.1111/j.1365-3059.1990.tb02470.x>.
48. Brasier, C.M.; Kirk, S.A. Designation of the EAN and NAN races of *Ophiostoma novo-ulmi* as subspecies. *Mycol. Res.* **2001**, *105*, 547–554, <http://dx.doi.org/10.1017/S0953756201004087>.
49. Brasier, C.M.; Gibbs, J.N. Origin of the Dutch elm disease Epidemic in Britain. *Nature* **1973**, *242*, 607–609, <https://doi.org/10.1038/242607a0>.
50. Brasier, C.M. Intercontinental spread and continuing evolution of the Dutch elm disease pathogens. In *The Elms*; Dunn, C.P., Ed.; Springer: Boston, MA, USA, 2000; pp. 61–72.
51. Vettraino, A.M.; Morel, O.; Perlerou, C.; Robin, C.; Diamandis, S.; Vannini, A. Occurrence and distribution of *Phytophthora* species in European chestnut stands and their association with ink disease and crown decline. *Eur. J. Plant Pathol.* **2005**, *111*, 169–180, <https://doi.org/10.1007/s10658-004-1882-0>.
52. Milgroom, M.G.; Wang, K.; Zhou, Y.; Lipari, S.E.; Kaneko, S. Intercontinental population structure of the chestnut blight fungus, *Cryphonectria parasitica*. *Mycologia* **1996**, *88*, 179–190, <https://doi.org/10.1080/00275514.1996.12026642>.
53. Panconesi, A. Canker stain of plane trees: A serious danger to urban plantings in Europe. *J. Plant Pathol.* **1999**, *81*, 3–15. <https://dx.doi.org/10.4454/jpp.v81i1.1041>.
54. Moricca, S.; Panconesi, A. Canker stain of plane-trees: A serious threat to North-European urban plantations. *Mitt. Biol. Bundesanst. Land-Forstwirtschaft. Berl.-Dahl.* **2000**, *370*, 97–100, ISSN: 0067-5849.
55. Panconesi, A.; Moricca, S.; Dellavalle, I.; Torraca, G. The epidemiology of canker stain of Plane tree and its spread from urban plantings to spontaneous groves and natural forests. In Proceedings of the Second International Symposium on Plant Health in Urban Horticulture, Berlin, Germany, 27–29 August, 2003; pp. 84–91.
56. Wagener, W.W. Diseases of Cupressus. In Proceedings of the FAO-IUFRO Symposium on Internationally Dangerous Forest Diseases and Insects, Oxford, UK, 20–29 July 1964; pp. 17–24.
57. Graniti, A. Cypress canker: A pandemic in progress *Annu. Rev. Phytopathol.* **1998**, *36*, 91–118.

58. Sutton, B.C.; Gibson, I.A.S. *Seiridium cardinale*. CMI Description of Pathogenic Fungi and Bacteria No. 326; Commonwealth Mycological Institute: Kew, UK, 1972.
59. Grasso, V.; Ponchet, J. Historique, distribution géographique et hôtes du *Coryneum cardinale*. *Wag. See Ref.* **1979**, *31*, 119–126.
60. Graniti, A. *Seiridium* blight of cypress—Another ecological disaster? *Plant Dis.* **1993**, *77*, 544.
61. Panzavolta, T.; Panichi, A.; Bracalini, M.; Croci, F.; Benigno, A.; Ragazzi, A.; Tiberi, R.; Moricca, S. Tree pathogens and their insect-mediated transport: Implications for oak tree die-off in a natural park area. *Glob. Ecol. Conserv.* **2018**, *15*, e00437, <https://doi.org/10.1016/j.gecco.2018.e00437>.
62. Fiala, T.; Holuša, J. Occurrence of the invasive bark beetle *Phloeosinus aubei* on common juniper trees in the Czech Republic. *Forests* **2019**, *10*, 12, <https://doi.org/10.3390/f10010012>.
63. Michalski, J. *Revision of the Palearctic Species of the Genus Scolytus Geoffroy (Coleoptera, Scolytidae)*; Panstwowe Wydawnictwo Naukowe: Warsaw, Poland, 1973, 214 pp.
64. Bloomfield, H. Elms for always. *Am. For.* **1979**, *85*, 24–26, 48, 50.
65. Lowe, S.; Browne, M.; Boudjelas, S.; De Poorter, M. *100 of the World's Worst Invasive Alien Species A Selection from the Global Invasive Species Database*; Invasive Species Specialist Group: Auckland, New Zealand, 2000; 12pp.
66. Bradshaw, C.; Leroy, B.; Bellard, C.; Roiz, D.; Albert, C.; Fournier, A.; Barbet-Massin, M.; Salles, J.M.; Simard, F.; Courchamp, F. Massive yet grossly underestimated global costs of invasive insects. *Nat. Commun.* **2016**, *7*, 12986, <https://doi.org/10.1038/ncomms12986>.
67. Montgomery, M.E.; Wallner, W.E. The gypsy moth. A westward migrant. In *Dynamics of Forest Insect Populations: Patterns, Causes, Implications*; Berryman, A.A., Ed.; Plenum Press: New York, NY, USA, 1988; pp. 353–376.
68. Leuschner, W.A.; Young, J.A.; Waldon, S.A.; Ravlin, F.W. Potential benefits of slowing the gypsy moth's spread. *South. J. Appl. For.* **1996**, *20*, 65–73.
69. Bigsby, K.M.; Ambrose, M.J.; Tobin, P.C.; Sills, E.O. The cost of gypsy moth sex in the city. *Urban For. Urban Green.* **2014**, *13*, 459–468, <https://doi.org/10.1016/j.ufug.2014.05.003>.
70. Morin, R.S.; Liebhold, A.M.; Gottschalk, K.W.; Acciavatti, R.; Twardus, D.; White, R.; Horsley, S.; Smith, W. *Forest Health Conditions on the Allegheny National Forest (1989–1999): Analysis of Forest Health Monitoring Surveys. NA-TP-04-01*; Department of Agriculture, Forest Service, Northeastern Area, State and Private Forestry: Newton Square, PA, USA, 2001.
71. CABI. Available online: <https://www.cabi.org/isc/datasheet/13579> (accessed on 26 July 2021).
72. O'Neil, C. *Cypress Aphid, Cinara cupressi*; The Entomology and Forest Resources Digital Information Work Group, College of Agricultural and Environmental Sciences and Warnell School of Forest Resources, The University of Georgia: Tifton, GA, USA, 1998. Available online: www.afea.org/html/98-202.html (accessed on 27 July 2021).
73. Watson, G.W.; Voegtlin, D.J.; Murphy, S.T.; Footitt, R.G. Biogeography of the *Cinara cupressi* complex (Hemiptera: Aphididae) on *Cupressaceae*, with description of a pest species introduced into Africa. *Bull. Entomol. Res.* **1999**, *89*, 271–283.
74. Jung, T.; Horta Jung, M.; Webber, J.F.; Kageyama, K.; Hieno, A.; Masuya, H.; Uematsu, S.; Pérez-Sierra, A.; Harris, A.R.; Forster, J.; et al. The destructive tree pathogen *Phytophthora ramorum* originates from the laurosilva forests of East Asia. *J. Fungi*, **2021**, *7*, 226, <https://doi.org/10.3390/jof7030226>.
75. Rizzo, D.M.; Garbelotto, M.; Davidson, J.M.; Slaughter, G.W.; Koike, S.T. *Phytophthora ramorum* as the cause of extensive mortality of *Quercus* spp. and *Lithocarpus densiflorus* in California. *Plant Dis.* **2002**, *86*, 205–214, <https://doi.org/10.1094/pdis.2002.86.3.205>.
76. Brasier, C.M.; Webber, J.L. Sudden larch death. *Nature* **2010**, *466*, 824–825, <https://doi.org/10.1038/466824a>.
77. Shearer, B.; Crane, C.; Cochrane, A. A thief of time: *Phytophthora cinnamomi* and threatened flora. *Austr. Plant Conserv.* **2005**, *13*, 14–15, <https://doi.org/10.1007/s13313-013-0215-1>.
78. Hansen, E.M. *Phytophthora* species emerging as pathogens of forest trees. *Curr. For. Rep.* **2015**, *1*, 16–24, <https://doi.org/10.1007/s40725-015-0007-7>.
79. Green, S.; Brasier, C.M.; Schlenzig, A.; McCracken, A.; MacAskill, G.A.; Wilson, M.; Webber, J.F. The destructive invasive pathogen *Phytophthora lateralis* found on *Chamaecyparis lawsoniana* across the UK. *For. Pathol.* **2013**, *43*, 19–28, <https://doi.org/10.1111/j.1439-0329.2012.00788.x>.
80. Hantula, J.; Scholler, M. NOBANIS—Invasive Alien Species Fact Sheet—*Melampsorium hiratsukanum*. Database of the European Network on Invasive Alien Species. NOBANIS, 2013. Available online: <https://www.nobanis.org/fact-sheets/> (accessed on 23 March 2021).
81. Moricca, S.; Benigno, A.; Oliveira Longa, C.M.; Cacciola, S.O.; Maresi, G. First documentation of life cycle completion of the alien rust pathogen *Melampsorium hiratsukanum* in the Eastern Alps proves its successful establishment in this mountain range. *J. Fungi* **2021**, *7*, 617, <https://doi.org/10.3390/jof7080617>.
82. McKinney, L.V.; Nielsen, L.R.; Collinge, D.B.; Thomsen, I.M.; Hansen, J.K.; Kjaer, E.D. The ash dieback crisis: Genetic variation in resistance can prove a long-term solution. *Plant Pathol.* **2014**, *63*, 485–499, <https://doi.org/10.1111/ppa.12196>.
83. Hill, L.; Jones, G.; Atkinson, N.; Hector, A.; Hemery, G.; Brown, N. The £15 billion cost of ash dieback in Britain. *Curr. Biol.* **2019**, *29*, R315–R316, <https://doi.org/10.1016/j.cub.2019.03.033>.
84. Nirenberg, H.I.; O'Donnell, K. New *Fusarium* species and combinations within the *Gibberella fujikuroi* species complex. *Mycologia* **1998**, *90*, 434–458.

85. Wingfield, M.J.; Hammerbacher, A.; Ganley, R.J.; Steenkamp, E.T.; Gordon, T.R.; Wingfield, B.D. Pitch canker caused by *Fusarium circinatum*—A growing threat to pine plantations and forests worldwide. *Australas. Plant Pathol.* **2008**, *37*, 319–334. <https://doi.org/10.1071/AP08036>.
86. Pehl, L.; Cech, T.L.; Ios, R. *Lecanosticta acicola* (formerly *Mycosphaerella dearnessii*), *Dothistroma septosporum* (formerly *Mycosphaerella pini*) and *Dothistroma pini*. *EPPO Bull.* **2015**, *45*, 163–182.
87. Barnes, I.; Crous, P.W.; Wingfield, B.D.; Wingfield, M.J. Multigene phylogenies reveal that red band needle blight of *Pinus* is caused by two distinct species of *Dothistroma*, *D. septosporum* and *D. pini*. *Stud. Mycol.* **2004**, *50*, 551–566.
88. Watt, M.S.; Kriticos, D.J.; Alcaraz, S.; Brown, A.V.; Leriche, A. The hosts and potential geographic range of *Dothistroma* needle blight. *For. Ecol. Manag.* **2009**, *257*, 1505–1519. <https://doi.org/10.1016/j.foreco.2008.12.026>.
89. Ghelardini, L.; Aglietti, C.; Loria, F.; Cerboneschi, M.; Giogni, A.; Goti, E.; Maresi, G.; Moricca, S.; Marchi, G. *Dothistroma* Needle Blight in protected pine forests in Italy. *Manag. Biol. Invasions* **2020**, *11*, 689–702. <https://doi.org/10.3391/mbi.2020.11.4.05>.
90. Wingfield, M.J.; Coutinho, T.A.; Roux, J.; Wingfield, B.D. The future of exotic plantation forestry in the tropics and southern hemisphere: Lessons from pitch canker. *S. Afr. For. J.* **2002**, *195*, 79–82. <https://doi.org/10.1080/20702620.2002.10434607>.
91. Bulman, L.S.; Bradshaw, R.E.; Fraser, S.; Martn-Garca, J.; Barnes, I.; Musolin, D.L.; La Porta, N.; Woods, A.J.; Diez, J.J.; Koltay, A.; et al. A worldwide perspective on the management and control of *Dothistroma* needle blight. *Forest Pathol.* **2016**, *46*, 472–488. <https://doi.org/10.1111/efp.12305>.
92. Gibson, I.A.S. Impact and control of *Dothistroma* blight of pines. *Eur. J. For. Pathol.* **1974**, *4*, 89–100.
93. Villebonne, D.; Maugard, F. Rapid development of *Dothistroma* needle blight (*Scirrhia pini*) on Corsican pine (*Pinus nigra* subsp. *laricio*) in France. In *La Sante des Forets, Annual Report 1998*; Les Cahiers du Département de la santé des forêts (DSF); DERF: Paris, France, 1999.
94. Newton, L.P.; Fowler, G.; Neeley, A.D.; Schall, R.A.; Takeuchi, Y. *Pathway Assessment: Geosmithia sp. and Pityophthorus juglandis Blackman Movement from the Western into the Eastern United States*; U.S. Department of Agriculture Animal and Plant Health Inspection Service: Raleigh, NC, USA, 2009; 50pp.
95. Montecchio, L.; Faccoli, M. First record of thousand cankers disease *Geosmithia morbida* and walnut twig beetle *Pityophthorus juglandis* on *Juglans nigra* in Europe. *Plant Dis.* **2014**, *98*, 696. <https://doi.org/10.1094/pdis-10-13-1027-pdn>.
96. Moricca, S.; Bracalini, M.; Benigno, A.; Ginetti, B.; Pelleri, F.; Panzavolta, T. Disease Note. Thousand cankers disease caused by *Geosmithia morbida* and its insect vector *Pityophthorus juglandis* first reported on *Juglans nigra* in Tuscany, Central Italy. *Plant Dis.* **2019**, *103*, 369. <https://doi.org/10.1094/PDIS-07-18-1256-PDN>.
97. Umeda, C.; Eskalen, A.; Paine, T.D. Polyphagous Shot Hole Borer and *Fusarium* Dieback in California. In *Insects and Diseases of Mediterranean Forest Systems*; Paine, T., Lieutier, F., Eds.; Springer: Cham, Switzerland, 2016; https://doi.org/10.1007/978-3-319-24744-1_26.
98. Haack, R.A.; Cavey, J.F.; Hoebeke, E.R.; Law, K. *Anoplophora glabripennis*: A new tree-infesting exotic cerambycid invades New York. *Mich. Entomol. Soc. Newsl.* **1996**, *41*, 1–3.
99. EPPO. *Anoplophora chinensis* Found under Glasshouse in Georgia (US). Available online: <https://gd.eppo.int/reporting/article-3421> (accessed on 26 July 2021).
100. Hérard, F.; Maspero, M. History of discoveries and management of the citrus longhorned beetle, *Anoplophora chinensis*, in Europe. *J. Pest Sci.* **2019**, *92*, 117–130. <https://doi.org/10.1007/s10340-018-1014-9>.
101. Haack, R.A.; Hérard, F.; Sun, J.; Turgeon, J.J. Managing invasive populations of Asian longhorned beetle and citrus longhorned beetle: A worldwide perspective. *Annu. Rev. Entomol.* **2010**, *55*, 521–546. <https://doi.org/10.1146/annurev-ento-112408-085427>.
102. Siegert, N.W.; McCullough, D.G.; Liebhold, A.M.; Telewski, F.W. Dendrochronological reconstruction of the epicentre and early spread of emerald ash borer in North America. *Divers. Distrib.* **2014**, *20*, 847–858. <https://doi.org/10.1111/ddi.12212>.
103. EPPO. *Agrilus planipennis*. EPPO Datasheets on Pests Recommended for Regulation. Available online. <https://gd.eppo.int> (accessed on 26 July 2021).
104. Orlova-Bienkowskaja, M.J.; Drogvalenko, A.N.; Zabaluev, I.A.; Sazhnev, A.S.; Peregudova, E.Y.; Mazurov, S.G.; Komarov, E.V.; Struchaev, V.V.; Martynov, V.V.; Nikulina, T.V.; et al. Current range of *Agrilus planipennis* Fairmaire, an alien pest of ash trees, in European Russia and Ukraine. *Ann. For. Sci.* **2020**, *77*, 29. <https://doi.org/10.1007/s13595-020-0930-z>.
105. Drogvalenko, A.N.; Orlova-Bienkowskaja, M.J.; Bieńkowski, A.O. Record of the emerald ash borer (*Agrilus planipennis*) in Ukraine is confirmed. *Insects* **2019**, *10*, 338. doi:10.3390/insects10100338.
106. Marzano, M.; Hall, C.; Dandy, N.; Fisher, C.L.; Diss-Torrance, A.; Haight, R.G. Lessons from the frontline: Exploring how stakeholders may respond to emerald ash borer management in Europe. *Forests* **2020**, *11*, 617. <https://doi.org/10.3390/f11060617>.
107. Thompson, I.; Mackey, B.; McNulty, S.; Mosseler, A. *Forest Resilience, Biodiversity, and Climate Change: A Synthesis of the Biodiversity/Resilience/Stability Relationship in Forest Ecosystems*; Technical Series no. 43; Secretariat of the Convention on Biological Diversity: Montreal, QC, Canada, 2009; 67pp.
108. Rytter, L.; Johansson, K.; Karlsson, B.; Stener, L.-G. Tree species, genetics and regeneration for bioenergy feedstock in Northern Europe. In *Forest Bioenergy Production, Management, Carbon Sequestration and Adaptation*; Kellomäki, S., Kilpeläinen, A., Alam, A., Eds.; Springer: New York, NY, USA, 2013; pp. 7–37.
109. Pérez, G.; Hunter, G.C.; Slippers, B.; Pérez, C.; Wingfield, B.D.; Wingfield, M.J. *Teratosphaeria* (*Mycosphaerella*) *nubilosa*, the causal agent of *Mycosphaerella* leaf disease (MLD), recently introduced into Uruguay. *Eur. J. Plant Pathol.* **2009**, *125*, 109–118. <https://doi.org/10.1007/s10658-009-9463-x>.

110. European Commission. *The Insect Killing Our Palm Trees. EU Efforts to Stop the Red Palm Weevil*; Office for Official Publications of the European Communities: Luxembourg, 2011.
111. Burks, R.A.; Mottern, J.L.; Waterworth, R.; Paine, T.D. First report of the *Eucalyptus* gall wasp, *Ophelinus maskelli* (Hymenoptera: Eulophidae), an invasive pest on *Eucalyptus*, from the Western Hemisphere. *Zootaxa* **2015**, *3926*, 448–450. <https://doi.org/10.11646/zootaxa.3926.3.10>.
112. Wittenberg, R.; Cock, M.J.W. Best practices for the prevention and management of invasive alien species. In *Invasive Alien Species: A New Synthesis*; Mooney, H.A., Mack, R.N., McNeely, J.A., Neville, L.E., Scheiand, P.J., Waage, J.K., Eds.; Island Press: Washington, DC, USA, 2005; pp. 209–232.
113. Rizzo, D.; Moricca, S.; Bracalini, M.; Benigno, A.; Bernardo, U.; Luchi, N.; Da Lio, D.; Nugnes, F.; Cappellini, G.; Salemi, C.; et al. Rapid detection of *Pityophthorus juglandis* (Blackman) (Coleoptera, Curculionidae) with the Loop-Mediated Isothermal Amplification (LAMP) method. *Plants* **2021**, *10*, 1048, <https://doi.org/10.3390/plants10061048>.
114. Piel, F.; Gilbert, M.; De Canniere, C.; Gregoire, J.C. Coniferous round wood imports from Russia and Baltic countries to Belgium. A pathway analysis for assessing risks of exotic pest insect introductions. *Divers. Distrib.* **2008**, *14*, 318–328, <https://doi.org/10.2737/PSW-GTR-250>.
115. Matthews, J.; Beringen, R.; Creemers, R.; Hollander, H.; Van Kessel, N.; Van der Kleef, H.; van der Velde, G.; Verbrugge, L.N.H.; Leuven, R.S.E.W. *Horizon Scanning for New Invasive Non-Native Species in the Netherlands*; Department of Environmental Science, Institute for Water and Wetland Research, Faculty of Science, Radboud University Nijmegen: Nijmegen, The Netherlands, 2014; 117pp.
116. Mack, R.N.; Barrett, S.C.H.; deFur, P.L.; MacDonald, W.L.; Madden, L.V.; Marshall, D.S.; McCullough, D.G.; McEvoy, P.B.; Nyrop, J.P.; Reichard, S.E.H.; et al. *Predicting Invasions of Nonindigenous Plants and Plant Pests*; National Academy of Sciences: Washington DC, USA, 2002; 194pp.
117. Shine, C.; Kettunen, M.; Genovesi, P.; Essl, F.; Gollasch, S.; Rabitsch, W.; Scalera, R.; Starfinger, U.; Ten Brink, P. *Assessment to Support Continued Development of the EU Strategy to Combat Invasive Alien Species*. Institute for European Environmental Policy (IEEP): Brussels, Belgium, 2010; 298pp.
118. Kenis, M.; Li, H.; Fan, J.T.; Courtial, B.; Auger-Rozenberg, M.A.; Yart, A.; Eschen, R.; Roques, A. Sentinel nurseries to assess the phytosanitary risks from insect pests on importations of live plants. *Sci. Rep.* **2018**, *8*, 11217, <https://doi.org/10.1038/s41598-018-29551-y>.
119. Vettraino, A.M.; Li, H.-M.; Eschen, R.; Morales-Rodriguez, C.; Vannini, A. The sentinel tree nursery as an early warning system for pathway risk assessment: Fungal pathogens associated with Chinese woody plants commonly shipped to Europe. *PLoS ONE*, **2017**, *12*, e0188800, <https://doi.org/10.1371/journal.pone.0188800>.
120. McCartney, H.A.; Foster, S.J.; Fraaije, B.A.; Ward, E. Molecular diagnostics for fungal plant pathogens. *Pest. Manag. Sci.* **2003**, *59*, 129–142, <https://doi.org/10.1002/ps.575>.
121. Rizzo, D.; Da Lio, D.; Bartolini, L.; Cappellini, G.; Bruscoli, T.; Bracalini, M.; Benigno, A.; Salemi, C.; Del Nista, D.; Aronadio, A.; et al. A duplex real-time PCR with probe for simultaneous detection of *Geosmithia morbida* and its vector *Pityophthorus juglandis*. *PLoS ONE* **2020**, *15*, e0241109, <https://doi.org/10.1371/journal.pone.0241109>.
122. Fekrat, L.; Aghl, M.Z.; Tahan, V. Application of the LAMP assay as a diagnostic technique for rapid identification of *Thrips tabaci* (Thysanoptera: Thripidae). *J. Econ. Entomol.* **2015**, *108*, 1337–1343, <https://doi.org/10.1093/jee/tov099>.
123. Blaser, S.; Diem, H.; Von Felten, A.; Gueuning, M.; Andreou, M.; Boonham, N.; Tomlinson, J.; Müller, P.; Utzinger, J.; E Frey, J.; et al. From laboratory to point of entry: development and implementation of a loop-mediated isothermal amplification (LAMP)-based genetic identification system to prevent introduction of quarantine insect species. *Pest Manag. Sci.* **2018**, *74*, 1504–1512, <https://doi.org/10.1002/ps.4866>.
124. Rizzo, D.; Luchi, N.; Da Lio, D.; Bartolini, L.; Nugnes, F.; Cappellini, G.; Bruscoli, T.; Salemi, C.; Griffo, R.V.; Garonna, A.P.; et al. Development of a loop-mediated isothermal amplification (LAMP) assay for the identification of the invasive wood borer *Aromia bungii* (Coleoptera: Cerambycidae) from frass. *Biotech* **2021**, *11*, 1–12, <https://doi.org/10.1007/s13205-020-02602-w>.
125. Tordoni, E.; Ametrano, C.G.; Banchi, E.; Ongaro, S.; Pallavicini, A.; Bacaro, G.; Muggia, L. Integrated eDNA metabarcoding and morphological analyses assess spatio-temporal patterns of airborne fungal spores. *Ecol. Indic.* **2021**, *121*, 107032, ISSN 1470-160X. <https://doi.org/10.1016/j.ecolind.2020.107032>.
126. Martin, R.R.; James, D.; Lévesque, C.A. Impacts of molecular diagnostic technologies on plant disease management. *Annu. Rev. Phytopathol.* **2000**, *38*, 207–239, <https://doi.org/10.1146/annurev.phyto.38.1.207>.
127. Li, M.; Liu, M.; Liu, M.; Ju, Y. Monitoring exotic forest pest based on high-resolution remote sensing image and CART model. In *Proceedings of the 3rd International Congress on Image and Signal Processing*; Yantai, China, 16–18 October 2010; Tan, Z.H., Wan, Y., Xiang, T., Song, Y., Eds.; Institute of Electrical and Electronics Engineers (IEEE): Piscataway, NJ, USA; pp. 2203–2206, doi:10.1109/CISP.2010.5647451.
128. Hall, R.; Castilla, G.; White, J.; Cooke, B.; Skakun, R. Remote sensing of forest pest damage: A review and lessons learned from a Canadian perspective. *Can. Entomol.* **2016**, *148*, S296–S356, <https://doi.org/10.4039/tce.2016.11>.
129. Hoyer-Tomiczek, U.; Sauseng, G.; Hoch, G. Scent detection dogs for the Asian longhorn beetle, *Anoplophora glabripennis*. *EPPO Bull.* **2016**, *46*, 148–155, <https://doi.org/10.1111/epp.12282>.
130. Mosconi, F.; Campanaro, A.; Carpaneto, G.M.; Chiari, S.; Hardersen, S.; Mancini, E.; Maurizi, E.; Sabatelli, S.; Zauli, A.; Mason, F.; et al. Training of a dog for the monitoring of *Osmoderma eremita*. *Nat. Conserv.* **2017**, *20*, 237–264, <https://doi.org/10.3897/natureconservation.20.12688>.

131. Brown, N.; van den Bosch, F.; Parnell, S.; Denman, S. Integrating regulatory surveys and citizen science to map outbreaks of forest diseases: Acute oak decline in England and Wales. *Proc. Royal Soc. B* **2017**, *284*, 20170547, <https://doi.org/10.1098/rspb.2017.0547>.
132. Panzavolta, T.; Bracalini, M.; Tiberi, R. Impatto delle invasioni biologiche sul paesaggio urbano. In *Paesaggi Abitati: Dalla Percezione al Sistema Complesso*; Bolletti, S., Puma, P., Eds.; Edifir Edizioni Firenze s.r.l.: Florence, Italy, 2021; pp. 73–79.
133. Bonney, R.; Shirk, J.L.; Phillips, T.B.; Wiggins, A.; Ballard, H.L.; Miller-Rushing, A.J.; Parrish, J.K. Next steps for citizen science. *Science* **2014**, *343*, 1436–1437, <https://doi.org/10.1126/science.1251554>.
134. Bonney, R.; Phillips, T.B.; Ballard, H.L.; Enck, J.W. Can citizen science enhance public understanding of science? *Public Underst. Sci.* **2016**, *25*, 2–16, <https://doi.org/10.1177/0963662515607406>.
135. Suckling, D.M.; Stringer, L.D.; Stephens, A.E.A.; Woods, B.; Williams, D.G.; Baker, G.; El-Sayed, A.M. From integrated pest management to integrated pest eradication: Technologies and future needs. *Pest Manag. Sci.* **2013**, *70*, 179–189, <https://doi.org/10.1002/ps.3670>.
136. Pluess, T.; Jarosik, V.; Pysek, P.; Cannon, R.; Pergl, J.; Breukers, A.; Bacher, S. Which factors affect the success or failure of eradication campaigns against alien species? *PLoS ONE* **2012**, *7*, e48157, <https://doi.org/10.1371/journal.pone.0048157>.
137. Moricca, S.; Bracalini, M.; Benigno, A.; Panzavolta, T. Observations on the non-native thousand cankers disease of walnut in Europe's southernmost outbreak. *Global Ecol. Conserv.* **2020**, *23*, e01159, <https://doi.org/10.1016/j.gecco.2020.e01159>.
138. Liebhold, A.M.; Kean, J.M. Eradication and containment of non-native forest insects: Successes and failures. *J. Pest Sci.* **2019**, *92*, 83–91, <https://doi.org/10.1007/s10340-018-1056-z>.
139. Vainio, E.J.; Bezos, D.; Bragança, H.; Cleary, M.; Fourie, G.; Georgieva, M.; Ghelardini, L.; Hannunen, S.; Ioo, R.; Martín-García, J.; et al. Sampling and detection strategies for the pine pitch canker (PPC) disease pathogen *Fusarium circinatum* in Europe. *Forests* **2019**, *10*, 723, <https://doi.org/10.3390/f10090723>.
140. Ramsfield, T.D.; Bentz, B.J.; Faccoli, M.; Jactel, H.; Brockerhoff, E.G. Forest health in a changing world: Effects of globalization and climate change on forest insect and pathogen impacts. *Forestry* **2016**, *89*, 245–252, <https://doi.org/10.1093/forestry/cpw018>.
141. Caltagirone, L.E.; Doutt, R.L. The history of the vedalia beetle importation to California and its impact on the development of biological control. *Annu. Rev. Entomol.* **1989**, *34*, 1–16.
142. McEvoy, P.; Cox, C.; Coombs, E. Successful biological control of ragwort, *Senecio jacobaea*, by introduced insects in Oregon. *Ecol. Appl.* **1991**, *1*, 430–442.
143. Radcliffe, E.B.; Flanders, K.L. Biological control of alfalfa weevil in North America. *Integr. Pest Manag. Rev.* **1998**, *3*, 225–242, <https://doi.org/10.1023/A:1009611219360>.
144. Ferracini, C.; Ferrari, E.; Saladini, M.A.; Pontini, M.; Corradetti, M.; Alma, A. Non-target host risk assessment for the parasitoid *Torymus sinensis*. *BioControl* **2015**, *60*, 583–594, doi:10.1007/s10526-015-9676-1.
145. Vasilias, R.; Larsson, E.; Larsson, K.-H.; Stenlid, J. Persistence and long-term impact of Rotstop biological control agent on mycodiversity in *Picea abies* stumps. *Biol. Control.* **2005**, *32*, 295–304, <https://doi.org/10.1016/j.biocontrol.2004.10.008>.
146. Tubby, K.V.; Scott, D.; Webber, J.F. Relationship between stump treatment coverage using the biological control product PG Suspension, and control of *Heterobasidion annosum* on Corsican pine, *Pinus nigra* ssp. *Laricio*. *For. Path.* **2008**, *38*, 37–46. <http://dx.doi.org/10.1111/j.1439-0329.2007.00519.x>.
147. Korhonen, K.; Stenlid, J. Biology of *Heterobasidion annosum*. In *Heterobasidion annosum. Biology, Ecology, Impact and Control*; Woodward, S., Stenlid, J., Karjalainen, R., Hüttermann, A., Eds.; CAB International: Wallingford, UK, 1998; pp. 43–70.
148. Slippers, B.; Hurley, B.P.; Wingfield, M.J. *Sirex* woodwasp: A model for evolving management paradigms of invasive forest pests. *Annu. Rev. Entomol.* **2015**, *60*, 601–619, <https://doi.org/10.1146/annurev-ento-010814-021118>.
149. Moricca, S.; Ragazzi, A. Biological and integrated means to control rust diseases. In *Integrated Management of Diseases Caused by Fungi, Phytoplasma and Bacteria*; Ciancio, A., Mukerji, K.J., Eds.; Springer: Berlin, Germany, 2008; pp. 303–329.
150. Van Lenteren, J.C.; Bale, J.; Bigler, F.; Hokkanen, H.M.T.; Loomans, A.J.M. Assessing risks of releasing exotic biological control agents of arthropod pests. *Annu. Rev. Entomol.* **2006**, *51*, 609–634, <https://doi.org/10.1146/annurev.ento.51.110104.151129>.
151. Yara, K.; Sasawaki, T.; Kunimi, Y. Hybridization between introduced *Torymus sinensis* (Hymenoptera: Torymidae) and indigenous *T. beneficus* (late-spring strain), parasitoids of the asian chestnut gall wasp *Dryocosmus kuriphilus* (Hymenoptera: Cynipidae). *Biol. Control.* **2010**, *54*, 14–18, doi:10.1016/j.biocontrol.2010.03.006.
152. Messing, R.; Brodeur, J. Current challenges to the implementation of classical biological control. *BioControl* **2018**, *63*, 1–9, <https://doi.org/10.1007/s10526-017-9862-4>.
153. ec.europa.eu. Available online: https://ec.europa.eu/commission/presscorner/detail/en/QANDA_19_6710 (accessed on 6 September 2021).
154. IPPC. *Establishing a National Plant Protection Organization.*; A guide to understand the principal requirements for establishing an organization to protect national plant resources from pests; FAO: Rome, Italy, 2015.
155. Scalera, R. How much is Europe spending on invasive alien species? *Biol. Invasions* **2010**, *12*, 173–177 <https://doi.org/10.1007/s10530-009-9440-5>.
156. Holdenreider, O.; Pautasso, M.; Weisberg, P.J.; Lonsdale, D. Tree diseases and landscape processes: The challenge of landscape pathology. *Trends. Ecol. Evol.* **2004**, *19*, 446–452, <https://doi.org/10.1016/j.tree.2004.06.003>.
157. Douglas, H.; Dang, B.T.; Gill, B.D.; Huber, J.; Mason, P.F.; Parker, D.J.; Sinclair, B.J. The importance of taxonomy in responses to invasive alien species. *Biodiversity* **2009**, *10*, 92–99, <https://doi.org/10.1080/14888386.2009.9712850>.

158. Gluck-Thaler, E.; Jason, C.; Slot, J.C. Dimensions of horizontal gene transfer in eukaryotic microbial pathogens. *PLoS Pathog.* **2015**, *11*, e1005156. <https://dx.doi.org/10.1371/journal.ppat.1005156>.
159. Brasier, C.M. The rise of the hybrid fungi. *Nature* **2000**, *405*, 134–135, <https://doi.org/10.1038/35012193>.
160. McMullan, M.; Rafiqi, M.; Kaithakottil, G.; Clavijo, B.J.; Bilham, L.; Orton, E.; Percival-Alwyn, L.; Ward, B.J.; Edwards, A.; Saunders, D.G.O.; *et al.* The ash dieback invasion of Europe was founded by two genetically divergent individuals. *Nat. Ecol. Evol.* **2018**, *2*, 1000–1008.
161. Albanese, G.; Saponari, M.; Faggioli, F. Phytosanitary certification. In *Olive Germplasm—The Olive Cultivation, Table and Olive Oil Industry in Italy*; Muzzalupo, I., Ed.; InTech Publisher: Rijeka, Croatia, 2012; pp. 107–132, ISBN 9789535108849.
162. Ricciardi, A.; Hoopes, M.F.; Marchetti, M.P.; Lockwood, J.L. Progress toward understanding the ecological impacts of non-native species. *Ecol. Monogr.* **2013**, *83*, 263–282, <https://doi.org/10.1890/13-0183.1>.