

# 4 Globalization and its implications to forest health

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## **Introduction**

Consideration of forest health is central to the sustainable management of forests. While many definitions of forest health have been proposed, the most widely adopted concept refers to the sustained functioning of desired forest ecosystem processes (Kolb et al., 1994). Legitimate complaints have been raised about the human-centric usage of the term “Forest Health,” particularly the inappropriate analogy to human health (Raffa et al., 2009), but the concept is widely applied and provides a useful guide for management of forests around desired ecosystem functioning. The term also provides a useful expression for describing work on forest disturbance agents such as insects and pathogens (e.g. Castello and Teale, 2011).

Certain forest disturbances caused by insects and pathogens play critical roles in ecosystem functioning. For example, recurrent bark beetle outbreaks often maintain regional equilibria of stand density and tree species composition (Amman, 1977). Forest defoliation caused by foliage-feeding insects often plays a crucial role in cycling nutrients within stands (Mattson and Addy, 1975). Guilds of insects and pathogens that play these important roles generally have existed in forest communities through much of their evolution. In contrast, the introduction of novel combinations of trees, insects and pathogens from different parts of the world can disrupt these ecosystem processes and thus impact very negatively on forest health.

Here we focus on how globalization is disrupting forest health conditions around the world and further, how this represents a threat to sustainable forest management. Novel associations brought about either by accidental invasions of insects and pathogens, or intentional introduction of tree species from one part of the world to another can result in combinations of species that degrade equilibrium ecosystem stability and consequently represent challenges to the sustainable management of forests (Liebhold et al., 1995; Wingfield et al., 2011)

Over the course of millions of years, the world’s fauna and flora have evolved in distinct biogeographic compartments, separated by oceans, mountain ranges and other barriers to dispersal. The end result of this

evolution in isolation is a collection of unique species assemblages. These forest community assemblages are comprised of species structured at many trophic levels, including trees (and other plants), herbivorous insects, insect predators, insect parasitoids, fungal symbionts, fungal pathogens and decay fungi. While the concept of a “balance of nature” is a gross simplification, it is legitimate to describe these species as existing in highly evolved ecological relationships. For example, there are many known mutualistic insect/fungal relationships (Six and Wingfield, 2011). Important ecosystem functions are facilitated by these species – herbivorous insects such as bark beetles play a crucial role in the cycling of forest nutrients; predators and parasitoids play critical roles in keeping herbivorous insects in check.

### **Globalization and breaking down barriers**

As David Cohen describes in Chapter 2, the emergence of human civilization has accelerated trade and connectivity – it has also brought about unprecedented movement of other species. Species ranges have never been static; paleontological evidence indicates that as climates have changed over the last several millennia, tree species ranges have shifted (Davis and Shaw, 2001) and no doubt so have shifted the ranges of insects and pathogens associated with these trees. But compared to current rates of species invasions, these prehistoric range shifts are orders of magnitude smaller, both in the number of species involved and their geographic scale.

The first significant wave of globalization began with European colonization of the world’s regions (Crosby, 2004). This first massive mobilization epoch brought with it the first large surge of species movement among continents. For example, earthworms were often inadvertently moved around the world in ship ballast by early European colonists (Bohlen et al., 2004). These invasions have had profound effects on ecological processes in forest and other ecosystems.

The industrial revolution began in Europe and spread to North America in the 1800s. Along with industrialization came increases in intercontinental trade in both raw and manufactured goods. These increases in trade resulted in both accidental and intentional movement of a wide variety of non-native species. Many of the most significant invasive forest insect pests in North America arrived via trade with Europe (Mattson et al., 2007).

World War II was another turning point in the global invasion problem. Several damaging species were accidentally transported as part of the movement of military equipment associated with the war (Hulme et al., 2008; Gonthier et al., 2007). More importantly, the end of World War II corresponded with a new global move toward free trade. This was solidified at the Bretton Woods conference held in 1944 which laid the groundwork for free trade agreements such as GATT and ultimately the WTO (Frieden, 2006). These agreements generally had a positive effect on invasions, both

by facilitating trade but also by making it more difficult for participating countries to impose quarantine regulations in response to perceived dangers of plant pest introductions.

Finally, the maturation of the global air transportation system in the 1970s and 1980s brought huge increases in air travel. While air passenger baggage has been implicated as an invasion pathway largely for agricultural pests (Liebhold et al., 2006), it has also facilitated unregulated importation of live plants by passengers. These plant imports provide a significant pathway for invasion by a variety of plant pests, including forest insects and diseases. For example, the Chestnut gall wasp, *Dryocosumus kuriphilus*, entered the USA in 1974 associated with chestnut plants transported by a private gardener in Georgia (Rieske, 2007).

### **Pathways for forest insect and pathogen invasions**

As discussed above, there are several different pathways by which forest insects and pathogens are transported from one part of the world to another. These include passenger baggage, mail and parcel post, intentional introduction and hitch-hiking (physical association with an object that is not host material – e.g. insect eggs laid on the outside of a shipping container) on cargo. An example of the hitch-hiker pathway is provided by the painted apple moth, *Teia anartoides*, a polyphagous foliage-feeder which is believed to have been accidentally introduced from Australia to Auckland, New Zealand in the late 1990s as eggs on the outside of a shipping container (Suckling et al., 2007). Examples of intentional introductions of forest pests include the horse chestnut leaf miner, *Cameraria ohridella*, which is believed to have been introduced to Austria intentionally by an amateur entomologist (Rabitsch and Essl, 2006) and the longhorn beetle, *Phoracantha semipunctata*, as well as other Eucalyptus-feeding insects, which are suspected of having been intentionally introduced to California by an unknown individual as part of an unauthorized campaign to control *Eucalyptus* spp. (Paine et al., 2010).

However, the two most important pathways for transport of forest insects and pathogens are the international movement of wood and importation of live plants. Figure 4.1 summarizes the results of several studies that identified the most likely pathways by which insect and pathogen species historically invaded various parts of the world. It shows that live plants are generally the largest single pathway, the only exception being wood-boring insects, for which imported wood is the principle invasion pathway.

Trade in round wood and lumber is well known as a pathway for invasions by wood-boring insects and pathogens. For example, the European elm bark beetle, *Scolytus multistriatus*, the primary vector of Dutch Elm disease, is believed to have been introduced to North America on imported logs (May, 1934). However, the form of wood that poses the greatest threat to pest invasions is solid wood packing material (SWPM) (Brockerhoff et al., 2006;

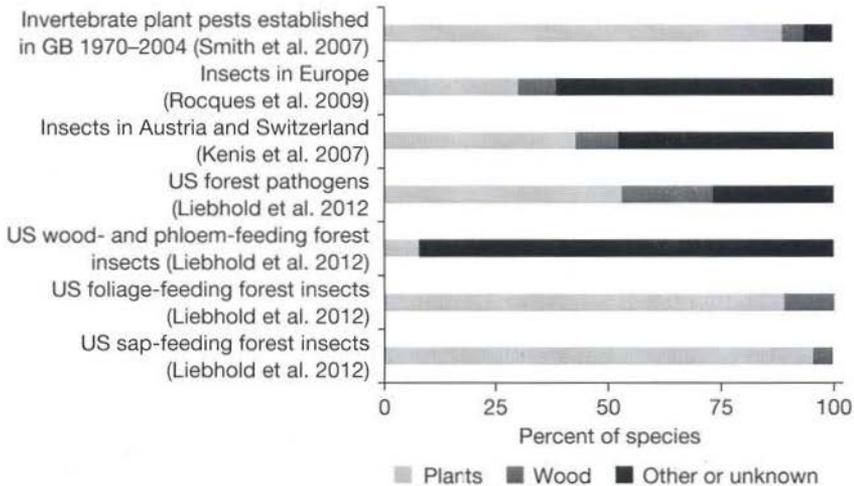


Figure 4.1 Pathways for invasive and pathogen species

Haack, 2006). This material includes wood used in crating, pallets, spools and dunnage. With the acceleration of post-World War II industrial trade, massive amounts of SWPM have moved around the world. Due to its low cost, low quality wood, including slab wood and other pieces retaining patches of bark, are used as SWPM but such wood often contains particularly large numbers of insects and pathogens. Associated with increasing worldwide movement of SWPM from the 1960s to the present has been a surge of invasions by bark and wood-boring insects (Aukema et al., 2010).

Recognizing the dangers of SWPM as a pathway for insect and disease invasions worldwide, the International Plant Protection Convention (IPPC) developed standards regulating the movement of SWPM in trade. This measure, International Standards for Phytosanitary Measures Number 15 (ISPM-15), prescribes heat treatment or fumigation of all SWPM used for export (IPPC, 2011). Recent results indicate that ISPM-15 is helpful in reducing movement of insects and pathogens, but it does not stop it; inspection data shows only a *ca.* 40 percent decrease in rates of SWPM contamination since implementation of ISPM-15 (Haack et al., 2014). While it is disappointing that ISPM-15 has not generated a larger decrease in arrival rates, the reasons for continued contamination of treated SWPM are non-compliance by exporters, infestation of SWPM post-treatment and failure of the treatments to kill 100 percent of all organisms present in SWPM. Revisions to ISPM-15 are being developed to address these issues.

Importation of live plants represents the most serious threat to insect and disease invasions worldwide (Liebhold et al., 2012); Figure 4.1 shows that it has historically been the most frequent invasion pathway for insects and pathogens. Live plants are the “perfect” medium for transplanting plant pests since the pests are essentially provided a meal to consume during their trip.

There are many reasons why plants are imported. First, the horticultural, agricultural and forestry industries are always searching for new plant varieties that are not native but may hold value for use in propagation. Second, low labor costs and favorable growing conditions in certain countries may create economic incentives to produce plants in one region and then ship them to another where they are sold and planted. So called “plants for planting” imports have massively increased over the last four decades in both Europe and North America with *ca.* four billion live plants imported annually to the USA alone (Liebhold et al., 2012).

Given the risks associated with plant imports, what measures can regulators implement to reduce these hazards? Measures taken by quarantine agencies include inspection, fumigation, heat/cold treatments, post-import quarantine observation as well as partial or total bans on imports. Approaches to regulating plant imports vary considerably among countries. Some countries, such as New Zealand, implement a “white list,” in which importation is limited to only specific taxa that have gone through a rigorous analysis of risk. Other countries, such as the USA, have historically implemented a “black list” system in which only plant taxa considered to be of high risk are banned and all other taxa are allowed to freely enter. In recent years however, the USA has implemented a “grey list” system in which imports of certain plant taxa are temporarily banned pending a risk assessment (Liebhold et al., 2012). Other plant import regulations vary considerably among countries; for example, the USA bans the import of soil with all imported plants while the European Union does not regulate soil at all. Soil is well known to commonly contain many harmful pathogens, nematodes and invertebrates and thus represents a risky part of the live plant pathway.

Another approach being implemented to minimize insect and disease introductions associated with plants is the “systems approach” (Parke and Grünwald, 2012). Such systems typically target specific potential invading species associated with certain plant genera. Under the systems approach, pest populations are managed during their production overseas and closely monitored prior to export for grower compliance of clean stock production.

### **Mechanisms of forest health dysfunction associated with invasions**

The problem of biological invasions is not limited to forest insects and pathogens. Considerable effort has gone into understanding why so many non-native species are problematic. Before addressing these theories, it must be pointed out that the vast majority of non-native species have no known impact; the so-called “tens rule” states that only one out of ten alien species are truly invasive in the sense that they become problems (Williamson and Fitter, 1996) and this appears to be approximately true for non-native forest insects (Aukema et al., 2010).

As described earlier, communities of species have evolved for millions of years in isolation of species in other communities located elsewhere in the

world. When a species invades a new region it comes into contact with species that do not have a previous evolutionary history of co-existence with it. While this is not always a recipe for disaster, these novel species associations can create unstable conditions. The two general categories of ecological interactions that frequently create instability in forest invader populations are enemy release and lack of host resistance.

Enemy release refers to the situation where an invading species escapes regulation from higher trophic levels and thereby exhibits extraordinary population growth. In highly evolved communities, most herbivore species are associated with guilds of predator, parasite and pathogen communities that maintain populations at moderate levels of abundance. These natural enemies may be specialists or they may be generalists and either through numerical or functional responses, these enemies exhibit density dependent effects that regulate host populations (Varley et al., 1974). By colonizing a novel habitat, herbivores and disease agents often escape this regulation and their densities may reach very high, damaging levels.

The enemy release mechanism serves as the foundation for classical biological control, which entails introduction of specialist natural enemies from a herbivore's native region. The success of many biological control efforts illustrates the importance of enemy release in explaining the virulence of invading species. A good example of this is provided by the winter moth, *Operophtera brumata*, which was accidentally introduced from Europe to Nova Scotia, Canada in the 1930s. Over a period of several decades, this species expanded its range and exhibited massive outbreaks, causing extensive forest defoliation until the 1950s when the parasitic fly *Cyzenis albicans* was introduced from Europe (Embree, 1965). The fly was released in 1954 but it did not cause extensive parasitism until 1961, after which the outbreak area greatly decreased and ultimately all outbreaks permanently ceased.

The other principle mechanism driving invasive population behavior is lack of host resistance. Over millions of years of evolutionary history, insects and pathogens have co-evolved with their host plants in something of an evolutionary "arms race" in which damage caused by these agents drives the evolution of resistance mechanisms in host plants (Fritz and Simms, 1992). These processes are varied but include both chemical and physical mechanisms that minimize the ability of insects and pathogens to deplete host plant tissue. When insects and pathogens invade new regions, they contact tree species with which they have no previous evolutionary history. In some cases, this results in explosive growth of the insect or pathogen population, sometimes resulting in extensive tree mortality. There are unfortunately many examples of this phenomenon, the earliest of which date back to the late 1800s (Wingfield et al., 2011). Classic early examples include Chestnut blight and Dutch Elm disease caused by *Cryphonectria parasitica* and *Ophiostoma ulmi/novo-ulmi* respectively (Brasier, 1990; Anagnostakis, 2001). A good recent insect example is provided by the

emerald ash borer, *Agrilus planipennis*. In its native range in East Asia, this insect is only able to colonize dead or dying host ash trees. But since its discovery in North America in 2002, little evidence of host resistance has been observed and this insect is able to colonize healthy trees, killing them in 1–3 years (Poland and McCullough, 2006).

In addition to the introduction of individual insect and pathogen species into ecosystems of native woody plants, there are growing numbers of examples where novel associations between insects and pathogens are emerging as devastating to native forests (Wingfield et al., 2010). These associations are sufficiently unusual and unexpected that they have recently been described using the metaphor of “black swans” (Ploetz et al., 2013). A shocking example is found in the association between the wood-boring insect *Xyloborus glabratus*, native to southeast Asia, and the fungal pathogen *Raffaelea lauricola*, of unknown origin. Together, these species are devastating bay laurel, *Persea borbonia*, in the southeastern USA (Fraedrich et al., 2008).

### Plantations of exotic trees

Like de Fégely and Neves Silva describe in their chapters, with an increasing global demand for wood fiber, plantations of non-native trees are playing an increasingly important role in forestry worldwide (Sedjo, 2001). Particularly in the southern hemisphere and tropics, exotic tree species such as *Pinus*, *Eucalyptus* and *Acacia* often provide considerably higher yields of high-quality fiber compared to native species.

At least a portion of these higher levels of productivity by non-native tree species can be attributed to their escape from herbivory by pathogens and insects that they face in their native range (Wingfield, 2003; Wingfield et al., 2008). A good example of this is provided by *Pinus radiata*. In its native range in North America, trees are poorly formed and slow growing, but in exotic plantations in New Zealand, Chile and Australia, they exhibit remarkable growth and are widely utilized for fiber production. At least some of this difference can be explained by the greater abundance and diversity of herbivorous insects in native stands compared to exotic plantations (Ohmart and Voigt, 1981).

The extraordinary productivity of exotic tree plantations may not continue indefinitely. It can be expected that pathogens and herbivorous insects will eventually “catch-up” with their host trees, i.e., insects and pathogens from a tree’s native range over time may accidentally be introduced, thus ruining the enemy release that the exotic trees have formerly enjoyed. For example, pines are not native to the southern hemisphere where they have been widely planted and exhibit remarkable productivity. However, one pine herbivore, *Sirex noctilio*, has colonized virtually every major pine-producing region in the southern hemisphere where it has often become a major pest that threatens plantation forestry

(Slippers et al., 2003). The species is native across temperate Eurasia and typically causes little damage, but in exotic pine plantations where no other bark- and wood-borers typically exist, this insect thrives, sometimes exhibiting massive outbreaks that cause the death of 50 percent or more of trees in a given stand. Mike May discusses in his chapter the potential for biotechnology to help address mortality and growth in plantations.

Another unfortunate trend in plantations of exotic tree species is host switching by native species to the exotic host (Slippers et al., 2005; Bertheau et al., 2010). There are several instances in which such host shifts have occurred though typically there is a delay of several decades between initial planting of an exotic tree species and the shift to this host by a native insect or pathogen. For example, large numbers of the wood-boring cossid moth, *Coryphodema tristis*, were discovered feeding and damaging *Eucalyptus nitens* in South Africa in the early 2000s, many decades after this tree species was first widely planted in that region (Gebeyehu et al., 2005). This species shifted to *Eucalyptus* from native trees in South Africa, presumably following selection for traits allowing it to utilize the new host. Likewise, virulent canker pathogens in the Chrysophthaceae are increasingly found moving from native Myrtales, especially Melastomataceae and Myrtaceae to infect *Eucalyptus* (Wingfield, 2003; Wingfield et al., 2010)

A new and potentially serious side-effect of planting exotic trees in forestry is the possibility that these plantations can serve as breeding grounds for potentially damaging new insect and disease strains having impacts worldwide. As described above, it is not unusual for native insect and pathogen species to make host shifts onto exotic tree species but these strains potentially pose a serious threat to the exotic tree species in their native range. At least one example of this phenomenon has emerged in the form of myrtle rust. This disease is caused by the fungal pathogen *Puccinia psidii*, which is native to Myrtaceae in South America but has made a host switch to *Eucalyptus* widely planted in Brazil (Glen et al., 2007). Unfortunately, the pathogen has now been accidentally transported to Australia where it has become established and causing considerable damage to native *Eucalyptus* stands there (Morin et al., 2012).

## The future

There is little doubt as to whether the current trend of increasing globalization is likely to continue indefinitely into the future. It is inevitable that trends of increasing international trade and travel will result in increases in invasive species propagule pressure into the future. Thus, the problem of non-native insects and pathogens is likely to intensify globally in coming years. With likely changes in geopolitics and economic forces, current patterns of dominant trade routes will change and this also can be expected to contribute to new combinations of insects, pathogens and tree

species. Given that the impacts of non-native species can be catastrophic to the ecological stability of forest ecosystems, consideration should be made to increasing phytosanitary regulations that might limit insect and disease movement in the future. Unfortunately, free trade and phytosanitary regulation are often incompatible. While promotion of free trade has considerable benefits, impacts of invasive species should be made part of the equation when trade agreements are developed.

The utilization of exotic tree species in plantation forestry is also a trend that can be expected to continue given expectations of increased global demands for fiber. Since the high productivity of exotic tree species results, in part, from their escape from herbivory and disease, countries that invest heavily on such plantations should also invest heavily on phytosanitary protection. Experience with exotic tree plantations demonstrates that escape from herbivory and disease cannot be expected to last forever. The recent experience with myrtle rust also demonstrates that widespread plantations of exotic species can potentially have adverse effects on the health of these same tree species worldwide, including in their native range.

## References

- Amman, G. D. (1977). The role of the mountain pine beetle in lodgepole pine ecosystems: impact on succession. In: W. J. Mattson (Ed.) *The Role of Arthropods in Forest Ecosystem* (3–18). New York: Springer-Verlag.
- Anagnostakis, S. L. (2001). The effect of multiple importations of pests and pathogens on a native tree. *Biological Invasions*, 3, 245–254.
- Aukema, J. E., McCullough, D. G., Von Holle, B., Liebhold, A. M., Britton, K. and Frankel, S. J. (2010). Historical accumulation of nonindigenous forest pests in the continental US. *BioScience*, 60, 886–897.
- Bertheau, C., Brockerhoff, E. G., Roux-Morabito, G., Lieutier, F. and Jactel, H. (2010). Novel insect-tree associations resulting from accidental and intentional biological “invasions”: a meta-analysis of effects on insect fitness. *Ecology Letters*, 13, 506–515.
- Bohlen, P. J., Groffman, P. M., Fahey, T. J., Fisk, M. C., Suárez, E., Pelletier, D. M. and Fahey, R. T. (2004). Ecosystem consequences of exotic earthworm invasion of north temperate forests. *Ecosystems*, 7, 1–12.
- Brasier, C. M. (1990) China and the origins of Dutch elm disease: an appraisal. *Plant Pathology*, 39, 5–16.
- Brockerhoff, E. G., Bain, J., Kimberley, M. and Knížek, M. (2006). Interception frequency of exotic bark and ambrosia beetles (Coleoptera: Scolytinae) and relationship with establishment in New Zealand and worldwide. *Canadian Journal of Forest Research*, 36, 289–298.
- Castello, J. D. and Teale, S. A. (eds). (2011). *Forest Health: An Integrated Perspective*. Cambridge: Cambridge University Press.
- Crosby, A. W. (2004). *Ecological Imperialism: The Biological Expansion of Europe, 900–1900*. Cambridge: Cambridge University Press.
- Davis, M. B. and Shaw, R. G. (2001). Range shifts and adaptive responses to Quaternary climate change. *Science*, 292(5517), 673–679.

- Embree, D. G. (1965). The population dynamics of the winter moth in Nova Scotia, 1954–1962. *Memoirs of the Entomological Society of Canada*, 97, 5–57.
- Fraedrich, S. W., Harrington, T. C., Rabaglia, R. J., Ulyshen, M. D., Mayfield, A. E., III, Hanula, J. L., Eickwort, J. M. and Miller, D. R. (2008). A fungal symbiont of the redbay ambrosia beetle causes a lethal wilt in redbay and other Lauraceae in the southeastern USA. *Plant Disease*, 92, 215–224.
- Frieden, J. A. (2006). *Global Capitalism: Its Fall and Rise in the Twentieth Century*. New York: WW Norton.
- Fritz, R. S. and Simms, E. L. (eds). (1992). *Plant Resistance to Herbivores and Pathogens: Ecology, Evolution, and Genetics*. Chicago: University of Chicago Press.
- Gebeyehu, S., Hurley, B. and Wingfield, M. (2005). A new lepidopteran insect pest discovered on commercially grown *Eucalyptus nitens* in South Africa. *South African Journal of Science*, 101, 26–28.
- Glen, M., Alfenas, A. C., Zauza, E. A. V., Wingfield, M. J. and Mohammed, C. (2007). *Puccinia psidii*, a threat to the Australian environment and economy – a review. *Australasian Plant Pathology* 36, 1–16.
- Gonthier, P., Nicolotti, F., Linzer, R., Guglielmo, F. and Garbelotto, M. (2007). Invasions of European pine stands by a North American forest pathogen and its hybridization with a native interfertile taxon. *Molecular Ecology* 16, 1389–1400.
- Haack, R. A. (2006). Exotic bark and wood-boring Coleoptera in the United States: recent establishments and interceptions. *Canadian Journal of Forest Research*, 36, 269–288.
- Haack, R. A., Britton, K. O., Brockerhoff, E. G., Cavey, J. F. Garrett, L. J., Kimberley, M., Lowenstein, F., Nuding, A., Olsen, L. J., Turner, J. and Vailaky, K. N. (2014). Effectiveness of the International Phytosanitary Standard ISPM No. 15 on reducing wood borer infestation rates in wood packaging material entering the United States. *PLoS ONE*, 9(5): e96611.
- Hulme, P. E., Bacher, S., Kenis, M., Klotz, S., Kühn, I., Minchin, D., Vilà, M. et al. (2008). Grasping at the routes of biological invasions: a framework for integrating pathways into policy. *Journal of Applied Ecology*, 45, 403–414.
- International Plant Protection Convention (IPPC). (2011). *International Standards for Phytosanitary Measures: Revision of ISPM 15, Regulation of Wood Packaging Material in International Trade*. Food and Agriculture Organization of the United Nations, Rome, Italy.
- Kenis, M., Auger-Rozenberg, M.-A., Roques, A., Timms, L., Péré, C., Cock, M. J. W., Settele, J., Augustin, S. and Lopez-Vaamonde, C. (2007) Ecological effects of invasive alien insects. In D.W. Langor & J. Sweeney (eds) *Ecological Impacts of Non-Native Invertebrates and Fungi on Terrestrial Ecosystems*, pp. 21–45. Springer Netherlands, 2009.
- Kolb, T. E., Wagner, M. R. and Covington, W. W. (1994). Concepts of forest health: utilitarian and ecosystem perspectives. *Journal of Forestry*, 92, 10–15.
- Liebholt, A. M., MacDonald, W. L., Bergdahl, D. and Mastro, V. C. (1995). Invasion by exotic forest pests: a threat to forest ecosystems. *Forest Science Monographs*, 30, 1–49.
- Liebholt, A. M., Work, T. T., McCullough, D. G. and Cavey, J. F. (2006). Airline baggage as a pathway for alien insect species entering the United States. *American Entomologist* 52, 48–54.
- Liebholt, A. M., Brockerhoff, E. G., Garrett, L. J., Parke, J. L. and Britton, K. O. (2012). Live plant imports: the major pathway for forest insect and pathogen invasions of the United States. *Frontiers in Ecology and the Environment* 10, 135–143.

- Mattson, W. J. and Addy, N. D. (1975). Phytophagous insects as regulators of forest primary production. *Science*, 190(4214), 515–522.
- Mattson, W., Vanhanen, H., Veteli, T., Sivonen, S. and Niemelä, P. (2007). Few immigrant phytophagous insects on woody plants in Europe: legacy of the European crucible? *Biological Invasions*, 9, 957–974.
- May, C. (1934). *Outbreaks of the Dutch Elm Disease in the United States*. US Department of Agriculture Circular 322.
- Morin, L., Aveyard, R., Lidbetter, J. R. and Wilson, P. G. (2012). Investigating the host-range of the rust fungus *Puccinia psidii* sensu lato across tribes of the family Myrtaceae present in Australia. *PLoS ONE*, 7, e35434.
- Ohmart, C. P. and Voigt, W. G. (1981). Arthropod communities in the crowns of the natural and planted stands of *Pinus radiata* (Monterey pine) in California. *Canadian Entomologist*, 113, 673–684.
- Paine, T. D., Millar, J. G. and Daane, K. M. (2010). Accumulation of pest insects on eucalyptus in California: random process or smoking gun. *Journal of Economic Entomology*, 103, 1943–1949.
- Parke, J. L. and Grünwald, N. J. (2012). A systems approach for management of pests and pathogens of nursery crops. *Plant Disease* 96, 1236–1244.
- Ploetz, R. C., Hulcr, J., Wingfield, M. J. and de Beer, Z. W. (2013). Destructive tree diseases associated with ambrosia and bark beetles: black swan events in tree pathology. *Plant Disease*, 95, 856–872.
- Poland, T. M. and McCullough, D. G. (2006). Emerald ash borer: invasion of the urban forest and the threat to North America's ash resource. *Journal of Forestry*, 104, 118–124.
- Rabitsch, W. and Essl, F. (2006). Biological invasions in Austria: patterns and case studies. *Biological Invasions*, 8, 295–308.
- Raffa, K. F., Aukema, B., Bentz, B. J., Carroll, A., Erbilgin, N., Herms, D. A., Wallin, K. F. et al. (2009). A literal use of "forest health" safeguards against misuse and misapplication. *Journal of Forestry*, 5, 276–277.
- Rieske, L. K. (2007). Success of an exotic gallmaker, *Dryocosmus kuriphilus*, on chestnut in the USA: a historical account. *EPPO bulletin*, 37, 172–174.
- Roques, A., Rabitsch, W., Rasplus, J. Y., Lopez-Vaamonde, C., Nentwig, W. and Kenis, M. (2009). Alien terrestrial invertebrates of Europe. In *Handbook of Alien Species in Europe* (pp. 63–79). Springer Netherlands.
- Sedjo, R. A. (2001). The role of forest plantations in the world's future timber supply. *Forestry Chronical*, 77, 221–222.
- Six, D. L. and Wingfield, M. J. (2011). The role of phytopathogenicity in bark beetle–fungus symbioses: a challenge to the classic paradigm. *Annual Review Entomology*, 56, 255–272.
- Slippers, B., Coutinho, T. A., Wingfield, B. D. and Wingfield, M. J. (2003). The genus *Amylostereum* and its association with woodwasps: a contemporary review. *South African Journal of Science*, 99, 70–74.
- Slippers, B., Stenlid, J. and Wingfield, M. J. (2005). Emerging pathogens: fungal host jumps following anthropogenic introduction. *Trends in Ecology & Evolution*, 20, 420–421.
- Smith, R. M., Baker, R. H. A., Malumphy, C. P., Hockland, S., Hammon, R. P., Ostojá-Starzewski, J. C. and Collins, D. W. (2007). Recent nonnative invertebrate plant pest establishments in Great Britain: origins, pathways, and trends. *Agricultural and Forest Entomology* 9, 307–326.

- Suckling, D. M., Barrington, A. M., Chhagan, A., Stephens, A. E. A., Burnip, G. M., Charles, J. G. and Wee, S. L. (2007). Eradication of the Australian painted apple moth *Teia anartoides* in New Zealand: trapping, inherited sterility, and male competitiveness. In: Vreysen, M. J., Robinson, A. S. and Hendrichs, J. (eds) *Area-wide Control of Insect Pests: From Research to Field Implementation* (pp. 603–615). Netherlands: Springer Netherlands.
- Varley, G. C., Gradwell, G. R. and Hassell, M. P. (1974). *Insect Population Ecology: An Analytical Approach*. Los Angeles: University of California Press.
- Williamson, M. and Fitter, A. (1996). The varying success of invaders. *Ecology*, 77, 1661–1666.
- Wingfield, M. J. (2003). Daniel McAlpine memorial lecture. Increasing threat of disease to exotic plantation forests in the southern hemisphere: lessons from *Cryphonectria* canker. *Australasian Plant Pathology* 32, 133–139.
- Wingfield, M. J., Slippers, B., Hurley, B. P., Coutinho, T. A., Wingfield, B. D. and Roux, J. (2008). Eucalypt pests and diseases: growing threats to plantation productivity. *Southern Forests* 70, 139–144.
- Wingfield, M. J., Slippers, B. and Wingfield, B. D. (2010). Novel associations between pathogens, insects and tree species threaten world forests. *New Zealand Journal of Forestry Science*, 40 (Supplement), S95–S103.
- Wingfield, M. J., Slippers, B., Roux, J. and Wingfield, B. D. (2011). Fifty years of tree pest and pathogen invasions, increasingly threatening world forests. In D. M. Richardson (Ed.), *Fifty Years of Invasion Ecology: The Legacy of Charles Elton* (pp. 89–99). London: Blackwell.

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