Chapter 7
Impact of Non-native Invertebrates and Pathogens on Market Forest Tree Resources

Marc Kenis, Alain Roques, Alberto Santini, and Andrew M. Liebhold

Abstract Several forest non-native pests and pathogens that are among the most frequently cited invasive species worldwide represent serious economic and conservation concerns for the forest ecosystems in their region of introduction. Such organisms can have adverse impacts on the yield of marketable wood products, such as timber and pulp, as well as non-wood forest products, such as nuts, fruits, and seeds. However, quantitative data about impacts on forest market resources are rare and usually restricted in time and space. Moreover, information on regional impacts, and aggregate data including multiple invasive species, are largely missing or miscalculated. The most comprehensive studies show that the greatest impacts of pest invasions on native tree species are effects on non-market values whereas losses in wood and non-wood forest products account for a small part of the total impacts. Patterns are somewhat different in plantations of non-native trees, where non-native pests are more likely to affect the forestry sector directly through reduced fibre yield and increased management costs, whereas non-market values and environmental impacts are of lesser concern. This chapter argues that direct impacts on market forest resources are sometimes largely exaggerated and provides reasons for these overestimations.

Keywords Economic impact • Forestry • Forest market resources • Invasive pests • Non-native trees • Non-wood forest products • Yield loss

M. Kenis (✉)
CABI, 2800 Delémont, Switzerland
e-mail: m.kenis@cabi.org

A. Roques
INRA, UR 633 Zoologie Forestière, 45075 Orléans, France
e-mail: alain.roques@orleans.inra.fr

A. Santini
Institute of Sustainable Plant Protection, C.N.R., 50019 Sesto Fiorentino, Italy
e-mail: alberto.santini@cnr.it

A.M. Liebhold
US Forest Service, Northern Research Station, Morgantown, WV 26505, USA
e-mail: aliebhold@fs.fed.us

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7.1 Introduction

Non-native damaging invertebrates and pathogens (hereafter pests) are a critical and increasing threat to trees and forest ecosystems. In contrast to many other invasive species arriving on new continents intentionally, tree pests are nearly always introduced accidentally, usually through the trade in live plants, wood, or wood products (Liebhold 2012). As a result, their introduction is particularly difficult to control and, despite the intensification of phytosanitary measures worldwide, the number of new establishments of non-native tree pests and their damage continue to increase (Aukema et al. 2010).

Although most non-native pests cause little impact, a few species cause substantial damage to their host trees and, in a few cases, can locally eliminate tree species and alter ecosystems (Kenis et al. 2009). Native forests of eastern North America have suffered particularly from non-native pests in the past century, with the strong decline of keystone species such as the American chestnut (through chestnut blight, *Cryphonectria parasitica*), elms (Dutch elm disease, *Ophiostoma ulmi* and O. *novo-ulmi*) (Fig. 7.1), eastern and Carolina hemlock (hemlock woolly adelgid, *Adelges tsugae*), Fraser fir and other firs (balsam wooly adelgid, *Adelges piceae*), and ash species (emerald ash borer, *Agrilus planipennis*) (Aukema et al 2010; Liebhold et al. 2013). Such declines affect ecosystems and their services in many ways.

Fig. 7.1 Elm tree killed by Dutch elm disease, *Ophiostoma ulmi* and *O. novo-ulmi*, in Italy (Photograph by Alberto Santini)

This review is restricted to the impact on production of marketable tree resources, that is, provisioning ecosystem services. For most forests, the primary market product is wood fibre, utilised primarily for lumber, pulp, and fuel, but non-wood forest products (NWFP) such as nuts, fruits, and seeds are also considered. The important ecological impacts that these invasive species have in forests on supporting, regulating, and cultural ecosystems services and human well-being are not considered, although it is clear that all these services are closely interconnected. Effects on ornamental trees and the ornamental plant market are also excluded.

Some studies indicate that wood and NWFP losses account for a small part of the economic impacts of forest pests, the largest part being represented by non-market tree values, such as loss of property values or federal and local government expenditures (Holmes et al. 2009; Aukema et al. 2011). They account for an even smaller part of the impacts when all ecosystem services are considered, even if comparing ecosystem services remains a challenge (Branco et al. 2015). This problem is particularly acute when pests affect native keystone tree species (Kenis et al. 2009; Aukema et al. 2010).

7.2 Impact on Wood Fibre Production

Impacts on wood fibre production can involve at least three mechanisms: first, pests can affect tree growth increment; second, they can kill mature trees; and third, they can affect regeneration by killing seeds or seedlings in either a seed orchard or nursery or a forest stand. Obviously, the same pest can affect wood production in two or three ways. Another useful categorisation is whether the pest affects native trees or plantations of non-native trees. This concern is important because damage to non-native plantations is likely to affect primarily the forest industry through wood fibre losses and management costs related to invasion, such as mandatory fumigations, whereas pests affecting predominantly native trees are likely to have more complex and integrated economic, social, and ecological impacts in which the damage to the forestry sector may be marginal. However, it is remarkable how few quantitative studies on their impact on wood production have been published. Most data only concern a single species in a single country or even in a specific stand during a limited period of time. Information on regional impacts and aggregate data including multiple pest species are largely missing. Table 7.1 provides a nonexhaustive list of forest pests for which some type of quantitative assessment of their damage to wood and non-wood forest products has been estimated.

7.2.1 Damage to Native Tree Species

One of the most comprehensive studies on the economic impact of forest pests was that of Aukema et al. (2011), who calculated the economic damage caused by three pests affecting mainly native trees in the USA: *Agrilus planipennis*, *Adelgid tsugae*,

Table 7.1 Examples of quantitative data of effects of forestry pests and pathogens on wood production (native and non-native trees) and non-wood forest products

Trees and country	Invasive species	Damage	References
Wood: native trees			
Hemlock in USA	*Adelges tsugae*	Average of US$ 1.1 million/year in timber loss (0.5 % of total costs)	Aukema et al. (2011)
Ash in USA	*Agrilus planipennis*	Average of US$ 60 million/year in timber loss (3.6 % of total costs)	Aukema et al. (2011)
Ash in Essex County, Canada	*Agrilus planipennis*	CAN$ 14–16 million/year for control	Colautti et al. (2006)
Pines in Japan	*Bursaphelenchus xylophilus*	Wood losses exceed 2,000,000 m^3 per year	CABI (2015) and references therein
Chestnut in eastern USA	*Cryphonectria parasitica*	Almost all canopy or 3.5 billion American chestnut trees were killed	CABI (2015) and references therein
Broadleaved trees in USA	*Lymantria dispar*	Average of US$ 4.6 million/year in timber loss (1.8 % of total cost)	Aukema et al. (2011)
Broadleaved trees in New England, USA	*Lymantria dispar*	Up to 50 % reduction in annual growth increment	Muzika and Liebhold (1999)
Broadleaved trees in Québec, Canada	*Lymantria dispar*	Average of 44 % reduction in annual growth increment in host trees	Naidoo and Lechowicz (2001)
Oak in Massachusetts, USA	*Operophtera brumata*	Up to 47 % reduction in annual radial growth	Simmons et al. (2014)
Elms in Europe and North America	*Ophiostoma ulmi* and *O. novo-ulmi*	Hundreds of millions of elms killed by the two Dutch elm disease pandemics	CABI (2015) and references therein
All forests in USA (mostly native)	Many invertebrates and pathogens	US$ 4.2 billion/year	Pimentel et al. (2000)
Canadian forests (mostly native)	Seven pests (projections)	CAN$ 9.6 billion ($7.7 billion to $20 billion)	Colautti et al. (2006)
Wood: non-native trees			
Pinus radiata in New Zealand	*Armillaria novae-zelandiae*	Reduction of 14–24 % in growth increment of 8- to 10-year-old trees	Shaw and Taes (1977)
Cypress in East Africa	*Cinara cupressivora*	Up to 1990, killed trees worth US$44 million and was causing an additional loss of a further US$14.6 million per year through reduction in annual growth increment.	Cock (2003)

(continued)

Table 7.1 (continued)

Trees and country	Invasive species	Damage	References
Pinus radiata in New Zealand	*Dothistroma septospora*	Annual cost to the forestry industry in New Zealand was estimated to be NZ$6.1 million in the 1980s in terms of direct control costs and residual growth loss	CABI (2015) and references therein
Pinus radiata in New Zealand	*Dothistroma septospora*	Reduction of 17–73 % in growth increment of 8- to 10-year-old trees	Shaw and Taes (1977)
Spruce in UK and Northern Europe	*Elatobium abietinum*	Reduces height increment by 20–60 % in the year of attack; reduces diameter increment for 7–8 years, with a mean reduction of 18.5–40.5 %.	CABI (2015) and references therein
Eucalyptus in Spain	*Gonipterus platensis*	Estimated to reduce tree growth by 30 %, causing an economic loss of $10.5 million annually in Galicia	Branco et al. (2015) and references therein
Eucalyptus in Portugal	*Gonipterus platensis*	Wood volume was estimated to decrease to 51 % in the affected areas in 2004–2006, with losses increasing exponentially with tree defoliation, by up to 43 % and 86 % corresponding to 75 % and 100 % defoliation, respectively.	Branco et al. (2015) and references therein
Eucalyptus in Spain	*Phoracanta semipunctata*	Loss of US$ 9 and 7 million for an area of 300,000 ha in Spain in 1983 and 1984	Branco et al. (2015) and references therein
Pines in East Africa	*Pineus boerneri* and *Eulachnus rileyi*	Loss of US$2.4 million per year caused by reductions in annual growth increment.	Cock (2003)
Pinus radiata in New Zealand	*Sirex noctilio*	Mortality rates of 30 % in 1946–1951	CABI (2015) and references therein
Pines in Australia	*Sirex noctilio*	Mortality rates of 40 % in Tasmania and up to 75 % in Victoria between 1932 and 1979; death of 5 million trees with a value of AUS $10–12 million in Southern Australia between 1987 and 1989	CABI (2015) and references therein

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Table 7.1 (continued)

Trees and country	Invasive species	Damage	References
Pines in Brazil	*Sirex noctilio*	Mortality rate of 60 % in Brazil in 1989.	CABI (2015)
All forests in UK (mostly non-native)	Many invertebrates and pathogens	US$ 2 million/year	Pimentel et al. (2000)
Non-wood forest products			
Chestnut in USA	*Cryphonectria parasitica*	Almost all mature chestnut trees killed in USA	CABI (2015) and references therein
Chestnut in Italy	*Dryocosmus kuriphilus*	Up to 80 % losses in chestnut production	Battisti et al. (2014)
Edible pine nuts in Italy	*Leptoglossus occidentalis*	Of the 2-year-old conelets, 80 % damaged	Roversi et al. (2011)
Conifer orchards in France	*Leptoglossus occidentalis*	Up to 25.7 % of the potential seed yield in Douglas-fir plantations in 2010, and by more than 15 % these of *Pinus nigra* and *P. sylvestris* in 2011	Lesieur et al. (2014)
Douglas-fir seed orchards in France	*Megastigmus spermotrophus*	Up to 95 % of loss of commercial seed crop	Auger-Rozenberg and Roques (2012)

and the gypsy moth, *Lymantria dispar*. They classified economic losses in five categories: (1) federal government expenditures (survey, research, regulation, management, and outreach); (2) local government expenditures (tree removal, replacement, and treatment); (3) household expenditures (tree removal, replacement, and treatment); (4) residential property value losses; and (5) timber value losses to forest landowners. For the three species, average annual timber losses in 2009 were estimated at US$60 million, US$1.1 million, and US$4.6 million, respectively. Interestingly, this represented only 3.6 %, 0.5 %, and 1.8 % of the total estimated costs calculated for the three insects, the majority of the costs affecting non-market values and borne by homeowners and municipal governments. When extrapolated across all non-native forest insect pests of the three main guilds (phloem and wood borers, sap feeders, and foliage feeders), the total annual cost was nearly US$5 billion, of which only US$65.7 million was related to timber value loss.

Interestingly, in an earlier study, Pimentel et al. (2000) had estimated the annual losses of timber caused by non-native pests to be much higher, that is, US$4.2 billion (arthropods and pathogens accounting for 50 % each). This estimate was based on an assumption that all (native and non-native) forest pests reduce overall timber productivity by 18 % and non-native species account for 30 % of the damage caused by all forest pests. Colautti et al. (2006) presented several cases of the economic costs of invasive species, including control costs for *O. ulmi* and *O. novo-ulmi* in Manitoba and of *A. planipennis* in a specific county. They also projected the economic losses in value to forest products in Canada to be CAN$9.6 billion (ranging from CAN$7.7 billion to CAN$20 billion). Although these and other basic calculations of economic impacts of invasive species have been useful for drawing attention to the significance of pests, they have been criticised for various reasons, such as failing to account for nonmarket economic values and the ability to substitute one resource for another and double-counting certain costs (Holmes et al. 2009; Aukema et al. 2011). Estimates in Colautti et al. (2006) were made using a price-times-quantity method (Holmes et al. 2009) in which impact is estimated as simply the volume of trees killed multiplied by a stumpage price. This method is problematic because it fails to account for the fact that (1) many affected stands would never be harvested; (2) other stands will be harvested sometime in the future and during this lag surviving trees will grow and compensate for the damage; and (3) forest managers may salvage affected trees, thereby recouping partial losses, or they may adjust their business plan in other ways (e.g., delay harvest or substitute other products). Unfortunately, the price-times-quantity method has been applied in other impact estimates as well.

Although historically European forests have suffered less from non-native pests than other continents, new forest pests are now introduced at a faster rate in Europe than in other continents. A long list of newly established species is threatening European forestry and urban forestry (Roques 2010; Santini et al. 2013). As elsewhere, economic impacts of pests on native ornamental trees are greater than in natural forests and, consequently, costs are mainly borne by municipalities and private owners. For example, damage by *O. ulmi* and *O. novo-ulmi* has cost €9–228 million annually since 1979, but mainly for felling and replacing ornamental trees in urban areas (Gren et al. 2009). High costs are also related to control measures, in particular mandatory phytosanitary measures related to eradication or containment programmes. The large efforts to eradicate and contain the pine wood nematode *Bursaphelenchus xylophilus*, causal agent of the pine wilt disease in Portugal, has been described in detail by Sousa et al. (2011). Although recent estimations of the costs to the Portuguese and EU authorities and the private sector are not available, they are undoubtedly much higher than the loss of timber directly attributable to the pest. Nevertheless, they are surely justified because damage at the European scale could be substantial. Soliman et al. (2012) estimated that an unregulated infestation of *B. xylophilus* in the EU could cause a loss of forestry stock over 22 years (2008–2030) that would cost €22 billion. In Japan, where the nematode is also invasive, wood losses exceed 2,000,000 m^3 per year (CABI 2015). Other examples of pests for which management costs for eradication or containment have so far largely exceeded direct wood losses are the two Asian longhorned beetles, *Anoplophora glabripennis* and *A. chinensis*. In the past two decades, both species have been under costly eradication programmes in various regions in Europe and North America. For example, from 1997 to 2006, US federal, state, and local authorities have spent more than US$800 million on *A. glabripennis* eradication measures in urban settings, involving surveys, removal, treatment to destroy all life stages present (e.g., chipping), and replacement (Smith and Wu 2008).

An example of a pathogen threatening native wood fibre production is the fungus *Cronartium ribicola*, the agent of the white pine blister rust. This pathogen

Fig. 7.2 Defoliation by gypsy moth, *Lymantria dispar*, in the United States (Photograph by Tim Tigner, Virginia Department of Forestry, Bugwood.org)

completes its life cycle between five-needle pines (*Pinus*, subgenus *Strobus*) and plants of the genus *Ribes*. This fungus is able to kill trees of all ages, but the rust is particularly damaging in young stands, preventing them from growing to a merchantable age. *Cronartium ribicola* is considered endemic to Siberia and was first reported in eastern North America in 1906 and western North America in 1921. It has become the most important disease of several white pine species in North America (Maloy 1997). However, damage is now most severe in Western North America, for example, on *Pinus monticola, P. flexilis*, *P. albicaulis*, and *P. lambertiana*, for which mortality rates of 95 % have been reported in Sierra Nevada. These species are not extensively planted for timber, and thus the pathogen now causes more concern for its environmental impact than for its impact on the forest industry (CABI 2015).

In contrast to bark and wood borers and certain tree pathogens, defoliators and sap feeders often do not directly kill trees but more commonly affect wood fibre production through growth losses. Outbreaks of the gypsy moth in North America can cause up to 50 % reduction in annual growth increment in broad-leaved trees (Muzika and Liebhold 1999; Naidoo and Lechowicz 2001) (Fig. 7.2). Simmons et al. (2014) also reported a growth rate reduction of nearly 50 % as a result of defoliation of oak by the winter moth, *Operophtera brumata*. However, defoliation can often lead to crown dieback and ultimately tree mortality, although very often secondary insects and pathogens are involved. In the case of outbreaks of the invasive gypsy moth in North America, this mortality can sometimes be extensive, especially in oaks, but then increased growth typically occurs in non-hosts and surviving hosts consequent to a thinning effect. As such, in many areas with a long history of gypsy moth outbreaks, long-term regional impacts on merchantable volume may be minimal (Gansner et al. 1993).

7.2.2 Damage to Non-native Tree Species

Fast-growing non-native tree species (e.g., eucalyptus, pine, cypress, spruce) are frequently planted in the Southern Hemisphere and elsewhere. These plantations often exhibit exceptionally high growth increment and their economic success can, at least in part, be attributed to the fact that trees are growing largely pest free (Liebhold 2012). These plantations are thus particularly sensitive to the introduction of non-native pests. Various introductions of insects and pathogens have seriously affected such plantations in the past century. For example, the most damaging pest of non-native pine plantations in the Southern Hemisphere is probably the European sirex woodwasp, *Sirex noctilio* (Fig. 7.3). However, only damage records in specific stands or areas are available (e.g., mortality rates of 30 % in New Zealand in 1946–1951; 40 % in Tasmania and up to 75 % in Victoria, Australia, between 1932 and 1979; 60 % in Brazil in 1989). In Southern Australia between 1987 and 1989, an outbreak of *S. noctilio* caused the death of 5 million trees with a value of AUS$10–12 million (CABI 2015), but such estimates are calculated using the volume-times-price method, which does not provide a meaningful quantification of economic impact, as described previously.

The green spruce aphid is one of the few species for which data are abundantly available. *Elatobium abietinum* originates in Central Europe where it occurs on *Picea abies* and has been introduced in many parts of the world, affecting both native and non-native spruce stands and plantations. In the UK and Northern Europe, it causes extensive defoliation of Sitka spruce, *Picea sitchensis*, severely reducing height increment by 20–60 % in the year of attack. Similarly, defoliation also decreases diameter increment for 7–8 years, with a mean reduction of 18.5–40.5 %. Even moderate defoliation can cause increment loss in some spruce species (CABI 2015). In Iceland, damage was so severe that initiation of new spruce plantations has largely been abandoned in southern regions (Halldórsson et al. 2003). Interestingly, although in Europe *E. abietinum* rarely kills trees, it has devastated natural stands of *P. englemannii* and *P. pungens* in the interior southwest USA. In New Zealand, tree mortality was also observed, and the aphid is considered to be the main factor preventing spruce being used as a production species in the country (CABI 2015).

Eucalyptus is one of the most widely planted tree genera worldwide (Branco et al. 2015). Various species are planted for pulp and other purposes in all tropical and warm temperate climates. In the past 20–30 years, almost all plantation regions have suffered from a series of invasions by insects originating from Australia (Branco et al. 2015). Damage has often been very serious but, here again, precise

Fig. 7.3 Pine plantation damage by sirex woodwasp, *Sirex noctilio*, in Australia (Photograph by Dennis Haugen, Bugwood.org)

data are scarce and limited in time and space. For example, in southwestern Spain, the cost of damage caused by the Australian longhorn borer, *Phoracantha semipunctata*, on timber yield losses, plus the costs of disposing of non-usable timber, were estimated at more than US$9 million in 1983, and US$7 million in 1984, for an area of 300,000 ha of eucalyptus plantations (Branco et al. 2015). In Galicia, Spain, the snout beetle, *Gonipterus platensis*, was estimated to reduce tree growth by 30 %, causing an economic loss of US$10.5 million annually. In Portugal, the same insect decreased wood volume (projected to 10 years of age) by 51 % in the affected areas in 2004–2006, with losses increasing exponentially with tree defoliation, by up to 43 % and 86 %, corresponding to 75 % and 100 % defoliation, respectively (Branco et al. 2015).

These and other pests have also caused serious problems to eucalyptus forestry elsewhere. In some areas, damage was so severe that planting of susceptible eucalyptus species was abandoned or greatly decreased, such as in New Zealand following the establishment of the eucalyptus tortoise beetle, *Paropsis charybdis*, and other insects and pathogens of Australian origin (CABI 2015). In the absence of precise data on economic losses, the abandonment of commercial tree species because of pests is a good indication of the economic importance of the damage. Another example is provided by cypress plantations in eastern Africa. In this region, damage from the cypress canker, *Lepteutypa cupressi*, led to the replacement of *Cupressus macrocarpa* by *C. lusitanica*, which in turn became severely affected by the introduced cypress aphid, *Cinara cupressivora*, in the 1980s (Cock 2003). Several studies attempted to estimate the economic damage of the latter species and two other invasive conifer aphids in eastern Africa, the pine woolly aphid, *Pineus boerneri*, and the pine needle aphid, *Eulachnus rileyi*, (Cock 2003). In 1991, it was estimated that, up to 1990, *C. cupressivora* had killed trees worth US$44 million and was causing an additional loss of a further US$14.6 million per year through reduction in annual growth increment. The two pine aphids caused a loss of US$2.4 million per year in the region by reductions in the annual growth increment. These figures were considered conservative because they did not include the impact of the aphids on indigenous tree species or allow for any subsequent mortality from *C. cupressivora*. In Kenya, another study estimated that *C. cupressivora* had the potential to kill up to 50 % of all cypress trees during the 30-year harvest cycle.

It should be noted that many insect pest problems in non-native plantations have been solved through the introduction of natural enemies from the area of origin of the pests. For example, the aforementioned beetles, *P. semipunctata* and *Gonipterus* spp., are successfully controlled by egg parasitoids and, to a lesser extent, populations of *C. cupressivora* in East Africa have also been reduced by a parasitoid (CABI 2015). *Sirex noctilio* has been controlled to varying degrees in New Zealand and Australia by introductions of a nematode and parasitoids. Changes in silvicultural practices have also greatly contributed to reducing impacts, particularly in New Zealand.

Plantations of non-native trees are also very sensitive to tree pathogens. A recent example is provided by the Japanese larch, *Larix kaempferi*, widely planted in the British Isles for timber production but also for landscaping and recreational purposes. Since 2009, a widespread dieback and mortality was reported in various parts of the UK and Ireland. Up to 2010, 2400 ha, or about 0.6 million mature larch, were affected. The disease was caused by *Phytophthora ramorum*, an invasive pathogen already known as the cause of "Sudden Oak Death" in western USA (Brasier and Webber 2010; CABI 2015). Trees in affected plantations are felled to minimise further spread, both to forests and to susceptible heathland vegetation. This development could therefore have a significant impact on local economies and Britain's strategic reserve of timber (Brasier and Webber 2010).

Another older case of an invasive pathogen affecting non-native plantations in Europe is that of the white pine blister rust, *Cronartium ribicola*. In addition to its damage on native five-needle pines in North America as already mentioned, it also eliminated plantations of the American white pine, *Pinus strobus*, in Europe in the nineteenth to twentieth century. In this case, the abandonment was also motivated by the fact that the disease was also seriously threatening cultivated *Ribes* plantations, in particular black currant, as the fungus requires the two hosts to complete its development (Maloy 1997; CABI 2015).

7.3 Impact on Non-wood Forest Products

A variety of other marketable products, such as nuts, berries, and seeds, game animals, mushrooms, oils, medicinal plants, tannins, peat, and forage are often harvested from forests and have considerable value. Their availability can also be affected by pests, but quantitative data are even scarcer than for wood.

Probably the best data on NWFP losses are from conifer seed orchards. Commercial seed production in the European seed orchards is largely affected by non-native seed chalcids of the genus *Megastigmus*, and especially by the American Douglas-fir seed chalcid, *M. spermotrophus*. Douglas-fir seeds for reforestation are sold at a price of approximately 6000 €/kg, but chalcid infestation may decrease the number of healthy seeds by as much as 95 % (Auger-Rozenberg and Roques 2012). The recent arrival of the western North American conifer seed bug, *Leptoglossus occidentalis*, decreased the seed yields in Douglas-fir and pine seed orchards in France by as much as 25.7 % and 15 %, respectively (Lesieur et al. 2014) (Fig. 7.4).

Wild fruits for human consumption can also be affected by forest pests. The strong decline in the production of edible nuts of the stone pine, *Pinus pinea*, observed all around the Mediterranean Sea, is attributed in large part to the arrival

Fig. 7.4 *Leptoglossus occidentalis* feeding on a pine cone (Photograph by Vincent Lesieur)

of *L. occidentalis.* Roversi et al. (2011) mention an unpublished study in an Italian forest measuring that 80 % of the 2-year-old conelets aborted, but large-scale assessments of the effect of the bug on seed production decline are still lacking.

Chestnut production, both in orchards and forests, has been devastated by two Asian invaders, the chestnut blight, *Cryphonectria parasitica*, and the chestnut gall wasp, *Dryocosmus kuriphilus*. In the first half of the twentieth century, almost all mature American chestnut trees were killed by chestnut blight (CABI 2015). The tree now survives as small understory trees. The disappearance of chestnut from American forests also affected the production of other NWFP, such as tannic acid used in leather production. In Europe, the pathogen has been less destructive but, recently the European chestnut has been strongly affected by the arrival of the chestnut gall wasp with losses in nut production as great as 80 % (Battisti et al. 2014).

7.4 Conclusions

There is no doubt that invasions of non-native invertebrates and pathogens can have dramatic economic and ecological impacts on trees and forests. However, direct impacts on market forest resources may sometimes be largely overestimated. Although there are numerous cases of serious impact on tree mortality or tree growth, we are aware of just a few cases where a pest invasion has actually reversed the profitability of forest production. Examples of such reversals include plantations of spruce in southern Iceland and New Zealand, as a result of invasion by *Elatobium abietinum*, and the abandonment of white pine plantations in Europe because of *Cronartium ribicola*, and of several eucalyptus species in New Zealand following the invasion of Australian insects and pathogens. There are numerous reasons why impacts may sometimes be exaggerated. First, for most species, a true assessment of pest species across entire regions over many years is often missing. Such assessments are necessary to form a reliable characterisation of the economic impact of an invading species over an extended period of time (Epanchin-Niell and Liebhold 2015). Second, studies that quantify impacts simply as total numbers of trees or volume killed are inadequate for evaluating the ultimate impacts of a pest on the forest, because between the time of tree mortality (or loss of growth) and harvest, trees in a stand will grow and compensate, at least partly, for mortality or growth loss (Holmes et al. 2009). Thus, simply multiplying the volume of trees killed by its value is completely inadequate for estimating impacts. Impacts on non-market values are undoubtedly highly important, especially when native trees are affected, and fully justify measures put in place to prevent and manage non-native pests (Aukema et al. 2011). However, methods need to be developed to quantify and aggregate market and non-market impacts caused by forest non-native pests.

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