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Invasive Cerambycid Pests and Biosecurity Measures

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13.1 Introduction

Longhorn beetles (Cerambycidae) in general, and some species in particular, have increased in importance for national and regional plant protection agencies over recent decades. Expensive eradication campaigns have been carried out in order to eliminate some longhorn beetles. For example, the cost of eradication campaigns undertaken between 1996 and 2013 against the cerambycid

Anoplophora glabripennis (Motschulsky), commonly called the Asian longhorn beetle, were estimated to have exceeded US$537 million for all U.S. infestations in Illinois, Massachusetts, New Jersey, New York, and Ohio (Rhonda Santos, USDA-APHIS, personal communication Feb 2014). Although other taxa—such as fungal pathogens [e.g., ash dieback, *Hymenoscyphus fraxineus* (T. Kowalski) Baral, Queloz, Hosoya, comb. nov., in Europe (Pautasso et al. 2013; Baral 2014)] and the buprestid emerald ash borer, *Agrilus planipennis* Fairmaire, in the United States (Kovacs et al. 2010)—have in some cases caused greater damage; the potential to counter outbreaks of some cerambycids is often larger in part due to their relatively slow rate of spread. The possibility of eradicating invasive populations of longhorn beetles has provided the justification for abatement efforts in North America and Europe against the Asian *Anoplophora* species, some of which have been successful (Haack et al. 2010).

In addition to the relatively slow rate of spread of many cerambycids, other factors relevant to their status as quarantine pests are (1) the many and diverse pathways along which they can be moved, (2) their potential for causing significant damage, and (3) the difficulties of detecting either juvenile stages within trees or wood or early stage outbreaks. Wood packaging, trees, timber, and wood products that are infested with the juvenile stages of cerambycids may have little or no external signs of infestation. As a result, visual inspection alone may be inadequate for detecting infested consignments and other more costly methods may be necessary to intercept infested materials or goods.

The estimated 36,000 described species of Cerambycidae worldwide (see Chapter 1) are divided into the xylophagous species that feed on wood and the phytophagous species that feed on herbaceous plants (Bense 1995). It is the xylophagous species that have drawn the greatest attention as invasive pests. Only a minority of longhorn beetles are significant pests; in Europe, for example, about 20% of all cerambycid species are thought to be important as forest pests or timber beetles (Hellrigl 1974). The xylophagous species tend to be specialized into those that attack different parts of their host—such as roots, stems, branches, or twigs, and there is also a spectrum of preferences for attacking either dead, dying, weakened, or healthy trees (Bense 1995; Hanks 1999). These preferences are an important indication of whether a species may become a significant invasive pest of standing trees. As is the case with other invasive species, the damage in the invaded area can be greater than the damage the pests cause in their native range due to the greater susceptibility of host trees in the invaded area, the lack of control by natural enemies, and the widespread planting of susceptible trees (Haack et al. 2010). This chapter provides a description of the impact that invasive longhorn beetles have had, the routes along which they have been moved to new areas, and the measures that have been taken to prevent their movement and establishment in new locations.

13.2 Interceptions of Cerambycids on Imported Materials

Databases of pests intercepted on imported materials have been analyzed to try to understand the most important pathways for the movement of pests. Although such databases are useful for establishing that there is a biosecurity threat associated with trade, it is more difficult to use such data to conclusively establish the lack of a threat for a particular trade or to provide a fair comparison of the relative threat of particular trades. Humble (2010) listed some of the shortcomings of most interception databases: (1) they are not based on random sampling; (2) negative inspections are not recorded; (3) once a quarantine organism has been discovered, consignments may be destroyed without further inspection, and thus other exotic organisms can be missed; (4) only a small percentage of individual shipments are inspected; and (5) organisms often are not identified as to species because many are intercepted as larvae that can be difficult to identify to species level. In addition to these shortcomings, trade volumes and sources can change rapidly, the number of consignments inspected varies from year to year in response to national and regional plant health and wider government priorities, and the method and intensity of quarantine inspections can vary within and among countries and also over time. Furthermore, different proportions of consignments from different trades can be inspected, reflecting the perceived quarantine risks of each trade. For example, plants for planting arriving into the European Union (EU) are treated in EU legislation as being high risk, and member states are required to inspect all consignments. In contrast, the movement of some genera of plants among EU member states is not regulated by plant health legislation, and other higher risk plants are controlled by the issuing of Plant Passports, which is an industry-led scheme rather than government-led scheme (EU 2000). Thus, consignments of plants being moved among EU member states are not routinely subject to official inspections despite the fact these movements have been shown to be pathways for the transplantation of longhorn beetles (Giltrap et al. 2009). This lack of official inspection means that there is a lack of knowledge concerning the extent and risk of longhorn beetles being moved among member states.

The Agricultural Quarantine Inspection Monitoring (AQIM) sampling strategy was developed by the U.S. Department of Agriculture (USDA) to try to overcome some of the difficulties relating to data gathered during routine plant health or biosecurity inspections. It is a random protocol designed to be sufficient to detect nonindigenous pests infesting greater than 10% of a shipment with 95% confidence (Venette et al. 2002). AQIM has been used to show (1) the arrival rate of insect species in the United States via foreign trade and the most important pathways (Work et al. 2005), (2) the importance of the live plant pathway for the importation of forest pests into the United States (Liebhold et al. 2012), and (3) the impact of international phytosanitary regulations such as International Standards for Phytosanitary Measures No. 15 (ISPM 15) (Haack et al. 2014).

An analysis of the 1985–2000 interception records of the USDA's Animal and Plant Health Inspection Service (APHIS) Port Information Network (now referred to as PestID) database by Haack (2006) revealed that Cerambycidae represented the second most frequently intercepted insect family associated with wood (1,642 interceptions) following Scolytidae, now considered to be a subfamily of Curculionidae (i.e., Scolytinae), of which there were 5,008 interceptions (Bright 2014; Jordal et al. 2014). However, analysis of this data set in four-year time periods showed that the number of Scolytinae interceptions declined from 2,215 during 1985–1988 to 687 during 1997–2000, whereas there was an increase in the number of interceptions of Cerambycidae from 211 during 1985–1988 to 686 during 1997–2000. The increase in the number of interceptions of Cerambycidae between 1985 and 2000 was mainly the result of an increase in the number of interceptions on material from China (from 15 interceptions during 1985–1988 to 357 during 1997–2000). The decline in the number of interceptions of Scolytinae was in part explained by a 1996 change in U.S. import regulations that required all unmanufactured solid wood items to be "totally free from bark" or else be certified by the exporting country as treated for wood pests (USDA-APHIS 1995; Haack 2006).

13.3 Pathways: Plants for Planting

The movement of plants for planting is thought to be the most important pathway for the introduction of nonnative forest pests into North America. Liebhold et al. (2012) estimated that 70% of damaging forest insects and pathogens established in the United States between 1860 and 2006 most likely entered on imported live plants. Smith et al. (2007) found that 89% of nonnative invertebrate plant pests introduced into Great Britain since 1970 had potentially been introduced with live plants, especially ornamentals.

Differences in the proportion of consignments inspected at the point of entry may have influenced the predominance of the connection between live plants and the number of forest pests that have been linked with their import. In the United States, approximately 50% of commerce is believed to be carried on wooden pallets (Haack et al. 2014) but only about 2% of cargo arriving at maritime ports, airports, and border crossings is inspected (Work et al. 2005). In contrast, although published figures are not available, the USDA is thought to inspect a portion of all consignments of plants for planting arriving in the United States. After consignments associated with wood packaging material arrive in a country, the packaging is often discarded because it will already have served its purpose to the importer. This means that any emerging pests are unlikely to be noticed. In contrast, live plants are usually imported in a dormant state and then grown on at a nursery for a period before they are sold. While the plants are held at the nursery, they will be watered or irrigated, examined for their general health and perhaps pruned, repotted, and treated with plant protection products. All these operations provide an opportunity for nursery employees to notice any diseases and emerging pests such as cerambycids and hence increase the chance of a connection being made between the trade and the pest. In the case of longhorn beetles, however, infestations may go unnoticed unless exit holes are found, frass builds up on the outside of the host, or an emerged adult is detected.

The citrus longhorn beetle, *Anoplophora chinensis* (Forster), is one of the most notable worldwide invasive longhorn beetles that has been transported with plants for planting. Some authors (e.g., Adachi 1994) refer to *A. malasiaca* (Thomson); however, *A. malasiaca* was synonymized with *A. chinensis* by Lingafelter and Hoebeke (2002). They argued that *A. chinensis* and *A. malasiaca* could not be separated on the basis of the color and size of elytral macula (spots) and the presence or absence of hair on the pronotum because there is considerable variation of such features and considerable overlap in specimens from the same locality (CABI 2014a). For the purposes of this chapter, the synonymization has been accepted, but some Japanese researchers still consider *A. chinensis* and *A. malasiaca* to be separate species on the bases of morphological characteristics and DNA from the CO1 sequence of the mitochondria (Ohbayashi et al. 2009; Iwaizumi et al. 2014).

A. chinensis is a damaging pest for a range of deciduous trees and originates in Asia, with most records being from China, Japan, and South Korea. Other Asian countries or regions where *A. chinensis* has been recorded are Malaysia, North Korea, Vietnam, Taiwan, the Philippines, Indonesia, and Myanmar, although there are many fewer records from these countries (Gressit 1951; CABI and EPPO 1997; Lingafelter and Hoebeke 2002). *A. chinensis* is a serious pest of fruit trees, especially citrus in Japan (Adachi 1994) and China (Lieu 1945). It was first discovered outside of Asia in 2000 when an outbreak (in this case meaning a breeding population in a nonnative area) was discovered in Parabiago, Lombardy, in northern Italy, and since then outbreaks have been discovered elsewhere in Italy and the rest of Europe. Table 13.1 and Figure 13.1 show that most outbreaks of *A. chinensis* in Europe have been in Italy and the Netherlands, which are the EU countries that import the greatest number of plants for planting (FAO 2014).

EUROPHYT is a phytosanitary database of interceptions of plant health pests and pathogens for the European Union and contains records that have been reported by member states or Switzerland to the European Commission. These data are published by the European and Mediterranean Plant Protection Organization (EPPO) and also by the EU (EPPO 2013a; EU 2014). Between 1998 and 2013, there were 455 Cerambycidae interception records in the EUROPHYT database. Table 13.2 shows the number of interceptions of Cerambycidae by year and product category, and Table 13.3 shows the taxa and origin of Cerambycidae intercepted on plants for planting.

Between 1998 and 2013, there were 54 interceptions of Cerambycidae on plants for planting reported on EUROPHYT. This includes plants described as "already planted," "not yet planted," "bonsais," and "seeds." This analysis has excluded 39 records from 2008 apparently relating to plant genera that were in the same consignment as an *Acer* sp. infested with *A. chinensis* but were not themselves confirmed as being infested. The only species of longhorn beetle recorded in association with plants for planting on EUROPHYT was *A. chinensis* (38 records); the other records were *Anoplophora* sp. (11, many of which

TABLE 13.1

Recorded Outbreaks of *Anoplophora chinensis* Outside the Countries Where It Is a Native Species as of February 2016

Country	Location	Outbreak Detected	Declared Eradicated	Eradication Year	References
Italy	Parabiago	2000	No	NA	Colombo and Limonota 2001, Caremi and Ciampitti 2006, Hérard et al. 2006, Tomiczek and Hoyer-Tomiczek 2007
France	Soyons	2003	Yes	2006	Hérard et al. 2006
Italy	Montichiari	2007	No	NA	Petruzziello 2009
Netherlands	Westland	2007	Yes	2010	Van der Gaag et al. 2010
Croatia	Turanj–Sveti Filip i Jakov	2007	No	NA	Van der Gaag et al. 2010, Vukadin and Hrasovec 2008, EPPO 2016
Italy	Gussago	2008	No	NA	Bazzoli and Alghisi 2013
Italy	Rome	2008	No	NA	Van der Gaag et al. 2010, Roselli et al. 2013, Peverieri et al. 2012
Netherlands	Boskoop	2009	Yes	2010	Van der Gaag et al. 2010
Italy	Prato	2014	No	NA	EPPO 2016

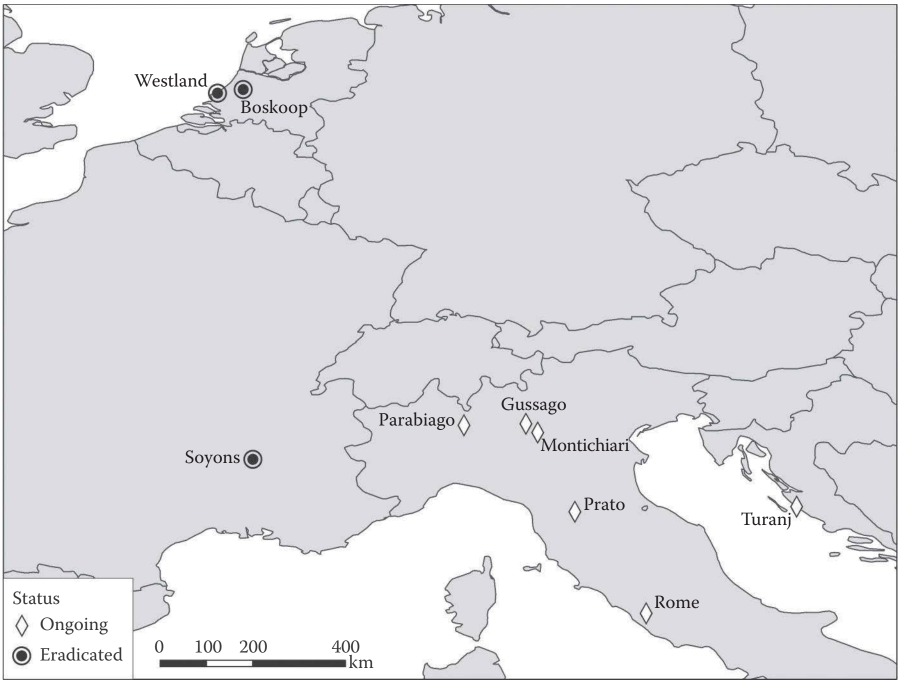

FIGURE 13.1 Locations of outbreaks of *Anoplophora chinensis,* the citrus longhorn beetle, in Europe as of February 2016.

were likely *A. chinensis*) and Cerambycidae (5). Maples were the reported hosts for *A. chinensis* for 37 of the 38 interceptions of *A. chinensis* on plants for planting, including *Acer palmatum* Thub. (20 interceptions), *Acer buergerianum* Miq. (3), *Acer rubrum* L. (1), and *Acer* sp. (13). The origin of consignments infested with either *A. chinensis* or *Anoplophora* sp. (49) was China (32), the Netherlands (8), Italy (3), Japan (3), South Korea (1), and unknown (2).

The predominance of live plant imports from China being the source of *A. chinensis* interceptions was also found in records from Europe, North America, and New Zealand between 1980 and 2008 (Haack et al. 2010). In total, there were 74 interceptions of *A. chinensis* between 1980 and 2008, with the highest number (24) in 2008; the highest number of interceptions (41) took place in the Netherlands. Most of the interceptions of *A. chinensis* were in live plants from China (85%), Japan (13%), and South Korea (2%) (Haack et al. 2010).

This data set also demonstrates the difficulties that national plant protection organizations (NPPOs) have faced when trying to detect *A. chinensis* at points of entry (Haack et al. 2010). For example, of the 74 interceptions, only 7 were at points of entry, with all the others occurring post-entry, although most (86) of the 145 interceptions of *A. glabripennis* were at points of entry. The majority (78) of the 86 interceptions at points of entry were in the United States (46) and Canada (32). In EU countries, the majority of interceptions of *A. glabripennis* were post-entry, with all 27 interceptions in the United Kingdom being post-entry (Haack et al. 2010). Most of these records refer to findings of the pest in close association with imported items, such as wood packaging materials, after they had been cleared through ports.

In 2008, there were multiple finds of *A. chinensis* in imported plants that had been planted in private gardens in the United Kingdom (Eyre et al. 2010). Plant health authorities in the United Kingdom first became aware of the situation when a member of the public from Tyne and Wear in northeast England reported finding a live adult *A. chinensis.* The beetle had emerged from an *Acer palmatum* that had been obtained via an offer of free plants in a national newspaper. The plant was traced to a mail order company in Guernsey (an island Crown dependency in the English Channel) that had imported the plants from China via the Netherlands. Approximately 60,000 *A. palmatum* had been sent to some 45,000 customers

TABLE 13.2

Number of Interceptions of Longhorn Beetles per Year in the European Union as Recorded on EUROPHYT

	Product Category	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Grand Total
Plants for planting and cut branches	Intended for planting: already planted					1			1	1	1	14	3	4			1	26
	Intended for planting: bonsais	1				1				2	2	2	2			2		12
	Intended for planting: not yet planted	1	1									5	4	4				15
	Intended for planting: seeds			1														1
	Cut flowers and branches with foliage							1										1
	Cut branches without foliage								1									1
Wood packaging	Dunnage		1										2	1	3	1	2	10
	Wood packaging material			3	3	9	8	12	12	6	10	3	8	7	10	22	30	143
	Wood pallet		1	1			1	5		1	5	6	7	6	4	16	28	81
	Wooden crate			14				3	3	2	3	4	2	1	6	20	14	72
Others	Products: wood and bark	2	7	13	2	5		3	12	7		2	1	4	11	2	2	73
	Object with wooden parts								1	1	1		1				1	5
	Packing materials	1	2									1				3		7
	Products: by-products of plant origin					1												1
	Others/unknown						1				3		1			1	1	7
Grand Total		**5**	**12**	**32**	**5**	**17**	**10**	**24**	**30**	**20**	**25**	**37**	**31**	**27**	**34**	**67**	**79**	**455**

TABLE 13.3

Number of Interceptions of Longhorn Beetles in the European Union on Plants for Planting between 1998 and 2013 by Taxon and Country of Export Sorted by Host Plant

Cerambycid Taxon	**Country of Export**	***Acer buergerianum***	***Acer palmatum***	***Acer rubrum***	***Acer* sp.**	***Cercis* sp.**	***Ilex* sp.**	***Pinus* sp.**	***Taxus cuspidata***	***Wisteria* sp.**	**Grand Total**
Anoplophora chinensis	China	2	10	1	9	1	0	0	0	0	23
	Italy	0	3	0	0	0	0	0	0	0	3
	Japan	0	1	0	1	0	0	0	0	0	2
	Republic of Korea	1	0	0	0	0	0	0	0	0	1
	Netherlands	0	6	0	1	0	0	0	0	0	7
	Unknown	0	0	0	2	0	0	0	0	0	2
Anoplophora sp.	China	0	4	0	4	0	1	0	0	0	9
	Japan	0	0	0	0	0	0	0	1	0	1
	Netherlands	0	1	0	0	0	0	0	0	0	1
Cerambycidae	China	0	0	0	1	0	0	0	0	0	1
	India	0	0	0	0	0	0	1	0	0	1
	Republic of Korea	0	1	0	0	0	0	0	0	0	1
	New Zealand	0	0	0	0	0	0	0	0	2	2
Grand Total		**3**	**26**	**1**	**18**	**1**	**1**	**1**	**1**	**2**	**54**

around the United Kingdom. The trees generally were small (with a maximum trunk diameter of only a few centimeters), and the probability of two or more *A. chinensis* being able to complete their development within the same tree was considered to be low. Given that *A. chinensis* reproduce sexually, an outbreak could only be initiated at locations where both a male and a female were to emerge, locate each other, and mate. Therefore, the risks of establishment were considered highest at sites where two or more of the potentially infested plants had been planted. In order to evaluate the risk, an estimated 326 trees were destructively sampled and a further 253 were visually inspected. No *A. chinensis* were found during the course of these inspections; hence, it was concluded that the risk of establishment was low.

In addition to the UK finds described here, the Netherlands reported numerous interceptions of *A. chinensis* on *Acer* trees imported from Asia in 2007 and 2008. In 2007, the Dutch Plant Health Service inspected approximately 100 sites holding *Acer* trees imported from China or Japan for the presence of *A. chinensis*, and infested consignments were found at six locations. At one of these six locations, live *A. chinensis* larvae were found in two consignments of *Acer* trees from two different locations in Japan, and a further three consignments of *Acer* (two from Japan and one from China) had exit holes that were probably caused by *A. chinensis*. Between January and March 2008, 45 consignments of *Acer* were imported into the Netherlands from China and Japan. *A. chinensis* was intercepted in two of these consignments at the point of entry and in a further 12 consignments during post-entry inspections (van der Gaag et al. 2008).

The outbreak of *A. chinensis* that was first discovered in 2000 in Parabiago, Lombardy, Italy, currently is the most significant *Anoplophora* outbreak in Europe, and the pest may have spread too far for eradication to be practical (Brockerhoff et al. 2010). Between 2001 and 2013, almost €18 (US$20) million was spent on eradicating *A. chinensis* in Lombardy, and 25,000 trees were cut down as part of the eradication campaign (Ciampitti and Cavagna 2014). Another very significant outbreak of *A. chinensis* was detected in Europe in December 2009 when Dutch inspectors detected seven exit holes in two dead stumps of *A. palmatum* and one exit hole in a *Carpinus* tree in Boskoop in the Netherlands (van der Gaag et al. 2010). The significance of this outbreak was not its scale but the importance of its location. Boskoop is an important center for the production of hardy ornamental nursery stock for Europe; therefore, an outbreak in this area meant that there was a significant risk that the pest could have been moved to other parts of the EU in infested plants.

As of February 2016, no established populations of *A. chinensis* have been reported in North America, although in 2001, five *A. chinensis* adults were thought to have emerged from *Acer* bonsai trees being held outdoors at a nursery in Washington State and possibly had become established nearby. Out of concern that the beetles could mate and lay eggs on nearby trees, an eradication program was initiated by Washington State in 2002. This involved cutting and chipping all potential host trees within 200 m of the nursery, treating all potential host trees within 200–400 m of the nursery with systemic insecticides, and conducting annual surveys of all host trees within 800 m of the nursery for five years. No evidence was ever found that *A. chinensis* had become established, and thus the quarantine was terminated in 2007 (Haack et al. 2010).

The lemon tree borer, *Oemona hirta* (Fab.), is another example of a pest that has been moved among continents in plants for planting. This beetle was intercepted in the United Kingdom once in 1983 and at two nurseries in 2010. The 2010 finds were entered on EUROPHYT as “Cerambycidae” and identified to species level at a later date. The pest is native to New Zealand and is not known to be established elsewhere. The 2010 interceptions were of larvae associated with *Wisteria* plants imported from New Zealand for growing on and then sale (EPPO 2013c).

13.4 Pathways: Wood Packaging Materials

Wood packaging materials are frequently made of raw wood that may not have undergone sufficient processing or treatment to remove or kill pests; therefore, it becomes a pathway for the introduction and spread of pests such as Cerambycidae (IPPC 2009). Of the 455 interceptions of longhorn beetles recorded on the EUROPHYT database between 1998 and 2013, the majority (306) were interceptions relating to consignments of wood packaging materials. The interceptions have been divided into those made on unspecified wood packaging material (143), wood pallets (81), wooden crates (72), and dunnage (10) (Table 13.2). When the beetles were identified to genus or species level (181 interceptions), almost half the interceptions were related to either *Anoplophora glabripennis* (57 interceptions) or *Anoplophora* sp. (22) (Table 13.4). The *Anoplophora* sp. are very likely to have been *A. glabripennis* given that there is only one record of another *Anoplophora* sp. being associated with wood packaging material in Europe—an interception of *A. chinensis* in 2007.

The second most commonly intercepted species of longhorn beetle was *Apriona germari* (Hope), with 26 interceptions being recorded on EUROPHYT and most of these being in 2012 (15) and 2013 (8). The risk of this pest, along with the risks relating to *Apriona japonica* Thomson and *Apriona cinerea* Chevrolat, has been assessed for the Netherlands (Justica et al. 2010) and the wider EPPO region (EPPO 2013b). The EPPO assessment was that *A. germari* presents a particular risk to the Mediterranean area, southeast Europe, northern Turkey, and to the oceanic areas of southwest Europe. The following hosts are those most commonly reported for these *Apriona* pests in the literature: *Morus* spp., *Populus* spp., *Salix* spp., *Malus* spp., *Ficus carica* L., *Broussonetia papyrifera* (L.) Hert. Ex Vent., *Artocarpus heterophyllus* Lamark, and *Sophora japonica* (L.) Schott (EPPO 2014).

Figure 13.2 shows the number of interceptions of Cerambycidae in association with wood packaging in the EU between 1999 and 2013. This figure indicates that there were more than double the number of interceptions in 2012 and 2013 than in all previous years, and that wood packaging from China was the source of the majority of interceptions every year.

During 1984–2008, there were 3,483 cerambycid interceptions associated with wood products or packaging at U.S. points of entry, of which 89% were identified to subfamily level or lower, 76% to genus, and 19% to species. The data set analyzed here is the same as the PestID data described in Haack et al. (2014) as well as the one described for just the Scolytinae in Haack and Rabaglia (2013). These 3,483 cerambycid interceptions represented at least 85 genera in six subfamilies and 86 distinct species. For those individuals that were identified to at least the genus level, the top 10 intercepted genera in decreasing order were *Arhopalus, Monochamus, Tetropium, Xylotrechus, Ceresium, Hesperophanes, Phymatodes, Callidium, Callidiellum*, and *Anoplophora*. Similarly, for those individuals identified to the species level, the top five intercepted species were *T. castaneum* (L.), *Arhopalus syriacus* (Reitter), *Arhopalus rusticus* (L.), *Callidiellum rufipenne* (Motschulskyi), and *Pyrrhidium sanguineum* (L.) (Table 13.5). Of the 677 interceptions that were identified to species level, there were 254 interceptions (38%) of *T. castaneum*, and the top five species accounted for 59% of all interceptions. This data set was likely influenced by the ease of identification to generic or specific level; for example, the lack of taxonomic keys or reference specimens could have made the identification of some of those intercepted Cerambycidae difficult or impossible.

Figure 13.3 shows the number of interceptions of Cerambycidae in the United States on wood packaging from various regions of the world and by the type of associated imported commodities between 1984 and 2008. Most Cerambycidae during that entire time period were intercepted on wood packaging from Europe, followed by Asia and North America (mostly Mexico). The United States has a policy of only inspecting limited amounts of wood packaging from Canada because most bark-infesting and wood-infesting insects native to Canada are also native to the United States and because of the long largely forested border between the two countries (Haack et al. 2014). Wood packaging associated with tiles and quarry products such as marble accounted for the majority of the cerambycid interceptions from Europe.

The link between heavy commodities such as stone and the interception of longhorn beetles may be due to the thickness of wood required to support the commodities, with thicker wood being both more likely to harbor insects and more difficult to heat treat or fumigate. A second explanation for the link between pest levels in wood packaging material and heavy consignments such as stone is that low-quality wood is more frequently used to make the wood packaging material (John Morgan, Forestry Commission, UK, personal communication). Wood packaging material used to transport heavy items is often damaged in transit; therefore, the wood packaging material is considered to be single use in contrast to wood packaging material that may be used to transport food or items to be stored in warehouses, which needs to be made of higher quality wood.

Figure 13.4 illustrates the number of interceptions of Cerambycidae in the United States on wood per year between 1984–2008 for the five countries which accounted for the highest number of interceptions: China, Italy, Mexico, Turkey and Spain. The highest number of cerambycid interceptions on imports

TABLE 13.4

Number of Interceptions of Longhorn Beetles in the European Union on Wood Packaging between 1998 and 2013 by Taxon and Country of Export

Cerambycid Taxon	Country of Export	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Grand Total
Anoplophora chinensis	China	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	1
Anoplophora glabripennis	China	–	–	4	–	1	–	3	3	–	–	4	3	4	5	11	19	57
Anoplophora sp.	China	–	–	–	–	1	2	–	6	–	4	1	–	1	–	5	2	22
Apriona germarii	China	–	–	–	–	–	–	–	–	–	–	–	2	–	1	15	8	26
Batocera lineolata	China	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	2	3
Batocera sp.	China	–	–	–	–	–	–	1	–	–	–	–	–	–	–	1	1	3
Cerambycidae	Australia	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	1
	Belarus	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	1
	Brazil	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	2
	China	–	1	1	–	3	7	8	1	3	7	4	2	6	9	19	28	99
	Costa Rica	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1
	Germany	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1
	India	–	–	–	–	–	–	–	–	–	2	2	–	1	–	1	2	8
	Indonesia	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	1
	Japan	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	1
	Portugal	–	–	–	–	–	–	–	–	–	–	–	1	–	1	–	–	2
	Russian Federation	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	1
	Turkey	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	1
	Ukraine	–	–	–	–	–	–	–	–	–	–	–	–	–	–	4	–	4
	Vietnam	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	1	2
Chlorophorus sp.	China	–	–	–	–	1	–	–	–	–	1	–	–	–	–	–	1	3
Criocephalus rusticus	South Africa	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	1
Monochamus alternatus	China	–	–	1	–	–	–	1	–	3	–	–	2	–	–	–	1	8

(Continued)

TABLE 13.4 ***(Continued)***

Number of Interceptions of Longhorn Beetles in the European Union on Wood Packaging between 1998 and 2013 by Taxon and Country of Export

Cerambycid Taxon	Country of Export	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	Grand Total
Monochamus sp.	Belarus	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1
	China	–	1	9	3	2	–	4	3	–	–	1	2	2	1	3	–	31
	Kazakhstan	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3	3
	Russian Federation	–	–	–	–	–	–	2	–	3	–	–	1	1	1	–	–	8
	Taiwan	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	1
	United States	–	–	1	–	–	–	1	–	–	1	–	–	–	–	–	1	4
Monochamus sutor	Latvia	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	–	1
	Russian Federation	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	2
Phoracantha semipunctata	Brazil	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
	China	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	1
Saperda sp.	China	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	1	2
Xylotrechus sp.	China	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	1
	India	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	1
Grand Total		–	2	18	3	9	9	20	15	9	18	13	19	15	23	59	74	306

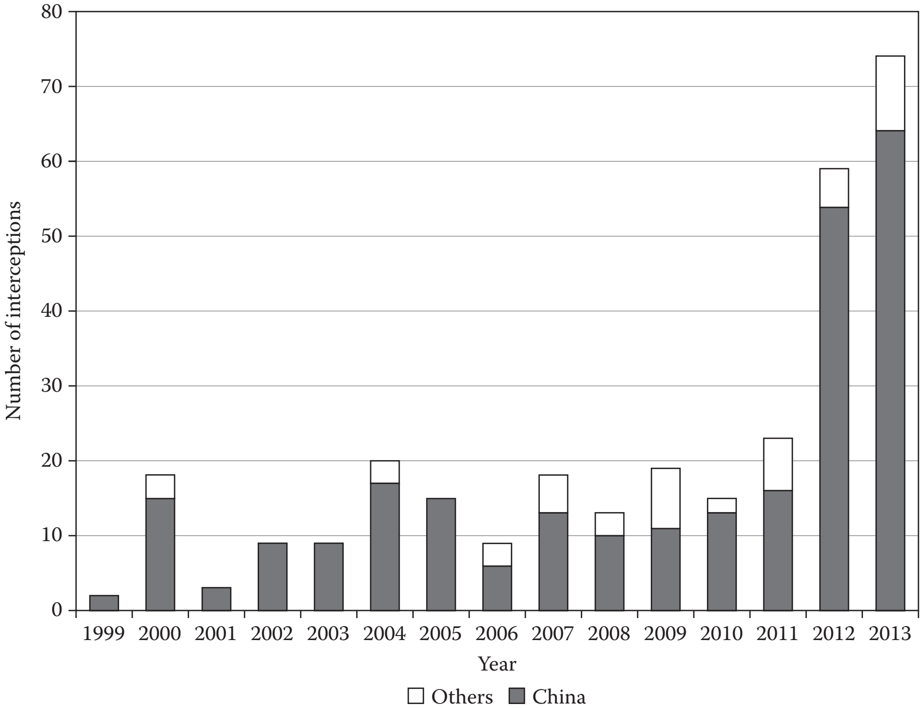

FIGURE 13.2 Annual number of interceptions of Cerambycidae in association with wood packaging material in the European Union as recorded on EUROPHYT between 1999 and 2013.

from China was in 1998, possibly reflecting more intensive inspections following the discoveries of *A. glabripennis* in New York City in 1996 and in Chicago in 1998 (Haack et al. 2010). The total number of cerambycid interceptions per year in the United States remained below 50 between 1984 and 1993 but had shown a dramatic increase between 1994 and 2008, with the highest number of interceptions in 2007 (377 interceptions).

Table 13.6 lists the top 20 combinations of imported commodity and country of origin in terms of the number of cerambycid interceptions made in association with imports to the United States between 1984 and 2008. The list is dominated by trades in either tiles (four of the top eight trades) or quarry products (8 of the top 20 trades), which include products such as marble, granite, and slate. The list also includes three metal commodity or product trades. Nine of the trades were with China and three with Italy. The number of interceptions per year relating to the top four commodities (Figure 13.5) shows that interceptions relating to tiles and quarry products significantly increased from the mid-1990s to 2008.

The prime example of a nonnative longhorn beetle that has been moved to new geographic regions in wood packaging material is *A. glabripennis*. There have been numerous outbreaks of this pest of deciduous trees in North America, Europe, and Japan. Table 13.7 lists the outbreaks of this pest that had been reported outside its native range by February 2016. Some of the listed outbreaks had multiple foci, which could indicate multiple introductions or possible natural or human-assisted spread, such as the outbreak areas in New York. Outbreaks have tended to occur in the more industrialized countries of the world, which is logical given that they are also likely to be importing the greatest volumes of products from China. In the United States, all the *A. glabripennis* outbreaks have been on the eastern side of the country—the area that has been judged to be most at risk based on host availability and climate (Peterson et al. 2004). *A. glabripennis* had been declared eradicated in 9 of the 35 outbreak areas as of February 2016. Nevertheless, it is anticipated that other currently undetected outbreaks exist in Europe and North America given that 16 *A. glabripennis* outbreaks were detected between 2012 and 2015. Figures 13.6 and 13.7 show the locations of the *A. glabripennis* outbreaks in North America and Europe, respectively.

TABLE 13.5

Cerambycidae Intercepted in the United States between 1984 and 2008 on Wood Packaging Material and Identified to Species Level

Cerambycid Taxon	No. Interceptions	Most Numerous Commodity	Second Most Numerous Commodity	Most Common Origin	Second Most Common Origin
Acanthocinus aedilis (Linnaeus)	2	Tiles		Spain	Turkey
Acanthocinus griseus (Fabricius)	2	Tiles		Spain	Turkey
Agapanthia irrorata (Fabricius)	1	Tiles		Spain	
Anaglyptus mysticus (Linnaeus)	1	Tiles		Italy	
Anelaphus moestus (Leconte)	1	Unknown		Honduras	
Anoplophora glabripennis Motschulsky	6	Iron	Machinery	China	
Arhopalus asperatus (Leconte)	1	Unknown		Unknown	
Arhopalus ferus Mulsant	3	Tiles		Turkey	
Arhopalus productus (Leconte)	1	Unknown		Honduras	
Arhopalus rusticus (Linnaeus)	33	Quarry product	Tiles	Spain	China
Arhopalus syriacus (Reitter)	56	Quarry product	Tiles	Italy	Turkey
Aromia moschata (Linnaeus)	1	Quarry product		China	
Asemum striatum (Linnaeus)	5	Quarry product	Tiles	Spain	China
Batocera rufomaculata (De Geer)	1	Unknown		India	
Callidiellum rufipenne (Motschulsky)	31	Steel	Machinery	Japan	China
Callidiellum villosulum Fairmaire	8	Woodenware	Engines	China	
Callidium aeneum (De Geer)	1	Tiles		Italy	
Callidium violaceum (Linnaeus)	6	Tiles	Quarry product	Italy	China
Chlorida festiva (Linneaus)	2	Tiles		Colombia	Dom. Rep.
Chlorophorus annularis (Fabricius)	6	*Bambusa* sp.	Household goods	China	Indonesia
Chlorophorus pilosus glabromaculatus Forster	1	Tiles		Italy	
Chlorophorus strobilicola Champion	2	Woodenware		India	
Clytus lama Mulsant	1	Tiles		Italy	
Dere thoracica White	1	Unknown		China	
Derobrachus geminatus LeConte	1	Unknown		Mexico	
Desmiphora hirticollis (Olivier)	1	Unknown		Mexico	
Eburia mutica Leconte	1	Unknown		Mexico	
Elaphidion irroratum (Linnaeus)	1	Tiles		Dom. Rep.	
Elaphidion mucronatum (Say)	1	Unknown		China	

(Continued)

TABLE 13.5 ***(Continued)***

Cerambycidae Intercepted in the United States between 1984 and 2008 on Wood Packaging Material and Identified to Species Level

Cerambycid Taxon	No. Interceptions	Most Numerous Commodity	Second Most Numerous Commodity	Most Common Origin	Second Most Common Origin
Euryscelis suturalis Olivier	1	Tiles		Colombia	
Gnaphalodes trachyderoides Thomson	2	Machinery		Mexico	
Gracilia minuta (Fabricius)	1	Unknown		France	
Hesperophanes campestris (Faldeman)	1	Unknown		China	
Hylotrupes bajulus (Linnaeus)	21	Tiles	Quarry product	Italy	China
Icosium tomentosum Lucas	5	Quarry product		Greece	Israel
Knulliana cincta (Drury)	1	Household goods		China	
Lagocheirus araneiformis Linnaeus	1	Tiles		Dom. Rep.	
Lagocheirus undatus (Voet)	1	Unknown		Costa Rica	
Lamia textor (Linnaeus)	4	*Quercus* sp.	Tiles	Italy	France
Lissonotus flavocinctus Dupont	1	Tiles		Colombia	
Megacyllene antennatus (White)	2	*Prosopis* sp.		Mexico	
Molorchus minor (L.)	15	Tiles	Quarry product	Italy	Spain
Monochamus alternatus Hope	17	Quarry product	Tiles	China	Taiwan
Monochamus carolinensis (Oliver)	2	Machinery		Mexico	Unknown
Monochamus clamator (Leconte)	1	Unknown		Unknown	
Monochamus galloprovincialis (Olivier)	5	Tiles	Quarry product	Spain	Turkey
Monochamus sartor (Fabricius)	5	Tiles	Aluminum	Italy	Greece
Monochamus scutellatus (Say)	2	*Pinus* sp.		Canada	China?
Monochamus sutor (Linnaeus)	9	Tiles	Quarry product	Spain	Turkey
Monochamus teserula White	1	Unknown		China	
Nathrius brevipennis (Mulsant)	2	Furniture		Chile	
Neoclytus caprea (Say)	1	Unknown		South Korea	
Neoclytus cordifer (Klug)	2	Foodstuffs		Honduras	
Neoclytus olivaceus L. & G.	1	Unknown		Brazil	
Nyssodrysina haldemani Leconte	2	Unknown		Bangladesh	
Oxypleurus nodieri Mulsant	7	Quarry product	Tiles	Turkey	Spain
Palaeocallidium rufipenne Motschulsky	1	Unknown		Japan	
Perissus delerei Tippmann	1	Unknown		Pakistan	

(Continued)

TABLE 13.5 ***(Continued)***

Cerambycidae Intercepted in the United States between 1984 and 2008 on Wood Packaging Material and Identified to Species Level

Cerambycid Taxon	No. Interceptions	Most Numerous Commodity	Second Most Numerous Commodity	Most Common Origin	Second Most Common Origin
Petrognatha gigas (Fab)	1	Unknown		Africa country unknown	
Phoracantha recurva Newman	2	Parts	Tiles	Brazil	
Phoracantha semipunctata Fabricius	4	Machinery	Tools	Australia	Brazil
Phymatodes testaceus (Linnaeus)	5	Tiles	Acer sp.	Italy	Germany
Plagionotus christophi Kraatz	3	Ironware		China	
Plagionotus detritus Linnaeus	1	Tiles		Italy	
Pogonocherus hispidus (Linnaeus)	3	Tiles	Quarry product	Italy	
Pogonocherus perroudi Mulsant	2	Tiles		Spain	Turkey
Prionus californicus Mots	1	Unknown		Indonesia	
Pyrrhidium sanguineum (Linnaeus)	25	Tiles	Steel	Italy	Belgium
Rhagium inquisitor (Linnaeus)	8	Tiles	Quarry product	France	Italy
Rhagium mordax (Degeer)	2	Tiles		Belgium	Italy
Saperda carcharias (Linnaeus)	5	Tiles	Parts	Italy	
Semanotus ligneus (Fabricius)	1	Decorations		China	
Smodicum cucujiforme (Say)	1	Paint		Unknown	
Stromatium barbatum (Fabricius)	1	Unknown		Taiwan	
Stromatium longicorne (Newman)	3	Equipment	Furniture	India	Pakistan
Tetropium castaneum (Linnaeus)	254	Tiles	Quarry product	Italy	France
Tetropium fuscum Fabricius	9	Tiles	Quarry product	Italy	China
Tetropium gabrieli Weise	11	Tiles	Quarry product	Italy	China
Trachyderes mandibularis Serville	2	Tiles		Italy	Mexico
Xylotrechus grayi (White)	1	Iron		China	
Xylotrechus magnicollis Fairmaire	10	Tiles	Electrical parts	China	Hong Kong
Xylotrechus pyrrhoderus (Bates)	2	Unknown		South Korea	Unknown
Xylotrechus rusticus (Linnaeus)	21	Tiles	Quarry product	Greece	Italy
Xylotrechus stebbingi Gahan	1	Tiles		Italy	
Xystrocera globosa (Olivier)	5	Hardware	Machinery	India	Singapore
Total	677				

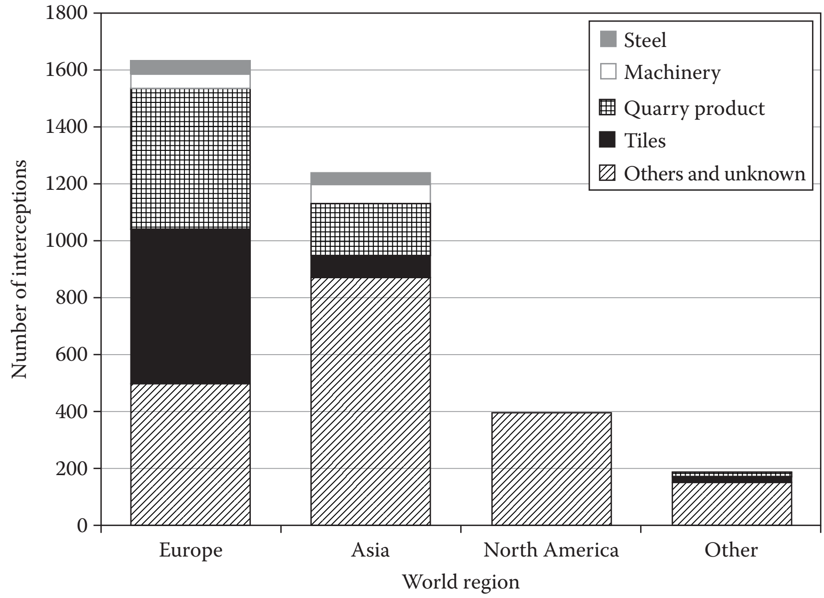

FIGURE 13.3 Number of interceptions of Cerambycidae on wood packaging material in the United States by world region for the period 1984–2008 divided by the type of imported commodity.

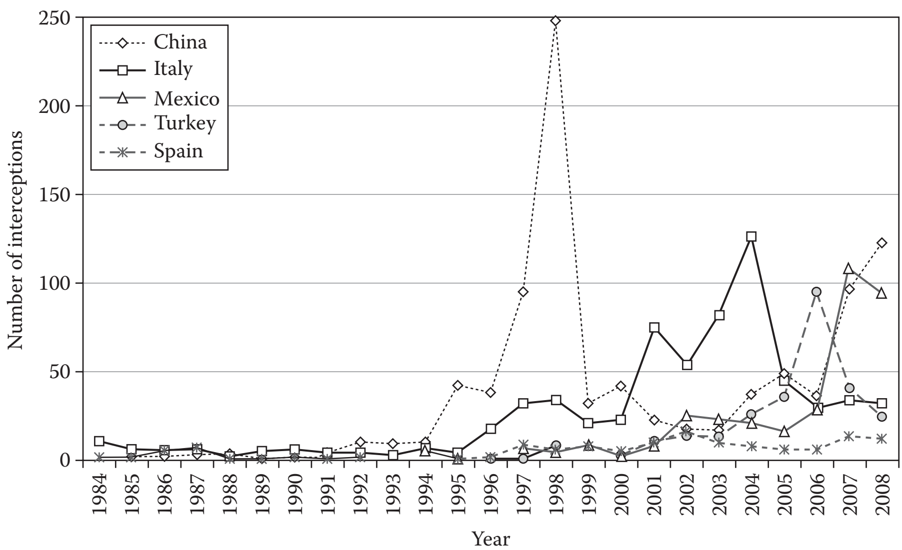

FIGURE 13.4 Annual number of interceptions of Cerambycidae on wood packaging material in the United States between 1984 and 2008 for the five countries with the highest number of interceptions. (From USDA APHIS PestID Database.)

Millions of hectares of monoculture forests have been planted in China since 1949 (Hsiao 1982), and in northern China these were mainly *Populus* species (Luo et al. 2003). The widespread planting of susceptible *Populus* spp. is thought to have led to the rapid spread and high outbreak levels of *A. glabripennis* within China (EPPO 1999) and the beetle has been a major pest there since the 1970s–1980s (Lingafelter and Hoebeke 2002; Haack et al. 2010). *A. glabripennis* is thought to be responsible for US$1.5 billion worth of damage to Chinese forests each year, and this represents 12% of all losses attributable to forest pests in that country (Hu et al. 2009; Meng et al. 2015). It has been estimated that, in China, hundreds

TABLE 13.6

Trades (country of origin and product combinations) Responsible for the Highest Number of Cerambycid Interceptions on Wood Packaging in the United States from 1984 through 2008

Origin	Commodity	No. of Interceptions
Italy	Tiles	347
Turkey	Quarry product	168
Italy	Quarry product	167
China	Quarry product	162
Turkey	Tiles	85
China	Iron	79
Spain	Tiles	75
China	Tiles	74
China	Machinery	51
China	Ironware	48
Italy	Metalware	46
Spain	Quarry product	45
France	Quarry product	32
China	Glass	27
Greece	Quarry product	24
China	Woodenware	20
Bulgaria	Quarry product	19
China	Equipment	17
Portugal	Quarry product	16
China	Metalware	15

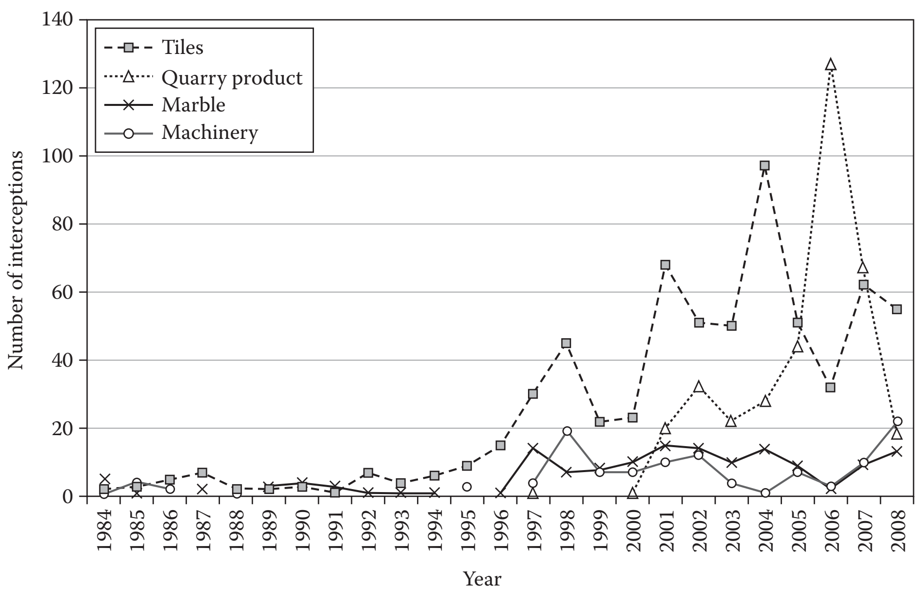

FIGURE 13.5 Annual number of interceptions of Cerambycidae on wood packaging material in the United States by commodity type between 1984 and 2008 for the top four commodity classes. (From USDA APHIS PestID Database.)

TABLE 13.7

Recorded Outbreaks of *Anoplophora glabripennis* Outside the Countries Where It Is Native

Country	Location	Outbreak Detected	Year Eradicated[a]	Source
United States	New York[b]	1996	–	Haack et al. 1997
United States	Chicago, Illinois	1998	2008	Poland et al. 1998, EPPO 2016
Austria	Braunau-am-Inn	2001	2013	Tomiczek et al. 2002, EPPO 2016
United States	Jersey City, New Jersey	2002	2013	Smith et al. 2009, EPPO 2016
Japan	Yokohama City	2002	2005	Takahashi and Ito 2005
France	Gien, Loiret, Centre	2003	–	Cocquempot and Herard 2003
Canada	Toronto, Ontario	2003	2013	Hu et al. 2009, EPPO 2016
France	Sainte-Anne-sur-Brivet	2004	–	Hérard et al. 2006
Germany	Neukirchen am Inn	2004	2016	Hérard et al. 2006, EPPO 2016
Germany	Bornheim North Rhine Westphalia	2005	–	Tomiczek and Hoyer-Tomiczek 2007
Italy	Corbetta, Lombardy	2007	–	Maspero et al. 2007
France	Strasbourg	2008	–	Hérard et al. 2009
United States	Worcester, Massachusetts	2008	–	Smith and Wu 2008
Italy	Cornuda	2009	–	Zampini et al. 2013
Netherlands	Almere	2010	2011	Morall 2011, PPS Netherlands 2010, PPS Netherlands 2011
United States	Boston, Massachusetts	2010	2014	Dodds and Orwig 2011,USDA-APHIS 2014
Germany	Weil am Rhein Baden-Wüerttemberg	2011	–	Saxony State Office for the Environment 2016
Switzerland	Brunisried (Canton of Fribourg)	2011	–	Forster and Wermelinger 2012
United States	Bethel, Ohio	2011	–	Dodds et al. 2013
Germany	Feldkirchen near Munich	2012	–	Bayerische Landesandstlt fur Landwirschaft 2012, JKI 2012
Netherlands	Winterswijk	2012	–	PPS Netherlands 2012
Switzerland	Winterthur (Canton of Zurich)	2012	–	Forster and Wemelinger 2012
United Kingdom	Paddock Wood, Kent,	2012	–	Straw et al. (2014)
Austria	Geinberg, Ried Im Innkreis	2012	–	Hoyer et al. 2013, EPPO 2016
France	Corsica	2013	–	EPPO 2016
Austria	Gallspach	2013	–	Schreck and Tomiczech 2013
Italy	Marche	2013	–	EPPO 2016
Canada	Mississauga[c]	2013	–	Turgeon et al. 2015
Switzerland	Marly	2014	–	EPPO 2016
Germany	Neubiberg	2014	–	EPPO 2016
Germany	Ziemetshausen (Schönebach)	2014	–	EPPO 2016
Germany	Magdeburg	2014	–	EPPO 2016
Turkey	Zeytinburnu[d]	2014	2015	Ayberk et al. 2014, EPPO 2016
Finland	Vantaa	2015	–	EPPO 2016
Switzerland	Berikon	2015	–	EPPO 2016

[a] En dash (–) indicates the outbreak has not been eradicated.

[b] *A. glabripennis* has been eradicated from three areas: Islip (2011), Manhattan (2013), and Staten Island (2013).

[c] Recent evidence from mitochondrial DNA haplotype studies and backdating of the two Canadian *A. glabripennis* infestations in the Toronto area suggest that the two populations could be related (Turgeon et al. 2015).

[d] The official status in Turkey is absent because the Turkish National Plant Protection Organization have not detected the pest, although investigations are ongoing.

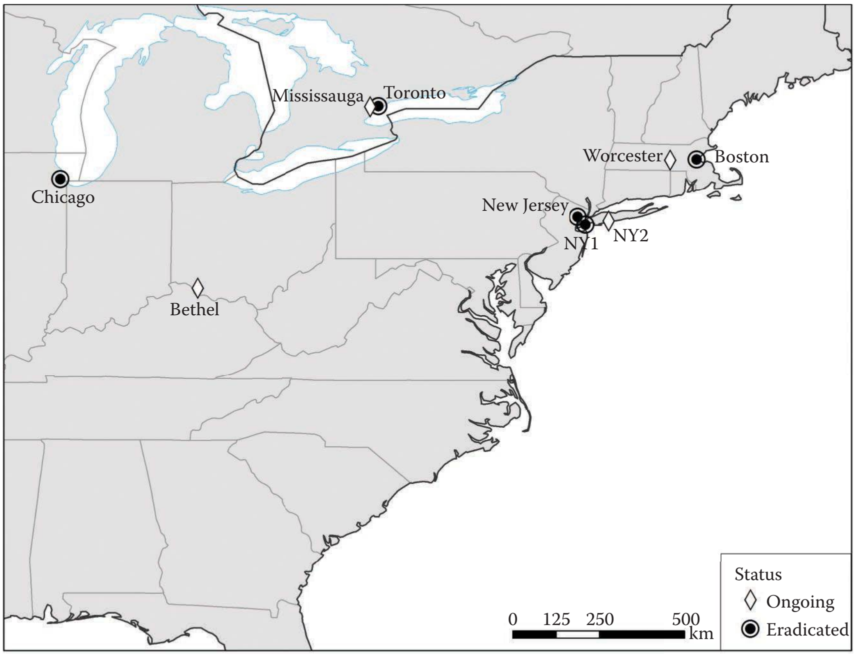

FIGURE 13.6 Locations of outbreaks of *Anoplophora glabripennis*, the Asian longhorn beetle, in North America as of January 2016. NY1 = The USDA have declared the Asian longhorn beetle as eradicated from Islip (2011), Staten Island (2013), and Manhattan (2013). NY2 = Outbreaks are ongoing in Brooklyn/Queens, central Long Island.

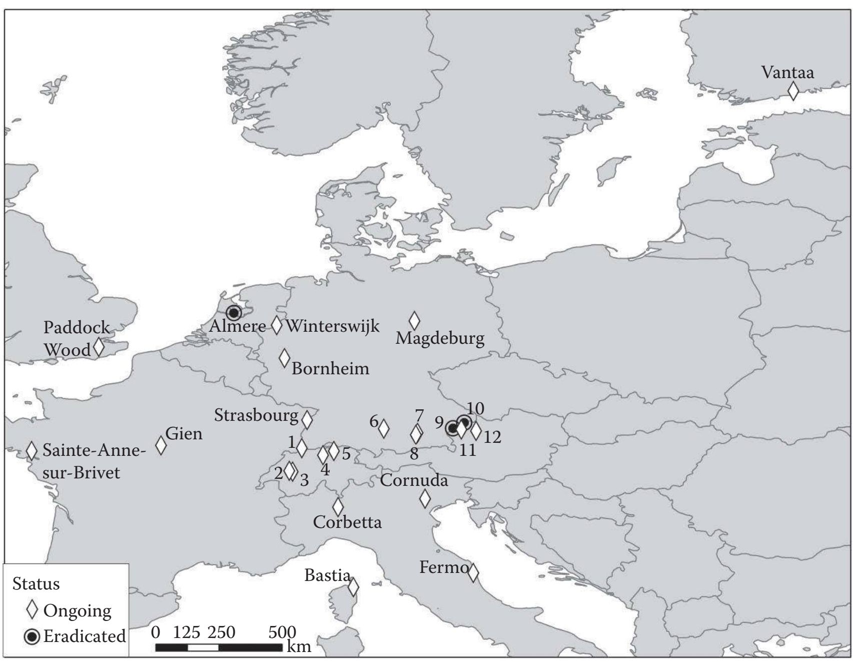

FIGURE 13.7 Locations of outbreaks of *Anoplophora glabripennis*, the Asian longhorn beetle, in Europe as of February 2016. 1 = Weil am Rhein, DE; 2 = Marly, CH; 3 = Brunisried, CH; 4 = Berikon, CH; 5 = Winterhur, CH; 6 = Ziemetshausen, DE; 7 = Feldkirchen, DE; 8 = Neubiberg, DE; 9 = Braunau am Inn, AT; 10 = Neukirchen am Inn, DE; 11 = Geinberg, AT; and 12 = Gallspach, AT (AT = Austria, CH = Switzerland, DE = Germany).

of millions of trees have been infested with *A. glabripennis* and cut down to slow the spread of the pest (Lingafelter and Hoebeke 2002). Some of these millions of *A. glabripennis*–infested trees likely were used to construct wood packaging, hence providing an easy pathway for the pest to be moved outside of Asia (Haack et al. 2010). An official EU visit to the areas of China that produce stone for Europe also found that exports were a small part of the market for many producers; thus they were not specialized in using wood packaging material complying with the requirements of ISPM 15 (EU 2013b).

13.5 Pathways: Finished Wood Products

The risks associated with finished wood products such as furniture or ornaments generally are considered low because of all the wood processing that takes place during production. Other factors that reduce the risk that finished wooden products would serve as a pathway for movement of cerambycids are: (1) these products are less likely to be stored outdoors and hence emerging pests have less chance of reaching host trees and (2) finished products are likely to be dispersed to retailers or consumers relatively quickly and not stored en masse in a single location like wood packaging material; therefore, the founder population likely would be smaller. Because Cerambycidae reproduce sexually, the risk of establishment would require that a male and female emerge near each other in both time and space. The emergence of one longhorn beetle of either sex is not a risk in itself.

Recorded interceptions of Cerambycidae in traded wooden products are rare in comparison with other pathways; for example, Cocquempot and Lindelow (2010) listed the main pathways for cerambycid introduction into Europe as timber, timber for pulp, wood packaging material, and plants for planting. However, many recent (2000–2010) interceptions of Cerambycidae have been related to manufactured wood products, including species such as *Chlorophorus annularis* (Fab.) and *Trichoferus campestris* (Faldermann) (Cocquempot and Lindelow 2010). One of the reasons for the relatively low number of cerambycid interceptions in manufactured wood products in the EU is that they are not "controlled goods," and there is no requirement to inspect such imported consignments on arrival in Europe. Given that these goods are not inspected at points of entry, many of the records associated with such goods originate from members of the public who are the eventual purchasers of products such as furniture. Between 1988 and 2008, for example, there were 83 detections of exotic organisms associated with imported furniture in New Zealand, and more than half of these occurred post-entry, with many being detected by members of the public (Froud et al. 2008). Even if the risks associated with individual consignments of manufactured wood products are judged to be very low, the large and increasing volume of wood furniture that is now being moved around the world suggests that the cumulative amount of goods moving via this pathway is sufficiently significant to deserve further investigation.

The brown fir longhorn beetle, *Callidiellum villosulum* (Fairmaire), is native to southeastern China and Taiwan, and known host plants are members of the Taxodiaceae including *Cunninghamia lanceolata* (Lamb.) and *Cryptomeria japonica* (L. f.) (Cocquempot and Mifsud 2013). In April 2013, *C. villosulum* was intercepted in Malta on saleable wooden commodities, some of which were not debarked and had arrived via Italy from China (Cocquempot and Mifsud 2013); this interception is believed to be the first for this beetle in Europe. This same pest was also found in Canada in 2012. Sections of logs with bark attached had been imported from China and used to provide the bases for artificial Christmas trees; a *C. villosulum* larva was found in association with one of these bases (Burleigh 2013). This was not the first time that such products had been associated with *C. villosulum*; there were 20 interceptions of the pest in Christmas tree bases imported from China in the United States (USDA-APHIS 2004). This provides an example of how difficult it is for plant health authorities to monitor and control the international movement of goods that may be infested with invasive pests, especially when the labeling on the product does not give any indication that there is a risk of invasive pests being present.

An analysis of the value of wood furniture imports into the United States between 1972 and 2010 demonstrates a switch from home-produced furniture to furniture imported from Asia (Luppold and Bumgardner 2011), hence increasing the risk of introduction of quarantine pests. In 1972, for example, the United States imported less than US$400 million dollars (adjusted for inflation to 1982 dollars) worth of wooden furniture, with Canada and Europe being the origin for most of the furniture. However, by 2006, imports of wood furniture into the United States reached a peak of US$6 billion, with the combined imports from China, Vietnam, Malaysia, Indonesia, Thailand, and the Philippines accounting for more than 65% (Luppold and Bumgardner 2011) (Figure 13.8).

In comparison with other manufactured goods, the risks of introducing wood-boring beetles have been demonstrated to be particularly high for upholstered furniture. Between 2000 and 2005, for example, imports of upholstered furniture from China into New Zealand increased from 962 units to 39,308 units, and similarly for Malaysia from 5,377 to 14,758 units, and for Thailand from 1,690 to 7,422 units (Froud et al. 2008). Overall, from 2000 to 2005, the total number of imports for upholstered furniture into New Zealand increased by more than fourfold from 16,895 to 65,456 units (Froud et al. 2008). In June 2006, teams from the Ministry of Agriculture and Forestry Biosecurity New Zealand purchased and destructively analyzed 49 imported couches—39 from China and 10 from Malaysia. This analysis confirmed the practice by some manufacturers of placing good quality (flawless) wood on visible surfaces and poor quality (insect damaged and bark covered) timber in internal sections of the furniture. Of the 49 couches inspected, 30 included wood with bark, 19 had insect contaminants, 32 had visible insect damage (including borer exit holes and bark beetle galleries), and fungal samples were collected from 11. Four longhorn beetles were found during the inspections, and the one that was identified to species was *Xylotrechus magnicollis* (Fairmaire) (Froud et al. 2008).

In July 2013, a member of the public in England reported an adult *Monochamus alternatus* Hope emerging from a recently purchased dining room chair (Ostojá-Starzewski 2014). The beetle had developed in the softwood framework that was covered in layers of foam and plastic. A further adult *M. alternatus* emerged from the chair, and three dead and one live larvae were found within the wood. Samples of wood in which the two beetles had developed were found to contain large numbers of pinewood nematodes, *Bursaphelenchus xylophilus* (Steiner and Buhrer). These examples demonstrate that there is a threat of invasive longhorn beetles becoming established in new environments as a result of the importation of finished wooden products; however, there have been few attempts to quantify the level of risk.

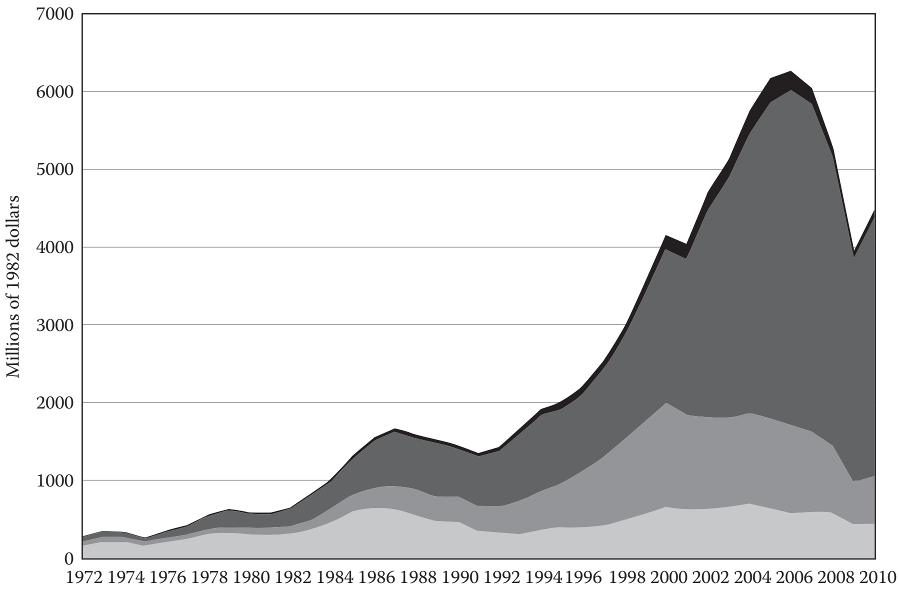

FIGURE 13.8 Value of U.S. imports of wood furniture by world region (in constant 1982 dollars), 1972–2010 (From Luppold, W. G., and M. S. Bumgardner, *Bioresources*, 6, 4895–4908, 2011.)

13.6 Pathways: Timber Other Than Wood Packaging Materials

There were 73 interceptions of Cerambycidae on "wood products or bark" between 1998 and 2013 recorded on EUROPHYT (Table 13.8). These interceptions were dominated by *Monochamus* spp. Of the 55 interceptions where the beetles were identified to at least the genus level, 51 were either *Monochamus* spp. (50 interceptions) or *M. alternatus* (1). All the *Monochamus* spp. interceptions were on commodities manufactured in either Europe (mainly non-EU countries) or Asia.

Monochamus galloprovincialis (Olivier) was intercepted in Turkey on industrial wood imported from the Ukraine in 2011 (Bozkurt et al. 2013). Three species of *Monochamus* were found in timber from the Komi Republic in northwest Russia during 1985–1989 in timber destined for Bulgaria—namely *M. sutor* (L.), *M. urussovi* (Fischer), and *M. galloprovincialis* (Olivier) (Tsankov et al. 1996). Between 2002 and 2005, Ostrauskas and Tamutis (2012) surveyed temporary storage sites for timber and wood imported into Lithuania from Russia using baited multiple-funnel traps. Seventeen species of longhorn beetles were caught, although all species were native to Europe. Similarly, four species of longhorn beetles were found in a timber mill in northern Sweden on timber imported from Siberia; these were *Tetropium gabrieli* Weise, *Tetropium aquilonium* Plavistshikov, *M. urrosovi* (Fischer & Walderheim), and *Acanthocinus griseus* (Fab.) (Lundberg and Petersson 1997). The arrival of these species was considered to be beneficial, however, because they are native to, but rare, in Sweden.

Kliejunas et al. (2001) assessed risks associated with the importation into the United States of unprocessed *Eucalyptus* logs and chips from South America. A number of species of wood-boring beetles were considered to be a high risk to U.S. *Eucalyptus* production including the following cerambycids: *Phoracantha semipunctata* (Fab.), *Chydarteres striatus* (Fab.), *Retrachyderes thoracicus* (Olivier), *Trachyderes* spp., *Steirastoma breve* Sulzer, and *Stenodontes spinibarbis* (L.). At the time of this assessment, *Eucalyptus* wood was not a regulated material in the EU; there was only one record of a pest being found on *Eucalyptus* wood, which was an unidentified Coleoptera. This unregulated pathway would have provided a potential introduction route for nonnative pests into Europe. *Eucalyptus* forestry is now extensive in Europe with more than 1.1 million ha being cultivated (Eyre 2005).

13.7 Pest Risk Assessments for Cerambycids

National and regional plant protection organizations have carried out numerous pest risk analyses (PRAs) for longhorn beetles in order to evaluate the threat they pose to countries and regions remote from the native regions of these beetles. Common triggers for carrying out a PRA are reports of a pest being moved in trade or successfully invading and damaging plants in a new environment. For example, the EPPO (2013c) carried out a PRA for *O. hirta*, a cerambycid native to New Zealand, following the discovery of the pest in the United Kingdom in association with plants from New Zealand, and MacLeod et al. (2002) performed a PRA for *A. glabripennis* following the confirmation of an outbreak of the beetle in New York and Illinois in 1996 and 1998, respectively (Haack et al. 1997; Poland et al. 1998).

The biology of some subfamilies of Cerambycidae makes them more likely to be moved in traded goods or wood packaging materials than others. For example, cerambycids in the subfamilies Prioninae, Lepturinae, and Parandrinae mostly develop in decaying wood, which is hence unlikely to be suitable for wood packaging, whereas most species of Cerambycinae and Lamiinae develop in living, dying, or recently dead plants, which are more likely to be used as wood packaging (Cocquempot and Lindelow 2010).

Polyphagous cerambycids such as the lamiine *A. chinensis* and *A. glabripennis* have been more successful at establishing in Europe than species with a narrower host range given that no strictly monophagous (feeding on a single host species) exotic longhorn beetles are known to have become established in Europe to date (Cocquempot and Lindelow 2010; Rassati et al. 2016). Table 13.9 shows the number of interceptions of longhorn beetles in wood at points of entry in the United States between 1984 and 2008 divided by subfamily. These data indicate that beetles in the subfamilies Spondylidinae (1,124 interceptions), Cerambycidae (1,081), and Lamiinae (814) accounted for 98% of

TABLE 13.8

Number of Interceptions of Longhorn Beetles in the European Union on Wood and Bark Products between 1998 and 2013 by Taxon and Country of Export

Harmful Organism	Country of Export	1998	1999	2000	2001	2002	2004	2005	2006	2008	2009	2010	2011	2012	2013	Grand Total
Cerambycidae	Cameroon										1		4			5
	China								1							1
	Congo													1	2	3
	Republic of the Congo												1			1
	Gabon									1						1
	Mongolia											1				1
	Russian Federation					2			2	1		1				6
Criocephalus rusticus									2							2
Monochamus alternatus	China		2													2
Monochamus sp.	Czech Republic		1	1												2
	Mongolia											1				1
	Romania												1			1
	Russian Federation			4	2	1	3	12	2				2			26
	Slovakia	2	3	8		2										15
	Ukraine												3	1		4
Tetropium sp.	Slovakia		1													1
Xylotrechus sp.	Tanzania											1				1
Grand Total		2	7	13	2	5	3	12	7	2	1	4	11	2	2	73

TABLE 13.9

Cerambycidae Intercepted in the United States between 1984 and 2008 on Wood Packaging Material by Subfamily

Subfamily	Number	Percent of Interceptions Identified to Subfamily (%)	Top Three Genera in Decreasing Order
Family only	396		
Cerambycinae	1,081	35	*Xylotrechus, Ceresium, Hesperophanes*
Lamiinae	814	26.4	*Monochamus, Anoplophora, Saperda*
Lepturinae	56	1.8	*Rhagium, Leptura*
Prioninae	12	0.4	*Prionus, Stenodontes, Mallodon*
Spondylidinae	1,124	36.4	*Arhopalus, Tetropium, Asemum*
Grand total	3,483	100	

all interceptions, while the Prioninae and Lepturinae comprised only about 2%. Six key elements of PRAs for longhorn beetles are discussed in the following text.

13.7.1 The Pathway of Pest Movement

Understanding the routes along which pest longhorn beetles may travel is an essential part of understanding the potential risk to an importing country. As discussed in previous sections, some pathways are inherently riskier than others due to (1) the volume of goods that are carried along the pathway, (2) the degree to which the goods are inspected on arrival in the importing country, and (3) the extent and duration that the potentially infested goods (and pests) are kept together after their arrival.

Population genetics can be used to establish the most likely source of invasive populations of insects; this could be populations in the native environment of the pest or another invasive population where the pest has become established. This can help explain the pathways along which pests may have moved. For example, Miller et al. (2005) indicated that there had been at least three separate introductions of the North American chrysomelid pest of maize, *Diabrotica virgifera virgifera* Leconte, into Europe and that some outbreaks were the result of intra-European movements. Carter et al. (2010) studied the mitochondrial sequence data of invasive populations of *A. glabripennis* in North America and Europe. They suggested that separate introductions of beetles from Asia were responsible for the appearance of *A. glabripennis* infestations in (1) New York City; (2) Carteret and Linden, New Jersey; and (3) Staten Island and Prall's Island, New York. It was indicated that local spread was responsible for moving the pest from New York City (e.g., Queens) to other areas of Long Island. Samples from outbreaks in Austria, France, Germany, and Italy indicated that there had been separate introductions to each of these locations—most likely from China rather than spread among the different outbreak areas in Europe. Carter et al. (2010) were not able to identify locations within China that might have been the source of the invasive *A. glabripennis* populations in North America or China, possibly because they were derived from areas of China where the populations of *A. glabripennis* were invasive, and therefore there was no clear link between the population genetics and locations. The outbreaks in Europe appeared to have been initiated with a low number of founders, and any genetic bottlenecks did not appear to inhibit population development.

13.7.2 Propagule Pressure

Propagule pressure is a measure of the number of individuals released into a nonnative environment and incorporates the number of introduction events and the number of individuals associated with each introduction (Reaser et al. 2008). Propagule pressure clearly plays an important role in invasion ecology (Reaser et al. 2008; Eschtruth and Battles 2011). Brockerhoff et al. (2014) proposed that propagule pressure may be the most important factor in establishment success of nonnative species of various taxa in a variety of ecosystems worldwide. Logically, this will only be the case when comparing taxa that are able to survive in both the biotic and abiotic environments being assessed. Propagule pressure is likely to be more important for sexually reproducing pests, such as Cerambycidae, than it is for pests that reproduce asexually, such as aphids. This is because when cerambycids are moved internationally as juveniles, there is a need for an individual of each sex to be introduced into locations close enough for them to be able to find each other once they have emerged as adults and mate. Brockerhoff et al. (2014) found a positive association between interception frequency and probability of establishment for bark beetles and longhorn beetles in the United States and worldwide. Their work showed that, for the most frequently intercepted species (i.e., those exerting the greatest propagule pressure), a fractional change (e.g., 50% fewer) in the numbers arriving will result in little change in establishment rates but that such fractional changes may have a strong impact on establishment success of species that arrive less frequently.

In a study of the destination of packaging materials that are frequently associated with exotic forest insects, Colunga-Garcia et al. (2009) found that 84–88% of the imported tonnage ended up at only 4–6% of the urban areas in the contiguous United States. Such studies are useful for assessing the overall risk of pests to countries and can also be used to target inspection and monitoring activities. Colunga-Garcia et al. (2010) analyzed the significance of a number of factors in determining the success rate of invasions of *A. glabripennis* and the Asian strain of the gypsy moth, *Lymantria dispar* (L.), in the United States and found (1) that propagule pressure was a more significant factor than percent tree cover in determining successful invasions and (2) that the predominant land use where most forest insect pests invaded was commercial–industrial. Such information could be used to optimize surveillance for these pests.

13.7.3 Pest Establishment in the Nonnative Environment

A range of techniques and tools can be used to evaluate the potential for a cerambycid species to survive in a nonnative environment, and several of these methods have been reviewed recently by Eyre et al. (2012) and Sutherst (2014). One of the indicators that can be used to evaluate the potential of an exotic cerambycid's survival at latitudinal extremes is the concept of degree-days. The number of degree-days needed to complete development can be measured in laboratory studies such as those by Adachi (1994) for *A. chinensis* and by Keena and Moore (2010) for *A. glabripennis*. Degree-days have been used in risk assessments by the EPPO (2013c) to illustrate the extent to which the climate that *O. hirta* experiences in its native environment is similar to the climate that it might experience in Europe were it to become established there.

Such analyses can be taken a step further by estimating the potential length of time for a species of longhorn beetle to complete its life cycle by equating the average climate conditions at a particular location to the number of degree-days above a threshold required for the organism to complete its life cycle. An example is shown in Figure 13.9 for *A. chinensis*. This is based upon a requirement for 1,900 degree-days in excess of a threshold of 11°C in line with Adachi (1994).

If risk assessors have either, or ideally both, records of where a pest insect is known to be present globally and laboratory temperature-response data, it is possible to create a model projecting where the pest may be able to survive in nonnative regions. Figure 13.10 shows the predicted environmental index (EI) for *A. glabripennis* in Europe from a CLIMEX model (Sutherst et al. 2007) that was published in MacLeod et al. (2012). Model parameter sets are developed based on the known distribution of a species in its native environment and/or the use of laboratory temperature response studies. The environmental index is a measure of how suitable the climate is for *A. chinensis* in different European locations. An EI value of zero is a prediction that the species would not be able to survive in that location for the longer term. Higher EI values are an indication of greater suitability for a species. Vanhanen et al. (2008) created CLIMEX models for three Asian species of longhorn beetles, *Aeolesthes sarta* (Solsky), *Tetropium gracilicorne* (Reitter), and *Xylotrechus altaicus* (Gebler), and predicted that all three had the potential to establish in Europe.

The Genetic Algorithm for Rule-set Prediction (GARP) ecological niche modeling technique was used to project the potential distribution of *A. glabripennis* and *A. chinensis* in the United States based on their distribution in Asia (Peterson and Vieglais 2001; Peterson et al. 2004). These analyses suggested that the area at greatest risk from *A. glabripennis* in North America

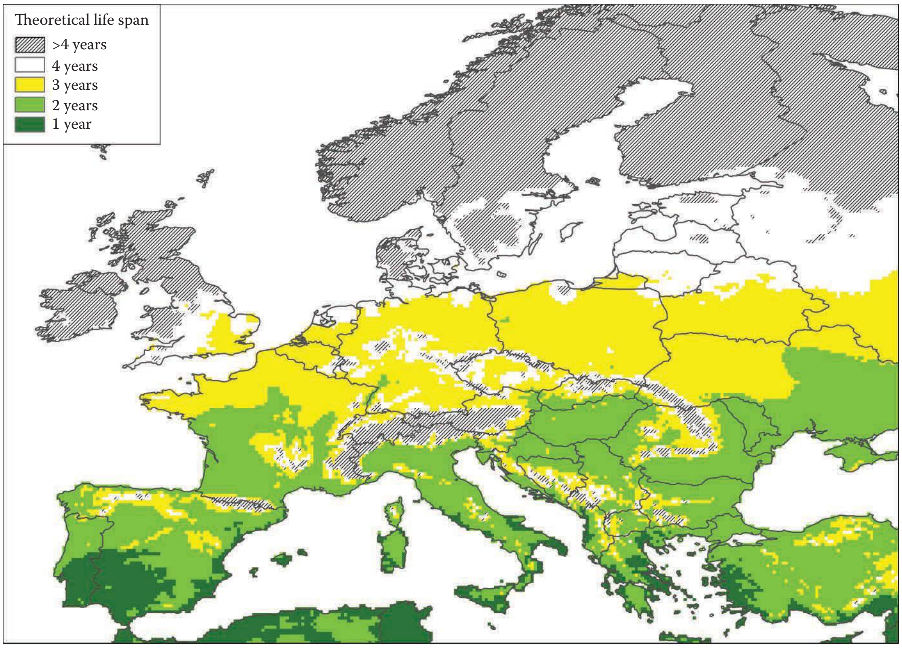

FIGURE 13.9 Predicted generation time for *Anoplophora chinensis* in Europe based on the CLIMEX model published in the supplementary material of Robinet et al. (2012).

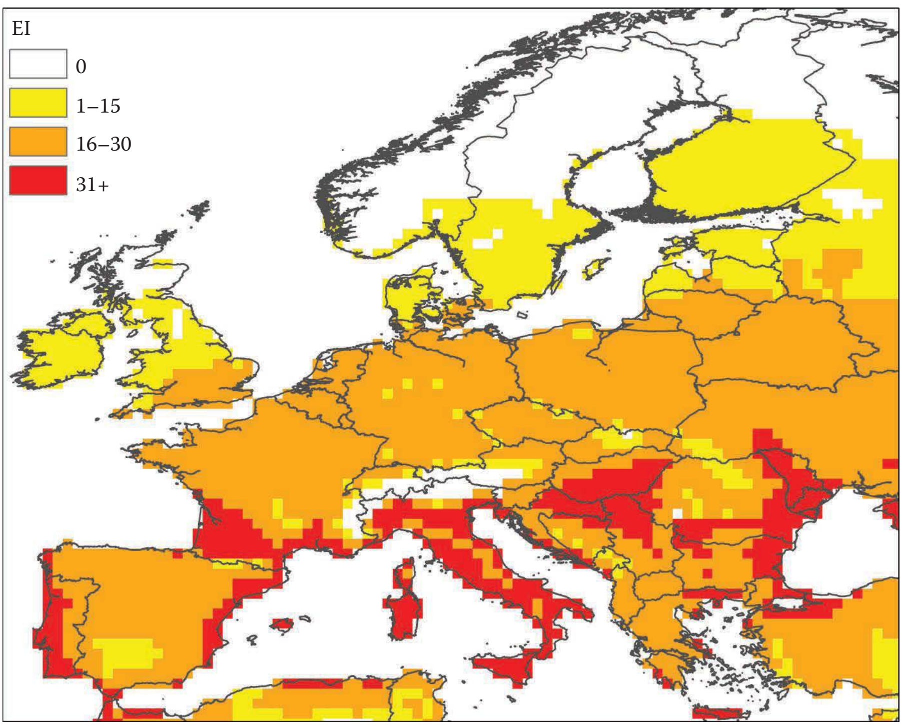

FIGURE 13.10 Environmental index for *Anoplophora glabripennis* in Europe based on a CLIMEX model published in the report of a project for the European Food Safety Authority. (From MacLeod, A., H., et al., External scientific report: Pest risk assessment for the European Community plant health: A comparative approach with case studies, Annex P2 ALB Method 3 no RROs. Available at: http://www.efsa.europa.eu/en/supporting/pub/319e.htm.)

was the eastern United States, especially the Great Lakes region. The predictions for *A. chinensis* (Peterson and Vieglais 2001) indicated that the areas at greatest risk were more southerly and dispersed across North America.

13.7.4 The Host Species

Whether host plants are native or exotic or a mixture of both is another important factor in the eventual impact of a longhorn beetle. If a longhorn beetle only attacks uncommon ornamentals, the overall impact is likely to be low. For example, *Frea marmorata* Gerstaecker is thought to have a very low chance of establishing in Europe because it is known from eastern Africa (Kenya, Malawi, Tanzania, and Zimbabwe), and the known host is coffee, *Coffea arabica*, which is not grown commercially in Europe (Cocquempot 2007). However, longhorn beetles that can damage widely planted exotic plants can be significant pests. *Phoracantha semipunctata* (Fab.) is native to Australia but has become established in all continents where eucalypts are grown, with the exception of Asia (Paine et al. 2011). This species has caused serious damage in some Mediterranean countries, including Morocco where around 170,000 ha of eucalyptus plantations were lost in 1981 (El-Yousfi 1982). The impact appears to be greatest in regions of the world with Mediterranean climates (CABI 2014c). Pests that have significant impacts on eucalyptus plantations have the potential to cause considerable economic impact because eucalypts have been planted in more than 90 countries, they account for 8% of productive planted forests worldwide, and in 2000 they provided 33% of the global wood supply (Laclau et al. 2013).

Some invasive longhorn beetles are important pests of fruit trees and have the potential to cause significant economic damage in invaded areas. *Aromia bungii* (Faldermann), the red-necked longhorn beetle, is an Asian pest of *Prunus* spp., especially *P. persica* L. (peach) and *P. armeniaca* L. (apricot) but to a lesser extent plum (e.g., *P. domestica* L.) and cherry (e.g., *P. avium* L.) and some other plants and deciduous trees such as *Populus* spp., *Punicia granatum* L. (pomegranate), *Olea europaea* L. (olive), and *Bambusa textilis* McClure (weaver's bamboo) (Liu et al. 1993; Anderson et al. 2013). In 2011, an outbreak of *A. bungii* was discovered near Kolbermoor in southern Bavaria, Germany, and in 2012, an outbreak of this pest was discovered between Napoli and Pozzuoli in southern Italy where it was infesting apricot, cherry, and plum trees (Anderson et al. 2013; EPPO 2016). *A. chinensis* is a significant pest of citrus and other fruit trees in China and Japan (Lieu 1945; Adachi 1994) and has the potential to cause severe damage in citrus groves and other fruit trees on other continents.

In addition to creating pest risk maps based on climate, it is possible to combine climate data with other risk factors in order to generate predictions of the endangered areas within a pest risk assessment area, that is, the areas where economically important loss is likely to occur (Baker et al. 2012). Magarey et al. (2011) described the North Carolina State University–APHIS Plant Pest Forecasting System (NAPPFAST), which links climatic and geographical databases with interactive templates for biological modeling. Three factors that can be used as indicators of overall plant pest risk in a particular location are host density, climate, and pathways. Decision makers may prefer to look at a single map that integrates the risks associated with these three factors, and NAPPFAST can be used to create such maps (Magarey et al. 2011). Pareto dominance is a technique for combining risk factors that does not rely on linear weighted averaging or standardization of the individual criteria (Yemshanov et al. 2010). The USDA has published a map based on a Pareto dominance analysis that shows which parts of the United States are most at risk of an outbreak of *M. alternatus* (USDA-CPHST 2011).

13.7.5 Preferences for Site of Attack and Health Status of Hosts

Some species of Cerambycidae have a preference for attacking hosts at a certain location and also for trees of a certain age or health status. These preferences will influence the nature of the damage that the beetle may cause and whether the damage is mainly economic or environmental. The eucalyptus longhorn borer, *P. semipunctata*, is an example of a pest that has a different pest status in its native environment when compared with its behavior in some invaded environments. In its native Australia, *P. semipunctata* primarily is a scavenger of dead, stressed, or dying trees, but it can cause significant mortality in invaded areas (CABI 2014c). It typically is associated with trees under moisture stress and therefore causes severe damage in semiarid regions as well as during drought periods as has occurred in southern Europe and northern Africa (Turnbull 1999; Kliejunas et al. 2001).

Trichoferus campestris was reported emerging from a cutlery drawer imported from China to the United Kingdom in June 2013 (Fera, unpublished data). An assessment of the phytosanitary risk of this beetle to the United Kingdom has been complicated because of conflicting evidence over whether it attacks live trees. For example, the Centre for Agriculture and Biosciences International (CABI 2015d) states that the economic impact of this beetle is comparatively small as with most drywood-boring pest species of Cerambycidae, whereas the EPPO (2009a) reported that *T. campestris* is able to attack healthy or slightly stressed trees of many important species. More recently, despite its establishment in Eastern Europe, apparent westward spread, and occasional finds in Canada and the United States, this pest's damage to living trees appears to have been minimal (Sabol 2009; Grebennikov et al. 2010; Dascalu et al. 2013; Bullas-Appleton et al. 2014; EPPO 2016). The current evaluation of the risks posed by this beetle to the United Kingdom can be seen on the UK plant health risk register (Baker et al. 2014). In common with many lamiine and cerambycine species, *A. glabripennis* can infest and develop in both healthy and stressed trees (EPPO 1999; Cocquempot and Lindelow 2010; Haack et al. 2010), a characteristic that has made it a highly invasive pest. Many of the outbreaks of *A. glabripennis* in North America and Europe have been in towns and cities such as New York, Chicago, Toronto, and Braunau-am Inn, Austria (Haack et al. 2010). In these locations, *A. glabripennis* attacks trees along streets and in yards and parks, resulting at first in upper trunk and branch dieback, which poses a threat to people, vehicles, or property (MacLeod et al. 2003). In China, damage by *A. glabripennis* has killed millions of trees, especially species of *Populus*, which were planted to counteract desertification in northern regions (Hu et al. 2009; Haack et al. 2010).

In contrast, *O. hirta*, which specializes in infesting small branches and twigs, rarely kills trees in its native environment, and mature trees with a large diameter trunk are unlikely to be killed. In addition, the damage to large branches of host trees does not tend to kill them but tends to degrade the condition of infested trees (EPPO 2013c).

Longhorn beetles can be vectors of highly damaging pests, for example, the pinewood nematode, *B. xylophilus,* which is native to North America. Without regulatory controls, the outbreak of this pest in Portugal and Spain has the potential to cause some US$24 billion damage in the EU (Soliman et al. 2012). There are also damaging outbreaks of the pinewood nematode in China where the pest is spreading both naturally as well as through human assistance (Hu et al. 2013). The pinewood nematode is discussed in more detail in Chapter 6.

13.7.6 Pest Spread in the Invaded Environment

The difficulty of detecting longhorn beetles makes the accurate assessment of their rate of spread in a new environment daunting, but this becomes more feasible when there is an efficient and systematic trapping system available for the pest. Species that are deemed by national or regional plant protection organizations to be significant enough pests to monitor are often subject to containment or eradication measures. Therefore, any measurements of the rate of spread can also be used to measure the effectiveness of the control methods. In general, the overall rate of natural spread of many invasive longhorn beetles is slow because adults reproduce near the host plant from which they emerge (Haack et al. 2010; Rhainds et al. 2011). In contrast, the rate of spread of other invasive wood-boring beetles can be much faster; for example, the buprestid *Agrilus planipennis* is estimated to be spreading at a rate of around 20 km a year in North America (Prasad et al. 2010), and the ambrosia beetle (*Xylosandrus germarus*) is able to spread over tens of kilometers per year (Rassati et al. 2016).

The spread of the invasive species *T. fuscum* (Fab.) has been studied in Canada by analyzing the results of a trapping program using traps baited with a male-produced pheromone and host volatiles (Rhainds et al. 2011). This species was first discovered in North America in Halifax, Nova Scotia, in 1999, where it was attacking red spruce, *Picea rubens* Sarg., but it is thought to have been established since at least 1990 (Rhainds et al. 2011). *T. fuscum* is native to Europe where it primarily infests Norway spruce, *P. abies* (L.) (Smith and Hurley 2000). There has been an eradication and containment program for this pest in Canada since May 2000 (Sweeney et al. 2007). A formal eradication program for *T. fuscum* took place in Nova Scotia from 2000 to 2006. This involved the cutting and disposal of selected high-risk trees and regulating the movement of high-risk materials. A containment program was enacted beginning in 2007 (Gregg Cunningham, Canadian Food and Inspection Agency, personal communication). Since the time of its original introduction in the early 1990s, the results of the trapping program indicated that between 1990 and 2010 the pest had spread approximately 80 km. The rate of spread of the beetle is thought to have been limited because spruce is rarely used as firewood in Canada, thus reducing the risk of the pest being spread by this pathway (Rhainds et al. 2011). The potential spread rate of longhorn beetles can also be studied using flight mills. For example, Sweeney et al. (2009) found that both sexes of *T. fuscum* flew an average of more than 1 km per day, with some individuals flying more than 9 km a day and some not flying at all.

Sawyer et al. (2011) have studied the spread of *A. glabripennis* in the United States at outbreak sites in suburban and urban areas and compared these findings with data from outbreaks in more open habitats. In urban and suburban landscapes where tree density is moderate to high and the tree diversity is high, *A. glabripennis* tends to spread slowly, developing in the initial years on just a few trees near the point of origin. In Chicago, surveys indicated that where hosts were readily available, females did not travel far from the trees from which they emerged, as evidenced by 90% of the oviposition sites being found within 140 m of the nearest exit hole and 99% of oviposition sites being within 300 m of the nearest exit hole. In contrast, at an outbreak site in Linden, New Jersey, which is a more open habitat with low tree density, *A. glabripennis* spread about 3.2 km to the south and west in five years. In line with the observations in the United States, an analysis of the trees infested with *A. glabripennis* in Mississauga, Canada, revealed that a population, possibly founded by one or a few individuals from a distant outbreak (at least 7.5 km away), remained on a single tree for about six or seven years before spreading naturally to other trees around 300 m away (Turgeon et al. 2015).

A model created using survey data from the outbreak of *A. glabripennis* in Cornuda, Italy, indicated that 80% of dispersal occurred within 300 m of the nearest infested tree-cluster, but some individuals could move farther than 2 km (Favaro et al. 2015). *A. glabripennis* dispersal distances in Cornuda were shown to lessen as the population density of the pest declined due to eradication activity (Favaro et al. 2015).

Keena and Major (2001) studied how various factors influenced the propensity of *A. glabripennis* to fly in the laboratory at 15°C, 22°C, and 30°C using fresh cut logs. Adults did not fly at 15°C, and the propensity to fly increased with temperature. Well-fed females would remain on good-quality hosts and chew oviposition pits rather than fly, but when host quality was poor, more than 50% of females flew within the first 30 minutes. Thus, if emerging female beetles detect that the tree from which they have emerged is in poor condition, perhaps as a result of successive generations of *A. glabripennis* infestation, they would be expected to be more likely to disperse than if the host was still in relatively good health.

Trotter and Hull-Sanders (2015) used data from the *A. glabripennis* outbreak in Worcester, Massachusetts, and graph theory to create four dispersal kernels for the beetle based on different assumptions. One of the assumptions of the models was that the dispersal of *A. glabripennis* could be the result of individuals dispersing a long way from heavily infested trees (those trees with >100 exit holes) or, alternatively, it could be the result of beetles dispersing shorter distances from trees with lower levels of infestation. Under the four different scenarios, the fiftieth percentile annual dispersal kernel was between 37 and 234 m and the ninety-ninth dispersal kernel was between 1,358 and 2,979 m.

The potential rate of spread of invasive longhorn beetles has been studied in three mark-recapture studies in Gansu Province, China. Smith et al. (2001) carried out a mark-recapture study of *A. glabripennis* using 16,511 adult beetles. The beetles were either captured as they emerged from poplar bolts that had been transported to the release site or were collected locally. Capture stations, consisting of about 12 poplar trees (averaging 7.2 cm diameter at breast height and 7.8 m tall) were established at varying distances from the release point. A total of 188 beetles were recaptured, and of these, the mean dispersal distance was 266 m, with 98% being recaptured within 560 m.

In a second study, Bancroft and Smith (2005) found strong evidence for density-dependent dispersal of *A. glabripennis*: the beetles were more likely to disperse when their density on a tree was high. Females and smaller beetles dispersed further than males and larger beetles. Flying *A. glabripennis* tended to head toward large, lush trees. Over the course of this study, the average daily temperature and humidity at 14:00 hours were 32°C and 51% relative humidity (RH). Beetles were captured by shaking trees in the early morning when temperatures were less than 20°C and adult beetles were less active.

The propensity of beetles to move declined with increasing temperature, but the distance traveled increased with increasing temperature. In a third, more recent mark-recapture study (Li et al. 2010), the mean dispersal distance of *A. glabripennis* was 424 m, there was no difference between male and female adults in dispersal direction or distance traveled, and the furthest dispersal distance recorded was 2,644 m. Beetles tended to fly into the wind, but there was no strong relationship found among wind speed, temperature, or relative humidity.

Previous studies show that spread of *A. glabripennis* can be very minimal at the start of outbreaks (Sawyer et al. 2011), but after this period it is likely to be in the region of hundreds of meters per year (Smith et al. 2001; Li et al. 2010; Sawyer et al. 2011). The spread rate can also be influenced by tree density and species composition (Sawyer et al. 2011), and some studies have shown that weather, including temperature and wind, can be a factor (Keena and Major 2001; Bancroft and Smith 2005). For example, the threshold for *A. glabripennis* flight is between 15°C and 22°C (Keena and Major 2001), and the optimum conditions for flight are likely to be warmer than 20°C (Bancroft and Smith 2005). In northern Europe, the number of days in the summer and the proportion of each summer day when conditions would be suboptimal for *A. glabripennis* flight would be much higher than those in southern Europe. A comparison of the actual spread rate of *A. glabripennis* in areas with very different climatic conditions—for example, comparing the rate of spread in northern Europe (the United Kingdom and the Netherlands) with the rate of spread in locations with much warmer summers such as Italy or Ohio (United States)—might provide an indication of how summer air temperatures affect rate of spread.

The studies described here for *A. glabripennis* have aimed to establish how far the beetle might be able to move without human intervention. However, in addition to the international movement of longhorn beetles in wood or plants, the risk of pests being moved by humans also needs to be assessed on a more local scale for outbreak situations. For example, following the discovery of *A. glabripennis* in Brooklyn, New York, in 1996, survey teams started to investigate areas where the pest might have been moved accidentally, which led to the discovery of a second infestation approximately 50 km east in Amityville. The Amityville infestation is thought to have been initiated by the movement of infested tree sections meant for disposal or sale as firewood (Haack et al. 1997).

13.8 Preventing the Establishment of Nonnative Longhorn Beetles

International and local movements of goods and people provide opportunities for nonnative longhorn beetles to establish in new locations. The sections that follow describe the measures that can be taken to prevent establishment of longhorn beetles at different stages before and after their arrival in a new location.

13.8.1 Pre- and Post-Export Treatments and Measures

There are a number of international advisory documents and standards that have been developed to reduce the risk of wood-boring pests such as Cerambycidae being moved in wood and wood packaging materials. The Food and Agriculture Organization (FAO) of the United Nations published a guide to the implementation of phytosanitary standards in forestry in 2011 (FAO 2011). Some of the postharvest measures recommended to reduce pest spread are: on-site treatment of freshly felled logs, inspection of logs entering sawmills, storing log piles under cover, general hygiene measures, and postharvest treatments such as fumigation.

The EPPO, the regional plant protection organization for Europe and the Mediterranean region, has developed and published a number of standards relevant to longhorn beetles in commodities. For example, EPPO PM 10/6 concerns heat treatments of wood to control insects (EPPO 2009c), EPPO 10/7 describes methyl bromide fumigation of wood to control insects and wood-borne nematodes (EPPO 2009d), and EPPO PM 10/8 covers the disinfestation of wood with ionizing radiation (EPPO 2009b). The EPPO also has developed two commodity-specific phytosanitary measures of relevance to Cerambycidae, one for Coniferae (PM 8/2) (EPPO 2009e) and another for *Quercus* and *Castanea* (PM 8/3) (EPPO 2010). These standards list the relevant pests for each plant genus and provide a description of what treatments would be appropriate for wood of the different tree genera that has been processed to different levels such as plants for planting, cut branches, or squared wood.

On an international level, phytosanitary treatments have been developed by the Technical Panel on Phytosanitary Treatments (TPPT) of the International Plant Protection Convention (IPPC). The TPPT evaluates data from national and regional plant protection organizations and develops wood treatment measures (IPPC 2014).

The IPPC is close to finalizing a standard called "Management of Phytosanitary Risks in the International Movement of Wood," which will include information on appropriate types of treatments to reduce risks associated with movement of wood other than wood packaging material (IPPC 2013). There is also a more recently commissioned international standard called "International Movement of Wood Products and Handicrafts Made from Wood." The commodities that are regulated for wood-boring pests vary among countries and regions. For example, finished wooden products such as furniture are not considered to be controlled goods within the EU (EU 2000), whereas there are treatment requirements for the import of wooden manufactured items into Australia (Australian Government 2015).

The international phytosanitary standard for wood packaging materials, ISPM 15, was published originally in 2002 (IPPC 2002) and has since been revised (IPPC 2009, 2016). The 2016 version of ISPM 15 gives the option of heat treatment using dielectric heating (e.g., microwave). Wood packaging materials composed of wood not exceeding 20 cm when measured across the smallest dimension of the piece or the stack must be heated to achieve a minimum temperature of 60°C for one continuous minute throughout the entire profile of the wood (including its surface) when using dielectric heating. The goal of ISPM 15 is to reduce the risks that wood-associated insect pests and diseases will be moved around in wood packaging through international trade (Haack and Brockerhoff 2011; Haack et al. 2014). Internationally moved wood packaging materials are required to be marked to indicate that they conform to this standard. To comply with the standard, the wood used needs to be debarked and either heat-treated or fumigated with methyl-bromide (IPPC 2016). Despite the introduction of this standard, interceptions of nonnative longhorn beetles continue with wood packaging materials (Figure 13.2). Using a compilation of interception records in North America, Europe, and Australasia, Haack et al. (2010) reported that of the interceptions of *Anoplophora* species where the country of origin was known (71%), 97% of the interceptions on wood packaging materials originated in China. Similarly, in the EUROPHYT records from 1999–2013, 257 (84%) of the 306 interceptions of Cerambycidae were in association with wood packaging materials from China.

In response to the link between wood packaging materials from China and the outbreaks of *A. glabripennis* in Europe, the EU introduced requirements to inspect set proportions of consignments of wood packaging materials associated with specified commodities (EU 2013a). This decision came into effect on March 31, 2013, requiring that the wood packaging materials associated with 90% of consignments of slate, marble, and granite should be inspected, along with 15% of consignments of two other categories of stone imports. In Austria, 451 consignments (1,374 containers) of stone imports were inspected between April 1, 2013 and April 14, 2014. Noncompliance with ISPM 15 was reported in 44 cases (9.8%), and live Cerambycidae were found in 38 consignments, including *A. glabripennis, T. campestris*, and *A. germari* (Krehan 2014).

In June 2013, the EU's Food and Veterinary Office (FVO) carried out an audit of the measures taken by China to ensure that wood packaging materials exported to Europe meet EU requirements (EU 2013b). The FVO concluded (p. 17) that "the current system of official controls in China did not adequately ensure that wood packaging materials which form part of consignments of goods exported to the EU are marked and treated according to ISPM 15." Thus, flaws related to the treatment of wood packaging materials in China have left open a pathway for the movement of *A. glabripennis* and other wood pests to other parts of the world. Although there is a strong link between wood packaging material from China and the spread of *A. glabripennis* to North America and Europe, problems with pests in wood packaging material are a worldwide problem. For example, Table 13.4 shows that, in the EU, in addition to wood packaging material from China, longhorn beetles have been found in wood packaging material from EU countries, other European countries, other Asian countries, Africa, Australasia, and from the Americas. Table 13.6 shows that the trades responsible for the greatest number of interceptions of longhorn beetles on wood packaging material in the United States includes those from Italy, Turkey, Spain, France, Greece, and Bulgaria, as well as from China.

Haack et al. (2014) compared pest interception rates in the United States from periods before and after the implementation of ISPM 15. Data from 2003 to 2009 (about two years before versus four years after implementing ISPM 15) indicated that infestation rates of wood-infesting insects declined between 36% and 52% to a level of about 0.11% following the implementation of ISPM 15. These results led the authors to conclude that ISPM 15 did result in a lowering of the level of infestation in wood packaging materials, but if infestation rates prior to 2003 had been available for making comparisons, it is likely that it would have been possible to demonstrate that the impact of ISPM 15 had been even greater. In addition, Haack et al. (2014) demonstrated the importance of an infestation rate even as low as 0.1% by estimating that this would represent 13,000 infested containers entering the United States each year based upon an annual total of 25 million shipping containers—of which 52% have wood packaging materials.

The main fumigants currently used for quarantine and biosecurity purposes are methyl bromide and phosphine, and there are problems with both. Methyl bromide is an ozone-depleting compound, and although there is an exemption from the control measures agreed under the Montreal Protocol (UNEP 2011) for quarantine and preshipment purposes, international policy requires its replacement if technically and economically feasible (Banks 2012). The use of phosphine requires long exposure times to be fully effective, which can make it inconvenient and costly (Banks 2012), and some storage pests have developed a resistance to it (Jagadeesan et al. 2012). The difficulty with the long exposure time needed for phosphine can be reduced if treatments are carried out during transit, which is the case for the export of *Pinus radiata* D. Don logs from New Zealand (Glassey et al. 2005). Disinfestation of wood and wood packaging materials is the largest global use of methyl bromide, even though heat is widely utilized as an alternative to satisfy the requirements of ISPM 15. To date, no alternative fumigation treatments have been found that provide an equivalent level of efficacy and hence allow inclusion in ISPM 15, but some of the alternatives that have been considered are sulfuryl fluoride, methyl isothiocyanate, hydrogen cyanide, and methyl iodide (Banks 2012).

Sulfuryl fluoride has been shown to be able to penetrate wood as effectively as methyl bromide (Ren et al. 2011), and its efficacy has been demonstrated against *A. glabripennis* in *Populus* logs (Barak et al. 2006), *Hylotrupes bajulus* L. in the timbers of an historic building in Istanbul (Yildirim et al. 2012), and the cerambycid-vectored pinewood nematode, *B. xylophilus,* in boards of *Pinus pinaster* Aiton (Bonifacio et al. 2014). The application of methyl isothiocyanate for 24 hours at 15°C killed all *Semanotus japonicus* Lacordaire (eggs), *C. rufipenne* (all stages), and *M. alternatus* Hope (eggs) at 20 g/m^3 and all *M. alternatus* larvae at 40 g/m^3; however, it had little effect on ambrosia beetles (Scolytinae) (Naito et al. 1999).

Stejskal et al. (2014) tested hydrogen cyanide (HCN) against three pests of trees. At a temperature of 20–21°C, all *A. glabripennis* and *H. bajulus* were killed by a dose of 20g/m^3 of HCN within one hour. Similarly, all *B. xylophilus* were killed by exposure to 20g/m^3 of HCN for 18 hours at 25°C. Methyl iodide has been shown to be effective at killing *M. alternatus* and *Arholalus rusticus* when applied for 24 hours at 84g/m^3 at 10°C, 60g/ m^3 at 15°C, or 36g/ m^3 at 25°C (Soma et al. 2006). Soma et al. (2007) found that when methyl iodide was applied at 60g/m^3 for 24 hours at around 10°C, it killed *M. alternatus* larvae and *C. rufipenne* adults.

Zahid et al. (2013) studied the efficacy of freezing naturally infested logs of tropical origin, *Acacia parramattensis* and *Acacia decurrens*, timber infested with termite (Isoptera), and timber blocks inoculated with Bostrichidae as a phytosanitary treatment. No insects were found alive after the wood had been subjected to temperatures of –18°C to –25°C for 24 hours. Dead insects recovered from the samples included Cerambycidae, Bostrichidae, and Scolytinae.

Zhan et al. (2011b) studied the impact of X-ray irradiation on *M. alternatus* mature larvae, pupae, and adults and found irradiation tolerance increased in older life stages. In order to sterilize logs infested with *M. alternatus*, the authors recommended a minimum dose of 60–80 Gy for larvae and 140 Gy for pupae and newly developed adults. Zhan et al. (2011a) obtained similar results for *Monochamus sutor.*

13.8.2 Detection of Infested Consignments

The majority of interceptions of longhorn beetles reported on the EUROPHYT database have been associated with wood packaging materials. Even though wood packaging is a known pathway for the international movement of longhorn beetles, the large volume of trade that arrives with wood packaging materials means that inspection of all consignments is not possible. In addition, shipping manifests do not currently state whether or not wood packaging materials have been used, making the targeting of inspections more difficult. However, there has been a history of longhorn beetles being found in association with certain types of cargo, for example, the top 20 trades listed in Table 13.6. These kinds of data can be used to target inspections on those consignments that are most likely to be infested as has happened for stone imports into the EU from China (EU 2013a).

In recognition of the difficulty of detecting longhorn beetle larvae in young trees, in 2012, measures were adopted in the EU to reduce the risk of *A. chinensis* being introduced in imported plants, which preceded a two-year ban on the import of *Acer* sp. from China (EU 2012). Among other requirements, the 2012 EU Commission Decision specified that 10% of *A. chinensis* host plants (or 450 plants if the consignment is >4,500 plants) imported into the EU should be destructively sampled. This practice should help overcome the difficulty of detecting early stage larvae in large consignments of young plants.

In addition to visual inspection, some new methods for detecting longhorn beetles in wood packaging materials and young plants have been researched and developed. A team in Austria has been using sniffer dogs to detect *Anoplophora* in wood packaging, imported trees, and at outbreak sites in Germany and Switzerland (Hoyer-Tomiczek and Sauseng 2013). In the United States, sniffer dogs were 80–90% effective at detecting *A. glabripennis* frass in controlled environments (Errico 2013; Meng et al. 2015).

Three types of infrared thermography camera have been evaluated for their ability to detect young larvae of insects such as *A. chinensis* within imported young trees, but currently available technology does not seem to be adequate for this use (Hoffmann et al. 2013). Mankin et al. (2008) and Schofield (2011) have investigated the use of acoustic equipment to detect and identify longhorn beetles within wood and have shown that it has some potential. In a study with bolts of wood infested with *A. glabripennis*, Zorovic and Cokl (2015) were able to demonstrate that laser vibrometry could be used to distinguish infested and noninfested bolts. In summary, although many cerambycids are intercepted, the methods and the resources available to plant protection services are not adequate to prevent the international movement of cerambycids on wood packaging materials and plants for planting.

13.8.3 Monitoring in and Around Ports and Other High-Risk Sites

Setting up traps at locations in and around ports provides an opportunity to detect beetles that have not been found in the course of inspections of imported goods and could provide an early indication of an outbreak near a port. Rassati et al. (2014) set up traps for wood-boring beetles around four international ports in northeastern Italy. In each port, four traps were baited with one of four different lures (single-lure traps) and one trap included all four lures (a multi-lure trap). Two of the lures tested were generic attractants for bark and wood-boring beetles (ethanol and [–] α-pinene), while the other attractants were specific for bark beetles (frontalin, ipsenol, and ipsdienol). Ipsenol and ipsdienol were tested together. The mean number of trapped species was significantly higher in multi-lure traps than in each individual single-lure traps. Multi-funnel traps were compared with cross-vane traps (Figure 13.11). Although there was no significant difference in their trapping performance, the multi-funnel traps were found to be more suitable than cross-vane traps around ports because they were easier and quicker to set up and more durable to adverse conditions such as high wind. Eleven species of longhorn beetles were trapped, including two nonnative species, *Neoclytus acuminatus* (Fab.) and *X. stebbingi* Gahan (Rassati et al. 2014).

A larger study was carried out at 15 Italian seaports in 2012 (Rassati et al. 2015a) using black multi-funnel traps and multi-lures composed of (-) α-pinene, ipsenol, ipsdienol, 2-methyl-3-buthen-2-ol, and ethanol. In this study, 81 species of wood-boring beetles were trapped, 49 Scolytinae, 26 Cerambycidae, and 6 Buprestidae. Three species of nonnative longhorn beetles were trapped, two of which were known to be established in Italy, *P. recurva* Newman and *X. stebbingi* Gahan, and one species *Cordylomera spinicornis* (Fabricius) that had not been recorded in Italy before but was not considered to have become established. Of the eight alien species (Scolytinae and Cerambycidae) that were considered established, one was trapped exclusively at ports, two exclusively in surrounding forests, and five in both locations. Of the six species not considered established, three were trapped only in ports and three only in forests. This result reinforced the recommendation of the pilot study (Rassati et al. 2014) that trapping should be carried out both within

FIGURE 13.11 Types of pheromone traps that can be used for surveying cerambycidae. Left: multi-funnel trap; right: cross-vane trap. (Courtesy of Toby Petrice, USDA Forest Service.)

ports and in surrounding forests. There was a significant effect of the volume of imported commodities on the alien species richness both in the ports and the surrounding forests, and broadleaf-dominated forests supported more alien species and individuals than conifer-dominated forests. Based on these conclusions, the authors recommended that extensive monitoring programs should be implemented and concentrated in ports with large volumes of imports and in the surrounding broadleaf forests.

The results of a field study in the tropical montane rain forest of southern China have provided some support to the hypothesis that pheromone traps can be used to attract a range of longhorn beetles species (Wickham et al. 2014). Ten compounds were tested for their attractiveness to Cerambycidae. In this study, 55 species were captured by traps baited with five compounds, (2R*,3S*)-2,3-hexanediol, 3-hydroxyhexan-2-one, (2R*,3R*)-2,3-octanediol, (2R*,3S*)-2,3-octanediol, and 2-(undecyloxy)ethanol, accounting for 77% of the total number of species captured in the whole study. In a study in Michigan, Graham et al. (2012) found that both cross-vane and funnel traps were effective at capturing cerambycids, although the number of cerambycids was higher in cross-vane traps. A second conclusion was that traps for cerambycids need to be placed on supporting bars (around 1.5 m above ground level) and also in tree canopies in order to catch the widest diversity of species. Cerambycid pheromones and their potential applications in pest monitoring are detailed in Chapter 5.

In addition to the use of insect traps, trap trees or "sentinel trees" can be used to monitor for the presence of invasive longhorn beetles. These could be locally important tree species or species that are known to be favored hosts of target species. They can be planted in the areas surrounding high-risk sites such as ports (Wylie et al. 2008) or used in outbreak situations (Hérard et al. 2009; Rassati et al. 2016); they must be monitored regularly for signs of infestation.

The Canneto sull'Oglio district is an important nursery production area in Lombardy, Italy, where around three million potential hosts of *Anoplophora chinensis* are grown. Plant health authorities in Lombardy have established a system of monitoring the nurseries and environment in this area for this pest. Over an area of 539 km^2, plants in every 0.5 by 0.5 km grid square are monitored annually to ensure that any outbreak of *A. chinensis* are detected at a very early stage and to minimize the possibility of infested nursery plants (Ciampitti et al. 2015).

Rassati et al. (2015b) surveyed around wood waste landfill sites in 12 Italian towns. They trapped 74 species of wood-boring beetles, including three nonnative species of longhorn beetles, and concluded that landfill sites for wood waste should be high-priority sites for the detection of nonnative species.

13.8.4 Detection of Outbreaks

One of the characteristics of *Anoplophora* outbreaks in Europe and North America has been that, in many cases, the confirmation of the outbreaks did not take place until many years after the pest became established. Table 13.10 shows examples of the estimates of when the beetles likely became established and the year when they were first detected—usually a lag of at least five years. The implication of such delays in detection are that the invasive beetles will have had a chance to build in numbers and spread geographically by natural means (flying) and anthropogenic means (human movement of felled trees, parts of trees, or plants for planting).

Host utilization data at the species level recorded from outbreak sites can be invaluable for targeting surveys toward the tree species that are most likely to be infested. Infestation records at outbreak sites in combination with data on the number of trees of different species present at a site can provide an indication of the plant species that longhorn beetles are likely to infest environments with a number of native and nonnative trees. For example, in a study of hosts in an area of Lombardy that was heavily infested with *A. chinensis*, 24.1% of *Corylus* trees in the area were infested, whereas only 2.2% of *Acer palmatum* were infested (Cavagna et al. 2013). Haack et al. (2006) analyzed the *A. glabripennis*-infested host genera present in Chicago between 1998 and 2003 and showed that most of the infested trees there were species of *Acer, Ulmus, Fraxinus, Aesculus, Betula*, and *Salix*. *Acer* and *Ulmus* trees were overrepresented among the infested trees when compared with the number of trees present in the area, whereas *Fraxinus, Aesculus, Betula*, and *Salix* were underrepresented.

It is important to note that there may be a difference between the tree species on which the female longhorn beetles lay the highest number of eggs and the tree species from which the highest number of adults emerge, reflecting differing survival rates or development rates within different hosts. For example, in parts of Lombardy, 81% of the infested *Acer pseudoplatanus* trees had *A. chinensis* exit holes compared with 16% of the infested *Malus* trees, that is, of the trees that had been infested by *A. chinensis*, complete development had occurred in a much higher proportion of the *Acer pseudoplatanus* than the *Malus* sp. (Cavagna et al. 2013). In general, it is necessary to find live stages of longhorn beetles in a host plant to confirm an established population of the pest. However, a method has been developed to confirm the

TABLE 13.10

Estimated Initiation and Detection Date for Selected *Anoplophora* Outbreaks

Species	Country	Location	Probable Initial Infestation	Outbreak Detected	References
Ac	Italy	Parabiago	1980–1990?	2000	Hérard et al. 2006
Ac	Italy	Rome	2000 or 2001	2008	Peverieri et al. 2012
Ac	France	Soyons	1998 or earlier	2003	Hérard et al. 2006
Ac	Netherlands	Westland	2002	2007	Van der Gaag et al. 2010
Ac	Croatia	Turanj	2007	2007	Van der Gaag et al. 2010
Ag	United States	Brooklyn, NY	1980s or early 1990s	1996	Haack et al. 1997
Ag	United States	Cataret, NY	1997	2004	Sawyer and Panagakos 2009
Ag	United States	Chicago, IL	1991–1993	1998	Poland et al. 1998
Ag	France	Strasbourg	2003	2008	EPPO 2016
Ag	United States	Worcester, MA	1998	2008	Dodds and Orwig 2011
Ag	Netherlands	Winterswijk	2007 or 2008	2012	PPS Netherlands 2012
Ag	Switzerland	Winterthur (Canton of Zurich)	2006	2012	Forster and Wermelinger 2012
Ag	Canada	Mississauga	2004 or earlier	2013	Turgeon et al. 2015

Note: Ac = *Anoplophora chinensis*; Ag = *Anoplophora glabripennis*.

presence of *A. chinensis* using PCR amplification of DNA extracted from fecal material (present in frass) collected in the field. This technique could be used to confirm the presence of the pest without having to cut and split trees to search for larvae (Strangi et al. 2013). Another novel technique being developed for identifying trees infested with *A. chinensis* is the use of an "electronic nose," but further research is needed before it can be used operationally (Villa et al. 2013).

13.8.5 Surveys

The standard method for surveying for *Anoplophora* species in detection and eradication campaigns is the visual inspection of trees for signs and symptoms of beetle damage. Surveying can be carried out from ground level, which is effective for detecting damage that is low down on host trees, and binoculars can be used to detect damage higher up in host trees. Surveying from the ground is appropriate for *A. chinensis* because this species tends to lay its eggs close to the base of trunks or on exposed roots, although this is not always the case (Hérard et al. 2006; van der Gaag et al. 2010).

Ground surveying, by naked eye for the lower trunks and branches and using binoculars for higher trunks and branches, also is a standard technique for survey of *A. glabripennis*, but it has been reported to be only around 20% effective at identifying infested trees (Nehme et al. 2010). For *A. glabripennis,* the inspection of trees using tree climbers is more effective because the female adults tend to initiate oviposition in the upper trunk and main branches (Haack et al. 2006). However, this survey technique should only be carried out by people specially trained in climbing trees. Also, it should be recognized that tree climbing is slower and hence more expensive than surveillance from the ground (Hu et al. 2009; Nehme et al. 2010).

Decisions on the size of the area to survey will be a balance between a judgment on how far the beetle may have spread or flown and the resources available to search for the pest. The EPPO has recommended that an intensive delimiting survey be carried out around infested trees to a radius of at least 1 km for *A. chinensis* (EPPO 2013e) and at least 1–2 km for *A. glabripennis* (EPPO 2013d). For *A. glabripennis,* the USDA has recommended surveys of all potential host trees within 1.5 miles (2.4 km), including a half-mile infested core area and a one-mile delimiting survey area of infested trees using a combination of ground surveyors, tree climbers (whenever possible), and inspectors in bucket trucks (cherry pickers) (USDA-APHIS 2008). Beyond the 1.5 mile radius, USDA guidelines suggest that high-risk sites be surveyed (e.g., around tree trimming companies that may have moved host material from the infested site) and an area-wide survey of a sample of host trees in each square mile within 25 miles of the center of the outbreak (USDA-APHIS 2008). In 2013, a member of the public found an adult *A. glabripennis* on their car at a location 2 km outside the regulated area covering 152 km^2 that had been established to contain the outbreak that had been discovered in Toronto, Canada, in 2003. The location was 10 km from the epicenter of the 2003 outbreak and 7.5 km from where the closest tree with an exit hole had been detected (Turgeon et al. 2015). This demonstrates that, even with a very extensive quarantine area, there is a possibility of satellite outbreaks in locations outside this area.

The results of surveys from the ground at Paddock Wood, Kent, UK, where an outbreak of *A. glabripennis* was confirmed in 2012, provide an example of how difficult it can be to spot signs of infestation from the ground. Intensive ground surveys in the area around known infested trees indicated that 24 trees were infested, but when trees within 100 m of known infested trees were felled and examined for signs of *A. glabripennis*, a further 42 infested trees were confirmed. Therefore, presuming that all infested trees were detected once the trees had been felled, surveillance from the ground was 36% effective (Straw et al. 2014).

Data relating to the ability of beetle species to disperse and the recorded rate of spread of invasive longhorn beetles can be used to plan surveys. Other considerations are the host and habitat preferences of the beetles. For example, *A. glabripennis* has been hypothesized as being specialized in colonizing trees on the edge of forests and having evolved in riparian habitats (Williams et al. 2004). Until recently, all the invasive populations of *A. glabripennis* in North America and Europe had been found in urban or open agricultural environments. However, surveys between 2008 and 2010 confirmed the presence of the pest in closed canopy forests close to Worcester, Massachusetts, a finding that has implications for planning surveys and the potential impact of the pest (Dodds and Orwig 2011). An analysis of the distribution records of *A. glabripennis* has shown that, despite the ability of the beetle to be able to colonize closed canopy forests around Worcester, the majority of locations where it had been found were within 30 m of a road (Shatz et al. 2013). This could be a product of the beetles preferred habitat and may also be linked to roads aiding the spread of the beetles. Both *A. glabripennis* and *A. chinensis* have been able to successfully colonize and spread in habitats dominated by humans (i.e., among urban trees). This ability could be one of the most significant factors in making these species two of the most important invasive longhorn beetles worldwide.

Investigations into identifying pheromones of *Anoplophora* species have been going on for more than a decade (Wang 1998; Zhang et al. 2002; see Chapter 5). Following trials in China in 2007 and 2008, traps using semiochemical baits were deployed in Worcester between 2009 and 2011. In 2009, nine *A. glabripennis* were caught, and the average distance to the closest infested host was 80 m. In 2011, a total of 500 traps (450 containing lures and 50 unbaited) were deployed, and 23 beetles were caught. The use of traps can reduce eradication costs by focusing survey work on those areas that are more likely to be infested and can speed up the removal of infested trees (Nehme et al. 2013).

13.9 Pest Management Actions and Movement Restrictions

Despite the legislation and measures that are in place to prevent the introduction of longhorn beetles, some cerambycids have been introduced into nonnative environments. Some of these species are known to be damaging pests, and state led eradication campaigns have been put in place to prevent the beetles becoming established. In other cases, the introduced cerambycid has been judged to be either not of sufficient threat or too widespread when discovered for an eradication campaign to be necessary or feasible.

13.9.1 Eradication of Invaded Pests

In eradication campaigns for *Anoplophora* species, the main eradication tool has been the felling and destruction of trees that are known to be infested as well as potentially infested or high-risk trees (i.e., known hosts in close proximity to the infested trees). The logic for felling trees that have not been confirmed as being infested is that it is currently not possible to confirm the presence or absence of larvae from the trees without felling and often splitting them. In common with making the decisions about how extensive surveys should be, decisions on which potentially infested trees need to be removed are also a balance between the risks of missing infested trees and the costs of removing more trees. When considering the costs of removing trees, in addition to the costs of the tree removal operation, the losses to landowners and environmental damage have to be weighed against the potential losses that could ensue if an invasive longhorn beetle were to become widely established. Other influences on the number of trees that should be removed are the number of trees of host species present in an outbreak area, as well as host size, nearby habitat types, and climatic conditions.

In the EU, there is now a requirement to remove all "specified plants" within 100 m of trees infested by *A. chinensis*, and emergency measures list 18 genera and 2 species of specified plants that are considered as its hosts in Europe (EU 2012). The EPPO recommends removal of all potential hosts within 100 m of infested trees for *A. glabripennis* and *A. chinensis* (EPPO 2013d, 2013e). The USDA guidelines list 10 genera and 1 species of trees that should be considered as hosts for *A. glabripennis* and state that total host removal and/or chemical treatment within a radius of half-mile (800 m) of infested trees would mean that only a low percentage of beetles would be likely to disperse beyond the treatment area (USDA-APHIS 2008). In Canada, *A. glabripennis*-infested trees and potential host trees in the genera *Acer, Betula, Populus,* and *Salix* growing within 400 m (and later changed to 800 m) of each infested tree are cut (Haack et al. 2010; Turgeon et al. 2015).

Because *A. chinensis* larvae tend to infest host trees near the base of the trunk, it is recommended that tree stumps be removed or, where this is not possible, the stumps should be ground down to at least 40 cm below the soil level (EPPO 2013e). In the eradication campaign for the outbreak of *A. chinensis* discovered in Rome in July 2008, some of the infested trees were close to Roman walls or in historic gardens, and the removal of these trees could have caused unacceptable damage. As an alternative to stump removal, some of the stumps and tree bases were covered in a fine wire mesh to prevent escape of any emerging *A. chinensis* adults in the future. A similar tactic was used for five standing *Platanus* trees in Rome, three of which were known to be infested. The base of the trees was covered in a combination of a mosquito polyethylene net and wire mesh that was buried in a ring around each tree trunk. There were several cases where beetles were trapped below this mesh screening, and thus, the method was judged to be effective (van der Gaag et al. 2010; Roselli et al. 2013).

Being the main tool of *Anoplophora* eradication, the felling of infested and potentially infested trees will help limit the extent of any outbreak by improving the possibilities of detecting all of the infested trees. It may also help reveal the history of the outbreak and hence may give indications of when and where the outbreak may have begun. For example, by analyzing the growth rings around the *A. chinensis* outbreak site in Rome, it was possible to trace the history of the outbreak back to the first emergence of a beetle in 2002 (Peverieri et al. 2012). Copini et al. (2014) have demonstrated that, in the temperate climate of northwestern Europe, it is possible to analyze the exit holes left by *Anoplophora* to determine which of three phases of the year the exit hole might have been created, namely: (1) during dormancy between October and late April/early May; (2) the period of tree-ring growth in which they would be created within the tree ring—between late April/early May and the beginning of September, and (3) during the end of the growing season, after September. Once infested trees and potentially infested trees have been examined for the pest, EPPO guidelines for *A. glabripennis* recommend that they be chipped to a size of less than 2.5 cm in any dimension or burned on site (EPPO 2013d). The USDA also permits the option of moving large trunks to approved burning sites with the condition that they are covered during transit and burned within 24 hours of arrival (USDA-APHIS 2008).

In eradication campaigns, when possible, all infested and potentially infested hosts should be cut down and destroyed before the next adult emergence period. Smith et al. (2004) studied the emergence of *A. glabripennis* in China and created a model that could be used to predict the emergence data of adults based on degree-days in excess of 10°C after January first each year. This model applied well to the emergence of *A. glabripennis* in Cornuda, Italy (Faccoli et al. 2015). Such models can be implemented using mean climatic data to estimate emergence in an average year and also with data from an individual year to get a more accurate projection of probable emergence dates.

The life cycle of longhorn beetles, with most time being spent as larvae feeding inside the host plant tissues, means that insecticide treatments only can be used to target some life stages of the pest and are unlikely to be the decisive factor in eradication campaigns. Two of the methods of using insecticides against longhorn beetles are (1) foliar sprays of the foliage and/or bark in order to target emerging adults that may be chewing out of tunnels in the trees or landing on the trees to feed or chew oviposition slits in the bark and (2) the injection of systemic insecticides into either the ground or the trunk. These systemic insecticides will move within the tree and are considered to be effective against adults feeding on leaves and young bark, ovipositing females, adults emerging from the tree, and young larvae as they first burrow into their host trees, but they are only partially effective against larvae that are already established deep in the sapwood or heartwood of the host trees (USDA-APHIS 2008).

Pyrethroid insecticides are recommended for application to bark of host trees in the United States in order to target *A. glabripennis* adults emerging from infested trees and to prevent their dispersal. They are also recommended for application to large tracts of wooded land as a quick means of suppressing populations or preventing infestation before arrangements can be made to destroy these trees (USDA-APHIS 2008). Deltamethrin, a pyrethroid insecticide, was applied to *Acer* trees within polytunnels (hoop greenhouses) at a nursery in southern England where *A. chinensis* adults had been found in order to kill any adults that had not been detected (Eyre et al. 2010). Another pyrethroid insecticide, lambda-cyhalothrin, was found to be the most effective product against *A. chinensis* adults, and neonicitinoids, including thiamethoxam, sprayed or painted onto trunks were found to be effective treatments at targeting young *A. chinensis* larvae in trials using potted trees in Italy (Cavalieri 2013).

In trials using insecticide injection into a range of deciduous trees in China that targeted *A. glabripennis*, Poland et al. (2006) found that injections with imidacloprid were more effective than injections with either emamectin benzoate or azadirachtin—although this result varied among tree genera. More recently, the impact of imidacloprid injections on adults feeding on treated trees has been studied by feeding adults with twigs collected between June and September from *Acer platanoides* L. trees that had been treated with imidacloprid as part of the *A. glabripennis* eradication campaign at Worcester, Massachusetts (Ugine et al. 2012). The authors reported: (1) 35% mortality within 21 days of beetles feeding on twigs from trunk-injected trees; however, the concentration of imidacloprid within the twigs was <1 ppm for 68% of these twigs. (2) Mortality of 82% for those that were fed on twigs with >1 ppm imidacloprid. (3) The number of larvae produced from adults that had fed on treated twigs over a three-week period was reduced by 67% compared to those that had fed on untreated twigs. (4) In choice tests, there was no tendency for beetles to move from injected to control twigs over a four-day test period. (5) There was great variability in the concentration of imidacloprid within twigs from treated twigs, with 39% of twig samples having no quantifiable imidacloprid in the bark. The overall impact of imidacloprid injections on *A. glabripennis* populations would be expected to be higher in the field than these results indicate because Ugine et al. (2012) did not take into account impacts on ovipositing females, egg hatch, and larval survival.

Preventing the movement of potentially infested plants or wood has been shown to be essential to avoid the pest being transported to new locations; for example, as described earlier in this chapter, *A. glabripennis* was found to have been moved in wood about 50 km from the original outbreak area in New York City (Haack et al. 1997). Furthermore, when an outbreak of *A. chinensis* was discovered in Boskoop, in the Netherlands, an important site for producing trees that are distributed throughout Europe, there was a risk that the pest may have been spread to multiple locations around Europe before the outbreak was detected (van der Gaag et al. 2010). EU member states are required to establish demarcated areas of at least 2 km around trees infested by *A. chinensis* and prevent the movement of any potentially infested material outside these areas (EU 2012).

Three methods of using pheromones for mating disruption as a population suppression tool have been tested against *T. fuscum* in Nova Scotia, Canada. Two studies were conducted in 2008 and 2009, using fuscomol, the aggregation pheromone for *T. fuscum*. In the first study, fuscomol in Hercon flakes was applied to two 4-ha plots twice a year in 2008 and 2009. In 2008, the flakes were applied from the ground using modified leaf blowers and, in 2009, they were applied from a helicopter (Sweeney et al. 2011a). In a second study, high densities of pheromone traps (100 per ha in a 10 m by 10 m grid) were set up in four 1-ha plots (Sweeney et al. 2011b). In both of these studies *Picea* logs were put into the plots to evaluate the efficacy of the treatments. The percentage of logs infested with *T. fuscum* was lower in the treated plots than in the control plots, and the number of larvae was lower per square meter of surface area of the bait logs. In 2012, a pilot study showed that pheromone traps baited with the fungus *Beauveria bassiana* (Bals.-Criv.) Vuill. in collecting cups contaminated 28% of *T. fuscum*, and 67% of these beetles became infected and produced conidia (Sweeney et al. 2013).

Tree removal is the main tool for eradicating *Anoplophora* sp. in Europe, but biological control could be used to compliment other management strategies and where eradication is no longer considered possible (Brabbs et al. 2015). In 2002, the eulophid egg parasitoid *Aprostocetus anoplophorae* Delvare was discovered in Italy infesting the eggs of *Anoplophora chinensis*. It is suspected to have arrived within *A. chinensis* eggs imported from Japan. Recorded levels of parasitism of *A. chinensis* in Italy vary between 21% and 72% (Hérard et al. 2005; Maspero et al. 2008). The beetle *Dastarcus longulus* Sharp (Bothrideridae) is an effective parasite of *A. glabripennis* (Li et al. 2009a), is amenable to mass rearing (Yang et al. 2014), and has strong natural dispersal (Wei et al. 2007; Li et al. 2009b; Wei and Niu 2011); but unfortunately, it is not host specific and so could potentially damage nontarget species of longhorn beetles (Brabbs et al. 2015). Some entomopathogenic fungi have been tested for their potential use against longhorn beetles, including *Anoplophora* sp. In Japan, nonwoven fiber bands impregnated with the entomopathogenic fungus *Beauveria brongniartii* (Sacc.) Petch are sold to be attached around tree trunks for the control of orchard pests such as *Psacothea hilaris* and *Anoplophora chinensis* (Hajek et al. 2006). Such products potentially could be incorporated in eradication programs for invasive longhorn beetles.

13.9.2 Publicity

Members of the public, including scientists, amateur entomologists, nursery workers, and arborists, can provide an invaluable addition to official staff in the detection of longhorn beetles. The size and distinctive appearance of many longhorn beetles naturally attract attention and hence make them more likely to be reported. Many outbreaks have been first reported by members of the public rather than by officials; for example, the confirmation of an outbreak of *A. glabripennis* at Paddock Wood, Kent, UK, in 2012, followed the initial report of an adult beetle by a member of the public (Straw 2014) as has been the case with many of the outbreaks in the United States and Canada (Haack et al. 1997; Haack et al. 2010). Awareness raising and education of the public are not only necessary to make people aware of invasive longhorn beetles but also essential to (1) encourage people working with potentially infested plants and wood to comply with voluntary or statutory measures that have been implemented to prevent the introduction and spread of invasive longhorn beetles, including those that work with trees in urban areas, woodlands, and forests, and beneath power lines—such as arborists, tree surgeons, foresters, and garden center workers, and (2) to explain the rationale and need for any measures that are being taken to eradicate longhorn beetles to those who are being affected most by such measures—such as residents who have trees in their gardens that may need to be removed or treated.

Raising public awareness of *Anoplophora* in the case of outbreaks is recommended by the EPPO and forms part of the measures required by the EU when outbreaks of *A. chinensis* are discovered in member countries (EU 2012; EPPO 2013d, 2013e). The U.S. guidelines for outbreaks of *A. glabripennis* include recommendations on how to inform the public by hosting public meetings, setting up *A. glabripennis* telephone hotlines to respond to queries from the public, notifying landowners about required measures, and engaging with the media (USDA-APHIS 2008). The Lombardy Plant Protection Service has implemented an information campaign about *A. chinensis* in order to educate the public about the pest. This led to (1) the report of a new outbreak of *A. chinensis* in Brescia Province, Lombardy, a site 150 km east of the main outbreak area (which is close to Milan), and 2) the first record of *A. glabripennis* in Italy. The media campaign has included articles in newspapers and magazines, features on television and radio, plus eye-catching posters on the Milan underground train network (Ciampitti and Cavagna 2014).

13.10 Outbreaks and Established Populations of Nonnative Species

Tobin et al. (2014) have collected records of eradication and containment programs of arthropod plant pests and plant pathogens from 104 countries around the world. Of the 299 taxa (mainly species but some genera) that were listed in the database as of February 2014, 159 were arthropods, including 27 Coleoptera, most of which were Curculionidae (9), Cerambycidae (6), and Chrysomelidae (5). The six species of Cerambycidae listed in the database were *A. chinensis, A. glabripennis, C. rufipenne, T. fuscum, Saperda candida* Fab., and *H. bajulus*. Although this database is not exhaustive, it provides a guide to the best publicized campaigns against exotic pests (including Cerambycidae) and pathogens. As mentioned in the introduction, some of the biological and ecological properties of Cerambycidae, especially their relatively slow rate of spread, have made expensive eradication efforts a better alternative than simply allowing a damaging nonnative pest to spread. Given a realistic chance of eradication, national plant protection organizations have carried out expensive campaigns that would not be implemented for more mobile pests.

Table 13.11 shows records of longhorn beetles that have managed to become temporarily or permanently established in Europe or North America, including species that have been damaging and those that have been comparatively benign in the invaded region. Some details of eradication campaigns against some of the species listed in Table 13.11 have been provided earlier in this chapter. Following is a description of two of the other species in Table 13.11 that have been subject to eradication or containment campaigns that have been described in publications (*Saperda candida* and *Hylotrupes bajulus*) and one species that became widely established before eradication could be implemented (*Psacothea hilaris*).

Saperda candida, the round headed apple borer, is native to the eastern United States and Canada; apple (*Malus*) is its preferred host plant but this species will also feed on other plants in the family Rosaceae, including *Cotoneaster, Crataegus, Cydonia, Prunus, Pyrus*, and *Sorbus*. It is no longer a significant pest in apple orchards because insecticide applications for other pests keep it under control, but it remains a major pest of several ornamental trees (Johnson and Lyon 1991; EPPO 2011). In 2008, the first outbreak of this pest in Europe was discovered on Ferhmarn, Germany, an island on the eastern

TABLE 13.11

Nonnative Longhorn Beetles with Temporary or Permanent Populations in Europe and North America

Cerambycid	Hosts in Invaded Regions	Country/Region of Origin	Country/Region Where Invasive (Year First Reported, if Known)	Species Known to be Under Eradication or Containment Programs	References
Acanthoderes jaspidea (Germar)	*Acacia, Albizzia*	Brazil	The Azores, Portugal (1880)	No	Cocquempot and Lindelow 2010
Acrocinus longimanus L.	Moraceae, Apocynaceae	Brazil	Madeira, Portugal, and mainland Portugal (1977)	No	Cocquempot and Lindelow 2010
Anoplophora chinensis (Forster)	*Acer, Betula, Carpinus, Corylus, Platanus, Fagus*, and others	Asia	Europe (2000)	Yes	Colombo and Limonata 2001
Anoplophora glabripennis (Motschulsky)	*Acer, Aesculus, Betula, Populus, Salix, Ulmus*, and others	China and Korea	North America (1996), Japan and Europe (2001)	Yes	Haack et al. 2010
Aromia bungii (Faldermann)	*Prunus, Populus*, and other broadleaved trees	Asia	Italy	Yes	Garonna et al. 2013
Callidium violaceum (L.)	*Juniperus*	Europe/Asia	USA (1907)—this species is possibly holarctic	No	Aukema et al. 2010, Maier 2009
Callidiellum rufipenne (Motschulsky)	*Cryptomeria, Chamaecyparis, Cupressus, Juniperus, Pinaceae Thuja*, and others	Japan	North America (1997), Europe (Italy, 1989), Spain, France	No	Poland and Haack 2003, Haack 2006
Chlorophorus annularis (Fab.)	*Citrus, Gossypium, Pyrus, Malus, Tectoan, Dipterocarpus, Vitis,* and *Liquidambar* (*Bambusa, Dendrocalamus*, and *Phyllostachys*)	Temperate Asia	Spain (1991); Europe	No	Cocquempot and Lindelow 2010, Mattson et al. 2007
Cyrthognathus forficatus (Fab.)	Unknown	Africa	Malta (1872)	No	Cocquempot and Lindelow (2010)
Derolus mauritanicus Buquet, 1840	*Nerium oleander*	Northern Africa	France (1884), Spain (these records are considered uncertain)	No	Cocquempot and Lindelow 2010
Deroplia albida (Brullé, 1838)	*Pelargonium*	Canary Islands, Spain	Mainland Spain (1988)	No	Cocquempot and Lindelow 2010
Hylotrupes bajulus L.	*Pinus, Picea, Abies*, and *Larix*	Europe and Asia	Much of the world, incl. USA (1850)	No	CABI 2015b; Aukema et al. 2010

(Continued)

TABLE 13.11 ***(Continued)***

Nonnative Longhorn Beetles with Temporary or Permanent Populations in Europe and North America

Cerambycid	Hosts in Invaded Regions	Country/Region of Origin	Country/Region Where Invasive (Year First Reported, if Known)	Species Known to be Under Eradication or Containment Programs	References
Neoclytus acuminatus (Fab.)	*Ulmus, Fraxinus, Juglans, Celtis, Morus,* and *Quercus ilex*	North America	Italy, Croatia, France, Slovenia, Serbia, and Montenegro (1908)	No	Jucker et al. 2006, Matosevic and Zivkovic 2013; Rassati et al. 2016
Parandra brunnea (Fab.)	*Tilia, Populus*, and other deciduous trees	North America	Germany	No	Katschak 2004, Vanhanen et al. 2008
Phorocantha recurva (Newman)	*Eucalyptus* spp.	Australia	USA (1995), Africa, South America, Asia, New Zealand, and Europe	No	Jucker et al. 2006; Grebennikov et al. 2010
Phorocantha semipunctata	*Eucalyptus* spp.	Australia	USA (1984), Africa (Egypt 1950), South America, Asia, New Zealand, and Europe (Sicily 1975)	No	Jucker et al. (2006); Grebennikov et al. 2010)
Phryneta leprosa (Fabricius)	*Morus nigra*	Tropical Africa	Malta, France (1997)	No	Mifsud & Dandria 2002, Cocquempot an Lindelow 2010
Phymatodes lividus (Rossi)	*Quercus, Ulmus*	Europe	North America	No	Mattson 1994, Swift and Ray 2010
Phymatodes testaceus (L.)	*Quercus, Tsuga, Abies, Malus, Fagus, Prunus, Castanea, Carya,* and *Salix*	Europe	USA (1903)	No	Aukema et al. 2010, LaBonte et al. 2005
Psacothea hilaris (Pascoe)	*Ficus* and *Morus*	Asia	Italy (2005)	No	Jucker et al. 2006, Lupi et al. 2013

(Continued)

TABLE 13.11 ***(Continued)***

Nonnative Longhorn Beetles with Temporary or Permanent Populations in Europe and North America

Cerambycid	Hosts in Invaded Regions	Country/Region of Origin	Country/Region Where Invasive (Year First Reported, if Known)	Species Known to be Under Eradication or Containment Programs	References
Saperda candida Fab.	*Malus, Pyrus, Prunus*, and other Rosaceous hosts	North America	Germany (2008)	Yes	Eyre et al. 2013
Saperda populnea L.	*Populus*	Europe	North America (this species is possibly holarctic)	No	Aukema et al. 2010
Sybra alternans (Wiedemann)	*Ficus*	Asia	USA (1992)	No	Haack 2006
Tetropium fuscum (Fab.)	*Picea*	Europe	Canada (1999)	Yes	Poland and Haack 2003, Smith and Hurley 2000
Tetrops praeusta (L.)	Rosaceae, including *Crataegus* and *Malus*	Europe	North America (1996)	No	Haack 2006
Trichoferus campestris (Faldermann)	Range of broadleaved trees, also timber of *Abies, Picea*, and *Pinus*	Asia and SE European Russia	North America (2002), Central Europe	No	Grebennikov et al. 2010, Sabol 2009
Xylotrechus stebbingi Gahan	*Quercus*	Asia	Europe (1990)	No	Biscaccianti 2007, Sama and Cocquempot 1995, Teunissen 2002, Rassati et al. 2016

side of the Jutland Peninsula (Nolte and Krieger 2008). An eradication campaign is underway involving surveillance of host plants, destruction of infested plants, the application of insecticides, and preventing host plants from being moved (Eyre et al. 2013).

Hylotrupes bajulus, the European house borer, is native to North Africa but is now found in Europe, North and South America, South Africa, Asia Minor, China, and Russia (Durr 1954; Duffy 1968). In the 1950s, it was detected in New South Wales, Queensland, and Victoria in Australia, following the importation of prefabricated houses from Europe, but these populations were eradicated 20 years later. In 2004, *H. bajulus* was detected in dead pine trees near Perth in Western Australia (Gove et al. 2007), which led to a response program that has reduced populations of the pest especially in suburban and residential areas. The program has now switched from eradication to containment, with a greater focus on self-management by stakeholders (Liu et al. 2010; DAFF 2011).

Psacothea hilaris (Pascoe), the yellow spotted longhorn beetle, is an Asian species that has become established in Italy (Lupi et al. 2013). It was first detected there in 2005, but a recent survey has found that the beetle has become established over an area of more than 60 km^2 south of Lake Como in Lombardy (Lupi et al. 2013), where it is damaging old, young, stressed, and healthy host trees, mainly figs, *Ficus carica*, and to a lesser extent mulberry, *Morus* sp. This pest has been found in the United States and Canada in warehouses in association with wood and wooden spools from Asia. It also has been found a few times in the United Kingdom but is not known to have become established there. In 2008, it was found in a private garden in Derbyshire (EPPO 2016), and in 2014, in a private home in South Yorkshire, but the source of the beetles in the United Kingdom could not be detected. The pest also has been found in an UK warehouse associated with goods on wooden pallets and among the wood packaging for imported medical equipment (Fera, unpublished data).

13.11 Conclusions

- In common with the spread of other invasive species, the movement of nonnative cerambycids to new locations is a by-product of increasing levels of international trade.
- Wood packaging, especially the wood packaging used to transport heavy commodities such as quarry products and tiles, has been a major pathway in the spread of nonnative cerambycids. The most significant pest moved along this pathway is *Anoplophora glabripennis*, the Asian longhorn beetle. There are outbreaks of this pest in Canada, the United States, and Western Europe. In excess of US$500 million has been spent on eradicating this pest from the United States since it was first discovered in 1996. However, there are a number of infestations in North America and Europe that had yet to be eradicated as of 2016.
- Plants for planting have been another major pathway for the spread of cerambycids. One of the most significant pests moved along this pathway is *Anoplophora chinensis*, the citrus longhorn beetle. More than 25,000 trees have been cut down in order to eradicate this pest from Lombardy, Italy. Although this pest is now considered established in Europe, all outbreaks are subject to ongoing containment and eradication campaigns.
- Invasive longhorn beetles can have large economic impacts—such as damaging commercial eucalyptus plantations, environmental impacts—such as damaging trees planted to prevent desertification in northern China, and social impacts—such as damaging street trees in North America and Europe.
- Measures have been introduced to try to prevent the movement of longhorn beetles such as ISPM 15, an international standard for treating wood packaging materials used in international trade, and the measures introduced by the European Union to prevent the introduction of longhorn beetles in *Acer* trees.
- Risk assessments are carried out by national and regional plant protection organizations in order to evaluate the threat posed by particular cerambycid species and pathways.

- Outbreaks of longhorn beetles often are not detected until many years after their initiation, and pests may have become well established before an eradication campaign can begin. Therefore, close monitoring and public education are extremely important.
- Eradication campaigns against longhorn beetles generally involve extensive removal of trees and labor-intensive visual surveys to detect infested trees.

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