

Impact of alien terrestrial arthropods in Europe Chapter 5

Marc Kenis¹, Manuela Branco²

1 CABI Europe-Switzerland, 1, Rue des Grillons, CH- 2800, Delémont, Switzerland **2** Centro de Estudos Florestais, Instituto Superior de Agronomia, Technical University of Lisbon, Tapada da Ajuda, 1349-017 Lisboa, Portugal.

Corresponding authors: Marc Kenis (m.kenis@cabi.org), Manuela Branco (mrbranco@isa.utl.pt)

Academic editor: David Roy | Received 31 January 2010 | Accepted 18 May 2010 | Published 6 July 2010

Citation: Kenis M, Branco M (2010) Chapter 5: Impact of alien terrestrial arthropods in Europe. In: Roques A et al. (Eds) Alien terrestrial arthropods of Europe. BioRisk 4(1): 51–71. doi: [10.3897/biorisk.4.42](https://doi.org/10.3897/biorisk.4.42)

Abstract

This chapter reviews the effects of alien terrestrial arthropods on the economy, society and environment in Europe. Many alien insect and mite species cause serious socio-economic hazards as pests of agriculture, horticulture, stored products and forestry. They may also affect human or animal health. Surprisingly, there is relatively little information available on the exact yield and financial losses due to alien agricultural and forestry pests in Europe, particularly at continental scale. Several alien species may have a positive impact on the economy, for example parasitoids and predators introduced for the biological control of important pests. Invasive alien arthropods can also cause environmental hazards. They may affect native biodiversity through various mechanisms, including herbivory, predation, parasitism, competition for resource and space, or as vectors of diseases. They can also affect ecosystem services and processes through cascading effects. However, these ecological impacts are poorly studied, particularly in Europe, where only a handful cases have been reported.

Keywords

Biological invasions, economic impact, environmental impact, alien arthropods

5.1. Introduction

Alien insects and other terrestrial arthropods are among the most numerous invaders worldwide. In Europe alone, the update of the DAISIE database (Roques et al. 2009) which is presented in this book considers that 1590 terrestrial arthropod species of

non-European origin are established in Europe, including 1390 insects, 47 spiders, 102 mites, 34 myriapods and 17 crustaceans. Many others originate from a restricted region in Europe but have invaded other parts of the continent. The establishment and spread of these alien species may have various effects. The best documented impacts are economic, particularly due to agricultural or forest pests (Pimentel et al. 2002a, 2002b). Alien arthropods also impact the environment by affecting populations or communities of native species and by disturb natural ecosystem processes and services (Kenis et al. 2009). They affect human and animal health. Finally, alien organisms have a social impact when they influence human well-being (Binimelis et al. 2007).

In this chapter, we review the socio-economic and environmental impacts caused by alien terrestrial arthropods in Europe. Human and animal health impacts will be considered with socio-economic impacts since they represent measurable economic and social costs. Although the social costs of invasions are often difficult to measure in monetary terms, we could not find a single example of an alien arthropod in Europe that primarily affects human well-being without an additional economic burden.

The impact of alien species is usually considered to be negative. In some cases, however, the introduction of an alien arthropod may have a positive impact on the economy or the environment, for example when an exotic biological control agent successfully controls a pest, reducing yield losses or preventing the use of pesticides. Positive impacts of alien arthropods will also be considered in this review.

The review is partly based on the DAISIE database, a pan-European inventory of alien species commissioned by the European Union (Hulme et al. 2009). When building the list of alien organisms in Europe, experts were asked whether the organism had an economic or environmental impact in a particular country. Although their judgement provides valuable opinions, these have to be taken with caution because they were largely subjective and often unsupported by published references.

5.2. Socio-economic impact

The economic impact of alien species has been described as the consequence of an interaction between the invader and economically valuable indigenous species (Williamson 1996). Alien arthropods can affect the economy and society in various ways, through their impact on agriculture, horticulture, forestry, stored products, human and animal health, or various services.

Economic impacts can be direct or indirect. Direct economic impacts occur when alien species that affect valuable species or goods cause damage that results in yield losses and increasing production costs. These types of economic impacts are those most often described and can be easily expressed in monetary values (Pimentel et al. 2002a, 2002b). Pest management costs contribute largely to the direct economic impact of alien species. Insect pests imply the yearly application of more than 3000 million kilograms of insecticides globally (Pimentel 2007), a large share of it targeting alien pest

species. An alien pest may also cause yield losses in its role as vector of other pests and diseases, through interference with indigenous pollinators or as competitors, parasites or predators of beneficial organisms.

Indirect socio-economic effects associated with the introduction of an alien pest include, among others, restrictions on trade flow, effects on market access, changes in market values, changes to domestic or foreign consumer demand for a product resulting from quality changes, changes in land use and landscape structure, public health concerns, costs associated with research and educational services, societal effects such as unemployment, effects on tourism, etc. Indirect effects are often difficult to evaluate because many of them cannot easily be expressed in monetary terms (Born et al. 2005).

Vilà et al. (2010) estimated from the DAISIE database that 24.2% of the alien invertebrates in Europe have an economic impact. More than a half (51.6%) of the terrestrial arthropods alien to Europe are herbivores and, similarly, about 50% of those with economic impact are phytophagous species. Kenis et al. (2007) found that 40% of the alien insects in Switzerland and Austria had at least one web page describing damage and control methods, suggesting a socio-economic impact. Kenis et al. (2007) also estimated that the rate of native insects reaching pest status in temperate countries is probably much lower than 5%. Alien arthropods are well known for being serious plant pests worldwide. More than half of alien arthropods of economic concern are plant pests, which may directly affect yield losses of a variety of forestry and agricultural crops, such as timber, fruits, vegetables, cereals, ornamentals, etc. Insect pests destroy approximately 14% of all potential food production globally (Pimentel 2007). It is estimated that between 30 and 45% of the insect pests in agriculture and forestry worldwide are of alien origin (Pimentel et al. 2002a, 2002b), despite the fact that they only represent a few percent of the insect fauna.

Economic studies on the impact of alien arthropods worldwide are numerous, but less so in Europe. Born et al. (2005) also stated that most economic analysis on the impacts of alien species has been undertaken outside Europe, particularly in North America, South Africa and Oceania. Below, we discuss the most serious economic alien pests of agriculture, protected horticulture, stored products and infrastructures, forestry and urban trees and human and animal health in Europe. Positive impacts of alien arthropods on the economy are discussed separately.

5.2.1. Outdoor agricultural and horticultural pests

Many alien arthropods affect European agriculture and horticulture, mainly through yield losses and management costs, but also through quarantine measures, market effects and foreign trade impact. Reliable data on average yield and financial losses due to alien agricultural pests are not frequently published, particularly in Europe. This may be partly due to the lack of controlled, replicated experiments in commercial fields required to document such information. Furthermore, crops are often attacked by several pest species and the contribution of yield or monetary loss due to a single species is difficult to assess. Pimentel (2002) has calculated for the British Isles that, since each

year arthropods damage or destroy approximately 10% of the crops and 30% of the pests are of exotic origin, alien arthropods cause yield losses of \$960 million per year. A similar calculation for the entire European Union would lead to annual economic losses of approximately 10 billion € caused by alien arthropods. This does not include control, eradication or quarantine costs, nor costs linked to foreign trade impact or market effects. The agricultural/horticultural insecticide market represents over one billion € per year in Europe (ECPA 2007), of which probably at least 20 to 30% is to control alien pests.

The first major alien agricultural insect pest that hit the European economy was the American vine phylloxera, *Viteus vitifoliae*, which, in the late 19th century completely destroyed nearly one-third of the French vineyards in the country, i.e. more than 1.000,000 ha, with incalculable economic and social consequences (CABI 2007). The problem was largely solved by replanting European cultivars grafted onto resistant American rootstocks, although some phylloxera biotypes have developed that may overcome the resistance of certain rootstock cultivars.

Another major arthropod that invaded the European fields a while ago is the Colorado potato beetle, *Leptinotarsa decemlineata*. Since its first occurrence in France in 1922, it has spread to most European countries, causing considerable yield losses in potato fields. Nowadays, effective routine control of the beetle has been incorporated into potato cultivation systems and it is difficult to properly assess the economic cost of the beetle alone. In the eastern USA, the cost of controlling infestations averages between US\$138 and \$368 per hectare but, in this region, infestations are higher than in Europe because of the local development of resistance to the major insecticides (CABI 2007). *Leptinotarsa decemlineata* has not yet invaded the whole of Europe and some countries are still spending significant amounts of money to prevent its entry. For example, in Finland, pre-entry control measures against the beetle cost an average of EUR 171,000 per year in the period from 1999 to 2004 (Heikkilä and Peltola 2006). A cost-benefit analysis showed that the benefit of these protection measures strongly depends on future scenarios, in particular regarding local climatic conditions and agricultural policies.

In the 1990s, the introduction into Europe of the western corn rootworm beetle *Diabrotica virgifera virgifera*, a serious maize pest in North America, generated much attention. A few years after its introduction, mean yield losses in Serbian Maize fields were estimated to be around 30% (Sivcev and Tomasev 2002). Baufelt and Enzian (Baufeld and Enzian 2005) calculated that the potential pecuniary losses in maize due to *D. virgifera virgifera* in a selection of European countries was as high as 147 million €/year, based on a conservative average yield loss of 10%. Consequently, most European countries apply costly regulatory control measures to prevent the pest's establishment in their countries. Nevertheless, in some countries, regulatory control measures may not be economically justified. For example, in UK a cost/benefit analysis showed that, in the absence of a statutory campaign, yield losses of 5% caused by the beetle in maize could have a present value of £0.6 to £2.8 million over 20 years. However, costs

of a statutory campaign against the pest over the same period could range from £2.5 to £7.1 million (MacLeod 2006).

Fruit orchards are particularly prone to alien insect invasions. Many of the most serious pests in European orchards are alien, such as the San José scale, *Diaspidiotus perniciosus*, the Mediterranean fruit fly, *Ceratitidis capitata*, the oriental fruit moth, *Grapholita molesta*, the citrus leaf miner, *Phyllocnistis citrella*, the woolly whitefly, *Aleurothrixus floccosus*, etc. Some arthropods are harmless by themselves but are vectors of serious diseases, such as the leafhopper *Scaphoideus titanus*, vector of Flavescence dorée in vineyards. These arthropods, and many other alien agricultural and horticultural pests are described in the factsheets (see Chapter 14). Despite their economic importance, there is little information on the exact costs related to orchard pests. However, when data are available, they are impressive. For example, in Israel, Palestine and Jordan, the annual fruit losses due to *C. capitata* were estimated to be about U.S. \$365 million, an amount which represents more than half of the total fruit revenue of the area (Enkerlin and Mumford 1997).

5.2.2. Pests of protected horticulture

Most plant pests that occur in greenhouses and other protected environments are of tropical or sub-tropical origin. Some of them also occur on outdoor crops in Southern Europe. Among the most serious alien pests of protected crops in Europe are the leaf miners *Liriomyza huidobrensis* and *L. trifolii*, the whiteflies *Bemisia tabaci* and *Trialeurodes vaporariorum*, the aphids *Aphis gossypii*, *Myzus persicae* and *Macrosiphum euphorbiae*, the western flower thrips *Frankliniella occidentalis* (see factsheets 23, 24, 33, 35, 37 and 78), the citrus mealybug *Planococcus citri* and the moth *Opogona sacchari*. Several of these, particularly aphids, whiteflies and thrips, are vectors of important plant viruses. Mediterranean arthropods such as the lepidopteran defoliator *Cacoecimorpha pronubana*, the leaf mining fly *Liriomyza bryoniae* and the spotted spider mite *Tetranychus urticae* have now invaded protected crops throughout Europe (Brødsgaard and Albajes 1999).

These alien pests cause enormous economic damage to the greenhouse and protected crops industry, through yield losses, control costs, contingency plans, eradication costs or losses in consignments for export. For example, Roosjen et al. (Roosjen et al. 1998) estimated that the annual cost of *F. occidentalis* to the Dutch greenhouse could be US\$30 million, plus a further US\$19 million from the effects of Tomato spotted wilt tospovirus transmitted by the thrips. An intensive eradication programme carried out to control an outbreak of the melon thrips, *Thrips palmi* in a UK greenhouse in 2000 cost £178,000 (MacLeod et al. 2004). A cost/benefit analysis showed that this eradication programme was four to 19 times cheaper compared with potential losses forecast by modelling the spread and impact of *T. palmi* in glasshouse crops over ten years. In another example, Rautapaa (1984) comparing all the costs caused by exclusion measures (eradication + quarantine) to maintain Finland free from *Liriomyza*

trifolii, with the costs of living with the pest, obtained ratios 1:3 to 1:13 in favour of eradication/quarantine measures.

5.2.3. Stored product and infrastructure pests

In Europe, 113 alien insect species are pests of stored products, feeding on products such as grains, seeds, fruits, fabrics, and wood products. Most are Coleoptera (e.g. Anobiidae, Bostrichidae, Chrysomelidae, Cucujidae, Curculionidae, Dermestidae, Mycetophagidae, Nitidulidae, Ptinidae, Silvanidae and Tenebrionidae), Lepidoptera (mainly Pyralidae; Gelechiidae and Tineidae) and Blattodea (cockroaches). Several alien xylophagous beetles and termites may also seriously damage public infrastructures and domestic impairments, furniture and buildings. Alien stored product and infrastructure pests are usually cosmopolitan insects of tropical or sub-tropical origin, being transported worldwide with their food (Rees 2004).

Both the quantity and quality of the stored products may be affected by pests. An economic evaluation has been carried out for three species in Germany (Reinhardt et al. 2003). The annual costs arising from the two grain beetles *Oryzaephilus surinamensis* and *Rhyzopertha dominica* vary from 11.2 to 35.3 million € and that of the flour moth *Ephestia kuehniella* from 4.6 to 12.3 million €. Considering that these numbers are only for Germany and for three pest species, it is likely that the costs due to the two dozen economically significant alien stored product arthropod pests in Europe exceed 1 billion € per year.

5.2.4. Forestry and urban tree pests

Alien arthropods can have severe economic impacts on forest plantations and urban parks. A total of 438 alien insects are associated with woody plants, representing 28.7% of all European alien species (Roques 2010). So far, European forests have suffered less from invasive arthropods than other continents, and the most important forest pests in Europe are still indigenous species. However, several potentially damaging alien forest pests have recently become established, such as the chestnut gall wasp *Dryocosmus kuriphilus*, the ambrosia beetle, *Megaplatypus mutatus* and the two Asian longhorned beetles *Anoplophora glabripennis* and *A. chinensis* (see factsheets 6, 7, and 17). Exotic trees tend to suffer more from alien pests than native trees (Day and Leather 1997). Forty-seven percent of the alien pest species affecting forest and urban trees are associated mainly or exclusively with exotic tree and shrub species (Roques 2010). For example, eucalyptus trees are particularly prone to damage by invaders from Australia. Nine alien arthropods are presently found in Europe feeding on eucalyptus, including two wood-borers, *Phoracantha semipunctata* and *P. recurva*, the eucalyptus snout beetle, *Gonipterus scutellatus*, three psyllids *Ctenarytaina eucalyptii*, *C. spatulata* and *Glycaspis brimblecombi*, two gall wasps *Leptocybe invasa* and *Ophelimus maskelli* and an eriophid mite, *Rhombacus eucalyptii*. In southern Spain, after the first detection of *P. semipunctata* in 1981, the average tree mortality in the subsequent two years was estimated to be about 3%,

equivalent to a loss of 6207 ha, despite the costly control measures applied during this period (Gonzalez Tirado 1986). *Gonipterus scutellatus* is considered to cause tree growth losses of up to 30% in Galicia (Mansilla et al. 1996). The arrival of alien forest pests may also have indirect effects on land use and land value. For example, in Portugal, in the years following the arrival of *P. semipunctata*, eucalyptus plantations situated in marginal areas, poorly suitable for the cultivation of this tree species, were abandoned and the land was used for other purposes (M. Branco, unpublished observation).

In contrast to what is observed in forests, a large proportion of the arthropod pests attacking ornamental and urban trees in streets, parks and gardens in Europe are alien, partly because many tree species planted in urban areas are exotic. Common non-European pests of urban trees and shrubs include, among others, the lace bug *Corythucha ciliata*, the scales *Pulvinaria regalis* and *Pseudaulacaspis pentagona*, the American false webworm *Hyphantria cunea* and the arborvitae leaf miner *Argyresthia thuiella* (See factsheets 41, 45, 52, 64 and 77). The citrus longhorned beetle *Anoplophora chinensis* was recently introduced from Asia to Italy, where it is now established and spreading, despite an eradication programme. This polyphagous wood borer has already killed thousands of urban trees and shrubs in an area of nearly 200 km² (Tomiczek and Hoyer-Tomiczek 2007). Ornamental palms and their trade in the Mediterranean region are seriously threatened by several alien insects, in particular the Asian weevil *Rhynchophorus ferrugineus* and the South American moth *Paysandisia archon* (EPPO 2008a, 2008b).

Several of the most important tree pests in Europe invaded from other parts of the continent. The maritime pine bast scale, *Matsucoccus feytaudi*, an Iberian species, destroyed thousands of hectares of maritime pine forest in South-eastern France, Corsica and Italy, e.g. (Covassi and Binazzi 1992, Jactel et al. 1998, Riom 1994). Important ornamental tree pests in Central and Western Europe originate from the Balkans, such as the horse-chestnut leaf miner *Cameraria ohridella* (Tremblay 1984) and possibly the plane leaf miner, *Phyllonorycter platani* (Schönrogge and Crawley 2000). Many forest pests from continental Europe have invaded the British Isles, where they may cause severe damage to forest plantations, such as the spruce aphid *Elatobium abietinum* or the larger spruce bark beetle *Dendroctonus micans* (Day and Leather 1997).

Tree pests may have a direct economic effect through decrease of timber value, wood increment loss and tree mortality, treatment costs and costs related to early harvesting and replanting. There are few examples where the costs of alien forest pests have been calculated precisely in Europe. In the British Isles, the estimated cost to losses in forestry products due to alien arthropods is about \$2 million per year, that is about 2% of the cost of alien arthropods in the agricultural sector (Pimentel 2002). These numbers may suggest that the direct economic impacts on forest products are much lower than on agricultural crops. The difference might partly be explained by the fact that trees may often sustain pest attacks without substantial growth loss and without tree mortality (Speight and Wainhouse 1989). Furthermore, dead trees may still have economic value as salvage. Still, it should be considered that forests account for only 11% of land cover in the British Isles (Forestry Commission 2006). In other European

countries where the percentage of forest land cover is higher (e.g. 72% in Finland), the relative direct economic impact of alien forest pests will be much higher.

Higher impact values are obtained when control costs are included. For example, Reinhardt et al. (Reinhardt et al. 2003) estimated that the control of the horse-chestnut leaf miner, *Cameraria ohridella*, in Germany would cost 10.02 to 33.8 millions € per year and the replacement costs for all horse-chestnut trees would be as high as 10.7 billion €. The eradication and control costs against *A. chinensis* in Northern Italy amounted to 900,000 € in 2005/2006, but are supposed to reach 10 million € in the period 2008–2010 (Ciampitti 2009). Furthermore, forest ecosystems provide a variety of environmental services with high socio-economic value, such as water resources, soil protection, climate amenity, carbon sequestration and leisure. All these may be seriously hampered by tree defoliation and tree mortality caused by alien forest pests.

5.2.5. Arthropods affecting human and animal health

Human and animal health can be affected by various groups of alien arthropods, in particular detritivorous and hematophagous species. These generate economic costs related to control strategies, public health measures, health treatments, sick leave, educational programmes, etc. Some detritivores may affect human health by both food poisoning and disease transmission. For example, cockroaches, four of which are listed as alien in the DAISIE database, can carry microbes on their body surface and infest human and animal food. They can also provoke allergic reactions, including asthma (Brenner et al. 1987, Rivault et al. 1993).

Hematophagous arthropods, besides being a human nuisance through their biting behaviour, are also able to transmit diseases or to cause allergies and dermatitis to human or domestic animals (Lounibos 2002). Seven alien mosquitoes (Diptera: Culicidae) are found in Europe. The Asian tiger mosquito, *Aedes albopictus*, and the Asian rock pool mosquito, *Aedes japonicus*, have already invaded several European countries. They both are natural vector of various viruses and filaria for humans and domestic animals (Mitchell 1995, Schaffner et al. 2009). In summer 2007, in Italy, for the first time in Europe *A. albopictus* was found to be the vector of an infectious disease, the Chikungunya virus (Enserink 2007). Tropical and sub-tropical mosquito species are often accidentally introduced in Europe and, with global warming, there is a risk that more mosquito species and their associated diseases could become established, particularly in southern Europe.

The DAISIE database also mentions six fleas (Siphonaptera), 27 sucking louses (Phthiraptera) and 20 mites that are also able to transmit diseases or to cause allergies and dermatitis to human and animals (Roques et al. 2009). Worth mentioning are the rat flea, *Nosopsyllus fasciatus*, which is the primary vector for bubonic plague and murine typhus (Beaucornu and Launay 1990) and alien ticks of the genus *Hyalomma* that represent emerging risks for humans and animals in Europe by transmitting tick-borne rickettsial diseases (Parola 2004) (see chapter 7.2.). Finally, although the vast majority of the 48 alien Araneae in Europe are of no medical concern, several species

of importance to human health are increasingly intercepted at entry ports, and a few are reported as being established, such as two *Loxosceles* spp. from America and a black widow, *Latrodectus hasselti*, from Australia (Kobelt and Nentwig 2008).

5.2.6. Arthropods with a positive economic impact

Although alien arthropods are mostly associated with negative effects, some alien species may generate substantial economic benefits. For example, many predators and parasitoids introduced as biological control agents to control alien pests have a positive economic impact. The update of the DAISIE database presented in this book lists 217 non-European arthropods acting as biocontrol agents of plant pests, or pests of stored products. Parasitoids include mostly chalcidoid wasps, in particular Aphelinidae (63 spp.) and Encyrtidae (55 spp.) whereas the most numerous introduced predators are Coccinellidae (12 spp.). Most of these species were intentionally introduced to control alien plant pests in outdoor crops or used as augmentative biological control agents in greenhouses. In Europe, the majority of the vegetable greenhouse area is under biological control or IPM (van Lenteren 2007), using a large variety of predators and parasitoids (van Lenteren et al. 1997). Various cost-benefit analyses have shown that, in greenhouses, biological control is the most cost-effective method (van Lenteren 2007). Many natural enemies established in the wild in Europe have a substantial impact on plant pests, such as the aphelinid *Aphelinus mali*, parasitoid of the woolly aphid *Eriosoma lanigerum*, and the coccinellid *Rodolia cardinalis*, predator of the cottony cushion scale *Icerya purchasi* (Greathhead 1976). Some species released locally have been to spread quickly and rapidly become established in the wild. For example, the Australian parasitoid wasp, *Psyllaephagus pilosus*, which was released locally in southern France in 1997 to control the eucalyptus psyllid *Ctenarytaina eucalypti*, by 1998 had become established and spread westwards by more than 85 km (Malausa 1998). Interestingly, some of the most efficient natural enemies in Europe were introduced unintentionally, such as *Avetianella longoi*, an egg parasitoid of the eucalyptus woodborer *Phoracantha semipunctata* in Italy and Portugal (Farrall et al. 1992, Siscaro 1992), and *Closterocerus chamaeleon*, an Australian parasitoid of the eucalyptus gall wasp *Ophelimus maskelli* found in Portugal in 2007 (Branco et al. 2009).

Pollinators are other insects whose introductions are often considered beneficial. Species and sub-species of honeybee and bumblebee have been introduced into many parts of the world, including Europe, to improve pollination of cultivated plants, either in outdoor crops or in greenhouses (Ings et al. 2005a, 2005b, Moritz et al. 2005). However, the introduction of exotic pollinators and biological control agents may also have negative effects on the environment (see section 5.3 below).

5.3. Environmental impact

Alien arthropods can affect native biodiversity and ecosystem services and processes through various mechanisms (Kenis et al. 2009). Herbivores feeding on native plants

can have a direct effect on host plant populations. Similarly, predators, parasites and parasitoids may directly affect their indigenous prey or host. Alien species may hybridize with native species, causing disturbances in native genetic resources. They can also affect the native flora and fauna and ecosystems indirectly, through cascading effects, or by carrying diseases, competing for food or space or sharing natural enemies with native species. However, these ecological impacts, their strength and the mechanisms underlying these impacts are poorly studied. Their interaction with the native fauna and flora has been rarely investigated, particularly if their habitat is of little economic concern. Based on the DAISIE database, Vilà et al. (2010) estimated that the percentage of alien terrestrial invertebrates having an ecological impact in Europe was 13.8%. However, in most cases, the notification of environmental impact was based on the fact that an alien arthropod may feed on a native plant or animal species and not on scientific evidence that populations or communities of native species are affected, or ecosystem processes are disturbed. In their extensive literature survey on the ecological effects of alien insects, Kenis et al. (2009) identified 72 alien insects worldwide for which an ecological impact had been investigated, and evidence for impact in the field was found for 54 of them. Among these, only a handful of cases came from Europe and, until now, none of them has had a tremendous impact on the environment, in contrast to what is observed in other continents. Table 1 shows the species for which an ecological effect on native biodiversity or ecosystems has been observed or investigated in Europe, and a selection of species for which an effect is suspected but for which scientific evidence is still lacking.

5.3.1. *Impact by herbivores*

In most continents, herbivores account for the largest number of alien insects of ecological concern. For example, several forest pests of Eurasian origin cause dramatic and irreversible effects on various forest ecosystems in North America (Kenis et al. 2009). In Europe, despite the fact that phytophagous insects largely dominate the alien fauna, hardly any are known to have an ecological impact on native biodiversity and ecosystems. A potential exception is the introduction of a butterfly, the small white, *Pieris rapae*, in Madeira, which coincided with the extinction of a congeneric species, the Madeiran large white, *P. brassicae wollastoni* (Wakeham-Dawson et al. 2002). The mechanisms involved in this extinction are unclear. Gardiner (2003) suggests that the introduction of *P. rapae* brought a different strain of the granulosis virus for which the native butterfly had no resistance, although loss of habitat, pollution from agricultural fertilisers and an exotic parasitoid are also blamed. Another study worth mentioning is that of Schönrogge and Crawley (2000), who investigated the impact of the invasion, in UK, of cynipid gall wasps of the genus *Andricus* on native gall wasps through the sharing of parasitoids and inquilines. They did not find evidence that the alien species had a long term effect on populations and communities of native species. Péré et al. (2010) observed that horse-chestnut trees *Aesculus hippocastanum* infested by the invasive leaf miner *Cameraria ohridella* had a negative effect on neighbouring populations

and communities of native leaf miners. Although they suspected that the effect is due to shared natural enemies, further studies did not confirm this hypothesis (P  r   and Kenis, unpubl. data).

Since recently, however, introductions of phytophagous insects in Europe are causing increasing concern for their current or potential impact on the native fauna or flora. The two most serious alien palm pests in Europe, *Rhynchophorus ferrugineus* and *Paysandisia archon*, are not only a problem for the trade of ornamental plants. They are also able to develop on, and kill three endemic palm species, *Phoenix theophrasti* in Crete and *P. canariensis* in the Canary Islands, in the case of both insects, and *Chamaerops humilis* in the western Mediterranean region in the case of *P. archon* (EPPO 2008a, 2008b). The Geranium bronze, *Cacyreus marshalli* is a South African lycaenid butterfly introduced into southern Europe, where it has developed as a serious pest of cultivated *Pelargonium* spp. Laboratory tests in Italy showed that it can also develop and kill native *Geranium* spp. (Quacchia et al. 2008) but further studies are needed to assess better the risk and impact on the wild flora and on native *Geranium*-consuming lycaenids.

The citrus longhorned beetle *Anoplophora chinensis* is presently still restricted to urban areas in Northern Italy, but it is expected to invade forests, where it could kill a large number of tree and shrub species and modify natural ecosystems. The chestnut gall wasp, *Dryocosmus kuriphilus*, a Chinese species damaging chestnut in Japan and North America has been recently found in Italy and is rapidly spreading to neighbouring countries, representing a serious threat for the European chestnut, a keystone species in some European forest ecosystems (Quacchia et al. 2008). Other alien phytophagous insects for which the ecological impact should be investigated include, among others: the western conifer seed bug, *Leptoglossus occidentalis*, which may affect the natural regeneration of conifers (Rabitsch and Heiss 2005); several seed chalcids of the genus *Megastigmus* that are suspected of displacing native congeneric species (Auger-Rozenberg and Roques 2008, Fabre et al. 2004); and *Metcalfa pruinosa*, a planthopper that massively attacks hundreds of different plant species in Southern Europe (Girolami et al. 1996).

However, the alien insect that represents the most serious threat to European biodiversity and ecosystems may well be the emerald ash borer, *Agrilus planipennis*, an Asian wood borer that was detected in North America in 2002. In a few years, it has already killed over 15 million ash trees, *Fraxinus* spp. (Poland and McCullough 2006). The beetle has recently been detected in the region of Moscow, where it has started to cause similar damage (Baranchikov et al. 2008). Considering its dispersal capacities, there is no doubt that *A. planipennis* will quickly invade the rest of Europe and poses a serious threat to the three European ash species which are valuable components of various European forest ecosystems.

5.3.2. Impact by ants

The alien arthropod which has been most studied for its ecological impact in Europe is undoubtedly the Argentine ant, *Linepithema humile*, a South American ant species

that has invaded most continents, becoming one of the most damaging invasive insects on earth (Holway et al. 2002). In Europe, it has been reported in several countries, and has established large wild populations in Spain, Portugal, southern France and Italy. In Spain and Portugal, *L. humilis* was observed to displace the native ants including myrmecochorous ants, which had a negative effect on seed dispersal of native plants (Carpintero et al. 2005, Gómez and Oliveras 2003, Gómez et al. 2003, Way et al. 1997). Blancafort and Gómez (2005) noted that the invasion of *L. humile* reduces fruit-set and seed set of the native plant *Euphorbia characias*. In Madeira, however, it seems that *L. humile* and another invasive ant, *Pheidole megacephala* have little impact, even after 150 or more years of residence, and are dominated by the better adapted native ant, *Lasius grandis* (Wetterer et al. 2006). Way et al. (1997) noted that the displacement of native ants in Portugal was most noticeable on disturbed habitats. Also, *L. humile* preys on and reduces populations of serious tree pests such as the pine processionary moth, *Thaumetopoea pityocampa*, and the eucalyptus wood borer (Way et al. 1992, 1999).

Lasius neglectus is another invasive ant in Europe, originating from Asia Minor. It is found in several European countries, but mainly in human-modified habitats, from strictly urban sites to gardens and urban woods. Nevertheless, it can be very aggressive against native ants and some populations in Spain have displaced other surface-foraging ants as well as other invertebrates, such as Lepidoptera (Espadaler and Bernal 2008). *Lasius neglectus* also tends arboreal aphids that may have a detrimental impact on trees. In England, Oliver et al. (2008) conducted laboratory studies on competitive interactions between native ants and *Technomyrmex albipes*, another alien ant that is presently restricted to protected habitats but may become invasive outdoors with future climate warming.

5.3.3. Impact by other predators and parasitoids

Biological control agents are usually considered as beneficial because they reduce the impact of pests and the use of pesticides. In some cases, however, they may become pests themselves and threaten non-target species or other beneficial organisms. The best known case in Europe is the harlequin ladybird, *Harmonia axyridis*, an Asian species used in biological control programmes against aphids on greenhouse and field crops since the 1980s. The first feral populations in Europe were found in Germany in 1999 and, since then, it has spread to at least 15 countries (Brown et al. 2008). In North America, where it was released earlier, it is known to displace native ladybirds through intra-guild predation and competition for food (Koch and Galvan 2008), and it is feared that the same effects will be observed on European ladybird species. Laboratory tests have already shown that European species are vulnerable to predation by *H. axyridis* (Burgio et al. 2002, Ware and Majer 2008, Ware et al. 2008), but evidence for displacement in the field needs to be further studied (Adriaens et al. 2008).

Two parasitoids released to control plant pests in Europe are known to have affected populations of native parasitoids. The North American aphid parasitoid *Lysip-*

blebus testaceipes, introduced in Mediterranean countries to control *Aphis spiraeicola*, may have displaced two congeneric parasitoids, *L. fabarum* and *L. confusus* (Tremblay 1984). Similarly, the introduction of the South American *Cales noacki* in Italy to control the whitefly *Aleurothrixus floccosus*, has resulted in the displacement of the indigenous parasitoid *Encarsia margaritiventris*, parasitoid of the viburnum whitefly *Aleurotuba jelineki* (Viggiani 1994). However, in a recent paper, Viggiani (2008) stated that, in the two cases, the effects on the native parasitoids were largely local, that none of the affected native parasitoids is now endangered and that this displacement had no effect on pest populations.

Alien mosquitoes are not only a threat for human or animal health. They may also affect native mosquito species through competition (Juliano and Lounibos 2005). Following the invasion of the tiger mosquito, *Aedes albopictus* in Italy, Carrieri et al. (2003) carried out laboratory experiments to investigate potential competitive interactions with the native *Culex pipiens*. They found that *A. albopictus* was competitively superior in resource competition but, to date, the displacement of native mosquitoes has not been demonstrated in the field.

5.3.4. Impact by pollinators and impact on pollination

In Europe, as in other continents, insect pollinators, particularly bees, are declining, which may have dramatic consequences for the functioning of natural ecosystems and agriculture (Biesmeijer et al. 2006). Although the exact mechanisms leading to bees' decline is a matter of debate, there is no doubt that the accidental introduction of natural enemies has played a significant role. In particular, the parasitic mite, *Varroa destructor*, which originates from the Far East and was accidentally introduced into most continents since the 1950s, has largely contributed to the decline of cultivated honeybee, partly because of its association with viruses (Sammataro et al. 2000). This has surely had an indirect ecological effect on plant pollination, although this effect is difficult to quantify. In other parts of the world, it has been shown that *V. destructor* also has a serious impact on feral honeybee populations (Kraus and Page 1995), but such studies are still lacking in Europe. Honeybees and wild bees may soon be threatened by a new invader, the Asian hornet, *Vespa velutina* (see factsheet 64). This species was introduced in south-western France some years ago, probably in pieces of pottery imported from China (Villemant et al. 2006). It is known as an important predator of bees in Asia, and it has already been reported preying on domestic honeybees in France. In addition, it may displace the European hornet, *Vespa crabro*. The current and potential impact of this new alien species should be assessed for the whole of Europe and management measures should be developed.

The release in western and Northern Europe of two subspecies of the honeybee *Apis mellifera* originating from southern and eastern Europe, *A. m. ligustica* and *A. m. carnica*, has caused large-scale gene flow and introgression between these sub-species and the native black honeybee, *A. m. mellifera* (De La Rúa et al. 2002, Jensen et al. 2005, Moritz et al. 2005). In the Canary Islands, Dupont et al. (2003) showed that the

introduced honeybees depleted nectar of a native plant, which reduced visitation by native pollinators and may have consequences on pollination. The bumblebee, *Bombus terrestris*, another important pollinator in Europe, is threatened by the importation of sub-species from the Middle East (*B. t. dalmatinus*) and Sardinia (*B. t. sassaricus*) introduced in Europe as pollinators of greenhouse crops. Commercial subspecies may hybridize with native ones and even displace them in the wild (Ings et al. 2005a, 2005b, 2006).

5.4. Acknowledgements

We thank Alain Roques and David Lees for their useful comments on the manuscript. MK was supported by the European Commission through the projects ALARM (GOCE-CT-2003-506675) and PRATIQUE (Grant No. 212459).

5.5. References

- Adriaens T, San Martin y Gomez G, Maes D (2008) Invasion history, habitat preferences and phenology of the invasive ladybird *Harmonia axyridis* in Belgium. *BioControl* 53: 69–88.
- Auger-Rozenberg MA, Roques A (2008) Share the resources or displace the natives: different strategies in invasive *Megastigmus* seed insects. In: Proceedings of the 23rd International Congress of Entomology, Durban (South Africa), July 2008.
- Baranchikov Y, Mozolevskaya E, Yurchenko G, Kenis M (2008) Occurrence of the emerald ash borer, *Agrilus planipennis* in Russia and its potential impact on European forestry. *Bulletin OEPP/EPPO Bulletin* 38: 233–238.
- Baufeld P, Enzian S (2005) Maize growing, maize high-risk areas and potential yield losses due to Western Corn Rootworm (*Diabrotica virgifera virgifera* LeConte) damage in selected European countries. In: Vidal S, Kuhlmann U, Edwards CR (Eds) *Western Corn Rootworm: Ecology and Management*. Wallingford, UK: CABI Publishing, 285–302.
- Beaucornu JC, Launay H (1990) *Les puces de France et du Bassin Méditerranéen Occidental*. *Faune de France* 76. Paris : Fédération Française des Sociétés de Sciences Naturelles. 548 pp.
- Biesmeijer JC, Roberts SPM, Reemer M, Ohlemuller R, Edwards M, Peeters T, Schaffers AP, Potts SG, Kleukers R, Thomas CD, Settele J, Kunin WE (2006) Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science* 313: 351–354.
- Binimelis R, Born W, Monterroso I, Rodríguez-Labajos B (2007) Socio-economic impact and assessment of biological invasions. In: Nentwig W (Ed) *Biological Invasions*. Berlin: Springer-Verlag.
- Blancafort X, Gómez C (2005) Consequences of the Argentine ant, *Linepithema humile* (Mayr), invasion on pollination of *Euphorbia characias* (L.) (Euphorbiaceae). *Acta Oecologica* 28: 49–55.
- Born W, Rauschmayer F, Bräuer I (2005) Economic evaluation of biological invasions -a survey. *Ecological Economics* 55: 321– 336.

- Branco M, Boavida C, Durand N, Franco JC, Mendel Z (2009) Presence of the Eucalyptus gall wasp, *Ophelimus maskelli* (Ashmead) and its parasitoid *Closterocerus chamaeleon* Girault, in Portugal: first record, geographic distribution and host preference. *Phytoparasitica* 37: 51–54.
- Brenner RJ, Koehler P, Patterson RS (1987) Health Implications of Cockroach Infestations. *Infections in Medicine* 4: 349–355.
- Brødsgaard HF, Albajes R (1999) Insect and mite pests. In: Albajes R, Lodovica Gullino M, van Lenteren JC, Elad Y (Eds) *Integrated Pest and Disease Management in Greenhouse Crops*. Amsterdam: Kluwer Academic Publishers, 48–60.
- Brown PMJ, Adriaens T, Bathon H, Cuppen J, Goldarazena A, Hägg T, Kenis M, Klausnitzer BEM, Kovar I, Loomans A, Majerus MEN, Nedved O, Pedersen J, Rabitsch W, Roy HE, Ternois V, Zakharov I, Roy DB (2008) *Harmonia axyridis* in Europe: spread and distribution of a non-native coccinellid. *BioControl* 53: 5–21.
- Burgio G, Santi F, Maini S (2002) On intra-guild predation and cannibalism in *Harmonia axyridis* (Pallas) and *Adalia bipunctata* L. (Coleoptera: Coccinellidae). *Biological Control* 24: 110–116.
- CABI (2007) *Crop Protection Compendium*. Wallingford, UK: CAB International. CD-ROM.
- Carpintero S, Reyes-López J, Arias de Reyna L (2005) Impact of Argentine ants (*Linepithema humile*) on an arboreal ant community in Doñana National Park, Spain. *Biological Conservation* 14: 151–163.
- Carrieri M, Bacchi M, Bellini R, Maini S (2003) On the competition occurring between *Aedes albopictus* and *Culex pipiens* (Diptera: Culicidae) in Italy. *Environmental Entomology* 32: 1313–1321.
- Ciampitti M (2009) Case study: *Anoplophora chinensis* and *A. glabripennis*. Oral presentation at the EPPO Workshop on eradication, containment and contingency planning. Nova Gorica, Slovenia, 10–12.02.2009.
- Covassi M, Binazzi A (1992) Primi focolai di *Matsucoccus feytaudi* Duc. nella Liguria orientale (Homoptera: Margarodidae). *Redia* 75: 453–466.
- Day KR, Leather SR (1997) Threats to forestry by insect pests in Europe. In: Watt, AD, Stork NE, Hunter MD (Eds) *Forests and Insects*. London: Chapman & Hall, 177–205.
- De La Rúa P, Serrano J, Galian J (2002) Biodiversity of *Apis mellifera* populations from Tenerife (Canary Islands) and hybridisation with East European races. *Biological Conservation* 11: 59–67.
- Dupont YL, Hanse DM, Valido A, Olesen JM (2003) Impact of introduced honeybees on native pollination interactions of the endemic *Echium wildpretii* (Boraginaceae) on Tenerife, Canary Islands. *Biological Conservation* 118: 301–311.
- ECPA (2007) European Crop Protection Association. <http://www.ecpa.be> [accessed 28.05.2009].
- Enkerlin W, Mumford J (1997) Economic evaluation of three alternative methods for control of the Mediterranean fruit fly (Diptera: Tephritidae) in Israel, Palestinian Territories, and Jordan. *Journal of Economic Entomology* 90: 1066–1072.
- Enserink M (2007) Tropical disease follows mosquitoes to Europe. *Science* 317: 1485.
- EPPO (2008a) Datasheets on quarantine pests. *Rhynchophorus ferrugineus*. *Bulletin OEPP/EPPO* 38, 55–59.

- EPPO (2008b) Datasheets on quarantine pests. *Paysandisia archon*. *Bulletin OEPP/EPPO* 38, 163–166.
- Espadaler X, Bernal V (2008) *Lasius neglectus*. <http://www.creaf.uab.es/xeg/lasius/index.htm>
- Fabre JP, Auger-Rozenberg MA, Chalon A, Boivin S, Roques A (2004) Competition between exotic and native insects for seed resources in trees of a Mediterranean forest ecosystem. *Biological Invasions* 6: 11–22.
- Farrall MH, Paiva MR, Albino P (1992) Registo de uma nova espécie do género *Avetianella* (Hymenoptera, Encyrtidae) parasitóide oófago da broca do eucalipto *Phoracantha semipunctata* (Fab.). *Actas do Congresso Iberica de Entomologia* 5: 475–480.
- Forestry Commission (2006) Forestry Statistics 2005. Available at [<http://www.forestry.gov.uk/website/foreststats.nsf/byunique/woodland.html#one>]
- Gardiner BOC (2003) The possible cause of extinction of *Pieris brassicae wollastoni* Butler (Lepidoptera: Pieridae). *Entomologist's Gazette* 54: 267–268
- Girolami V, Conte L, Camporese P, Benuzzi M, Martir GR, Dradi D (1996) Possibilita di controllo biologico della *Metcalfa pruinosa*. *Informatore Agrario*, 52: 25.
- Gómez C, Oliveras J (2003) Can the Argentine ant (*Linepithema humile* Mayr) replace native ants in myrmecochory? *Acta Oecologica* 24: 47–53.
- Gómez C, Pons P, Bas JM (2003) Effects of the Argentine ant *Linepithema humile* on seed dispersal and seedling emergence of *Rhamnus alaternus*. *Ecography* 26: 532–538.
- Gonzalez Tirado L (1986) *Phoracantha semipunctata* dans le Sud-Ouest espagnol: lutte et dégâts. *Bulletin OEPP/EPPO* 16: 289–292.
- Greathead DJ (Ed) (1976) *A review of biological control in western and southern Europe*. Technical Communication No. 7. Farnham Royal, UK: Commonwealth Institute of Biological Control CAB. 182 pp.
- Heikkilä J, Peltola J (2006) Phytosanitary measures under uncertainty: a cost benefit analysis of the Colorado potato beetle in Finland. In: AGJM Oude Lansink (Ed) *New Approaches to the Economics of Plant Health*. Heidelberg, Germany: Springer-Verlag, 147–161.
- Holway DA, Lach L, Suarez A, Tsutsui N, Case TJ (2002) The causes and consequences of ant invasions. *Annual Review of Ecology and Systematics* 33: 181–233.
- Hulme PE, Nentwig W, Pyšek P, Vilà M (Eds) (2009) DAISIE, *The Handbook of Alien Species in Europe*. Dordrecht: Springer. 399 pp.
- Ings TC, Raine NE, Chittka L (2005a) Mating preference of commercially imported bumblebees (*Bombus terrestris*) in Britain (Hymenoptera: Apidae). *Entomologia Generalis* 28: 233–238.
- Ings TC, Schikora J, Chittka L (2005b) Bumblebees, humble pollinators or assiduous invaders? A population comparison of foraging performance in *Bombus terrestris*. *Oecologia*, 144: 508–516.
- Ings TC, Ward NL, Chittka L (2006) Can commercially imported bumble bees out-compete their native conspecifics? *Journal of Applied Ecology* 43: 940–948.
- Jactel H, Menassieu P, Ceria A, Burban C, Regad J, Normand S, Carcreff E (1998) Une pullulation de la cochenille *Matsucoccus feytaudi* provoque un début de dépérissement du pin maritime en Corse. *Revue Forestière Française* 50: 33–45.

- Jensen AB, Palmer KA, Boomsma JJ, Pedersen BV (2005) Varying degrees of *Apis mellifera ligustica* introgression in protected populations of the black honeybee, *Apis mellifera mellifera*, in northwest Europe. *Molecular Ecology* 14: 93–106.
- Juliano SA, Lounibos LP (2005) Ecology of invasive mosquitoes: Effects on resident species and on human health. *Ecology Letters* 8: 558–574.
- Kenis M, Rabitsch W, Auger-Rozenberg M-A, Roques A (2007) How can alien species inventories and interception data help us prevent insect invasions? *Bulletin of Entomological Research* 97: 489–502.
- Kenis M, Auger-Rozenberg M-A, Roques A, Timms L, Péré C, Cock MJW, Settele J, Augustin S, Lopez-Vaamonde C (2009) Ecological effects of invasive alien insects. *Biological Invasions* 11: 21–45.
- Kobelt M, Nentwig W (2008) Alien spider introductions to Europe supported by global trade. *Diversity and Distributions* 14: 273–280.
- Koch RL, Galvan TL (2008) Bad side of a good beetle: the North American experience with *Harmonia axyridis*. *BioControl* 53: 23–35.
- Kraus B, Page RE Jr. (1995) Effect of *Varroa jacobsonia* (Mesostigmata: Varroidae) on feral *Apis mellifera* (Hymenoptera: Apidae) in California. *Environmental Entomology* 24: 1473–1480.
- Lounibos LP (2002) Invasions by insect vectors of human disease. *Annual Review of Entomology* 47: 233–66.
- MacLeod A (2006) The benefits and costs of specific phytosanitary campaigns in the UK. Examples that illustrate how science and economics support policy decision making. In: AGJM Oude Lansink (Ed) *New Approaches to the Economics of Plant Health*. Heidelberg, Germany: Springer-Verlag, 163–177.
- MacLeod A, Head J, Gaunt A (2004). An assessment of the potential economic impact of *Thrips palmi* on horticulture in England and the significance of a successful eradication campaign. *Crop Protection* 23: 601–610.
- Malausa JC (1998) Des insectes au secours des eucalyptus. *Biofutur* 176: 34–37.
- Mansilla P, Pérez R (1996) El defoliador del eucalipto *Gonipterus scutellatus*. *Phytoma España* 81: 36–42.
- Mitchell CJ (1995) Geographic spread of *Aedes albopictus* and potential for involvement in arbovirus cycles in the Mediterranean basin. *Journal of Vector Ecology* 20: 44–58.
- Moritz RFA, Härtel S, Neumann P (2005) Global invasions of the western honeybee (*Apis mellifera*) and the consequences for biodiversity. *Ecoscience* 12: 289–301.
- Oliveira MRV, Henneberry TJ, Anderson P (2001) History, current status, and collaborative research projects for *Bemisia tabaci*. *Crop Protection*. 20: 709–723.
- Oliver TH, Pittitt T, Leather SR, Cook JM (2008) Numerical abundance of invasive ants and monopolisation of exudate-producing resources – a chicken and egg situation. *Insect Conservation and Diversity* 1: 208–214.
- Parola P (2004) Tick-borne rickettsial diseases: emerging risks in Europe. *Comparative Immunology, Microbiology and Infectious Diseases*. 27: 297–304
- Péré C, Augustin S, Tomov R, Peng L-H, Turlings TCJ, Kenis M (2009a) Species richness and abundance of native leaf miners are affected by the presence of the invasive horse-chestnut leaf miner. *Biological Invasions*. Online first. Doi: 10.1007/s10530-009-9518-0.

- Péré C, Augustin S, Turlings TCJ, Kenis M (2009b) The invasive alien leaf miner, *Cameraria ohridella* and the native maple, *Acer pseudoplatanus*: a fatal attraction? *Agricultural and Forest Entomology*. In press.
- Pimentel D (2002) Non-native invasive species of arthropods and plant pathogens in the British Isles. In: Pimentel D (Ed) *Biological Invasions. Economic and Environmental costs of Alien Plants, Animal and Microbe Species*. Boca Raton, USA: CRC Press, 151–155.
- Pimentel D (2007) Area-Wide Pest Management: Environmental, Economic, and Food Issues. In: Vreysen MJB, Robinson AS, Hendrichs J (Eds) *Area-Wide Control of Insect Pests: from research to field implementation*. Dordrecht, The Netherlands: Springer, 35–47.
- Pimentel D, Lach L, Zuniga R, Morrison D (2002a) Environmental and economic costs associated with non-indigenous species in the United States. In: Pimentel D (Ed) *Biological Invasions. Economic and Environmental costs of Alien Plants, Animal and Microbe Species*. Boca Raton, USA: CRC Press, 285–306.
- Pimentel D, McNair S, Janecka J, Wightman J, Simmonds C, O'Connell C, Wong E, Russel L, Zern J, Aquino T, Tsomondo T (2002b) Economic and environmental threats of alien plant, animal and microbe invasions. In: Pimentel D (Ed) *Biological Invasions. Economic and Environmental costs of Alien Plants, Animal and Microbe Species*. Boca Raton, USA: CRC Press, 307–330.
- Poland TM, McCullough DG (2006) Emerald ash borer: invasion of the urban forest and the threat to North America's ash resource. *Journal of Forestry* 104: 118–124.
- Quacchia A, Ferracini C, Bonelli S, Balletto E, Alma A (2008a) Can the Geranium Bronze, *Cacyreus marshalli*, become a threat for European biodiversity? *Biodiversity and Conservation* 17: 1429–1437.
- Quacchia A, Moriya S, Bosio G, Scapio I, Alma A (2008b) Rearing, release and settlement prospect in Italy of *Torymus sinensis*, the biological control agent of the chestnut gall wasp. *BioControl* 53: 829–839.
- Rabitsch W, Heiss E (2005) *Leptoglossus occidentalis* Heidemann, 1910, eine amerikanische Adventivart auch in Österreich aufgefunden (Heteroptera, Coreidae). *Berichte des naturwissenschaftlichmedizinischen Verein Innsbruck* 92: 131–135.
- Rautapaa J (1984) Costs and benefits of quarantine measures against *Liriomyza trifolii* in Finland. *EPPO Bulletin*: 14: 343–347.
- Rees D (2004) *Insects of Stored Products*. Collingwood, VIC, Australia: CSIRO Publishing, Australia.
- Reinhardt F, Herle M, Bastiansen F, Streit B (2003) Economic impact of the spread of alien species in Germany. Berlin, Germany: Federal Environmental Agency (Umweltbundesamt). 229 pp.
- Rivault C, Cloarec A, Le Guyader A (1993) Bacterial load of cockroaches in relation to urban environment. *Epidemiology and Infection* 110: 317–325.
- Riom J (1994) Le dépérissement du pin maritime dans le Sud-Est de la France au cours des années 1960–1970: Le rôle de la cochenille *Matsucoccus feytaudi* Duc. (Coccoidea, Margarodidae). *Revue Forestière Française* 66, 437–445.
- Roosjen M, Buurma J, Barwegen J (1998) Verbetering schade-inschattingsmodel quarantaine-organismen glastuinbouw. *Verslagen en Mededelingen, Plantenziektenkundige Dienst, Wageningen* 197: 1–24.

- Roques A (2010) Alien forest insects in a globalized, warmer world: Impacts of global change (trade, tourism, climate) on forest biosecurity. *New Zealand Journal of Forestry Science* (in press).
- Roques A, Rabitsch W, Rasplus JY, Lopez-Vaamonde C, Nentwig W, Kenis M (2009) Alien terrestrial invertebrates of Europe. In: Hulme PE, Nentwig W, Pyšek P, Vilà M (Eds) *DAISIE, The Handbook of Alien Species in Europe*. Heidelberg, Germany: Springer, 63–79.
- Sammataro D, Gerson U, Needham G (2000) Parasitic mites of honey bees: life history, implications, and impact. *Annual Review of Entomology* 45: 519–548.
- Schaffner F, Kaufmann C, Hegglin D, Mathis A (2009) The invasive mosquito *Aedes japonicus* in Central Europe. *Medical and Veterinary Entomology* 23: 448–451.
- Schönrogge K, Crawley MJ (2000) Quantitative webs as a means of assessing the impact of alien insects. *Journal of Animal Ecology* 69: 841–868.
- Šefrová, H (2001) *Phyllonorycter platani* (Staudinger) a review of its dispersal history in Europe (Lepidoptera, Gracillariidae). *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis* 49: 71–75.
- Siscaro G (1992) *Avetianella longoi* sp. n. (Hymenoptera, Encyrtidae) egg parasitoid of *Phoracantha semipunctata* F. (Coleoptera, Cerambycidae). *Bollettino di Zoologia agraria e di Bachicoltura* 24: 208–211.
- Sivcev I, Tomasev I (2002). Distribution of *Diabrotica virgifera virgifera* LeConte in Serbia in 1998. *Acta Phytopathologica et Entomologica Hungarica* 37: 145–153.
- Speight MR, Wainhouse D (1989) *Ecology and Management of forest insects*. New York: Oxford University Press.
- Tomiczek C, Hoyer-Tomiczek U (2007) Asian longhorned beetle (*Anoplophora glabripennis*) and citrus longhorned beetle (*Anoplophora chinensis*) in Europe - actual situation. *Forstschutz Aktuell* 38: 2–5.
- Tremblay E (1984) The parasitoid complex (Hym.: Ichneumonidea) of *Toxoptera aurantii* (Hom.: Aphidoidea) in the Mediterranean area. *Entomophaga* 29: 2003–2010.
- Valade R, Kenis M, Hernandez-Lopez A, Augustin S, Mari Mena N, Magnoux E, Rougerie R, Lakatos F, Roques A, Lopez-Vaamonde C (2009) Mitochondrial and microsatellite DNA markers reveal a Balkanic origin for the highly invasive Horse-Chestnut leaf miner *Cameraria ohridella* (Lepidoptera, Gracillariidae). *Molecular Ecology* 18: 3458–3470.
- van Lenteren JC (2007) Biological control for insect pests in greenhouses: an unexpected success. In: Vincent C, Goettel MS, Lazarovits G (Eds) *Biological Control. A Global Perspective*. Wallingford, UK: CAB International, 105–117.
- van Lenteren JC, Roskam MM, Timmer R (1997) Commercial mass production and pricing of organisms for biological control of pests in Europe. *Biological Control* 10: 143–149.
- Viggiani G (1994) Recent cases of interspecific competition between parasitoids of the family Aphelinidae (Hymenoptera: Chalcidoidea). *Norwegian Journal of Agricultural Sciences Supplement* 16: 353–359.
- Viggiani G (2008) Reflections and evidences on the present status of biological control of arthropod pests. Presentation at the International Congress of Entomology, 6–12 July 2008, Durban South Africa.

- Vilà M, Basnou C, Pysek P, Josefsson M, Genovesi P, Gollasch S, Nentwig W, Olenin S, Roques A, Roy D, Hulme PE, DAISIE partners (2009) How well do we understand the impacts of alien species on ecosystem services? A pan-European, cross-taxa assessment. *Frontiers in the Ecology and the Environment*. Online first. doi:10.1890/080083.
- Villemant C, Haxaire J, Streito JC (2006) Premier bilan de l'invasion de *Vespa velutina* Lepelletier en France (Hymenoptera, Vespidae). *Bulletin de la Société entomologique de France* 111: 535–538.
- Wakeham-Dawson A, Franquinho Aguiar AM, Martin G (2002) The distribution of endemic butterflies (Lepidoptera) on the island of Madeira, Portugal since 1850, with comments on their current conservation status. *Entomologist's Gazette* 53: 153–180.
- Ware RL, Majerus MEN (2008) Intraguild predation of immature stages of British and Japanese coccinellids by the invasive ladybird *Harmonia axyridis*. *BioControl* 53: 169–188.
- Ware RL, Evans N, Malpas L, Michie LJ, O'Farrell K, Majerus MEN (2008) Intraguild predation by the invasive ladybird *Harmonia axyridis*. British and Japanese coccinellid eggs. *Neobiota* 7: 263–275.
- Way MJ, Cammell ME, Paiva MR (1992) Studies on egg predation by ants (Hymenoptera: Formicidae) especially on the eucalyptus borer *Phoracantha semipunctata* (Coleoptera: Cerambycidae) in Portugal. *Bulletin of Entomological Research* 82: 425–432.
- Way MJ, Cammell ME, Paiva MR, Collingwood C (1997) Distribution and dynamics of the Argentine ant *Linepithema (Iridomyrmex) humile* (Mayr) in relation to vegetation, soil conditions, topography and native competitor ants in Portugal. *Insectes Sociaux* 44: 415–433.
- Way MJ, Paiva MR, Cammell ME (1999) Natural biological control of the pine processionary moth *Thaumetopoea pityocampa* (Den. & Schiff.) by the Argentine ant *Linepithema humile* (Mayr) in Portugal. *Agr Forest Entomol* 1: 27–31.
- Wetterer JK, Espadaler X, Wetterer AL, Aquin-Pombo D, Franquinho-Aguilar AM (2006) Long-term impact of exotic ants on the native ants of Madeira. *Ecol Entomol* 31: 358–368.
- Williamson M (1996) *Biological Invasions*. Chapman and Hall, London, p. 244.

Table 5.1. Examples of alien species with current or potential environmental impact in Europe. **A** Species for which field studies have been published **B** Species for which only laboratory studies have been published **C** Species that may have an environmental impact now or in the near future and for which studies are needed. Details and references are found in the text.

	Impact observed	
	In the field	In the lab
A		
<i>Andricus</i> spp. (Hym.: Cynipidae)	No	
<i>Apis mellifera</i> L. subspecies <i>carnica</i> , <i>caucasica</i> and <i>ligustica</i> (Hym.: Apidae)	Yes	
<i>Bombus terrestris</i> (L.) subspecies <i>dalmatinus</i> and <i>sassaricus</i> (Hym.: Apidae)	Yes	
<i>Cales noacki</i> Howard (Hym.: Aphelinidae)	Yes	
<i>Cameraria ohridella</i> Deschka & Dimic (Lep.: Gracillariidae)	Yes	
<i>Lasius neglectus</i> Van Loon, Boomsma & Andrásfalvy (Hym.: Formicidae)	Yes	
<i>Linepithema humile</i> (Mayr) (Hym.: Formicidae)	Yes	
<i>Lysephlebus testaceipes</i> (Cresson) (Hym.: Braconidae)	Yes	
<i>Megastigmus rafni</i> Hoffmeyer (Hym.: Torymidae)	Yes	
<i>Megastigmus schimitscheki</i> Novitzky (Hym.: Torymidae)	Yes	
<i>Pieris rapae</i> (L.) (Lep.: Pieridae)	Unclear	
<i>Pheidole megacephala</i> (F.) Hym.: Formicidae)	No	
B		
<i>Aedes albopictus</i> (Skuse) (Dipt.: Culicidae)		Yes
<i>Cacyreus marshalli</i> Butler (Lep.: Lycaenidae)		Yes
<i>Harmonia axyridis</i> (Pallas) (Hym.: Coccinellidae)		Yes
<i>Technomyrmex albipes</i> Smith (Hym.: Formicidae)		Yes
C		
<i>Agrilus planipennis</i> Fairmaire (Col.: Buprestidae)		
<i>Anoplophora chinensis</i> (Forster) (Col.: Cerambycidae)		
<i>Dryocosmus kuryphilus</i> Yasumatsu (Hym.: Cynipidae)		
<i>Leptoglossus occidentalis</i> Heidemann (Hem.: Coreidae)		
<i>Metcalfa pruinosa</i> Say (Hem.: Flatidae)		
<i>Paysandisia archon</i> (Burmeister) (Lep.: Castniidae)		
<i>Rhynchophorus ferrugineus</i> (Olivier) (Col.: Curculionidae)		
<i>Varroa destructor</i> Anderson & Trueman (Acari: Parasitidae)		
<i>Vespa velutina nigrothorax</i> Lapeletier (Hym.: Vespidae)		