Food and Agriculture
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Pocket guide

to monitor important bark and wood-boring forest insects in Europe and Central Asia

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Introduction

Damage caused by bark and wood-boring insects has increased significantly in recent decades across Europe and Central Asia. Both native (e.g. *Ips typographus*) and non-native (e.g. *Agrilus planipennis*) species are the cause. Their presence and subsequent impacts are expanding due to many factors, including increased international trade, domestic movement, as well as climate change impacts such as storms and range expansion. Recent advancements in early detection and monitoring methods and tools can provide effective options for the management and protection of trees and forests impacted by bark and wood-boring insects.

This guide was prepared to fulfil one of the outcomes of the 2022 meeting of the Forest Invasive Species Network for Europe and Central Asia (REUFIS) on Monitoring of native and introduced saproxylic (bark and wood boring) insects for effective prevention and management, held at the University of Sopron, Hungary. It is designed for forest practitioners and researchers interested in protecting forest resources. It will help to improve capacity for the early detection and monitoring of insect pest populations that impact or could impact forest resources in the region. Knowledge gained from the monitoring information gathered will help support evidence-based decision- and policy-making for sustainable forest management.

The guide is divided into six chapters. Chapter 1 discusses general insect monitoring and introduces tools and procedures for early detection and monitoring of bark and wood-boring insects. Chapters 2–6 focus on different insect groups that are known to have impacts in the region, including jewel beetles (*Buprestidae*); longhorn beetles (*Cerambycidae*); bark and ambrosia beetles (*Scolytinae, Platypodinae*); wood wasps (*Siricidae, Xiphydriidae*), and other invasive insects and organisms such as nematodes, weevils and moths. Each chapter provides a general summary of the biology, distribution, and morphology of that group. Specific examples of insect species with high impact on forests in the region further reinforce current knowledge and recommended monitoring methods and practices.

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Chapter 1.

Monitoring of bark and wood-boring insects

The aim of insect monitoring

Obtaining reliable data about insect species occurrence, population, and life cycle requires direct or indirect monitoring methods. The former includes determining the number of individuals in various developmental stages (egg, larva, pupa, imago). The latter concentrates, for example, on measuring leaf mass consumed by the insect, assessing trees killed by beetles, or using sniffer dogs to detect an insect species in a tree. A recent development involves detecting insect species via DNA analysis of environmental samples (eDNA) without needing to locate individuals from the species. The range of monitoring possibilities is vast, but most depend on the kind of data sought. When investigating invasive species, the main goal usually involves detecting the first individuals in a given area before determining the direction and speed of further spread. Monitoring aims of native species involves tracking population development or insect damage. Monitoring goals can also focus on detecting protected and/or endangered species. In such cases, the methods employed are similar to those used for invasive species because both are low-density; however, the subsequent monitoring steps differ considerably.


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Figure 1.1 Typical forest site for bark beetle monitoring with traps

Bark and wood-boring insect monitoring tools

Except for a short dispersal period, bark and wood-boring (BWB) insects spend their lives inside trees. Assessing the presence/absence, population levels, and fluctuations of these insects requires specific monitoring methods for the short flying periods, the attack density, breeding success in a host tree, or damage caused (visual surveys or remote sensing).

Trapping flying insects entails placing insect traps in their flight paths (e.g. window trap). These methods are advantageous because they can trap a diverse array of insects within a given area; however, they usually capture only a few individuals daily, making them inefficient. Adding attractants to the traps increases efficiency. For example, adding light helps attract nocturnal insects. In this case, the colour temperature and wavelength of the light source can help determine which species the trap will catch. Today's LED technologies allow for accurate determinations of both characteristics, and their lower power source requirements allow for mobile light traps.

Most bark and wood-boring insects are more active during daylight hours, and can be lured to traps using various attractants, including food attractants, which emit odours mimicking suitable food sources for the insects. The specificity of these substances is usually low, and they attract a wide range of insects associated with the given host plant using either the whole tree (trap tree) or a selected part of it (trunk or branch) as the attractant. This method has been widely used for decades to monitor the flight activity of BWB insects.

Semiochemicals represent another group of potential chemical attractants that the insect or the host plant emits. Semiochemicals with effects within the same species (intraspecific) are called pheromones, and semiochemicals with interspecific (among species) effects are called allelochemicals. Using species-specific attractants like pheromones is more appropriate to monitor the presence or flight activity of a specific insect species. However, the lack of available pheromones can be a problem in many cases. A lack of pheromones occurs because 1) the selected


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Figure 1.2 Cross-window trap ***(Econex)***


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Figure 1.3 Funnel trap ***(Lindgren)***


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Figure 1.4 Window trap ***(Theysohn)***

insect species have no pheromones at all; 2) the substances have not been identified; 3) even if the substances are known, their production has not been successfully reproduced yet; 4) or the production process is too complicated, so the pheromone is difficult or costly to access. Nevertheless, the number of identified pheromones is increasing continuously, and a detailed list of available pheromones (with references) is available on The Pherobase website. Allelochemicals – including the various alcohols produced at the beginning of the wood degradation process – have varying attractant effects on many bark and wood-boring insects. Many allelochemicals are combinable. Specific colours and attractants can be used together to enhance the trapping efficiency of targeted insects.

There are many options for choosing the right type of trap. As a broad principle, general attractants are recommended for traps with large surfaces, while smaller traps may work for specific attractants.

In addition to selecting the appropriate attractant, the following characteristics require consideration for trap selection:

Design and shape: The window trap is a basic insect trap with a large surface area to catch flying insects. Various modified versions include 1) the cross-window trap with mutually perpendicular surfaces and 2) the slot trap with smaller or larger openings on the trap surface. The multiple funnel trap imitates the silhouette of a tree trunk. The most basic window trap is made of PET bottles and placed on the trunk of the host plant.

Trap colour: Transparent material is preferable for window traps. Any additional colours are determined either by a design imitating the silhouette of the host plant (black or brown) or by a colour that has an attractive effect on the target organism (yellow, green, or purple).

Sticky or non-sticky surface: Sticky surfaces offer the advantage of trapping insects within the trap; however, this advantage fades once the trap accumulates a high density of individuals covering the sticky surfaces. Sticky surfaces may also hinder species identification, and the further use of trapped insects, such as for collection or genetic identification, may become impossible. Saturation is not an issuewith non-sticky surface traps; however, the collection container design must prevent captured insects from escaping. Additional coatings can enhance trap surfaces and make them slippery, thus reducing the possibility of insects clinging to the trap instead of falling into the collection container.

Dry or wet trap: Most insect traps are operable in dry and wet modes. Dry traps offer the advantage of keeping insects alive for experiments and collection. A dry trap disadvantage is that it may also attract natural enemies of the targeted insects that could then consume or destroy the targeted insects within the trap. The problem is particularly significant when the number of captured target insects is low.

The following chapters discussing the various groups contain additional specifics for different groups of insects.

Effectiveness of bark and wood-boring insect trapping

The ratio of insects captured to the total population depends on several factors (attractant, trap, population size, and weather) and never reaches 100 percent, which is acceptable for monitoring, as the ratio is not a primary monitoring goal. Accurate information about the presence of each insect species, its swarming time and swarming intensity, the number of generations, and the development of the population is far more vital. Data series spanning several years indicate that accurate forecasts about the number of individuals are possible.


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Figure 1.5 Trapped bark beetles *(Ips typographus)*

Chapter 2.

Jewel beetles *(Buprestidae)*

Biology – general remarks

Jewel beetles (*Buprestidae*) form a family of over 15 000 species occurring predominantly in temperate and warm regions. Most of these species have a narrow spectrum of hosts, preferring only a single genus or closely related genera. Utilizing visual and chemical stimuli, adult buprestid females find living trees weakened by abiotic factors like water stress and/or other biotic factors like fungal infections or pest infestation. Females lay their eggs on the bark or within surface cracks of such weakened trees. Larvae eventually move to the phloem and feed over several instars until pupation and adult emergence. Larval development lasts up to two years, and emergence holes on twigs and branches have a very typical D-shaped form. Adult buprestids feed on the pollen, nectar, and even the foliage of host trees.

Not all buprestids are significant pests; only a few have caused extensive forest damage. However, the damaging species prefer warmer regions, entailing that climate change will increase the impact of these warm-region beetles in the coming decades. The spread of such damage is already observable.

Distribution

Buprestids occur in temperate and warm regions of the globe, as adults prefer sunny habitats. Under the scenario of global warming, the impact of warm-region jewel beetles is expected to increase, not only in the southern areas but even further north.

Morphology

The most identifiable feature of adult buprestid morphology is the metallic body colour that lends the species its common name – jewel beetle. Otherwise, buprestids vary in size, shape (from narrow and elongated to flat and round), and coloration (from black to brightly coloured). The flat bodies and the enlarged thoracic segments of buprestid larvae are usually easily distinguishable.


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Figure 2.1 Emerging jewel beetle *(Agrilus viridis)* in the bark

Monitoring

Unlike bark and ambrosia beetle monitoring, jewel beetle monitoring – including the research on their visual orientation and chemical communication – began only a few decades ago because most species are rare or only secondary in their native environment. However, jewel beetle species that expand or are introduced to environments beyond their native ranges can cause considerable damage. Buprestid flight and swarming characteristics differ considerably from those of other insect species; therefore, collecting them requires traps and attractants dissimilar from those already used for other insect groups. In general, the species relies on visual stimuli for orientation, so coloured traps with no attractants can be employed in monitoring. It is believed that beetles can recognize conspecifics by their shape and colour.

Traps, lures, setup and effectiveness

Traps must have specific colours. Several studies recommend light green and dark purple traps to attract jewel beetles. Vertical delta traps, funnel traps, and their specific combinations have successfully attracted jewel beetles. Green, purple, or yellow sticky traps are also widely used. Recent studies have identified several chemical compounds that may play a role in intra-specific communication, but traps lacking chemical attractants also work well. Most jewel beetles achieve maturation by feeding on host plant leaves. Thus, leaf alcohols or general green leaf volatiles may increase trap efficiency. Traps should be placed in tree crowns, but only in spots that allow researchers easy access. Jewel beetle monitoring is usually applied as interception trapping in areas with low beetle density , entailing that only a few beetles are caught despite the abundance of traps. Nevertheless, traps are useful tools for detecting the first invasive jewel beetle individuals.


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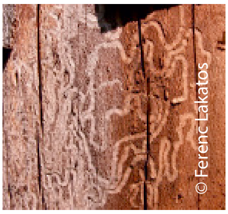
Figure 2.2.a Jewel beetle *(Agrilus viridis)* larva


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Figure 2.2.b Jewel beetle *(Agrilus viridis)* galleries under the bark


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Figure 2.2.c Jewel beetle *(Chalcophora mariana)* imago

Emerald ash borer (EAB) – *Agrilus planipennis*


© David Cappaert/Bugwood.org

Figure 2.3 Emerald ash borer *(Agrilus planipennis)* imago

Distribution: *A. planipennis* is native to East Asia (China, Japan, the Democratic People's Republic of Korea, the Republic of Korea and the Russian Far East), but its current distribution far exceeds its natural range and has reached as far as North America and Europe. Although the emerald ash borer is a capable flyer (flying more than 7 km/day), human-mediated transport of wood, wood products, and wooden packaging materials has facilitated its expansion beyond its natural range.

Biology: The common name of *A. planipennis* adults derives from its striking, bright, emerald-green elytra, while its larvae bear features characteristics of other buprestid larvae. Beetles feed predominantly on ash tree (*Fraxinus* spp.) phloem. Emerald ash borers are considered univoltine (one generation/year), though they may require two years to complete their development in unfavourable conditions (e.g. cool summer temperatures or even a vigorous host tree). The larval stage is about 300 days, during which *A. planipennis* passes through four instars. Depending on latitude and longitude, adults emerge late spring to mid-summer and lay eggs in bark cracks and crevices.

Impact: The impact of the emerald ash borer is considerable both in its natural range and in invaded areas. Although *A. planipennis* damage is most apparent on stressed ash trees, it can inflict mortality even on healthy trees, particularly trees that have not coevolved with emerald ash borers and lack adapted defensive mechanisms. Trees in North America and Europe lack such defensive mechanisms. Consequently, *A. planipennis* is ranked high on the list of phytosanitary risks, as it is highly probable that the emerald ash borer will become established in Europe and threaten common, native *Fraxinus* species.

Cypress jewel beetle (CJB) – *Lamprodila festiva*

Distribution: Native to the Mediterranean region of Europe, the cypress jewel beetle exemplifies how a native (rare and even protected in several countries) insect species can become invasive by expanding its distribution (maybe because of climate change) and changing its host preference (from *Juniperus* and *Cupressus* to cultivated *Thuja* spp.). Recent spread includes vast parts of Central and Eastern Europe (Austria, Hungary, Romania, etc.).


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Figure 2.4 Cypress jewel beetle *(Lamprodila festiva)* imago

Biology: Cypress jewel beetles are mid-sized (6–10 mm) and have metallic green heads, pronotums, elytra, and dark blue spots, mainly on the elytra. Lifecycles range from one to four years, depending on temperature and humidity. Cypress jewel beetles fly from May until July and lay their eggs in small groups on the bark of various Cupressaceae. Hatched larvae feed in the cambial layer before turning to the sapwood. Larval galleries – mostly flat and frass-filled – are characteristic of jewel beetles. Pupation occurs in the deeper parts of the softwood. Emergence holes tend to be D-shaped.

Impact: Due to its earlier restricted distribution and limited ecological impact, the cypress jewel beetle remains a protected species in several European countries; however, the recent area expansion and host shift have rendered it a significant pest of several *Thuja cultivars* (e.g. *Platycladus orientalis*, *T. occidentalis* 'Smaragd'). The species has caused considerable damage in its native distribution, where it attacks various *Juniperus*, *Cupressus*, and *Thuja* species. Human activity via live plant transport to urban areas aided its establishment in the invaded areas. The positive effects of climate change (e.g. higher average winter temperatures) have favoured the cypress jewel beetle, which is now more widely spread and causes considerable damage, primarily in populated areas.

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Chapter 3.

Longhorn beetles *(Cerambycidae)*

Biology – general remarks

Longhorn beetles (*Cerambycidae*) belong to large beetle families comprising 25 000 species occurring worldwide. Despite their large numbers, longhorn beetles exhibit a strict adaptation to either broadleaf or conifer trees and even a feeding preference for specific parts of the plants (roots, wood, trunk, branches). Substrate conditions (e.g. temperature and humidity) are crucial to initiating and establishing an infestation. Longhorn beetles use visual and tactile clues to locate a suitable tree and use their long antennae to orientate themselves by sensing the volatiles of weakened and dying trees. Once they find a suitable host, females usually lay eggs under the bark or in cracks using a long ovipositor. Some species can even make their own excavations in which to lay eggs. Larvae develop over one to several years under the bark (at least during their first larval stages) before pupating in pupation cells under the bark, but more frequently in the wood. Most adult longhorn beetles feed on flower nectar and pollen, but some feed on the bark of host trees.

Although some longhorn beetle species can damage healthy trees and timber, the majority do not. On the contrary – together with other saproxylic families – longhorn beetles can be indicators of woodland biodiversity and stability. Forest management practices like dead tree removal have driven some species into extinction. Consequently, a few cerambycid species are protected in some countries according to the Bern Convention and the Nature 2000 directive (e.g. *Cerambyx cerdo*).

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Figure 3.1 Longhorn beetle *(Monochamus galloprovincialis)* copulating adults

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Figure 3.2 Longhorn beetle *(Rhagium bifasciatum)* adult

Distribution

Despite their worldwide distribution, longhorn beetles occur predominantly in tropical and subtropical regions. They exhibit a decreasing tendency towards the poles, expressed as a south-to-north gradient in Europe, with fewer species occurring in the north.

Morphology

As the common name of the species indicates, long antennae – mostly on males – characterize cerambycids. In some cases, like *Acanthocinus* spp., the antennae exceed the body in length. Antennae length and ovipositors are the two traits that differentiate males from females (sexual dimorphism). Otherwise, adult longhorn beetle bodies are cylindrical and range from a few millimetres up to several centimetres in size. The insects vary in colour depending on their habitats – from black and dull brown to bright yellow, green, and red. *Cerambycid* larvae are white and soft. Those living in the phloem are relatively compressed and are easily confused with buprestid larvae (see Chapter 2).

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Figure 3.3 Flower visiting longhorn beetle *(Chlorophorus varius)*

Monitoring

Longhorn beetle monitoring comprises three main directions. The first entails adequate information on the presence of rare and protected species, which is essential (e.g. *Cerambyx cerdo*). The second stresses awareness of population dynamics of native species that may cause forest protection problems (e.g. *Monochamus* spp.). The third focuses on monitoring the potential appearance of introduced invasive species (e.g. *Anoplophora* spp.). Applying various methods may be appropriate to achieve specific goals. This chapter focuses primarily on monitoring native but occasionally damaging and introduced invasive longhorn beetles.

Longhorn beetles use visual and odour stimuli in their orientation and communication. Establishing an effective monitoring method involves considering the two stimuli. Trap shape and colour may be crucial, while additional attractants (either to mimic the host plant or the conspecifics) may increase capture efficiency. The low density of the target species requires consideration when setting up any invasive species monitoring system.

Figure 3.4 Longhorn beetle larval galleries

Figure 3.5 Longhorn beetle *Rhagium* inquisitor in the pupation chamber under the bark

Figure 3.6 Longhorn beetle larvae and frass

Trap trees/logs/piles

Whole trap trees, harvested logs, or log piles are widely used to monitor longhorn beetles. Large-sized traps like these are the only way to monitor species like cerambycid that take several years to develop in the wood before emergence. Choosing the correct tree species and suitable dimensions of trap trees/logs for the target beetle species is imperative when using such methods. Placing trap trees/logs in warm, sunny places is essential since longhorn beetles prefer such locations, especially when laying eggs. However, trap trees/logs do not work for all longhorn beetle species. Saproxylophagous species may also appear and, in some cases, suppress or cover the developing larval cerambycid galleries.

Trap types and setup

Traps with large surfaces are ideal for catching longhorn beetles. Cross window and multi-funnel traps are the most suitable for effectively capturing cerambycids. The collection container design should ensure that beetles easily access the trap but cannot escape it. Regularly inspected wet collection containers filled with the appropriate preservative liquid and placed in tree crowns where beetles fly are recommended to monitor invasive species.

Lures

Research into the chemical ecology of cerambycids has grown exponentially in recent decades, and many molecules that play significant roles in the intra- and interspecific communication of longhorn beetles have been identified. Nevertheless, little is known about the chemical ecology of other species. Several species can be baited effectively with general attractants like red wine or ethanol, and the method is widely used to monitor protected (Natura 2000) species like *Cerambyx cerdo*. Thankfully, the emitted and detected attractants that can be used to monitor economically important longhorn beetle species are, in many cases, already known.

Effectiveness

The aim of longhorn beetle monitoring – detecting target beetle species with low population densities – is the same for rare/protected and introduced/invasive species. Looking for traces of an insect's presence or using traps requires careful and persistent work. Some native cerambycid species can be trapped in significant numbers, but in most cases, the goal focuses on detected species that are present in small numbers only.

Asian long-horned beetle (ALB) – *Anoplophora glabripennis*

Distribution: The Asian long-horned beetle is native to East Asia (China, the Democratic People's Republic of Korea, the Republic of Korea and Japan) but has become invasive in North America (United States of America, Canada) and several countries in Europe (Austria, Belgium, France, Italy, and the United Kingdom of Great Britain and Northern Ireland), prompting many eradication campaigns to eliminate it from invaded areas. Some countries have succeeded (e.g. Belgium and the United Kingdom), but most have failed. The species entered Europe via wood packaging materials.

Biology: Adult beetles are 25–35 mm long and shiny black with white spots on the elytra and bodies. Females have relatively short antennae (approximately the length of the body), and males have much longer antennae (2.5 times as long as the body). Emerged beetles do fly, but usually not further than a few hundred metres, indicating that the inadvertent spread of the species has been human-assisted. Freshly emerged beetles engage in maturation, feeding on small branches high up in the canopy of host trees. They lay eggs in small pits that they have chewed through the bark of the host. The hatched larvae are typical round-headed, develop over two to three years, and grow to 50 mm when fully developed. In its native range, the species feeds mainly on poplars (*Populus*) but utilizes all broadleaved tree species as hosts in the invaded range.

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Figure 3.7 Asian long-horned beetle *(Anoplophora glabripennis)* adult

Impact: The species has been reported primarily in densely inhabited areas, but its wide range of potential host trees poses a high-risk threat to forests. Asian long-horned beetles cause considerable tree mortality in urban areas. Monitoring, surveying, and eradicating the species is labour and cost-intensive. Specific programmes – including professionals and the broader public – must be initiated if the species appears, but implementing such programmes takes several years, making eradication even more difficult.

Non-native Monocahmus spp. – e.g. *Monochamus alternatus, M. urussovi*

Distribution: The *Monochamus* genus contains over 150 species worldwide. Most are distributed in the northern hemisphere, and four – *M. galloprovincialis, M. saltuarius, M. sartor,* and *M. sutor* – are native to Europe. However, morphologically identifying the various species is challenging, and the overlapping distribution of European and Asian species makes separating the species even more difficult. In addition to the species native to Europe, many species in Asia can easily be introduced to distant countries through roundwood, sawn wood, and wood packaging materials. The Japanese pine sawyer (*M. alernatus*) is native to Japan and several countries in the Far East and feeds on various *Pinus* species, while *M. urussovi* distributes across continental Asia and Northern Europe and feeds on many conifer tree species.

Biology: *Monochamus* beetles are large (10–35 mm), have long antennae, and are dark (black, brown) coloured, sometimes with yellowish hairy spots on the elytra. *Monochamus* species are usually univoltine (one generation/year). Depending on the latitude and altitude, they fly from June to September. Freshly emerged beetles need maturation feeding before copulating. They lay their eggs on the bark of various coniferous tree species, mainly pine and spruce, and prefer freshly cut or fallen trees. Hatched larvae feed under the bark but eventually consume the outer part of the sapwood. Galleries are established in the deeper parts of the wood.

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Figure 3.8 Japanese pine sawyer *(Monochamus alternatus)* adult

Impact: Neither the native nor the introduced *Monochamus* species cause significant problems alone, but all species are potential vectors for the pine wood nematode (PWN) (see also Chapter 6), which can cause significant mortality in pine forests. The process of infection: Pine trees infected and killed by PWN are ideal breeding places for *Monochamus* species. In the last phases of beetle development (pupation and before emergence), the nematodes hide in the tracheal system of the imagoes. After emerging, the beetles engage in maturation feeding in crowns of still healthy pine trees, and it is during this feeding that nematodes exit the tracheal system and infect the tree. Beetles can traverse long distances hidden within timber bark and wood packaging material, allowing them to appear in the most distant and unexpected places.

Tiger longhorn beetle (TLB) – *Xylotrechus chinensis*

Distribution: The Tiger Longhorn Beetle is native to Far East Asia (China, Japan, the Korean peninsula, and Taiwan) but has been introduced to some European countries (Spain, Greece, and France), with further introductions expected. Mulberry (*Morus spp.*) has been the chief host plant, but *Malus*, *Pyrus*, and grapevine (*Vitis vinifera*) have been reported as host plants.

Biology: Tiger longhorn beetles are 15–25 mm and yellowish, with deep brown/black stripes and markings across the pronotum and elytra. The species is univoltine, and beetles emerge between May and August. It lays its eggs on the bark of the host plant, and larvae excavate tunnels to the phloem first. After some development, they also bore tunnels in the xylem, where they pupate.

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Figure 3.9 Tiger longhorn beetle *(Xylotrechus chinensis)* adult

Impact: Mulberry (*Morus*) trees are a vital tree species in several Mediterranean countries. Tiger longhorn beetle galleries in Mulberry phloem impede water and nutrient transport in the tree and weaken it, leading to the potential death of the tree.

Red-headed ash borer – *Neoclytus acuminatus*

Figure 3.10 Red-headed ash borer *(Neoclytus acuminatus)* adult

Distribution: The red-headed ash borer is native to America, most likely the central region of the Eastern United States. However, the original area cannot be determined precisely because the species increased its distribution via the development of road traffic and human-assisted migration through transporting infested wood. The species is now present in Cuba, Argentina, Canada, Puerto Rico, and Mexico. In Europe, the beetle was first observed along the Adriatic Sea (Rijeka, Zadar) in the middle and end of the 19th century and has appeared in other European countries since. Although ash is the species' main host plant, recent detailed investigations have revealed several more host plants in the invaded areas.

Biology: Red-headed ash borers are mid-sized (12–16 mm) beetles with brownish heads, pronotums, and elytra. The four yellow stripes on the elytra make species identification easy. The red-headed ash borer is usually univoltine, but development could last three to four years, depending on the food quality of the selected tree part. Beetles are active from April to July. Females lay the eggs in small cracks on the bark of recently dead branches and trunks up to 30 cm in diameter. Newly hatched larvae feed in the cambial zone between the phloem and xylem and later excavate deep tunnels into the xylem.

Impact: The red-headed ash borer dispersed rapidly across Europe due to its broad host plant spectrum and favourable conditions in invaded areas. The pathway during this expansion was the human-mediated transport of firewood and other wooden materials across long distances. Despite the rapid dispersal and broad host spectrum, the species has no considerable negative effect on its host plants in invaded areas because red-headed ash borers attack weakened trees, broken branches, and harvested wood rather than healthy trees. It also avoids wood with thicker dimensions (-30 cm).

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Chapter 4.

Bark and ambrosia beetles *(Scolytinae, Platypodinae)*

Biology – general remarks

Bark and ambrosia beetles (*Scolytinae* and *Platypodinae*) include at least 6 000 species worldwide. Despite their morphological similarities, they vary significantly in their ecology and behaviour. In a broader sense, *Scolytinae* also contains the so-called true bark beetles that feed on the phloem (phloeophagous species) and the so-called ambrosia beetles (*Scolytinae* and *Platypodinae*), which bore into the wood and feed on the symbiotic ambrosia fungi (Xylomycetophagous species). Despite the vast variability among the species in this group, life cycles are well separable into four general phases: reproduction, larval development, maturation feeding, and dispersal.

The reproduction phase starts with mature beetles selecting and arriving on their host tree. Even though most species (e.g. *Ips* spp., *Pityogenes* spp.) are aggregative – meaning that numerous adults land on the host tree simultaneously – some species find and attack a tree alone (e.g. *Dendroctonus* spp.). In polygamous species (e.g. *Ips* spp., *Pityogenes* spp.), males arrive first and bore the nuptial chamber under the bark where mating occurs. In monogamous species (e.g. *Dendroctonus* spp., *Tomicus* spp.), females arrive first, bore the entrance hole, and construct the galleries. After mating, females lay eggs on the sides along the breeding (mother) galleries, whereas males occasionally assist by removing the produced frass but never by boring the breeding galleries. Gallery patterns are characteristic of many species and can help with species identification.


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Figure 4.1 Bark beetle *(Ips sexdentatus)* in the bark


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Figure 4.2 Bark beetle *(Ips sexdentatus)* gallery

The development phase occurs solely in the host tree because larvae and pupae cannot survive outside the galleries. Phloeophagous species larvae bore their galleries in the phloem or the outer bark and eventually pupate in little individual chambers at the end of these larval galleries. Xylomycetophagous larvae do not bore larval galleries but stay in the mother gallery and feed on the mycelium of ambrosia fungi. A short maturation period follows the emergence of adults. During this time, adults sexually mature and can reproduce. For most species, maturation occurs at the same place where development occurs (inside the galleries), but some species (e.g. *Tomicus* spp., *Scolytus* spp.) undergo maturation feeding in the crown of healthy trees. Such species might even change trees several times during maturation feeding, further exacerbating their impact. Once they become mature, adult beetles search for a suitable host for reproduction (dispersal) and initiate their basic life cycle again. Choosing a suitable host is essential for bark beetle survival because it determines their chances to establish brood galleries and secure their progeny. Bark beetles prefer to colonize trees with weakened physiologies caused by biotic and/or abiotic factors instead of healthy trees.

Bark beetles locate potential host trees by tracking the semiochemicals (monoterpenes – kairomones) the weakened trees emit. The full spectrum of a tree's defensive mechanisms confronts the first attacking beetle individuals (so-called pioneer beetles). To overwhelm these defences, bark beetles feed on the bark and transform these semiochemicals into aggregation pheromones that attract many conspecifics to a particular host. Nevertheless, host colonization does not last infinitely due to the limited food and habitat resources. To avoid unnecessary intraspecific competition, bark beetles stop producing the aggregation pheromone and change it to an anti-aggregation pheromone that deters other conspecifics from attacking the same host and other potential hosts nearby.

In addition to the symbiotic association of ambrosia fungi with the xylomycetophagous (ambrosia) beetle species, some phloeophagous (true) bark beetles are commonly associated with various fungi, in particular blue-stain fungi of the *Ceratocystis* and *Ophiostoma* genera. While ambrosia fungi serve as a food source for ambrosia bark beetles, blue-stain fungi contribute actively to exhausting tree defence mechanisms. The simultaneous bark beetle and blue stain fungi attack increases the success rate for both partners within this mutualistic association.

Figure 4.3 Ambrosia beetle *(Gnathotrichus materiarius)* gallery

Distribution

Bark and ambrosia beetles occur on every continent, but tropical and subtropical regions are the centre of their geographical distribution. They exhibit their highest diversity in such regions, with many species still undescribed (e.g. more than 600 species occur on the island of Borneo, which is one-tenth the size of Europe). Climate and distribution of key host plants and sudden increases in food sources resulting in population outbreaks predominantly determine the regional distribution of bark and ambrosia beetles. As with many other flora and fauna species, globalization and increased international trade have facilitated the introduction of bark and ambrosia beetles in regions with similar climatic conditions beyond their native range. The impact of these exotic (alien) species is noteworthy because they are unrestricted by any other biotic and/or abiotic factor in their new areas, which favours their unimpeded population growth, resulting in host preference adjustments (alternative host plants) and biological adaptations (increasing the life cycles as a response to warmer climates).

Figure 4.4 Bark beetle ***(Scolytus ratzeburgi)***

Morphology

Bark and ambrosia beetle species are small – only a few millimetres long – and difficult to identify without a stereoscope, especially by non-expert entomologists. A common visible morphological trait among many bark and ambrosia beetles are the heads concealed under the dorsal part of the pronotum (a thorax modification in insects), which makes the heads invisible when viewed from above. Other general distinguishing features include species-specific structures (“teeth”) on the elytral declivity of the species belonging to Ipini and the row of crenulations on Hylesinini. Finally, male and female bark and ambrosia beetles may differ in morphology (sexual dimorphism), expressed in various traits (e.g. frons, elytral declivity).

Monitoring

Bark and ambrosia beetle monitoring is widely investigated and practiced. Numerous publications have explored and continue to examine the tools and methods applicable to the various species. Trap trees/logs were the first methods used to obtain, at least, approximate information about present beetle species and their population density. Selected trees were felled in the forest at the end of winter and left for beetles to colonize. Monitoring the colonization process (the number of entry holes appearing) was continuous. Though time and labour-intensive, this method serves many research purposes today, including assessing bark and wood-boring insect communities and their natural enemies. Timber harvested in the winter and stored in the forest for longer or shorter periods is also perfectly suitable. Nowadays, the main monitoring tools are various traps combined with attractants.

Ambrosia beetles differ significantly from bark beetles in biological terms (see above) and the attractants used for monitoring. While species-specific (or at least genus-specific) pheromones are usually used to trap bark beetles, generic lures (like ethanol) are used to trap ambrosia beetles.

Trap trees/logs for monitoring

The selected trees/logs must be harvested during the winter before the beetles begin swarming. Some species (e.g. *Trypodendron* spp.) start flying early (February), while others (e.g. *Platypus* spp.) start flying in summer (June). When using the trap tree/log method, it is advisable to cut a new tree approximately every other month to have an attractive trap tree throughout the vegetation period. Removing branches and twigs will slow the drying out of the tree, while leaving them on will accelerate the process. If the aim is to assess the insects in the branches/twigs as well, then the limbs should be removed and placed close to the trunk. Trap tree placement is also critical. Sun-exposed locations encourage quick drying, while shaded locations extend the attractiveness of the tree. In some cases, trap trees placed in the forest stand may induce beetle attacks on neighbouring trees; therefore, caution is warranted. Although trap trees/logs attract most bark and ambrosia beetles, some species have limited reactions due to specific stages of decaying wood. Obtaining a complete picture of the beetles in a given area entails performing the monitoring across the entire vegetation period (e.g. new trees cut every other month) with trap trees placed in separate locations. If needed, the attractivity of a trap tree can be increased with lures.


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Figure 4.5 Bark beetle sawdust


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Figure 4.6 Bark beetle *(Ips cembrae)* pupae

Traps

Bark beetle trap development goes back several decades. One developmental direction aimed at diverse designs (cylindrical, window, funnel). Another involved colour selection. The results of such research prompted the use of modified versions of window traps (cross window, parallel surface window with slots). Multi-funnel traps have also become widespread. Since most bark and ambrosia beetles react to attractants with less accurate flight directions (in contrast to e.g. moth species), traps with larger surface areas are more effective. Dry traps should be used when a regular control is provided and trapped beetles are designated for further research purposes. Wet traps are recommended if even a single trapped specimen of a species is of significance (e.g. monitoring the arrival of new invasive species) because predatory insects cannot destroy the captured specimens (see also Chapter 1).

Lures/pheromones

The number of known attractants/lures/pheromones and their availability for practical use is extremely diverse. Simple ethanol dispensers can achieve high ambrosia beetle trapping results, while species-specific pheromones may provide poor captures. Generic blends may be used to obtain an overview of beetle species present in the area or if the species-specific lure of the target species is unavailable/unknown. Species-specific pheromones will reduce the number of species in the trap, but will not exclude all non-target species because the pheromone blend may overlap with the target species. It is advisable to check the local possibilities before selecting lures for monitoring. Most countries have producers and/or dealers who distribute the various pheromones of bark and ambrosia beetle species characteristic of a specific country.

Most available pheromones are obtainable via online shops. Users must pay attention to the method, quantity, and duration of the pheromone release. The most suitable pheromone dispensers are those that provide temperature-dependent pheromone release and allow for the checking of the volume present within the trap (transparent). Under natural conditions, bark and ambrosia beetles usually emit substantial amounts of pheromone, so the artificial pheromone source must emit high quantities. A single dispenser usually does not provide effective lures for more than six weeks. After that, the dispenser must be replaced.

Ethanol-based general attractants draw ambrosia beetles efficiently. However, adding a host plant-origin compounds or species-specific pheromones can increase efficiency significantly.


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Figure 4.7 Bark beetle *(Pityogenes chalcographus)* galleries


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Figure 4.8 Bark beetles *(Pityogenes chalcographus)* in the galleries

The pheromone mixture bark beetles emit usually consists of several components, some of which play a role in long-distance attraction, while others play a role in selecting and landing on the host plant. Bark beetle pheromones are usually produced by a minimal transformation of various compounds taken from the host plants (e.g. alpha-pinene). The final product of the chemical transformation often depends on the effect (aggregating or rather anti-aggregating the conspecifics) the beetle wants to achieve. In terms of chemical structure, pheromones are mostly cyclic molecules (e.g. terpene) and, accordingly, are highly volatile compounds.

Figure 4.9 Bark beetle *(Ips acuminatus)*

Set up of a trap, or a trap system

Selecting an optimal location for the trap is crucial to successful monitoring. Sites with ongoing damage are recommended to obtain information about an already established species. The lures used in the traps in such conditions are aggregation pheromones, so the beetles only fly in the approximate direction of the source. Therefore, traps must be set up at a specified distance (10–15–20 m) from the nearest host tree. The traps can be prepared individually or in a series. Individual traps often attract more beetles than they can catch, so beetle attacks on the surrounding trees may occur. The traps can be placed on a wooden frame or mounted on wooden poles with the help of a tie wire. In this case, hanging the trap on a host tree branch should be avoided. The ideal height of the traps is 1.5–1.8 m above ground. Catching the first individual of a possibly introduced beetle species entails low-density conditions, so the trap should be prepared as close as possible to the potential source of invasion (e.g. airport, port, warehouse). A set of traps (e.g. along an airport road) may increase the chances of trapping beetles.

Monitoring the traps after they have been set up is crucial (weekly for dry traps, and every other week for wet traps).

Figure 4.10 Bark beetle *(Ips cembrae)* male and female in the gallery

Effectiveness

The two most vital aspects of bark and ambrosia beetle monitoring are 1) detecting the appearance of a new, invasive species and 2) monitoring the population dynamics of native species. Mass trapping is optimal for some species (e.g. *Ips* typographus), which can significantly reduce beetle populations and decrease beetle damage. However, one or even several traps will not capture all individuals. The effectiveness of pheromone traps varies between wide limits (50–250 m radius, 20–80 percent of the population) depending on the specific beetle species and location. On the other hand, we can obtain crucial data on the swarming dynamics of each species (beginning and length of swarming), the number of generations (1–2–3), the differences between certain monitored areas, and the population dynamics in each year.

Non-native ambrosia beetles (*Xylosandrus* spp., *Xyleborus* spp.)

Distribution: Timber transport is the primary vector that moves ambrosia beetles from one continent to another, making ambrosia beetles the most invasive species in the bark- and ambrosia beetle group (*Scolytinae*). Ambrosia beetles refer to the groups because the methods used to detect and monitor each species are remarkably similar. Most of the *Xylosandrus* and *Xyleborus* species have a tropical or subtropical distribution, and a significant part of the introduced species also comes from tropical or subtropical areas of Asia (*X. morigerus, X. crassiusculus, X. compactus*) or America (*X. affinis*). However, many species also originate from the temperate parts of Asia (*X. germanus, X. attenuatus*) and America (*Gnathotrichus materiarius, X. morigerus*). Although some species known today (e.g. *X. germanus*) have been present in Europe for several decades, most have only entered the continent in the past 20 years.

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Figure 4.11 Ambrosia beetle *(Xylosandrus germanus)* in the gallery

Biology: Most ambrosia beetles exhibit significant dimorphism. Males are often flightless and remain in the galleries where they developed. By contrast, females are avid flyers. Human activities profoundly influence the global distribution of the species. Ambrosia beetles are fungus-farming beetles, and both the adults and the larvae feed mainly on the fungal mycelia growing in the tunnels the beetles excavate in the wood. Most species have two generations. However, the overlapping generations and long egg-laying periods make it possible to find flying beetles from mid-April until the end of October.

Impact: Ambrosia beetles are significant for two reasons. Their galleries damage wood, and the pathogenic fungi they introduce to the wood cause tree mortality and dieback. In most cases, the fungi exceed the damage caused by boring. The microbiome of some ambrosia beetles may even change in the new, invaded environment and evolve new host-insect-pathogen interactions.

Various ethanol-containing lures can effectively attract Ambrosia beetles, and the lures can besupplemented with host plant-specific elements (e.g. alpha-pinene in the case of coniferous host trees). Several types of traps, like cross window and multi-funnel, are suitable. Insecticides and preservatives may help to kill and preserve collected specimens for later identification.

Four eyed fir bark beetle *(Polygraphus proximus)*

Distribution: The genus *Polygraphus* comprises almost a hundred species worldwide. Five are native to Europe, and nine are native to the Russian Federation. Morphological identification of the species is challenging because the beetles are small and difficult to distinguish from other species in a given area. The Far East (Eastern Siberia, Russian Far East, Eastern China, Republic of Korea, Japan) is the original distribution area of the four-eyed fir bark beetle. The species began to expand its distribution area westward within the borders of the Russian Federation via the railway transport of Siberian fir. The species is now present in the Tomsk region and some restricted areas in European Russia.

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Figure 4.12 Four-eyed fir bark beetle (*Polygraphus proximus)* adults and gallery

Biology: The four-eyed fir bark beetle is a small (2.5–3.5 mm), brownish beetle with distinct scales over its pronotum and elytra (typical for all palearctic *Polygraphus* species). Various fir species found in the Far East are the main hosts (*Abies nephrolepis, A. holophylla,* and *A. sachalinensis*), but other coniferous tree species may also be hosts (e.g. *Pinus, Picea*, and *Larix*). The species (beetles and larvae) feed on the inner bark of the host tree. Though they can attack and kill healthy trees, they usually feed on weakened trees or cut wood. *P. proximus* infestation causes the infection and reproduction of various ophiostomatoid fungi, leading to tree-weakening. It takes a tree two to four years to die after the initial beetle attack. *P. proximus* usually has two swarming periods annually (bivoltine), but developmental time depends on local climatic conditions.

Impact: Assessing the impact of *P. proximus* is challenging. Although its ecologic al impact is minimal in its native range, the attacks on healthy trees in the invaded Tomsk region have caused significant fir mortality. Since fir and the other reported possible hosts (spruce, pine, and larch) have large distribution areas across Eurasia, the establishment of the species and its associated fungi beyond the native range could cause considerable tree mortality.

Walnut twig beetle *(Pityophthorus juglandis)*

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Oregon Department of Agriculture

Figure 4.13 Walnut twig beetle *(Pityophthorus juglandis)* adult

Distribution: The species originates from the United States, and its native distribution is primarily in western states (Arizona, California, New Mexico, Oregon, Utah, and Washington). The species is considered invasive even within the United States, and recent records have been published by several eastern states (e.g. Maryland, Virginia, and North Carolina). The species was introduced to Europe via Italy (2013), where it may have established a population. France has also recently reported (2022) the presence of walnut twig beetles. No other European country has recorded the presence of the species yet, despite the intensive surveys conducted to detect the beetles. The species likely arrived in Europe through the transport of infested wood.

Biology: The walnut twig beetle is small (1.5–1.9 mm) and shiny. The genus *Pityophthorus* has 18 native and two introduced species (*P. juglandis* and *P. solus*) in Europe. Beetles construct their galleries in the bark of twigs, larger branches, and sometimes, the trunks of walnut (*Juglans*) and wingnut (*Pterocarya*) trees. Beetles prefer sun-exposed sites for boring. Overwintering beetles disperse in spring when the mean air temperature reaches 18 °C. The species has two to three partly overlapping generations per year. Swarming beetles can be observed from mid-April until late October. Italy has two swarming periods – the first in May and the second in July.

Impact: The walnut twig beetle is a vector of *Geosmithia morbida*, a highly pathogenic fungus to walnut trees that causes the so-called Thousand Cancers Disease (TCD). The first reported symptoms in trees appeared in the mid-1990s, but the first fungus report is from 2011. Initial symptoms include tree crown wilting and yellowing, followed by massive mortality after two or three years. Walnut twig beetles and TCD are grave threats to *Juglans* trees across Europe. Several countries have included both the beetle species and the pathogenic fungus on quarantine lists, making monitoring essential.

Walnut twig beetle pheromones are known and commercially available for detecting and monitoring flyingbeetles with traps and lures. Multi-funnel traps containing pheromone capsules are effective for monitoring. Walnut twig beetle flight activity is highest from June to September, making this period the best time for trapping.

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Chapter 5.

Wood wasps *(Siricidae)*

Biology – general remarks

Wood wasps (*Siricidae* and *Xiphydriidae*) are the only two existing hymenopteran families that include wood borers, as other sister families have become extinct. These two families include no more than 300 species occurring worldwide. Wood wasps colonize weakened or stressed hosts, fire-damaged trees, and freshly cut timber. *Xiphydriidae* prefer dead tree branches, and *Siricidae* attack tree trunks. Females of both families bear a distinct and long ovipositor. *Siricidae* have an additional spine-like structure at the tip of the abdomen that penetrates bark and inserts eggs into the wood. When inserting eggs, female wood wasps deposit fungal spores (e.g. *Amylostereum* spp.) that serve as food for the larvae after hatching. Larvae remain active for two or three years, feeding on fungus spores and boring a C-shaped tunnel into the wood. Before pupation, larvae bore closer to the inner bark, where they spin their silken cocoons. This movement toward the inner bark ensures that emerging adults will not have to make a long journey through the wood, thus minimizing the risk of damaging the delicate wings.

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Figure 5.1 Wood wasp *(Sirex noctiluco)* adult laying egg

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Figure 5.2 Wood wasp galleries with larva

Even though the damage caused by wood wasps is most of the time negligible, when breeding material is abundant, populations of these species can increase rapidly. This can have an impact on wood and timber, as wood-rotting fungi that grow in the tunnels cause rapid deterioration. However, even healthy can be affected, as the symbiotic fungus deposited with the eggs is sometimes accompanied by a mucoid substance that is toxic to the tree, aiding in tree decline.

Distribution

Wood wasps are rarely considered significant pests in their native range; however, they may become pests when introduced to new areas, become invasive, and inflict considerable damage on native hosts.

Morphology

Adult horntails and wood wasps are usually brown, blue, or black with yellow or red parts and are up to 4 cm long (not counting the ovipositor). Larvae are whitish, have six legs, and hardened mouthparts that allow them to bore tunnels into the wood.

Monitoring

Wood wasp monitoring tools and methods are not as advanced as those used for bark beetle monitoring because wood wasps are only secondary pests in their native range (continental Eurasia) and cause significant economic damage only in introduced areas (South Africa, South and North America, Australia, New Zealand). Using trap trees together with some herbicide treatment is the most obvious method for monitoring saproxylic insects.

Wood wasp monitoring efficiency varies in introduced areas. South African experiments reported high efficiency, but other investigations in North America and South America were far less efficient. In some cases, they were total failures.

Trap trees/logs/piles

Artificially weakened trap trees are usually effective for attracting the females of different wood wasp species. Although labour-intensive, applying herbicides or girdling tree trunks can initiate tree weakening. Some countries use these methods (e.g. Brazil), but they are recommended only when no other trapping method is possible.

Traps and lures

Interception traps with large surfaces – either multi-funnel or (cross)panel – are the most suitable for trapping wood wasps. Although some studies found a correlation between the height placement of individual traps and trapping efficiency, other studies could not corroborate such findings. Thus, there are no clear recommendations for trap placement.

The chemical communication of wood wasps has been extensively studied in recent years, and species-specific pheromones have been identified for some species. Nevertheless, general attractants such as ethanol or alpha-pinene provide better collections than synthetic pheromones. Significant differences in attractant effectiveness have been observed in various areas, though these can arise from differences in insect responses. Overall, general attractants (e.g. ethanol) or a combination of different lures and methods can provide good collections.

Sirex wood-wasp (SWW) – *Sirex noctilio*

Distribution: The Sirex wood-wasp is native to Europe, the temperate part of Asia, and northern Africa. It has been introduced to Australia, New Zealand, the United States, Canada, Argentina, Brazil, Chile, and South Africa. Coniferous forests rich in pine are characteristic habitats for the species. *S. noctilio* attacks pine species with varying intensity and success, making some species seem more susceptible than others.

Biology: Adults vary in size (9–35 mm) depending on sex and the food quality the larva has consumed. Females are larger and are easily distinguishable by their ovipositor, which they use to lay eggs deep into the bark. While depositing eggs, females simultaneously deposit spores of a symbiotic fungus (e.g. *Amylostereum areolatum*) for the larva to feed upon after hatching. The symbiotic fungi are often pathogenic to the host tree. Wood wasp larvae are yellowish white, with three pairs of underdeveloped legs and a dark tip at the end of their abdomens. Larval development duration depends on two significant factors – temperature and food quality. Larvae develop quicker in higher temperatures if food is available and abundant. Food quality depends on the fungal tissues within the wood. The time required for full development can vary from a few weeks (2–5) to several years (2–5).

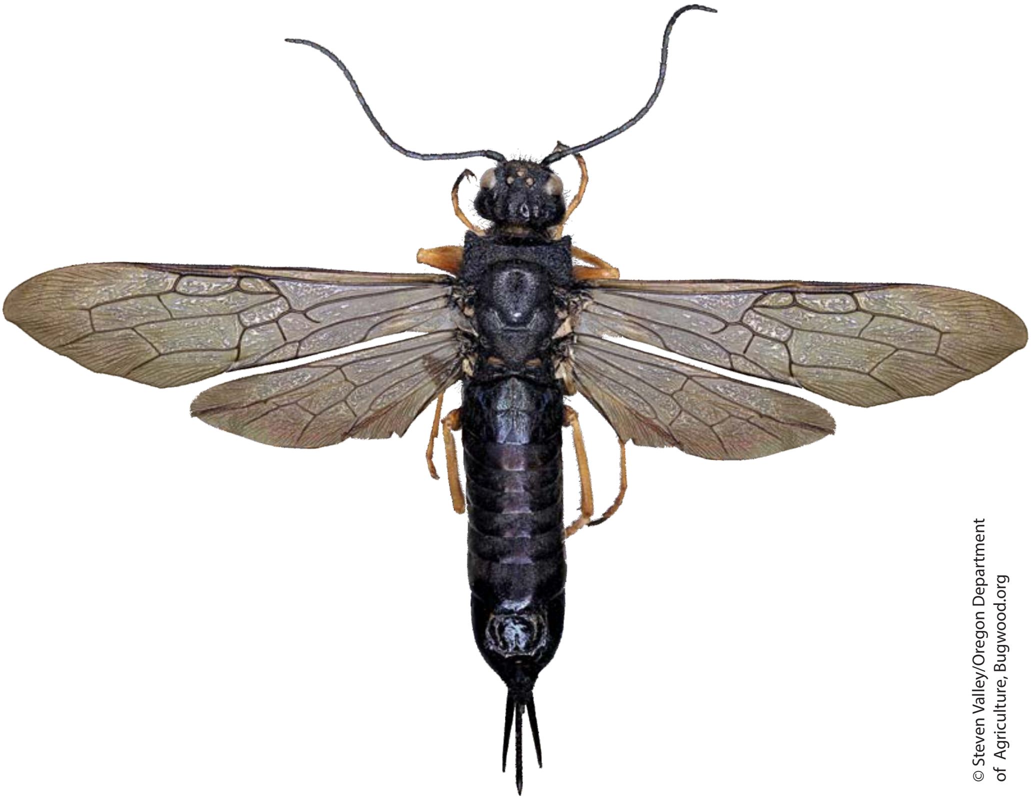

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Figure 5.3 Wood wasp *(Sirex noctiluco)* adult

Impact: Like many bark and wood-boring insects, the Sirex wood-wasp is not considered a pest in its native distribution area, even when it attacks a large variety of pine trees (e.g. *Pinus sylvestris*, *P. nigra*, *P. pinaster*). However, it is considered a significant pest to radiata pine (*P. radiata*), which is planted and cultivated in large plantations spanning several countries and often poses a threat to the survival of these trees. As with many bark and wood-boring insects, the wood wasp is the vector of a pathogenic fungus that contributes to tree mortality. The Sirex wood-wasp features on the quarantine lists of several countries. Regulations like the Food and Agriculture Organization of the United Nations (FAO) ISPM-15 reduce the possibility of introducing the species to new environments, but do not eliminate the risk.

Monitoring Sirex wood-wasps is challenging. Trap trees and various trap types and lures have been tested to monitor the presence of the species; however, most proved ineffective, especially at low densities when it is virtually impossible to trap the first flying individuals and, subsequently, prevent species establishment.

Chapter 6.

Impact of other invasive insects and organisms

Figure 6.1 Longhorn beetle larva in the gallery

The pine wood nematode (PWN) *Bursaphelenchus xylophilus* (Nematoda, Secernentea, Parasitaphelenchidae) is notorious for the damage it causes. *B. xylophilus* is the causal agent of pine wilt disease and was first detected as an invasive species in Europe (Portugal) in 1999. Its detection in Europe triggered broad and conclusive discussions regarding spread control measures, some of which set the standards for protocols and procedures for other invasive species in Europe. Pine wood nematodes spread quickly because wood-inhabiting longhorn beetles (*Monochamus* spp., Insecta, Coleoptera, Cerambycidae) can transfer them from tree to tree by the wood-inhabiting longhorn beetles. *B. xylophilus* also bore into and infest wood products and wood packaging material, exponentially increasing the risk of rapid, international spread, vividly underscoring the need for international-level collaboration. Despite the many stringent measures implemented, *B. xylophilus* was not contained and was soon detected in Spain. *B. xylophilus* infestations are strongly associated with high tree mortality, particularly in southern Europe, which is particularly alarming given the broad distribution of susceptible hosts (e.g. *Pinus* spp.) in these regions. Inhibiting *B. xylophilus* expansion is an expensive endeavour. The countries the species has invaded spend tens of millions of dollars annually to hinder the spread (e.g. Japan, Portugal, Spain).

The red palm weevil (RPW) *Rhynchophorus ferrugineus* (Insecta, Coleoptera, Curculionidae) is by far the most notorious palm tree stem and trunk borer, with an occurrence that has increased rapidly over the past few decades. First detected in Europe (Spain) in 1995, the species has since expanded to almost every other Mediterranean country, primarily through human-mediated transport of date palms from infested areas. In Europe, palm trees are predominantly grown for ornamental purposes in urban areas and resorts; thus, the ecological impact of the initial invasion and establishment of *R. ferrugineus* was considered limited. However, RPW also threatens palm locations in unique and fragile habitats such as those in the Canary Islands, Crete, and south-eastern Spain, where specific measures have been taken to avert infestation. In addition to the red palm weevil's negative ecological impact, the species also damages the economy by affecting 15 percent of the coconut-growing countries and 50 percent of palm-growing countries, resulting in significant production losses. The exact global economic impact is estimated only after the cost of control and containment measures have been factored in, which raises the economic damage total to many tens of millions of dollars annually.

Figure 6.2 Red palm weevil pupa *(Rhynchophorus ferrugineus)*

Figure 6.3 Red palm weevil *(Rhynchophorus ferrugineus)*

Ornamental plant trade has also facilitated the invasion of the box tree moth (BTM) *Cydalima perspectalis* (Insecta, Lepidoptera, Crambidae) from Asia to Europe. Soon after its first detection in Europe (Germany, 2007), BTM appeared in many other central and southern European countries, threatening *Buxus* species in more than 30 Eurasian countries. Box trees (particularly the susceptible *B. sempervirens*) widely serve as ornamental plants; nevertheless, the ecological impact of BTM is not negligible because consecutive infestations coupled with caterpillars feeding on the leaves can cause tree mortality. This ecological impact is magnified in some Mediterranean mountain ecosystems (e.g., central Greece, Catalonia), where the box tree is the main natural undercover species. The exact economic impact of *C. perspectalis* has not been precisely estimated, but the cost of measures to control its population and international trade losses (box trees have a high commercial trade value) have an undeniably severe financial impact.

Figure 6.4 Box tree moth *(Cydalima perspectalis)* larvae on the box tree

Figure 6.5 Damaged box trees

Invasive species origins are not always clear. For example, the horse chestnut leaf miner (HCLM) *Cameraria ohridella* (Insecta, Lepidoptera, Gracillariidae) first appeared in the 1980s in the Balkans and has since expanded over most of Europe, causing permanent outbreaks on horse chestnut trees. The ecological impact of HCLM concentrates in the Balkan peninsula, where

Aesculus hippocastanum is endemic and grows naturally in small stands or even individually. *C. ohridella* is a survival concern for this rare species. On the other hand, the economic impact of *C. ohridella* appears in Central and Northern Europe, where the horse chestnut is a commonly planted tree in towns and cities. The severe aesthetic damage caused by consecutive defoliations has convinced some municipalities to replace the species with other ornamental trees, albeit at a significant economic cost.

Figure 6.6 Damaged horse chestnut leaves by leaf miner *(Cameraria ohridella)*

Figure 6.7 Horse chestnut leaf miner *(Cameraria ohridella)* larva in the mine

The oak lace bug (OLB) *Corythuca arcuata* (Insecta, Heteroptera, Tingidae) is a recent invasive insect. The species was first detected in Italy in 2000 and has since spread to every central and southern European country. The potential harm OLB may cause is speculative due to the relatively recent detection of the species in Europe and its low impact in its native range. However, leaves dry out and fall much earlier than during normal leaf abscission whenever OLB reaches high densities. In that sense, photosynthesis is also strongly impaired, which negatively influences the physiology of host trees, rendering them more susceptible to other biotic and abiotic threats, especially when the damage repeats over the years. Additional studies are needed to accurately estimate the economic and ecological impact of this recently invaded and currently expanding species.

Figure 6.8 Oak lace bug *(Corythucha arcuata)* adult

Figure 6.9 Oak leaves damaged by oak lace bug *(Corythucha arcuata)*

Finally, the insect genus *Pissodes* spp. (Insecta, Coleoptera, Curculionidae) is a potential invasive threat. All species of this genus (except *P. validirostris*) feed on and develop in the cambium and phloem of conifer stems, infesting both healthy and weakened trees. Among them, *P. nemorensis, P. nitidus, P. strobi, P. terminalis*, and *P. yunnanensis* are the most likely to invade new areas from their native range (North America, Central America and Asia). The exact impact of *Pissodes* spp. can only be assumed presently. The data and information from their native ranges suggest that it is highly likely that these weevils will cause economic harm to plantations. The most severe harm will emanate from species that infest the terminal shoots rather than species that develop in tree trunks.


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Figure 6.10 Pine weevil (*Pissodes* spp.) pupal chambers in the bark

References

Allison, J. D. & Redak, R. A. 2017a. The impact of trap type and design features on survey and detection of bark and wood-boring beetles and their associates: A review and meta-analysis. *Annual Review of Entomology*, 62: 127-146. https://doi.org/10.1146/annurev-ento-010715-023516

Allison, J. D. & Redak, R. A. 2017b. Monitoring and management of the invasive bark and wood-boring beetle, *Agrilus planipennis*. *Journal of Integrated Pest Management*, 8(1), 12. https://doi.org/10.1093/jipm/pmw009

Brockerhoff, E. G. & Liebhold, A. M. 2017. Ecology of forest insect invasions. *Biological Invasions*, 19(11): 3141-3159. https://doi.org/10.1007/s10530-017-1514-1

Byers, J.A. 2009. Chemical ecology of bark beetles in a complex olfactory landscape. In: Lieutier F. *et al.* eds.: *Bark and Wood-boring Insects in Living Trees in Europe, a Synthesis*, pp. 89-134. https://doi.org/10.1007/978-1-4020-2241-8_8

Ciesla, W. M. 2011. *Forest Entomology: A Global Perspective.* Oxford: Wiley-Blackwell. https://doi.org/10.1007/s10841-011-9452-1

FAO. 2011. *Guide to Implementation of Phytosanitary Standards in Forestry*. Food and Agriculture Organization of the United Nations. ISBN: 978-92-5-106785-7

Francese, J.A., Fraser, I. & Lance, D.R. 2009. Efficacy of multi-funnel traps for capturing wood-boring beetles (Coleoptera) with varying behavioral and ecological characteristics. *Journal of Economic Entomology*, 104(3): 901-908. https://doi.org/10.1603/EC11038

Herms, D. A. & McCullough, D. G. 2014. Emerald ash borer invasion of North America: history, biology, ecology, impacts, and management. *Annual Review of Entomology*, 59(1): 13-30. https://doi.org/10.1146/annurev-ento-011613-162051

Liebhold, A.M. & Tobin, P.C. 2008. Population ecology of insect invasions and their management. *Annual Review of Entomology*, 53: 387-408. https://doi.org/10.1146/annurev.ento.52.110405.091401

Liebhold, A. M., Brockerhoff, E. G., Garrett, L. J., Parke, J. L. & Britton, K. O. 2012. Live plant imports: The major pathway for forest insect and pathogen invasions of the US. *Frontiers in Ecology and the Environment*, 10(3): 135-143. https://doi.org/10.1890/110198

Muirhead-Thomson, R.C. 1991. *Trap Responses of Flying Insects: The Influence of Trap Design on Capture Efficiency*. Academic Press. https://doi.org/10.1016/C2009-0-02686-5

Rassati, D., Faccoli, M., Petrucco Toffolo, E., Battisti, A. & Marini, L. 2015. Improving the early detection of alien wood-boring beetles in ports and surrounding forests. *Journal of Applied Ecology*, 52(1): 50-58. https://doi.org/10.1111/1365-2664.12347

Schlyter, F. & Birgersson, G. 1999. Forest beetles. In: Hardie J. & Minks A. eds: *Pheromones of Non-Lepidopteran Insects Associated with Agricultural Plants*. pp: 113-148. CABI Publishing

Wermelinger, B. 2004. Ecology and management of the spruce bark beetle *Ips typographus* - A review of recent research. *Forest Ecology and Management*, 202(1-3): 67-82. https://doi.org/10.1016/j.foreco.2004.07.018

Wingfield, M. J., Brockerhoff, E. G., Wingfield, B. D. & Slippers, B. 2015. Planted forest health: the need for a global strategy. *Science*, 349(6250): 832-836. https://doi.org/10.1126/science.aac6674

Notes

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