

Magali Toriti · Aline Durand · Fabien Fohrer

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Atlas of Identification – Western Europe



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# Foreword

## A Professional Passion Turned into a Much-Needed Book

I was a student in wood science when I stumbled on wood-boring insects. I loved thinking, talking and studying about wood-boring insects. I even thought of a possible career in entomology. But the prospect of drilling deeper into a single academic field felt confining. So, I ended up building my academic career around the anatomy and ecology of plant stems. I do teach about these topics too. It was while teaching at an International Course on Wood Anatomy and Tree-Ring Ecology held in Switzerland that I met Magali Toriti. At that time she was a PhD student in archaeology supervised by Aline Durand. Both Magali and Aline were curious about some small circular holes in charcoal samples. But both didn't know if it was worth exploring further into them. Thus we compared the holes in the charcoal with the material available in the teaching slide collection. And we found similarities to traces from wood-boring insects. To further meet Magali scientific curiosity the expertise in entomology of Fabien Fohrer came into play. Some years later Fabien also attended the same course on Wood Anatomy. Once I got acquainted with both Magali and Fabien, I felt so fortunate to share their motivation in understanding wood-boring insects with my old passion for the topic. Together we spent much time collecting insects, looking at wood samples, cutting thin anatomical sections and learning from the microscope.

The result of these efforts is summarised in the *Traces of Common Xylophagous Insects in Wood. Atlas of Identification—Western Europe* which gathers the knowledge they collected over the past eight years of collaboration. The book, after presenting some distinctive biological features of various types of wood pests and introducing wood structure, details the life cycle of a wood-boring beetle and provides a guide to using the identification keys. Two identification keys are introduced. The first focuses on the galleries and faecal pellets of wood-boring insects and is useful for applications when the damaged piece of wood is still visible, such as a museum object. The second key describes the sole faecal pellets of wood-boring insects. It helps when the wood is completely decayed or not readily available, such as in archaeological wood. Later (chapter 3), the bulk of the book describes the most common xylophagous insects. They are described by family within the Coleoptera, Curculionidae, Lyctidae, Ptinidae, and Hymenoptera and Isoptera.

This book represents what I was desperately looking for at the beginning of my career: a guide for the beginner into the world of wood-boring insects. But the book is also a valid tool for the expert of the field looking for a comprehensive description of the problem of wood pests.

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# Introduction

Wood-boring insects are natural pests of trees, stored wood or timber. In forests, they participate in the partial or total degradation of dead wood. Depending on the species, they can be major pests of forests, of a given woody species population, or even destroy museums and wooden heritage collections. As for wood, it is a key element of the economy and the environment, both past and present.

In Western Europe, fundamental works on wood anatomy and keys for determining the comparative anatomy of insects only emerged in the last 80 years. They described the great variability of the discriminating characteristics of wood (Huber and Rouschal 1954; Greguss 1955; Brazier and Franklin 1961; Jacquot et al. 1973; Couvert 1977; Schweingruber 1990; Vernet et al. 2001; Ruffinatto and Crivellaro 2019) and in insects and other arthropods (Lepesme 1944; Bremond and Lessertisseur 1973; Hoffmann 1986; the XIXth c. Die Kafer Europas collection, or the fauna collections “Faune de France”, “Fauna Iberica”, “Fauna Italiana”, *per* country (e.g. Berger 2012)).

The starting point of this book was the analysis of charred wood from an alpine archaeological Gallo-Roman site. The rural settlement, well preserved according to archaeological criteria, was burnt down in the third century AD. As a result, various wooden construction elements were preserved and with them numerous traces of wood-boring insects (galleries and frass). In the absence of elements from the adult insect(s), it was not possible to identify the agent(s) of such an infestation, which could affect *pro parte* more than a third of the structure. Within the community of bioarchaeologists, many have noticed these traces, noted as “holes” on both charred and waterlogged wood, but few have attempted to identify the insect(s) that bored them. Most of the time, the more or less hazardous conservation of archaeological woody heritage makes the task even more difficult. For example, the ship *The Mary Rose*, discovered in the 1960s, was infested by *Nacerdes melanura* from the 1990s, when she was stored in a wet warehouse (Pitman et al. 1993). It was only by comparing these archaeological traces with those of current insects, whose exact species are known, that identification was made possible.

For a decade now, various tests have been carried out to identify the traces left by larvae on/in the wood. These tests concern only a few large families of woodborers. Sometimes it is necessary to evaluate and quantify the damage caused by an insect to a structure before insecticide treatment, in particular by observing the number of flight holes and trying to identify them due to the absence of an adult individual. Within the museum environment, one of the rare cures used until the 1950s consisted of regular checks of the collections in order to limit damage. Subsequently, notably with the commercialisation of organo-chlorinated insecticides among others, and especially the awareness of their toxicity for humans, interest in and knowledge of wood-boring insects and lignivorous fungi increased, with the aim of better preserving the woody heritage while eliminating pest threat. Thus, beyond museums, these methods are opening up and adapting to different media (ancient carpentry *in situ*, organ pieces in a church, current furniture and architecture, underwater wrecks ...). A few rare works (Gambetta 2010; Blanchette 1991; CTBA 1996; Bobadilla et al. 2015) or mentions (Lepesme 1944; Español 1992) underline the importance or specificity of the traces left by the larvae of wood-boring insects in the wood, i.e., galleries and larval dejections.

This book is based on the knowledge acquired by crossing over two disciplines, i.e., archaeology and heritage conservation-restoration. This crossover led to the creation of an original identification key, applicable to these two scientific fields. In addition to these two sectors, the key is also applicable to other fields: forest protection, wood industry and engineering, building and public works, or in the judicial field, for example in a dispute due to an infestation after or before property purchase. In the field of heritage conservation, insects damage works and buildings, making them a source of concern. In view of the diversity of species of wood-boring insects, their identification makes it possible to choose the best way to protect the object, structure, building, etc. Similarly, in forests, it is essential to know the causal agent of the decline of a woody population in order to better control it and face up with the situation.

There are currently more than 600 species of xylophagous insects in Western Europe. Each of these species preferentially colonises one or more woody species, whatever the context. Each of them usually has specific requirements, as insects do not attack any wood under any conditions: softwood or hardwood, coniferous or deciduous wood or both, standing wood,

dead wood, decaying wood or storage wood, in the presence of fungi or not, etc. Each one should therefore be studied on a case-by-case basis. To sum up, infestation can occur at the following times, ranked from the most ancient to the most recent one: when the wood is standing in full vigour, when it is diseased or freshly felled/dead, during a possible storage phase, when it is used as timber or as an object, when it is in advanced decomposition. In archaeology, infestation can be recorded after burying the remains and before archaeological investigations between two excavation campaigns or during excavation (if it rains a lot, for example, or if conditioning is bad), or even after the wooden remains have been conditioned. Then comes the heritage area with infestations during exhibitions or during the storage of works in collections.

This book is thus devoted to insects with a xylophagous diet, particularly in their larval state, more rarely in the adult state, as well as to some insects that perforate wood in order to nest (carpenter bees, ants, termites). Woodborers are insects whose larvae develop in woody plants and mainly belong to four main orders: beetles (capricorns, Ptinidae, bark beetles, weevils ...), isopteran (termites), hymenopteran (*sirex*) and certain diptera such as the wood-cake beetle for example. In fact, all the insects that degrade wood and thus affect its mechanical properties are concerned. However, this excludes live-wood pests such as biting-sucking insects, phytophagous insects and most saproxylophagous insects such as chafers, which are more often found in litter or compost. A few other xylophagous insects belonging to beetles (such as certain buprestes, platypus) but also belonging to Lepidoptera (*Cossus cossus*, *Zeuzerina pyrina*, some Sessidae ...) could not be studied. Consequently, they are not mentioned in this work and will be the subject of a later addition. Finally, marine woodborers, which are not insects but molluscs such as *Teredo navalis*, whose biology and ravages could be the subject of specialised and independent work, were also excluded.

The present work is primarily a practical tool to assist in the work of determining the indirect traces left by insect pests, i.e., galleries and frass. For this reason, it is largely based on the presentation of various anatomical sections of infested wood combined with the description of the indirect traces left by wood-boring insect larvae on their feeding material. Since its aim is to help preserve forests, buildings or objects, whether heritage ones or not, it is a means of gaining a better understanding and assessing the condition of a wood, structure, tree, forest, etc., and even of being able to reconstruct the environment and/or the context that led to this condition. This way, it helps in writing the history of the construction and deconstruction of buildings.

Because they are perfectly integrated into the forest ecosystem or the timber, it is essential to know the main biological characteristics of these insects (their diet, reproduction cycle, mode of action) in order to better prevent their multiplication and control them.

In addition, it is necessary to be aware of the anatomical diversity of wood species and insects and, above all, of the adaptability of living organisms to different habitats and environmental or climatic conditions, which offers thousands of possible combinations that cannot all be described here.

The identification key is accompanied by an atlas illustrating some of the various families, genera and species of wood-boring insects. This book does not claim to be exhaustive, but is intended to be a workbook for the reader, who should take the potential of such a subject, its variability and therefore its complexity into consideration.

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# Chapter 1

## Presentation and Work Guide

### 1.1 Starting Point

The starting point of this work is a study of archaeological carbonised wood. The entomological remains had not been preserved by the burial of the remains, whereas the wood had, thus limiting interpretations. Wood, although rare in archaeology, is only preserved in certain forms and in certain specific cases: charcoal (following fires), silicified wood (in the desert), waterlogged wood (in humid, sub-aquatic contexts ...). But insect galleries and frass can also be preserved (Fig. 1.1). It was during these studies that observations of insect traces on existing woods began. This led to the finding that these traces were family- or even species-specific, and that the condition of the wood varied very little in terms of macroscopic and microscopic measurements and characteristics. This fact was confirmed by carbonisation experiments on infested wood under different hygrometric and thermal conditions (Fig. 1.2). The characterisation effort initially focused on the insects most frequently encountered in dry and worked wood such as *Anobium punctatum* and *Hylotrupes bajulus*. Then, in a second step, pests of standing and dead forest wood were observed. Finally, the bioecology was found species-specific.

The observations of insect traces recorded in the atlas come from infested wood collected during harvesting missions in the forest or resulting from laboratory rearing. Given the high number of European wood-boring insects, choices had to be made. Obviously enough, the species most frequently encountered during our investigations were selected. But this tool is flexible: the possibility of adding new species remains open as this is a long-term task that has only just begun.

The construction of this atlas lies at the interface of animal and plant biology. The traces of woodworm larvae on wood, and more broadly the pathologies of wooden structures, are an increasingly important concern for the building sector, but also for heritage conservation and archaeology. It is therefore essential to explain the codes used in the present work.

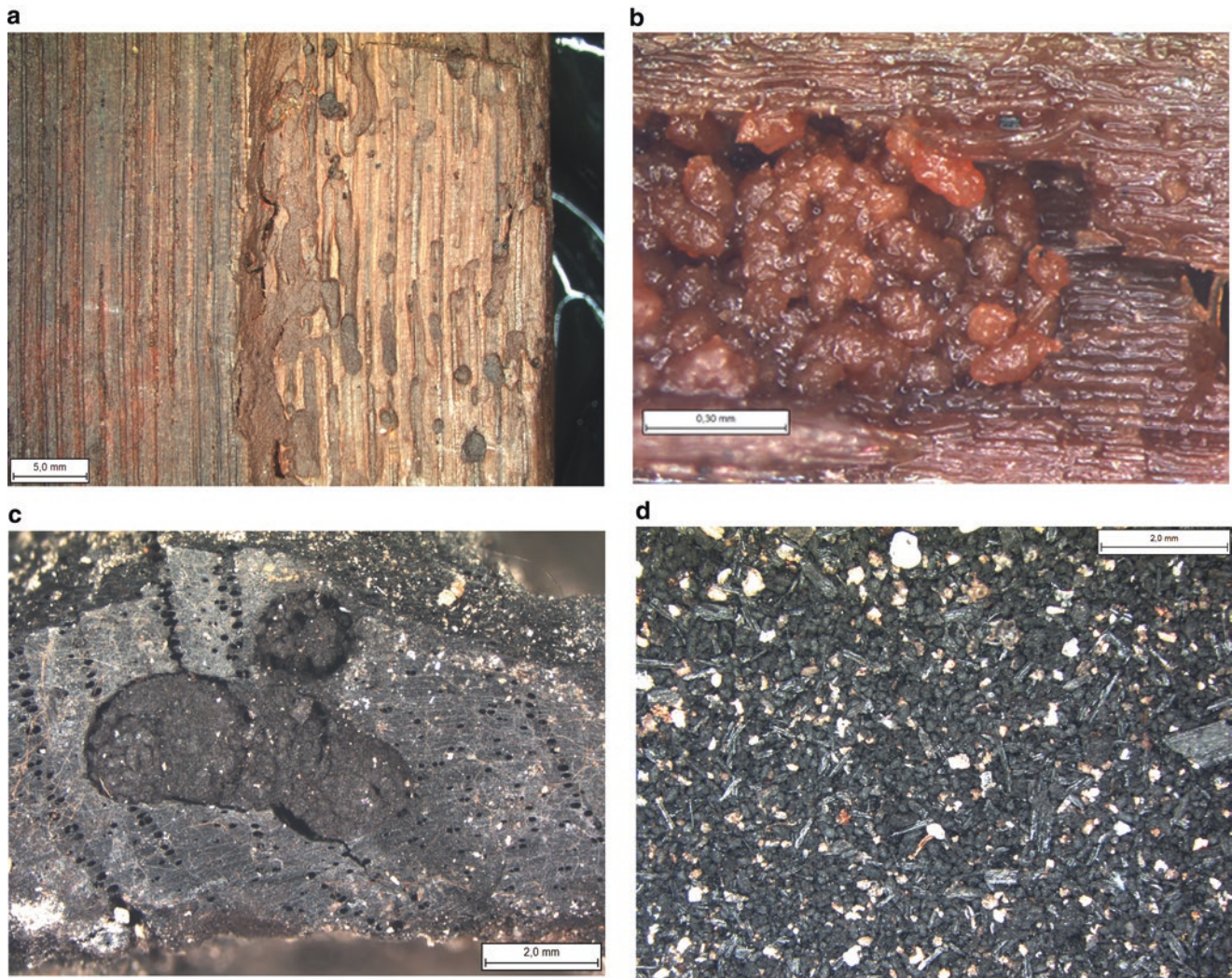
Thus, the description of xylophagous insects is based on the current international entomological nomenclature, i.e., the nomenclature used for the construction of taxonomic keys. Updates in the names of certain families, genera or species, such as Anobiidae now called Ptinidae, have been taken into account. Species are designated using Latin terms in order to avoid confusion. A same common name is indeed sometimes given to several species, even though they are different, e.g., for Ptinidae, whose subfamily Anobiinae includes 108 species. Or again, it is a question of avoiding confusions in the taxa of the former identification key that has been revised since: for example, the “Bostryche typographer”, from the Latin *Ips typographus*, actually belongs to the family Scolytinae and not to the family Bostrichidae. Likewise, references to woody species and the anatomical elements of plants are based on the vocabulary generally used in biology, xylology and bioarchaeology.

### 1.2 A Few Biological Elements

#### 1.2.1 Various Types of Pests

Four main types of wood pests are considered in this book:

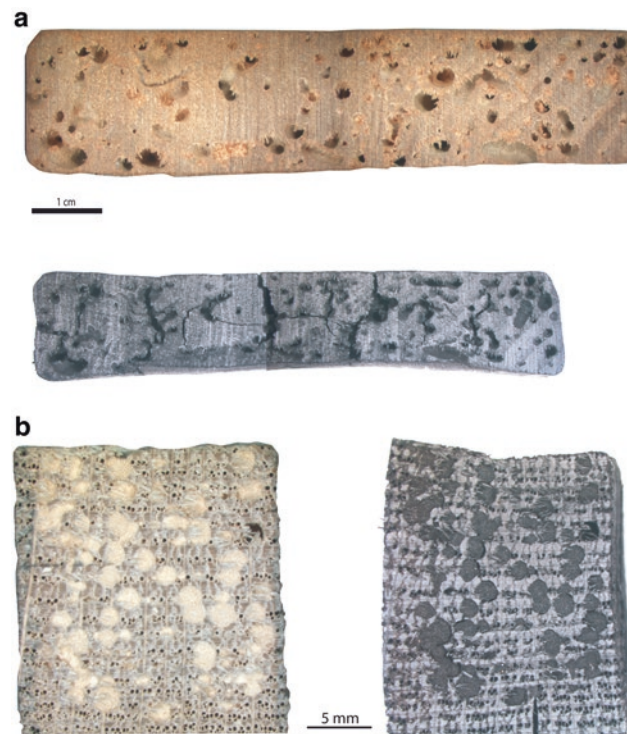
- Corticophagous pests live on or under the more or less dehiscent bark of healthy, diseased or dead (standing or felled) trees and shrubs. The rather cambiofagous larvae (see below) colonise stumps and recently cut roots. Only the adult is considered to be corticophagous, notably because it feeds on the bark of young stems and branches, most often from outside the tree, causing small wounds to the subject (e.g., *Hyllobius* spp., some tenebrionids, psocids ...). Entire planta-



**Fig. 1.1** **a** Archaeological waterlogged wood with *Anobium* infestation, galleries. **b** Archaeological waterlogged wood with *Anobium* infestation, faecal pellets. **c** Galleries on medieval wood charcoal. **d** Frass composed by faecal pellet carbonised, preserved on ancient wood charcoal

tions can be decimated in case of an outbreak. This type of pest is to be differentiated from biting-sucking insects (aphids, scale insects: Homoptera) which are not dealt with in this book (Table 1.1).

- Cambiophagous pests are specifically sub-cortical insects whose larvae feed exclusively on the cambium of the tree, destroying the wood-generating base of the trunk and branches. These insects are among the most formidable parasites of forest trees. They usually attack weakened trees, but their development can sometimes become epidemic (e.g., *Ips* spp., *Scolytus* spp., *Tomicus* spp., (Scolytinae); *Pissodes* (Curculioninae); *Agrilus* spp., *Melanophila cyanea* (Buprestidae); *Dioryctria sylvestrella* (Lepidoptera, Pyralidae)).
- Xylemophagous pests represent the largest group of woodborers; these insects feed on the whole wood, from the bark to the sapwood, passing through the cambium, and sometimes penetrating the heartwood. They infest dry wood and fresh or dead wood (e.g., *Saperda* spp. (Cerambycidae); *Cryptorhynchus* (Curculioninae); some Bostrichidae, Buprestidae, Lyctidae, Ptinidae, some Scolytinae; *Xyleborus*, *Platypus*; *Sirex* spp. (Hymenoptera, Siricidae); termites (Isoptera); *Zeuzera* spp., *Cossus cossus* (Lepidoptera, Cossidae)).
- Saproxylophagous pests are insects and other organisms that infest wood whose decomposition stage is advanced (worm-eaten, spongy, powdery wood) generally by the above-mentioned xylemophagous insects, mostly in association with lignivorous fungi. This is an important part of biodiversity (e.g., Cetoniidae, some Curculionidae, Melolonthinae ...).



**Fig. 1.2** **a** Experimentation before and after carbonisation (*Oligomerus* infestation). **b** Experimentation before and after carbonisation (*Lyctus* infestation)

**Table 1.1** Frequency rating of the type of pest according to the condition of the wood. x: infrequent; xxx: very frequent

	Diseased tree	Felled/logged wood	Dry wood/timber	Damp wood/dead wood	Decayed wood
Corticophagous	xx				
Cambiophagous	xx	xx	x		
Xylèmophagous	x	xx	xxx	xx	x
Saproxylophagous				xx	xxx

The biology of some families, genera or even species is still poorly understood. On the one hand, a large part of the existing bibliography mainly corresponds to systematics, i.e., the description of the different anatomical parts of adult insects and larvae: elytra, genitalia, mandibles, antennae, bristles ... On the other hand, some species, although found in large numbers in a given place, region or forest, remain rare for a given territory as a whole, and their habits are difficult to observe. In certain rare but possible cases, problems arising from the systematic approach, sometimes since the beginning of the history of the disciplinary field, have led to confusion between several species and their biology. Methods for observing and identifying insects have made great progress over the last 40 years, particularly through the use of new technologies such as molecular biology and insect DNA sequencing. However, there is still a tangible knowledge gap about the habits and bio-ecology of woodborers. Certain re-observations made in the 1940s–1950s, themselves based on old observations sometimes dating back to the nineteenth century (1870s) have to be taken into consideration, as well as certain confusions or “inaccuracies” in the anatomical descriptions of the individuals or their bio-ecology. Little by little, current tools and research are tending to update these states of knowledge. Finally, the sometimes very important adaptability of a species to its environment must be taken into account. This makes it difficult to give an exhaustive description of all its habits and preferences.

### 1.2.2 Wood Composition: What a Mixture!

Xylophagous insects do not attack any wood under any conditions. In general, three conditions favour colonisation: temperature, wood humidity and wood nutritional value. Thus, depending on their nutritional needs, wood-boring insects and more particularly beetles infest living wood, or dead and more or less dry wood, or wood colonised by fungi ... Just like insects,

each wood species has its own chemical composition (mineral elements and organic substances) with concentrations sometimes varying among individuals depending on the environment (shaded slopes, thermophilic species, calcareous soils, tropical woods ...). Each insect adapts, chooses and digests some of these elements according to its digestive juices (diastases, enzymes) and its nutritional needs (cellulose, starch ...). The digestive system of insects feeding on fresh wood is more complex than that of insects feeding on dry wood.

Below are the main feeding characteristics selected by insects, common to all woods but in different concentrations depending on the wood:

- 50% cellulose, a major, hydrophilic, polysaccharide-type (sugar) constituent of cell walls
- 25% hemicellulose, more complex polysaccharides
- 25% lignin, a hydrophobic constituent of the secondary wall of wood cells (phenylpropane, alcohols).

These three macromolecular substances include attractive or repellent extractables depending on the wood-eating insects:

- mineral salts
- starch
- reducing/soluble sugars (e.g., glucose, fructose, sucrose)
- proteins (amino acids, peptides) (1–2% in dead wood)
- tannins
- oleoresins
- oils and fats
- organic acids
- organic nitrogen compounds.

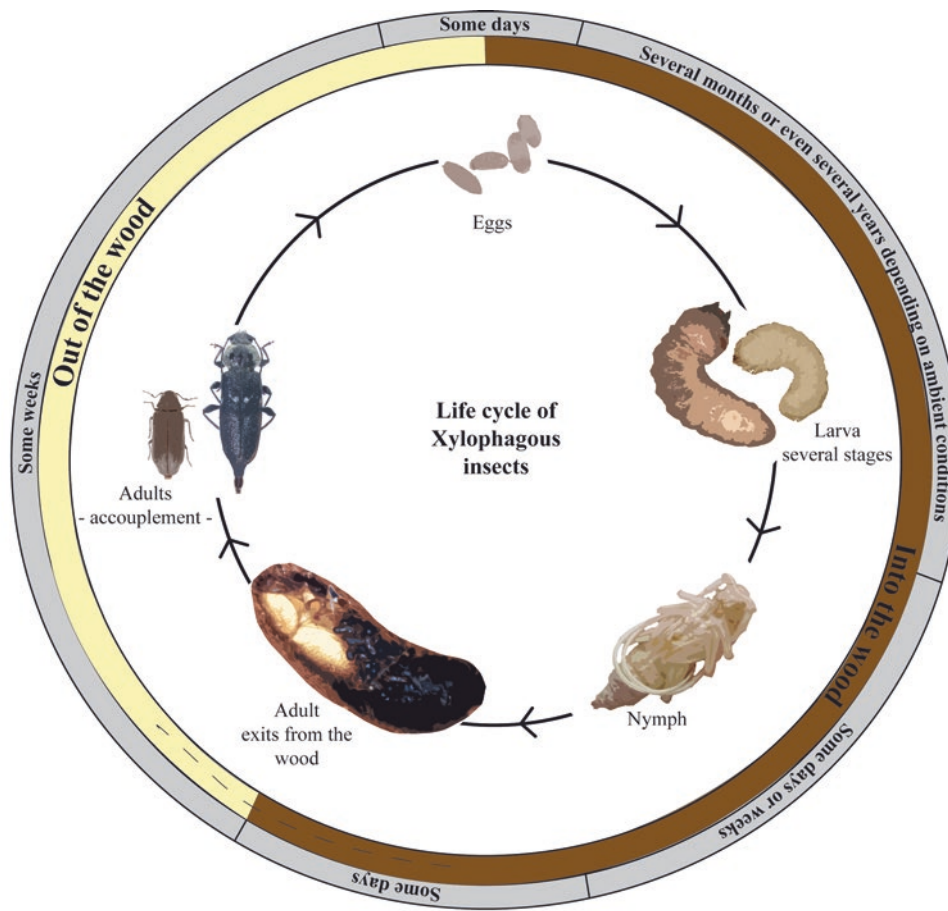
For example, Lyctidae and Bostrichidae feed on intermediate polysaccharides such as starch and hemicelluloses. Digestion by Scolytidae is more complex, as they assimilate polysaccharides from the cell content, but also from the cell walls, including hemicelluloses and wall carbohydrates (other than cellulose). Ptinidae and Cerambycidae use all the polysaccharides of the cell walls and cell contents (proteins and lipids) as well as celluloses. Buprestidae seem to favour hemicelluloses and xyloses. Finally, saprophagous insects such as chafers (genus *Cetonia*) or rhinoceros beetles (genus *Oryctes*) favour cellulose and pentosans.

As each species has a specific biology, the consequences of infestation on wood health are variable, all the more so as these biological alterations are not the only ones to interplay (fungi, pesticide treatments, the environment of the structure, its age ..., also play a role). Generally speaking, biological alteration alters the mechanical and structural qualities of the wood, making the whole structure much more fragile under the load it is supposed to carry, until the most important parts break. Two different species of insects will take different lengths of time for this stage to be reached. For example, infestation by capricorn beetles will be much more destructive in the short term than infestation by Ptinidae.

### 1.2.3 The Life Cycle of a Wood-Boring Beetle

The life cycle of wood-boring beetles is simple. It includes the time following egg laying, the larval stages, pupation, and transformation into an adult. This time varies across species, ranging from a few months to several years. In fact, the egg, deposited in a gallery or in a crack in the wood, has a lifespan of a few days. After hatching, the larvae move into the wood and feed on it, causing damage. The larvae evolve through successive moults called “larval stages”. The duration of each larval stage depends on the environmental conditions and the nutritional quality of the wood: the more favourable the conditions, the faster the cycle will be; otherwise, the larva may remain dormant for several months or even years. The pupal stage lasts a few weeks and corresponds to a phase of transformation into an adult during which the larva no longer feeds. Finally, the imago comes out. It does not feed, only lives a few weeks, and its function is essentially related to reproduction. However, in certain families such as bark beetles, the female bores a gallery in the wood to lay her eggs. Similarly, most weevils, once adult, continue to live and feed on wood before laying their eggs (Fig. 1.3).

The issue of the duration of an infestation is a regular concern for heritage officers in museums and the judiciary. For the latter, these questions arise during a dispute after the purchase of an infested property, most often caused by the merula—a lignivorous fungus—or a dry-wood-boring insect. An expert then tries to deduce “a first date” from the infestation state in order to tell who should pay for the repair work—the former owner or the new one. The age of the frass on old or recent wood, church or house frames, art objects, furniture, etc., is a complex point to apprehend. At present, it is impossible to determine with certainty whether the frass visible on a structure is recent or whether it has been present for several years. The hypothesis that the frass is compressed and detaches itself “en bloc” from the gallery would be an indication of age, as



**Fig. 1.3** Development cycle of wood-boring insect, coleoptera

opposed to “light and volatile” frass. However, no precise study has yet been carried out on the subject. DNA analysis and analysis of amino acids and other enzymes used in insect digestion are ways of answering this question. But everything still remains to be developed.

For the frass preserved in archaeological woods, the question remains the same when it comes to waterlogged wood taken from ancient excavations and dried naturally, increasing its attractiveness to today’s insects. On the other hand, in the case of waterlogged wood from recent excavations, which has been removed and properly conditioned to keep it in a good state, insect traces can be considered to be original, i.e., dating back to before the remains were buried. The case is simpler for carbonised wood because no insect can feed on carbonised wood. Thus, when a charred structure is discovered, the preserved galleries and frass attest to an infestation before the charring event and probably at the time the structure was used.

The duration of colonisation by xylophagous insects can be more easily apprehended based on knowledge of the insect’s biology, i.e., the length of the development cycle and the number of generations observable in the woods. This known period of time would open up new prospects for interpretation. For the moment, however, it is impossible to define an exact number of generations, as this number depends on the species in question and on the ambient environment (temperature, humidity, etc.). If conditions are optimal, generations follow one another more quickly than in difficult conditions (harsh winter, too dry weather, etc.). Data about the development cycle of each species are therefore only indicative and do not constitute absolute truth.

## 1.3 Guide to Using the Identification Key and the Atlas

### 1.3.1 Useful Points

The traces of xylophagous insect activity were identified, in parallel with the identification of the woody species, on the basis of three main criteria: the host, the gallery, and the frass.

The predominance of one or the other character in the samples made it necessary to develop two distinct identification keys: one for the galleries and frass, and one for the frass alone. Galleries are the most easily observable and common characteristic. They can be filled with frass or sawdust. However, it is possible to harvest the frass outside the context of the source gallery, especially when it is rejected outside the wood by the larvae. Finally, knowledge of the feeding host may exclude certain species.

Depending on the work context and disciplinary field, as much data as possible should be collected on the sample before starting to read the key.

- **The first criterion to be taken into account concerns the host, i.e., the feeding medium.**

*Angiosperm, gymnosperm or other*

Some insects are polyphagous, but others are inferred from a particular woody species or group that depends on an anatomical or nutritional characteristic of the tree.

Is the support a deciduous or a coniferous tree? Or a monocotyledonous plant?

Is it a soft wood such as poplar (*Populus*) or willow (*Salix*) for example?

Is it a wood with large vessels (vessels of the earlywood) such as oak (*Quercus*), chestnut (*Castanea*), fig (*Ficus*)?

*Host part*

As mentioned above, some insects will prefer one or more parts of the host: branches, crown, trunk, roots ....

*State of the wood*

Depending on the case, it is possible to know the state of the wood before the identification of insect traces, while in other cases, as in archaeology, it is the identification of insect traces that helps to grasp this aspect.

Is it a living tree in full vigor? A dead tree, still standing, or fallen to the ground? A freshly felled tree that has not been debarked? Is it wet/dry? Is it worked wood? To what extent are the mechanical properties of the wood impaired?

*Did the wood react to the infestation?*

All the wood cells affected by a wood borer's attack should be observed. When dead, stored or worked wood is infested, not all the cells are deformed before and after the infestation. In contrast, during infestation of standing wood, the wood cells continue to grow and try to repair the damage caused by the insect or parasite. In this case, deformations of the wood anatomy are observed, with scarring cells and rings that shift the arrangement of the wood cells in the infested area.

- **The true first characteristic marker of a family of xylophagous insects is the gallery.** Observed alone, it does not provide enough information to determine the species. Priority is given to the analysis of exit galleries or flight holes, i.e., the galleries bored and used by adult individuals just after nymphosis to get out of the wood and reproduce.

*Shape and diameter*

The general shape of the gallery is an important determination criterion, together with the size of the flight hole. For diameter measurements, insect flight holes are preferred because they are closer to the maximum size of the species.

*The position of the gallery in the wood*

The gallery should be localised within the anatomy of the wood: under the bark only, under the bark and plunging into the sapwood, specifically in the sapwood, the heartwood, or in the entire wood.

*The targeting of specific wood cells*

Depending on the species, the larvae may prefer certain wood cells rich in nutrients such as starch, that are necessary for their development. Pests then focus on only those cells with a high parenchyma content, such as the cells of the earlywood. Others do not seem to distinguish between the different parts of the wood (rays, initial/final wood, etc.).

*Gallery arrangement*

Depending on the species or more broadly on the families, it is possible to observe a certain organisation in the layout of galleries. For example, they may be parallel to each other, starting all from the same point of origin (a mother's gallery, for example).

Sometimes the galleries are arranged in different ways, which can be seen in relation to the grain of the wood (parallel, oblique, perpendicular). In general, wood-boring larvae generally avoid competition with their congeners. Crossing galleries can be observed in case of overpopulation or several successive generations. In this case, the galleries intersect in an anarchic manner ("networks").

- **The second milestone in the identification of woodworm traces is the frass.** Shapes vary from one species to another, but the same type of shape is generally found *per* family. The frass (or excrement) of wood-boring insect larvae is observed from the largest to the smallest scale. Apart from its presence or absence, not to be confused with the wood chips produced by some wood-boring insects, we must first try to determine whether it is homogeneous or not; then characterise

the shape of the faecal pellet that composes this frass, which is often different for each family, or even each species on a microscopic scale.

#### *Presence or absence of frass*

The observation of a gallery does not necessarily induce the presence of frass. In fact, the presence or absence of frass may indicate the presence of a particular group or family of xylophagous insects.

However, we should be careful with archaeological wood:

- Charcoal may vitrify to a higher or lesser degree during carbonisation. Frass can also be deformed by this phenomenon.
- It is important to know that frass is not easily preserved in waterlogged wood, where it is also waterlogged and may therefore swell and deform more easily. It is necessary to dry the sample to the critical point (dehydration by progressive dilutions with ethanol) to restore the original aspect of the frass, which becomes identifiable in this way. However, this process does not always produce reliable results, and measurements made in this way must be treated with caution because of the margin of error.

#### *General aspect of the frass*

The homogeneity or heterogeneity of the frass should be observed, i.e., whether the frass as a whole is only made up of individualisable faecal pellets (larval excreta with a particular shape depending on the species), or whether it is made up of various debris, excreta, pellets and more or less digested debris.

Homogeneous frass is composed of small elements of the same type and shape, called pellets. These pellets can also correspond to a set of digested wood debris without any particular agglomerate.

Heterogeneous frass is made up of elements that vary according to the frass type: wood fibres, digested wood agglomerates, powders of different types within the same gallery ....

#### *Shape and size of a faecal pellet*

Measurements of length and width or diameter can discriminate between a group of species or even a particular species. It is also essential to examine the general shape of a unit (spherical, cylindrical, fusiform, variable ...) and to observe its occurrence within the whole frass.

#### *Microscopic characteristics*

A set of photographs of the faecal pellets, taken with a scanning electron microscope, brings to light details that may link them to a given species. The main ones are listed below:

- pellets made up of various digested wood debris arranged differently according to the species: parallel, anarchic, layered, smooth ....
  - pellets displaying distinct features: a hollow or streaked line, a sharp apex, a rounded or curved base, a spiral apex ....
  - the presence within the pellet of undigested woody cells (perforations, areolated punctuations, vessels, etc.).
- **Other clues are interesting such as the presence of fungi** (hyphae, cubic type rot ...), pupal shells, seeds, etc.; they can be spotted during frass observation and provide valuable identification clues.

### **1.3.2 Decoding Atlas Data**

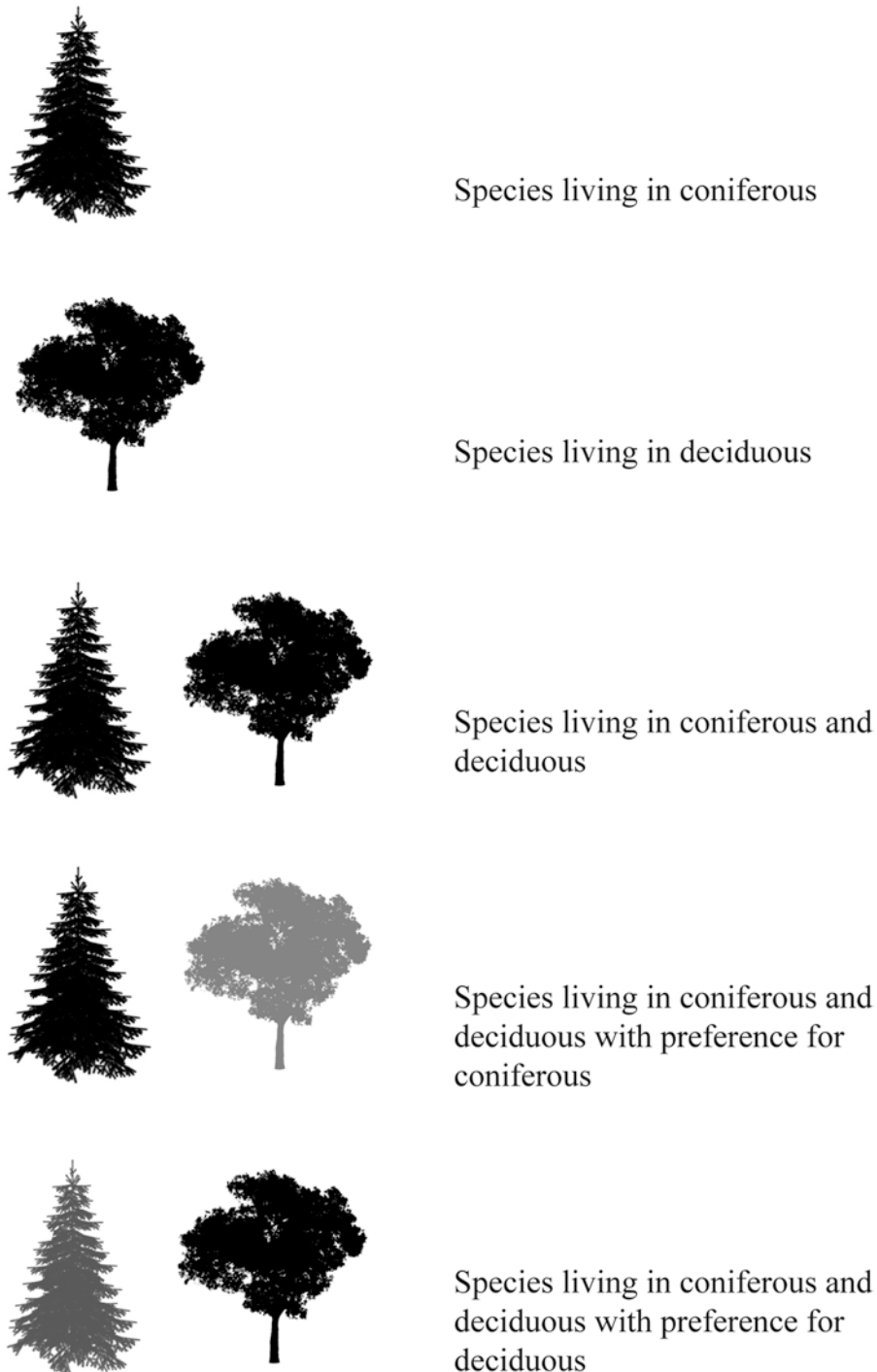
The key described in Chap. 2 is more particularly composed of two distinct keys: the first one is useful if the sample to be analysed is complete (wood, gallery and frass), the second one is essential when the sample contains only frass with very little or no gallery, e.g., in certain heritage conservation diagnoses or in archaeology with often degraded galleries on the surface of burnt wood.

The key is also presented in the form of a diagram (Sect. 2.3).

The resulting atlas contains a variety of information that can be used by botanists, entomologists, archaeologists-botanists, etc. It is currently composed of several large groups of xylophagous organisms: Coleoptera, Hymenoptera and Isoptera. These large groups are divided according to large families in alphabetical order (Bostrichidae, Cerambycidae ...). This is followed by a general description of the common biological characteristics of each family. Then a table of the most common species of this family in Western Europe is generally proposed. It brings together various data on the insect's food preferences and biology, when known. This data will certainly need to be updated according to future discoveries. It is followed by an individual presentation sheet for each species listed in the key. The sheet provides a brief description of the adult insect, its colour and size in particular. The current geographical distribution and possible origin of the species are given as an

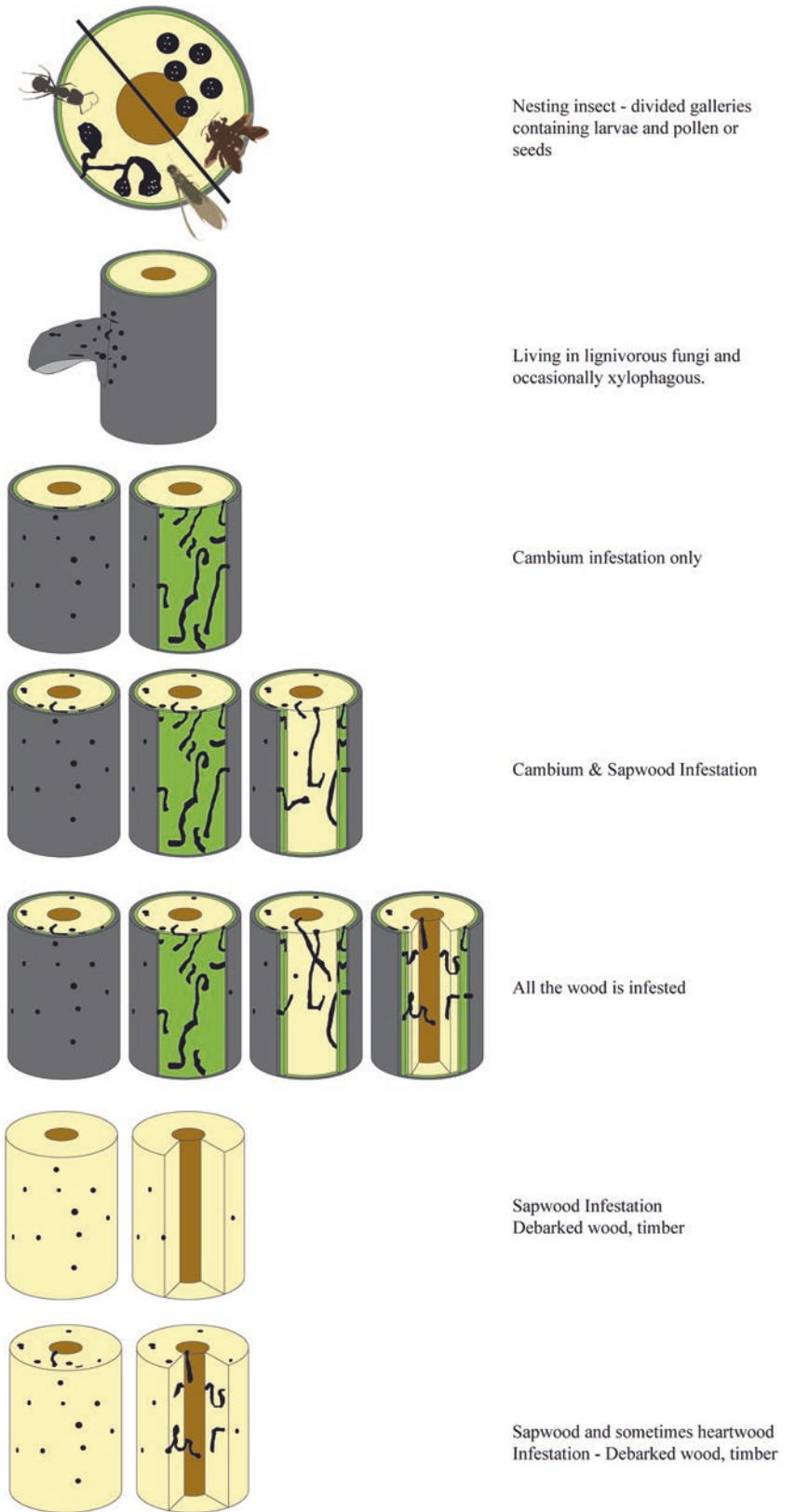
indication if the species is exogenous to Europe. Then, the bio-ecology of the insect is presented as well as its preferences, the infested wood, the minimum/maximum temperature and humidity when these indications are known. Finally, some indications on its development cycle can be provided.

Insects are included in each sheet; they enable the reader to spot the preferred hosts and the infestation type at a glance (Figs. 1.4 and 1.5).



**Fig. 1.4** Legend found in the species sheets concerning the type of infested tree

**Fig. 1.5** Legend to be found in the species sheets concerning the type of infestation



Each species sheet is accompanied by a series of illustrations:

**Macroscopic characteristics**

Photographs taken with a binocular microscope show galleries, which are the first visible signs of infestation. General views are followed by increasingly detailed views. The same is true for frass when it is present for the given species.

A description of the specific characteristics of each element (gallery and frass) can be found under each series of photographs.

**Microscopic characteristics**

These are SEM images enriching the previous illustrations with details invisible or difficult to see with a binocular microscope, especially as regards the faecal pellets composing the frass.

**Drawings**

A drawing board of the faecal pellets can also be added. These are schematic representations of the pellets aimed at showing the range of their variability.



## Chapter 2

# General Identification Keys