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**Department of Land, Environment, Agriculture, and Forestry**

**Second Cycle Degree (M.Sc.) Forest Science**

# Ecology and impacts of insect communities on Lebanese Cedar *Cedrus libani* (A. Rich)

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At the end of all journeys comes a time for reflection. And as all journeys go, it is the people you encounter on the way that make it all worthwhile.

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*Abstract*

Over the past thirty years, there has been a global observation of the expansion of the geographic range of key forest insect pests due to rising winter temperatures. Significant challenges have been posed to cedar forest reserves, which are distinctive of the Mediterranean Montane zone and are valued for their biological, cultural, historical, and social significance worldwide. The survival of numerous significant cedar forests in the Lebanese mountains is currently under threat due to the Cedar Web-Spinning Sawfly outbreak that devastated 70% of one of the greatest populations of these forests (Tannourine forest) in the late 1990s. This study investigates the range of insect pests associated with *Cedrus libani* and assesses their ecological impact on cedar forests. Through a comparative analysis, we identify pest-hosting cedar species and evaluate the correlation of insect populations. Drawing from ecological data and pest control studies, we propose practical measures to protect Lebanon's cedar forests. In addition, forest managers planning to use Lebanese cedar in planting programs would greatly benefit from the review of the insect pests associated with this species, predominantly due to its adaptation to harsh climatic conditions.

*Abbreviations*

| | |
|---|---|
| **EPN** | Entomopathogenic nematode |
| **IGR** | Insect Growth Regulator |
| **IUCN** | International Union for Conservation of Nature |
| **MOA** | Ministry of Agriculture |
| **TNCFR** | Tannourine Nature Cedar Forest Reserve |
| **UNEP-GEF** | United Nations Environment Programme – Global Environment Facility |

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## *Chapter 1. Introduction*

### 1.1. History of Cedars in Lebanon

There looms a dark fate for the Cedars of Lebanon. They are not fearful, they are strong and mighty. Fearful we ought to be, should they one day leave our mountains and only remain as a silhouette on our flag.

The mountains of Lebanon once harbored broad cedar forests (*Cedrus libani* A. Rich), extending from the mountain chains of Lebanon to Syria in the north-west and the southern mountains of Turkey where they are most abundant today. The accurate extension of Cedar forests of the past is not well documented but can be deduced from the current presence of plants that are associated with cedar trees (Beals 1965, Mikesell 1969). The area where cedars were present was well known for the valuable timber these trees had to offer. Overexploited throughout history by ancient Mesopotamia, the Egyptians, Phoenicians, and Romans, cedar forests now remain as relic forest ecosystems mainly due to inaccessibility and protection by the government (Chaney and Basbous 1978). Historical records show that even in past times action was taken to protect cedar forests from continuous exploitation by Emperor Hadrian who used stone markers to delineate forest boundaries that he put under his protection (Mikesell 1969). Despite efforts of preservation, cedar timber was used heavily over time: to build tombs by the Egyptians, as trade currency by the Phoenicians, to construct temples for King Solomon, for building ships by the romans and for railroads by the Turks. And so, cedar forests' presence became smaller and smaller leading to the fragmented state they are in today (Mikesell 1969).

As the emblematic symbol of Lebanon, the cedar maintained its place in the hearts of the Lebanese people as a heritage that is part of our identity worth protecting and conserving. To the extent that nowadays, a law prohibits the cutting of cedar trees, thinning and prescribed burning even if it be for their benefit.

### 1.2. Cedar of Lebanon in Europe

Literature on botany and horticulture from the 19$^{th}$ century is filled with mentions of the populations of Cedar of Lebanon. According to the works of several European botanists who explored and documented the flora of Asia Minor, the natural range of cedar was becoming increasingly studied and understood (Aiello and Dosmann 2007). The studies continued well into the 21$^{st}$ century on several *Cedrus* species and the possibility of integrating them in European landscapes, be it for aesthetic or productive reasons. In the case of *C. libani*, research

focused on the adaptability of the species to drought and growth performances. A study done by Sabatier et al. (2003) compared the growth of both *C. libani* of Turkish and Lebanese origin with French populations of *C. atlantica* under adverse climatic conditions and how this growth is affected by polycyclism (producing multiple cycles of growth within a single growing season) which, in the case of *C. libani*, was a way to adapt to climatic changes. Being a species that tolerates long periods of drought, *C. libani* shows continuous growth patterns in its natural range, however several studies show that more water availability will further increase growth thus making it a suitable species outside its range as well (Güney et al. 2015, Güney et al. 2020, López-Tirado et al. 2021).

The projected climate conditions of Central Europe are comparable to current climate in the Mediterranean and so it is hypothesized that some exotic species to Europe will be more suitable than native ones (Schelhaas et al. 2015, Frischbier et al. 2019, Pötzelsberger et al.2020). Particularly, *C. libani* has been getting increasing attention as a promising species that could be introduced to forests and plantations in Central Europe. Messinger et al. (2015) investigated the possibility of introduction of *C. libani* to European forestry for afforestation stating that it could be beneficial for timber production as well as ecosystem services. Due to its high light requirements and strong resilience to drought and frost, it can also be mixed with less light demanding species and will present no competition with better performance than existing conifer species. In light of climate change, *C. libani* has considerable ecological and economic aptitude for forestry in Central Europe.

### 1.3. Cedar forests in Lebanon

Data from 2020 shows that forests covered 14.01% (143,333 ha) and other wooded lands covered 16.63% (170,160 ha) of the total surface area of the country (FAO 2020). The country's mountainous topography and differences in elevation make for diverse bioclimatic conditions making it part of the biodiversity hotspot in the Mediterranean basin (Myers et al. 2000). Lebanon's forests are broadly divided into three main classes: Coniferous forests, broadleaved forests, mixed forests. Coniferous forests are mainly composed of *Pinus* tree species (*Pinus brutia* and *Pinus halepensis*) which account for 40% of the total coniferous forest area. The other coniferous species are *Juniperus* (23.4%), *Pinus pinea* (17.7%), *Cedrus libani* (4.5%), *Cupressus* (2.8%), and mixed conifers (11.6%). *Pinus brutia*, and *Pinus halepensis*, are pioneer species that live in elevations up to 1500 m. They occupy the largest area due to their adaptability to different types of soil, their fast-growing nature, as well as their ability to regenerate after fires (MOA/FAO 2005).

The Cedar of Lebanon, *Cedrus libani* (A. Rich), survives as a relic forest ecosystem in Lebanon, Syria, and Turkey. Following centuries of over-exploitation, this species now covers only about 5% of its assessed old range in Lebanon (Cheddadi and Khater 2022). *Cedrus libani* is closely related to the other *Cedrus* species: *C. atlantica*, in Morocco*, C. brevifolia*, in Cyprus, and *C. deodara*, in the Western Himalayas (Farjon 2010). The largest populations of *C. libani* are located in Turkey in the mountains South of Anatolia at elevations between 1000 and 2300 m a.s.l. (Güleç et al. 2022). In Lebanon and Syria however, the populations of *C. libani* are scattered and fragmented. In Syria, there is one reported population in the north, on the eastern side of Jabal an-Nusayriya (Khouzami 1994). In Lebanon, cedars are found on the western mountain range in 15 fragmented populations at elevations ranging between 1100 and 1925 m a.s.l. which are degrading at varying levels. Most stands are pure cedar stands and half of them are less than 50 ha in area (Khuri et al. 1999). Young trees are infested with the cedar shoot moth (*Dichelia sp*.), and many of the trees are showing typical symptoms of the web-spinning sawfly (*Cephalcia sp*.) infection, mainly necrosis on new shoots (Nemer et al. 2005). The first outbreak of *Cephalcia tannourinensis* was reported in 1997, damaging 70% of cedars in the biggest cedar forest in Lebanon, Tannourine forest, of which 8% died (Nemer and Nasr 2004, Nemer et al. 2005). Other insects were also identified to be noxious of cedars, such as *Ernobius sp.* and *Dasineura cedri*, who took advantage of the weakened cedar trees that were previously attacked by the web-spinning sawfly (Nemer and Nasr 2004).

The cedar forests of Lebanon have been subject to many changes in last three decades and climate change is one of the factors that influences the growth rate of trees, structures of forests, and disturbance regimes (Sattout and Nemer 2008). The increase in temperatures will cause a shift in habitat of the cedars in the Lebanese mountains however they have proven to be resilient to the climate changes so far (López-Tirado 2021). Rising winter temperatures have also been linked to the extension of the geographic range of key forest insect pests during these past three decades and insects are likely to adapt by moving the borders of their ranges in response to the changes in global warming trends (Sattout and Nemer 2008). The importance of the cedar forests historically and as an emblematic symbol of Lebanon calls for efforts to manage and preserve these relic forests through sustainable and integrated pest management techniques. One of the first steps is to assess current insect pest populations and their interaction with cedar trees, as well as their relation to other insects that are also hosted by other species of cedar trees in nearby regions. Understanding how these relative species are treated also offers insight into the management of the insects of the forests in Lebanon.

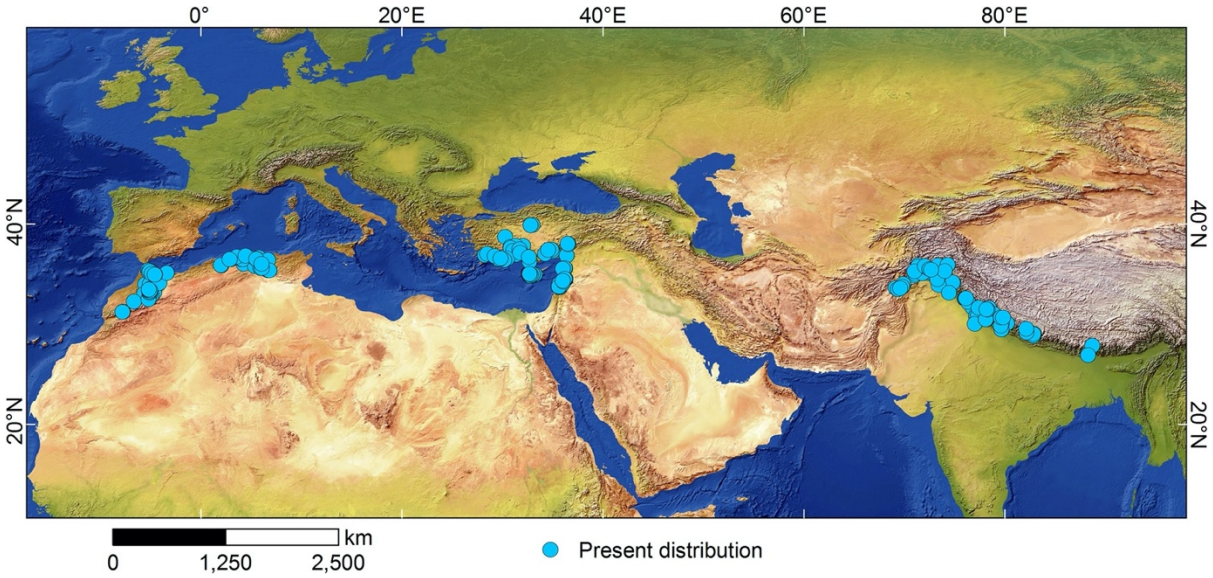


**Figure 1.** The modern original distribution (native range) of *Cedrus* spp. in the Mediterranean and western Himalaya. The blue dots represent the distribution of *Cedrus* (Xiao et al. 2022)

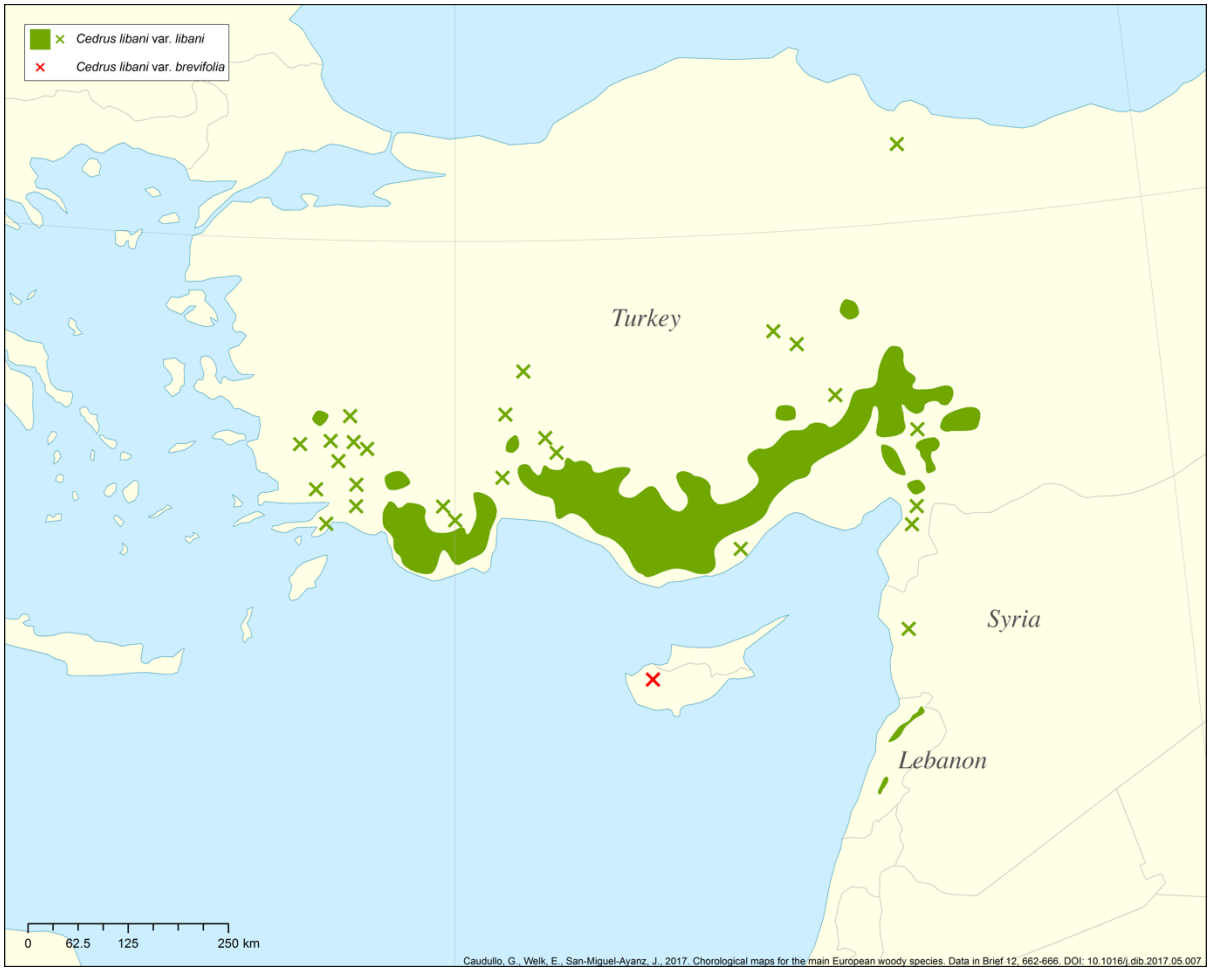


**Figure 2.** The distribution (native range) of *C. libani* and *C. brevifolia* in the Mediterranean, x's signify fragmented isolated populations (Caudullo et al. 2017).


**Figure 3.** The geographical positions of the fragmented *C. libani* populations in Lebanon. Information adapted from Khuri et al. (2000)

1.4. Botanical description of Cedars

*Cedrus libani* (A. Rich) is an evergreen conifer and is the oldest cultivated species of all *Cedrus* species. Marked by outstanding longevity, these trees can live up to 1500 years. It is said to be a slow-growing giant that reaches 20-40m in height with a thick trunk. It has a pyramidal shape when young and broadens as the tree grows older. On older trees the branches are horizontal and firm, creating a wide-spreading flattened canopy. The bark starts smooth and dark gray and later transforms with age into a rough scaly texture displaying deep horizontal cracks (Nemer 2008, Farjon 2010).

The leaves of *C. libani* have a triangular shape in section and are spirally arranged on long shoots that are very crowded and rigid. They have a green, dull greyish-green or blue color. It is a monoecious tree where the male and female flowers grow on the same tree. Male cones are solitary, cylindrical in shape, 3-5cm long with grey-green color, while female cones are ovoid, 1-2cm long and have a purple-green color. Male cones release pollen in autumn that are received by female cones (strobili) which close once fertilized. At the end of the third year after fertilization the cones become mature with barrel shape and a length of 8 to 10 cm.

Over the three years of maturation the cones transition from smooth green, to brown and scaly, and finally they fray open and the scales fall from the central axis. The seeds are irregularly triangular with orange-brown wings that get dispersed via wind. Germination happens at the end of winter with rain or snow still present.

*Cedrus libani* grows best in the highlands of the eastern Mediterranean basin. Preferring slopes that face north between 1100 and 3000 m a.s.l. These habitats have a temperate climate with cool, wet winters that receive between 1000 and 1500 mm of precipitation annually, and warm, dry summers, and where winter provides an abundance of snowfall to the highest altitudes. (Farjon 2010)

1.5. Cedrus libani and other Cedrus species

The genus *Cedrus* encompasses four species, three of which present in the Mediterranean: *C. atlantica*, *C. libani*, and *C. brevifolia*; and one native to the Himalayas: *C. deodara* (Bou Dagher-Kharrat et al. 2006). The morphological characteristics that are frequently employed to delineate and differentiate the several species that comprise the genus Cedrus don't seem to be absolute according to Farjon (2010). These different species of *Cedrus* are distinguished by the length of their needles. The average length of *Cedrus libani* needles is at 16.7 mm, *Cedrus brevifolia* needles averaged a length of 9.8 mm, and *Cedrus atlantica* at 13.3 mm (Jasińska et

al. 2013), while *C. deodara* presents the longest needles between 25 and 37 mm (Orwa et al. 2009). *C. brevifolia* was previously established as a separate species from *C. libani* however after genetic analysis it is now considered a subspecies of *C. libani* (Bou Dagher-Kharrat et al. 2001).

Despite being recognized as four different species historically, they are spread in geographically disconnected areas. It is clear that this fragmentation happened in the distant past if the genus previously displayed a more continuous distribution, with populations that might have once linked them together are now extinct. As a result, this kind of geographical isolation eventually leads to genetic differences between the surviving populations, which in turn leads to the creation of unique species. (Farjon 2010)


**Figure 4. a)** *Cedrus libani* tree in Tannourine Nature Cedar Forest Reserve, **b)** Cones of *Cedrus libani*. Taken in May of 2024 in TNCFR.

## *Chapter 2. Objectives*

This body of work's main goal is to provide an organized study of the present literature on the variety of insects that *Cedrus libani* hosts in Lebanon's surviving cedar forests. In order to highlight the ecological roles played by these insects and their interactions with their habitat, and to support the development of long-term plans that will preserve the resilience and regeneration of these forests in the face of pest outbreaks, a compilation and analysis of the scientific works currently available on the entomofauna related to *C. libani* has been conducted. Moreover, this research attempts to pinpoints gaps in the knowledge and databases for what concerns the insect pests and their respective management plans, to ultimately be able to recommend prospective research areas for *C. libani*'s ecosystem and provide insights into the conservation of these relic forests. Ultimately, this study seeks to inspire efforts targeted towards the preservation and amelioration of Lebanon's natural heritage by providing a broader understanding of the current ecological status of its forests and their prospective requirements. The objectives are as follows:

- Identify the insect pests that are hosted by *Cedrus libani*,
- Analyze the current ecological impact of the outbreaks on the cedar forest,
- Determine potential future threats from the other insect pests hosted by other cedar species in the region,
- Provide a review of the insect pests of Lebanese cedar that could be use by forest managers for assessing risks in relation to future use of this species in European forestry.

*Limitations*

This study includes just a few sample collections from the field due to time constraints and limited personnel. Considering the limited amount of literature available on some novel species endemic to Lebanon, comparative analysis will be conducted utilizing literature on direct relatives of the species in question in neighboring countries or areas with resembling criteria such as same genus of insects and cedar trees.

## *Chapter 3. Methodology*

To date there is no comprehensive review that has been done on insect species hosted by Lebanon cedar, therefore to expansively review the insects associated with *Cedrus libani*, a systematic methodology was used to gather, evaluate, and synthesize existing literature on the different species associated with *C. libani*, as well as other *Cedrus* species in the Mediterranean region. This process began with the focus on the insects hosted by *Cedrus libani*, guided by the significance of this tree species as culturally and ecologically significant in its native range in the Eastern Mediterranean region.

A widespread search of literature was conducted using academic databases such as: Google Scholar, Scopus, Research Gate and Springer Link. The search applied a combination of keywords and phrases related to Cedrus libani and insect diversity, including terms such as "Cedrus libani", "Lebanon cedar", "insect pests", "insects hosted by cedar", and "pest management". After identifying the species associated with *C. libani*, each insect was then researched on its own in order to find literature on its range and ecological and economic impact in relation to *C. libani*. For each insect species associated with *Cedrus libani*, research into literature was conducted to identify the possibility of the species being hosted by two other cedar species, *C. atlantica* and *C. brevifolia*. Despite being a close relative, *C. deodara* was excluded due to its presence being in a different geographic and climatic region.

A critical evaluation was conducted on the acquired literature to determine its quality, credibility, and usefulness. Peer-reviewed books, dissertations, journal papers, and credible scientific reports were emphasized. The publication's occurrence, the writers' experience, the objectivity of the research process, and the publication's location were all considered evaluating criteria. The identified material was then categorized thematically on the basis of shared characteristics and important features of insect interactions with *Cedrus libani*. Insect variety, pest species, ecological connections, and conservation implications were among the categories covered. The identification of principal patterns and themes as well as the methodical investigation of the literature were made easier by this structural framework.

## *Chapter 4. Insects hosted by Cedrus libani (A. Rich)*

### 4.1. Pests and their damage

Cedar-targeting insect outbreaks can cause substantial damage to forests, including slowed growth, decreased productivity, and the spread of weak or dead trees, which eventually lowers the biodiversity of the forest (Nemer 2008). Insects are known to be essential to the health of forest ecosystems due to their great variety and quantity. Some species of phytophagous insects are beneficial because they aid in pollination, act as biological control agents, or are even endangered, but others cause serious problems because they impede the production of wood. Therefore, to achieve the production of high-quality wood as well as the long-term sustainability of ecosystems, controlling insect populations in a way that maintains the natural equilibrium is a must.

Conifer insects can be divided into three main groups: defoliators, wood borers, and cone and seed insects (Table 1). Research on cedar insects is mainly conducted during infestations. Therefore, the entomofauna of Lebanon, especially in cedar forests, is largely unknown despite the important role that they present.

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***Table 1.*** *Insects hosted by* C. libani *in the Cedar Forests of Lebanon, Syria, and Turkey*

| Guild | Order | Species | Lebanon | Syria | Turkey |
|---|---|---|---|---|---|
| Sap feeder | Homoptera | ***Cinara (Cedrobium) laportei* (Remaudière, 1954)** | x | | |
| Sap feeder | Homoptera | ***Cinara cedri* (Mimeur, 1936)** | x | | |
| Sap feeder | Homoptera | *Cinara confinis* (Koch, 1856) | | | x |
| Sap feeder | Homoptera | *Cinara curvipes* (Patch, 1912) | | | x |
| Sap feeder | Homoptera | *Cinara indica* (Verma, 1970) | | | x |
| Sap feeder | Homoptera | *Cinara intermedia* (Pasek, 1954) | | | x |
| Leaf feeder | Hymenoptera | *Acantholyda nemeri* n. sp. | x | | |
| Leaf feeder | Hymenoptera | ***Cephalcia tannourinensis* (Chevin, 2002)** | x | | |
| Leaf feeder | Lepidoptera | *Acleris undulana* (Walsingham, 1900) | | x | x |
| Leaf feeder | Lepidoptera | ***Dichelia (Syndemis) cedricola* (Diakonoff, 1974)** | x | | x |
| Leaf feeder | Lepidoptera | ***Epinotia cedricida* (Diakonoff, 1969)** | x | | x |
| Leaf feeder | Lepidoptera | ***Thaumetopoea libanotica* (Kiriakoff and Talhouk, 1975)** | x | | |
| Leaf feeder | Lepidoptera | *Thaumetopoea ispartaensis* (Doganlar & Avci, 2001) | | | x |
| Leaf feeder | Lepidoptera | *Thaumetopoea pityocampa* (Denis and Schiffermüller, 1776) | x | x | x |
| Cone and seed | Coleoptera | ***Ernobius libanensis* n. sp.** | x | | |
| Cone and seed | Hemiptera | ***Leptoglossus occidentalis* (Heidemann, 1910)** | x | | x |
| Cone and seed | Hymenoptera | ***Megastigmus schimitscheki* (Novicky, 1954)** | x | | x |
| Cone and seed | Lepidoptera | ***Barbara osmana* (Obraztsov, 1952)** | x | | x |
| Gall maker | Diptera | ***Dasineura cedri* (Coutin, 2000)** | x | | x |
| Gall maker | Prostigmata | ***Trisetacus cedri* (Nalepa 1920)** | x | | x |
| Wood borer | Coleoptera | ***Callidium libani* (Sama and Rapuzzi, 2002)** | x | | |
| Wood borer | Coleoptera | *Carphoborus henscheli* (Reitter, 1887) | | | x |
| Wood borer | Coleoptera | *Carphoborus minimus* (Fabricius, 1798) | | | x |
| Wood borer | Coleoptera | *Crypturgus numidicus* (Ferrari, 1867) | | | x |
| Wood borer | Coleoptera | *Crypturgus pusillus* (Gyllenhal, 1813) | | | x |
| Wood borer | Coleoptera | *Hylastes batnensis anatolicus* (Brisout, 1883) | | | x |
| Wood borer | Coleoptera | *Orthotomicus erosus* (Bright and Skidmore, 1997) | | x | x |
| Wood borer | Coleoptera | *Orthotomicus erosus* (Wollaston, 1857) | | | x |
| Wood borer | Coleoptera | *Orthotomicus robustus* (Knotek, 1899) | | | x |
| Wood borer | Coleoptera | *Orthotomicus tridentatus* (Eggers, 1921) | | | x |
| Wood borer | Coleoptera | *Phloeosinus acatayi* (Schedl, 1958) | | x | x |
| Wood borer | Coleoptera | ***Phloeosinus cedri* (Brisout, 1883)** | x | | x |
| Wood borer | Coleoptera | *Pityogenes bistridentatus* (Eichhoff, 1878) | | | x |
| Wood borer | Coleoptera | *Pityogenes calcaratus* (Wood and Bright, 1992) | | x | x |
| Wood borer | Coleoptera | *Pityokteines curvidens* (Germar, 1824) | | | x |
| Wood borer | Coleoptera | *Scolytus major* (Stebbing, 1903) | | | x |
| Wood borer | Coleoptera | *Tomicus minor* (Hartig, 1834) | | | x |

4.1.1. *Cinara* spp.

*Cinara* aphids mainly infest conifer species in the Pinaceae and Cupressaceae families, feeding on the leafy and woody parts of the plant potentially causing permanent damage such as wrapping and drying (Blackman and Eastop 1994). Species include *Pinus*, *Abies*, *Larix*, *Picea*, and *Cedrus*. While *Cedrobium* species are confined to North Africa and Europe, *Cinara* species are found all over the world. Six species of *Cinara* have been found in Turkey hosted by *Cedrus* spp., *Cinara cedri*, *C. confinis*, *C. curvipes, C. indica, C. intermedia,* and *C. laportei* with the most common on *C. libani* being *C. cedri* (Akyıldırım Beğen et al. 2019). *C. confinis* and *C. curvipes* are usually associated with *Abies* and seldom found on *Cedrus*.

Recently, *C. cedri* was subdivided into two subspecies: *C. cedri cedri* and *C. cedri brevifoliae* after a new subspecies of *C. cedri* was discovered in Cyprus in 2017 on *C. brevifolia* (*C. cedri brevifoliae)* (Binazzi et al. 2017). Originally thought to have been only present in the Mediterranean basin and Europe, yet new records show the presence of *Cinara cedri* on *C. deodara* in China, Korea, and Japan (Yu and Wang 2014, Lee et al. 2020, Nozaki et al. 2022).

In Algeria, a new species of *Cinara*, *C. tellenica* Binazzi F. et Strangi, has been described on *Cedrus atlantica*. In this region it coexists on the same tree species with *C. cedri*, and preliminary studies suggest that the two species of Aphids could be similar in terms of biology and ecology though further investigations are needed for the new taxon to fully explain its traits (Ayache et al. 2020). Even though the two species are currently sharing the same host and geographical distribution in Algeria, their speciation could have occurred due to the fragmentation of the *Cedrus* population which lead to genetic differences between populations of *Cinara*. Another hypothesis for the creation of a new taxon is the intense human pressure and exploitation of cedar stands, and so it is possible that the trade in plant material from different parts of North Africa triggered the establishment and spread of Aphid populations in new areas (Ayache et al. 2020).

4.1.1.1. *Cinara cedri* Mimeur, 1936

*Cinara cedri* is the cedar bark aphid, and is specific to *Cedrus* species (*C. atlantica, C. brevifolia, C. libani, C. deodara*) with *C. libani* being the favored host. It lives in colonies on the branches and trunk. In 1936, J.M. Mimeur first identified *Cinara cedri* on *Cedrus atlantica* in Morocco. It belongs to the Hemiptera order and Aphididae family with cedar species being its preferred hosts (Binazzi et al. 2015). It has been reported after that for the first time in Turkey on *C. libani* by Tuatay and Remaudiere in 1964, and later found in Europe and the Middle East, which suggests that this species has spread to *C. deodara* and *C. libani* as new hosts (Blackman and Eastop 1994, Binazzi et al. 2017). Recent studies have also identified *C. cedri* on *C. deodara* in Japan where the tree was introduced as an ornamental plant (Nozaki et al. 2022).

In Lebanon, this Aphid is distributed in the cedar forests (*C. libani*) of Qammoua, Bcharre, Tannourine - Hadath El-Jebbeh and Chouf, and multiplies parthenogenetically during warm temperatures. The damage caused to cedars is strongest during summer when generations overlap (Nemer 2008). *Cinara cedri* is a sap sucking pest attacking shoots and foliage, causing needles to dry and turn red, and damaging young branches. *C. cedri*'s sap sucking causes honeydew secretion which sticks to leaves and stems thus inhibiting photosynthesis and can

cause growth inhibition. Additionally, fungus grows on the honeydew secretions and causes sooty mold to develop on the tree (Binazzi and Scheurer 2009, Binazzi et al. 2015, Oğuzoğlu and Avcı 2019a).

A variety of natural enemies were found in a study done in Turkey on *C. cedri* in the region of Isparta (Oğuzoğlu and Avcı 2019b). Of them, the largest number of species—18—belonged to the Coccinellidae family. As well, a number of species from different families, including the Syrphidae, Chrysopidae, and Raphidiidae, were identified as *C. cedri* predators for the first time. The most prevalent predator was *Pauesia anatolica* (Braconidae). The existence of these natural enemies points to a strong biological control mechanism, which may account for the relatively low levels of damage to cedar woods recorded in the forests of Isparta. The preservation of mixed forests emphasizes the potential for using these natural predators as a biological control strategy should pest populations rise by improving biological diversity and the effectiveness of natural enemies in managing *C. cedri* populations (Oğuzoğlu and Avcı 2019b).

4.1.1.2. *Cinara (Cedrobium) laportei* Remaudière, 1954

*Cinara laportei* (previously *Cedrobium laportei*) is the brown cedar aphid that is native to the Atlas Mountain Range in North Africa and hosted by *Cedrus atlantica*. The species has been expanding its range to other *Cedrus* species becoming harmful also to *C. libani* and *C. deodara*. Like *C. cedri*, *C. laportei* has spread from the Atlas to Europe and the Middle East (Binazzi et al. 2017). There have been reports of *C. laportei* from Algeria, France, India, Palestine, Italy, Lebanon, Morocco, South Africa, and Spain (Aytar 2006).

What differentiates *C. laportei* from *C. cedri* is the number of antenna segments (Blackman and Eastop 1994, Binazzi et al. 2017). *Cinara laportei* feeds on lower branches, shoots and young branches of trees, larvae and wingless adults are visible on the underside of branches in Spring or Fall. The Aphid causes early needle loss, slowed growth and the drying of branches and eventually the crown, all of which lead to the death of the tree (Fabre, 1982).

*Cinara* species are difficult to identify from one another due their similarities, with the only morphological differentiation between them being color and sheen. Identification becomes especially difficult when they occur in mixed colonies that feed on the same host, such as the case of *C. cedri* and *C. laportei* on *C. libani* (Akyıldırım Beğen et al. 2019).

As for *Pauesia cedrobii*, a parasitoid of *C. laportei*, it was discovered and described for the first time in Morocco by Starý and Leclant in 1977.

#### 4.1.2. *Cephalcia* spp.

In Europe, stressed spruce stands (*Picea abies*) are susceptible to outbreaks by web-spinning sawflies of the genus *Cephalcia*, namely *C. abietis*, *C. arvensis* and *C. alpina*. Stands affected by abiotic factors such as drought and pollution are the perfect environment where sawflies thrive, noting that other *Cephalcia* species that also feed on spruce and other conifers only cause sporadic damage in other areas of the world (Battisti et al. 2000). The most significant pest species in Europe is *C. abietis*, and outbreaks of *C. arvensis* present lesser frequency though this later species is present in abundance in non-outbreak conditions. Concerning *C. alpina*, this species has caused outbreaks in mountainous areas between Poland and Czech Republic mainly in polluted areas (Battisti et al. 2000). More recent outbreaks of *C. arvensis* have been linked to higher temperatures and water stress, and damage is observed to be higher in homogeneous stand structures (Marchisio et al., 1994, Battisti et al. 2000).

Spatial distribution of *Cephalcia* spp. could be influenced by the choice of host by the adult females and the survival of eggs as well as host plant quality and predation rates by natural enemies (McMillin and Wagner, 1998). As long as the right circumstances persist, sawflies can use a tree as shelter, and when mature larvae fall to the ground and burrow into the soil beneath the same tree, they frequently go into a lengthy diapause which allows the same insect cohort more time to colonize an area extending up to three years (Rodeghiero and Battisti 2000). It is suggested that adult females, after having laid some of their eggs, are continuously in search for other trees suitable as hosts as some species of sawflies were found on young trees away from original study sites (Rodeghiero and Battisti 2000).

##### 4.1.2.1. *Cephalcia tannourinensis* Chevin 2002

*Cephalcia tannourinensis* is the cedar web-spinning sawfly whose larvae feed on conifer buds while spinning webs. Larvae of this genus are well known to severely defoliate conifer forests in the northern hemisphere, resulting in financial losses. The species *C. tannourinensis* is specific to *Cedrus libani* and was discovered not long ago when an outbreak occurred in the Tannourine Cedar Nature Forest Reserve (TNCFR) in 1998 that caused major defoliation of trees. First described in 2002 by H. Chevin, *Cephalcia tannourinensis* Chevin was declared in 2001 an endemic species of the cedar forest of Northern Lebanon including the Bcharré cedars (Cedars of God) (Démolin et al., 2001). It is a highly monophagous species that only lays eggs on cedar trees and requires less humid environments than other species of *Cephalcia* (Nemer et al. 2021). Adults swarm from mid-April to mid-June with a short lifespan and limited time to reproduce, thus mating immediately after emergence. A female *C. tannourinensis* has a high

egg laying potential of about 50 eggs on the new buds which hatch within 2 to 4 weeks and the larvae start feeding on the needles of a cedar tree for 2 months (7 needle buds per larva). A larva will pass through three instars, and after the last molt it will drop to the ground and make a hole for hibernation usually in the month of July (Kawar and Nemer 2002a, Kawar and Nemer 2002b, Nemer et al. 2021). Depending on climatic conditions, the pupae can remain in the soil for several years before emerging as adults. The exact duration has not yet been determined, however outbreaks of this pest have been shown to be related to climatic conditions, soil temperature and moisture content (Nemer et al. 2014).

The cedar trees attacked by *C. tannourinensis* exhibit extensive browning, resembling the aftermath of a wildfire. Three years in a row of larvae feasting on its buds, a cedar tree can die. Only the Tannourine – Hadath El Jebbeh cedar forest and the Bcharré cedars are affected by *C. tannourinensis.* It is capable of physiologically adjusting its life cycle to suit the conditions of its surroundings, which enables it to emerge and begin feeding on trees at the exact moment when fresh cedar buds begin to form (Nemer et al. 2021). After experiencing defoliation by *C. tannourinensis*, a cedar tree will form emergency buds in July, and the quantity of the buds that branches develop to replace their lost foliage is directly proportional to the intensity of the *C. tannourinensis* attack (Nemer 2008).

The first outbreak was determined to be in 1997 right before the species was identified and caused damages to 70% of the cedar trees in TNCFR killing 8%. Following that, monitoring of *C. tannourinensis* between the years 1998 and 2002 determined a high number of larvae present in the soil indicating that future outbreaks were highly likely. As a response to that, the forest underwent an aerial spraying treatment with insect growth regulator (IGR) diflubenzuron from 1999 to 2004 which decreased the population number. As of 2006, the use of IGR has been prohibited in forests due to some negative effects on general insect populations. Lacking alternative measures, more outbreaks have occurred between 2013 and 2019, albeit not as severe as the first outbreak of 1998 (Nemer et al. 2021).

Monitoring of *C. tannourinensis* done in the years 2018, 2019 and 2020 concluded its presence only in the northern cedar forests (Tannourine, Horsh Ehden, and Bcharré) with no trace of it in the central cedar forests (Maaser el Chouf, Barouk, Niha, and Ain Zhalta). Monitoring was only done on adults using yellow sticky traps which estimated the number of emerging sawflies and not the number of pupae in diapause (Nemer et al. 2021). Monitoring done from 1999 to 2006 showed a significant decrease in population number which is most probably due to the treatment with IGR but possible influence could be due to climate, after

2006 and to this day the number has been increasing due to lack of action taken in terms of control (Nemer, unpublished).


**Figure 5. a)** Visible damage of *C. tannourinensis* on *C. libani* in TNCFR, **b)** Larva of *C. tannourinensis* dropping down to the soil. **c)** and **d)** Larvae in webs. Taken in May of 2024 in TNCFR.

Outbreaks are linked to climatic variables and winter/spring temperatures, and with population numbers increasing it is therefore fundamental to set an integrated pest management plan that excludes IGR and utilizes biocontrol agents and silvicultural practices. A study conducted using *Beauveria* fungi species on *C. tannourinensis* eggs and larvae in isolation yielded high rates of mortality (72.6% to 93.1%). In terms of managing eggs and larvae, *Beauveria bassiana* outperformed diflubenzuron (IGR) indicating its potential as a biocontrol agent for handling outbreaks of *C. tannourinensis*. *Beauveria*'s effectiveness against *Cephalcia* species emphasizes its potential as a substitute for chemical treatments that have detrimental effects on the environment (Abdo et al 2006). Depending on the stage of development of the pest, the time it takes to get infected by *Beauveria* will vary (eggs and early stages are damaged faster). Since 2013, the TNCFR has successfully employed this pest management method on a small scale (Nemer et al. 2021).

Entomopathogenic nematodes (EPNs) are also an important biocontrol agent in pest management. Research done by Noujeim et al. (2015) isolated an ENP found in the soil near Tannourine Cedar forest, *Heterorhabditis bacteriophora*, and when compared with the commercial strain it proved as effective against *C. tannourinensis*, yielding 85% mortality. Another study done by Rehayem et al. (2018) found that *C. tannourinensis* pupae were sensitive to the indigenous strain of EPN *Steinernema feltiae*, with 65% mortality.

EPNs have proved to have a faster effect on *C. tannourinensis* pronymphs and eonymphs than *B. bassiana*, and when both fungi and nematodes are mixed together in a treatment the effect is strongest and mortality rates are the highest (Al Khoury et al. 2019). This synergic interaction of both biocontrol agents could be the best option to be implemented in an integrated pest management plan against *C. tannourinensis* in the future.

Even though the effect *C. tannourinensis* on cedar forests is mostly a negative one, seeing as outbreaks cause mortality of trees and the scarcity of the *C. libani* population currently in Lebanon, it is worthy to consider regeneration dynamics that occur with the change of the forest structure. After 1999, sawfly infested forest plots in Tannourine lost a large number of old trees, which resulted in wide canopy openings that let light into the understory. These conditions favor regeneration, survival, and growth of young cedar trees, and can be matched to those that result from harvesting shelter-wood systems (Bassil et al. 2018).

In protected places such as the Tannourine Cedar Forest Nature Reserve, restrictions on thinning, tree cutting, and controlled fire use might result in excessively dense forests, consequently worsening pest problems.

4.1.3. *Dichelia* spp.

*Dichelia* is a genus of moths that currently comprises 5 documented species (Brown 2005). *Dichelia histrionana* (Frölich, 1828) is predominantly found in Europe with host plants of the larvae being *Abies*, *Picea*, and *Pinus*. Recent records of its presence in Turkey on *Abies nordmanniana* and *Pinus sylvestris* have been confirmed (Seven and Özdemir, 2007)

*Dichelia numidicola* n. sp. was first described in Algeria on *Abies numidica* by Chambon (1990), and when compared with *D. cedricola* was confirmed to be a new species. Although similar, *D. numidicola* is smaller in size with a lighter color than *D. cedricola*, as well as having different preferred hosts where *D. cedricola* is known to live on cedar while *D. numidica* lives on *Abies numidica* (Chambon et al. 1990). This leaf roller, though having a main host, was also found later on cedar trees that grow in mixed stands with *Abies*, further laboratory tests confirmed the ability of the insect to colonize Atlas cedar (Fabre et al. 1999).

4.1.3.1. *Dichelia (Syndemis) cedricola* (Diakonoff, 1974)

*Dichelia cerdicola* (Lepidoptera), also known as the Cedar Shoot Moth (CSM), aggressively attacks cedar leaves, which leads to March to June being the time of year when the defoliation is at its worst. When the larvae are active, they spin webs that resemble cotton, and the damaged tree sections that have dead agglutinated needles persist long after the feeding phase. The host cedar trees respond to the extreme defoliation caused by the CSM by producing an abundance of epicormic shoots, even destroying buds making it possible to identify intervals of mild to severe CSM outbreaks (Carus and Avci 2005).

According to research done by Carus and Avci (2005), tree ring analysis on cedar trees in Turkey shows that CSM outbreaks occur every 15-30 years on average, where rings show alternating wide and narrow increments. Baloch and Kawar (1978) described the biology of this leafroller in Lebanon; adults emerge in June when conditions are right, while mating occurs early in the morning. The average female CSM is capable of laying up to 126 eggs, which hatch after 7 to 12 days. The eggs are arranged in a double row on the cedar needles, one atop the other. In its first two instars, which occur between July and October, the young caterpillar enters a needle of the year and becomes a leaf miner.

It is wildly distributed in Lebanon and Turkey on *C. libani* but has not yet been detected on *C. atlantica* neither in North Africa nor in France (Fabre et al. 2001). In Lebanon it has been found in 1992 in Barouk, Maaser El Chouff, Jabal Kammoua, and in 1998 again in Maaser El Chouff (Nemer and Diakonoff, unpublished). Loss of leaves in the spring can impact all of the

foliage, including the needles from prior years. The needles are joined by silk threads, and the existence of caterpillars is confirmed by the abundance of droppings (Fabre et al. 2001).

Because of safety and environmental considerations, toxic insecticides are becoming a less appealing alternative in the fight against moth pests like *D. cedricola*. The molecules used by moths to communicate, known as pheromones, offer a viable substitute that scientists are searching for. The sex pheromone of *D. cedricola* was discovered in a study conducted at the Tannourine Nature Reserve in Lebanon by Nemer et al. in 2014. According to the study's findings, the synthetic pheromones Z11-14:Ac 65% and Z11-14: OH: 35% can be used in integrated forest pest management programs to monitor *D. cedricola* in Lebanese cedar forests and to identify the species in other cedar forests in the Mediterranean countries, including *C. libani*, *C. brevifolia*, and *C. atlantica* (Nemer et al. 2014).

#### 4.1.4. *Epinotia* spp.

With 172 known species, the genus *Epinotia* Hübner represents 1.9% of the diversity of tortricids and is distributed throughout the world. The genus's larvae are typically found in rolled leaves, open leaf buds, or the branches of plants. They overwinter as larvae or eggs and are typically univoltine (Brown 2005).

*Epinotia algeriensis* was first described from individuals found on *Cedrus atlantica* in mixed cedar-fir forests in Algeria (Chambon et al. 1990). Later surveys also confirmed its presence in all Algerian and Moroccan cedar forests with visible damage at the end of fall (Fable et al. 1999). It shares the same habitat as *E. cedricida* in North Africa and the two species are often confused with one another due to similar phenology, though one thing that distinguishes them is that adults of *E. algeriensis* fly in June earlier than those of *E. cedricida*. Therefore, in natural conditions the adults of these two species do not occur at the same time (Mouna and Fabre 2005).

##### 4.1.4.1. *Epinotia cedricida* Diakonoff, 1969

There has been speculation over the years on the origins of the leaf roller moth *Epinotia cedricida* whether it is native to North Africa or the Middle East. It was first described in France in 1969 where it colonized most cedar plantations (*C. atlantica*) that were introduced from Algeria which suggested that the pest was of North-African origin. This hypothesis was later reconsidered after the discovery of this tortricid in *C. libani* stands in Turkey and led to the conclusion that the moth was not specific to *C. atlantica* and that it could have equally been introduced from Turkey (Fabre 1997). Today, it has been identified in several other countries

– including France, Austria, Morocco, Algeria, Lebanon and Turkey – on both *C. libani* and *C. atlantica* (Fabre et al. 1999).

*E. cedricida* had been first discovered in Lebanon in 1997 in the Tannourine cedar forest (Fabre and Dereix, unpublished). Its presence in Turkey remained masked probably due to the fact that it was often confused with another tortricid in Turkey, *Acleris undulana*, which is considered one of the most common pests in the Taurus cedar forests and causes extensive damage to *C. libani* groves (Fabre 1997, Fabre et al. 1999, Coban 2014). Thus far no elaborate research has been done on the extent and damage of *E. cedricida* in Lebanon's cedar forests and considering its resemblance to *Dichelia cedricola* and *Acleris undulana* it would be wise to further investigate this pest. Research done by Fabre (1997) concluded the absence of this pest in most of the cedar groves in Lebanon, however its wide geographical distribution in Turkey could possibly forecast its expansion and outbreaks in nearby countries.

Where this moth is present, the damage is most visible in winter and spring while remaining unnoticeable prior to that in the fall. Only going through one generation per year, it all starts with oviposition in late summer where eggs are laid in the crevices of the branches' bark. The caterpillars consume the needles at all stages of growth possibly leading to the defoliation of the entire tree, additionally, a silk tunnel can be visible on the needles which serves the purpose of protecting the caterpillars against the elements in winter. The caterpillars mature from September to April, after which they fall to the ground and pupate underground in a silk cocoon, a process that takes place between February and May. A few months after the bud break and new needles grow, adult emergence is observed from mid-July to August (Fabre et al. 1999, Mouna and Fabre 2005).

Control methods for this pest have not yet been established although several species of parasitoids that target the caterpillars have been observed in Turkey and Algeria. In France one egg parasitoid is adapted to this pest, speculated to be *Trichogramma cacoeciae*, as well as the entomopathogenic fungi *Beauveria bassiana* (Mouna and Fabre 2005). Furthermore, identification and synthesis of the sexual pheromone of *Epinotia* has been achieved making sexual trapping and monitoring of this pest possible in order to identify its presence in cedar stands be it damaged or healthy (Mouna and Fabre 2005).

#### 4.1.5. *Thaumetopoea* spp.

Host plant diversity notably drives the diversification of herbivorous insects, with about half of speciation events being linked to host plant shifts. These shifts, often due to climatic changes, can lead to geographical range expansion, creating opportunities for further speciation

through geographical isolation or local adaptation (Simonato et al. 2013). For Lepidoptera, particularly the genus *Thaumetopoea*, evolution is driven by host plants and natural enemies. *Thaumetopoea* species, known as Processionary moths, are primarily found in the Western Palaearctic region (comprising Eurasia north of the Himalayas, together with North Africa and the temperate part of the Arabian Peninsula), particularly the Mediterranean Basin. Their larvae feed on resin-rich trees and shrubs, except for one species that feeds on Fagaceae (Oak) (Simonato et al. 2013).

The ancestral *Thaumetopoea* likely had a Mediterranean distribution and evolved from African taxa. Independent host plant shifts to higher latitudes occurred for *T. pinivora*, *T. processionea*, and *T. pityocampa* following the last Pleistocene glaciation. *T. pityocampa* and *T. wilkinsoni* show polyphagy within Pinaceae, while *T. bonjeani*, *T. ispartaensis*, *T. libanotica*, and *T. pinivora* are specialized, with some feeding exclusively on *Pinus* or *Cedrus* (Simonato et al. 2013).

The species belonging to the genus *Thaumetopoea* (Lepidoptera, Notodontidae, Thaumetopoeinae) are important for both human health and forest ecosystems because they defoliate trees and emit prickly hairs during their larval stages, which can trigger allergic reactions. According to Basso et al. (2016), this genus of moths includes two groups related to conifers: the "summer" and "winter" processionary moths, so named because of when their larvae feed. Processionary moths (Thaumetopoeinae) are found on cedar (*Cedrus* spp.) in three different species: *T. libanotica* (Kiriakoff and Talhouk) in Lebanon, *T. ispartaensis* on *C. libani* in Turkey, and *T. bonjeani* (Powell) on *C. atlantica* in North Africa (Tunisia, Morocco, and Algeria) (Battisti et al., 2015).

#### 4.1.5.1. *Thaumetopoea libanotica* Kiriakoff and Talhouk, 1975

*Thaumetopoea libanotica* was initially identified by Kiriakoff and Talhouk (1975) as a new species. After providing a thorough description of the insect, they concluded that it is not the same as *T. bonjeani* Powell. However, *T. libanotica* responded to *T. bonjeani* pheromones, according to field experiments conducted on Lebanon's cedars, therefore, the two species can be identical. The front wings of adult moths are darker than the rear wings, and they have a light brown tint. Females have a wingspan of around 24 mm and measure about 15 mm in length. Males measure around 12 mm in length and 22 mm in width at the wings.

The biology of *T. ispartaensis* and *T. libanotica* are very similar. They are both summer Processionary moths, and both hosted by *C. libani*. *T. libanotica* is found in the Lebanon forests of Bsharry, Tannourine, and Shouf and *T. ispartaensis* in the cedar forests of Turkey in the

Isparta region and in the Taurus Mountains in the South. The home of *T. libanotica* ranges in elevation from 1400-2000 m above sea level, and this moth has an adult phase from August through October (Kiriakoff and Talhouk, 1975; Nemer et al., 2018).

Each egg is 1.5 mm in diameter and has an ivory tint. An egg mass has dimensions of 5–10 mm in breadth and 20–30 mm in length. The scales on the eggs are grayish in color. The recently emerged larva has a yellowish hue. The mature caterpillar grows to a length of 40 mm, whereas the first larval instar measures only 3.54 mm. There are five instars for the caterpillar. From early September until late October, the adults are visible. Egg masses are laid by females on branches. In one mass, there are typically 135 eggs. The following year, in April or May, the eggs begin to hatch. Summer feeders are the five stages of larvae. Caterpillars travel in a procession to the earth in late July or early August, where they pupate. Defoliation is caused by caterpillars feeding in groups on needles, which begin at the tips and go downward (Kawar and Nemer 2002b).

4.1.5.2. Other *Thaumetopoea* hosted by cedar

It has been determined that *T. ispartaensis* is a monophagous species that only consumes *Cedrus libani*. Like *T. pinivora*, it is a member of the summer processionary moth group and is acclimated to high heights. The time of the adults' emergence, which occurs earlier at lower elevations and depends on temperature, varies from mid-August to the end of September. Copulation commences a few hours after the adults emerge, and egg-laying follows shortly after. On the underside of *C. libani* twigs, females deposit their eggs. The egg batches are hard to tell apart because of their grayish-brown scales, which resemble the color of the bark (Küçükosmanoğlu 2019).

*T. bonjeani*, as well, is a monophagous species that feeds exclusively on Atlas cedar at high elevations and was documented in Algeria in 1986 (Démolin 1988). It impacts trees by reducing wood growth and causing wood to dry, moreover it poses health risks to humans, which include skin lesions, conjunctivitis, respiratory issues, and anaphylactic shock (Rahim 2016). Several natural enemies of *T. bonjeani* have been identified in Algeria: the pupal parasitoid *Heterospilus sp.*; early larval predators *Xanthandrus comtus* and *Sphedanolestes sanguineus*; and mature larval predators *Ocypus olens*, *Dermestes sp.*, *Hister thoracicus*, *Calosoma sycophanta*, and *Lygaeus sp.*. Additionally, an entomopathogenic fungus, *Beauveria sp.* was found in the pupae (Rahim et al. 2021a). Among these natural enemies of *T. bonjeani*, *Calosoma sycophanta* is a major predator of several processionary moth species, including *T. pityocampa*, *T. wilkinsoni*, and *T. processionea* (Avci 2000; Battisti et al. 2015).

4.1.6. *Ernobius* spp.

*Ernobius* is a genus of beetles that are native to Europe and North America. The genus includes more than 60 species that vary between wood, bark and cone ravaging beetles. They are usually saproxylic, relying on already dead plant material, nonetheless they can cause destruction of the seeds in cones before the cones start to decay (Nemer 2008). Several species of *Ernobius* colonize *C. libani* trees at the larval stage, such as *E. abietis*, *E. anatolicus* and *E. angusticollis*, while *E. fructuum*'s host is *C. atlantica* (Luik 1995, Roques 1983). *E. abietis* is also present on *Picea abies* in Europe. On the other hand, *Ernobius mollis* develops in the phloem including the inner layer of the bark, the cambium, the surface areas of the wood of dead (or, less frequently, dying) conifers, and occasionally, in their cones. Several types of pine (e.g., *Pinus sylvestris, P. nigra, P. radiata, P. pinaster, P. halepensis, P. taeda, P. canariensis*), European larch (*Larix decidua*), Douglas fir (*Pseudotsuga taxifolia*), giant sequoia (*Sequoiadendron giganteum*), and Norway spruce (*Picea abies*) are among the hosts (Urban 2005). Additional Coleoptera species that feed on the reproductive organs of cedars in North Africa include: *Ernobius pruinosus*, *Ernobius mulsanti* and *Ernobius pini* (Mouna and Avcı 2016).

4.1.6.1. *Ernobius libanensis* n. sp.

*E. libanensis* is a new species that was found on Lebanon's cedar trees in 1998 during the first surveys of *C. tannourinensis*. It is a univoltine species whose adults' diapause is in summer and the eggs' diapause in winter (Nemer 2008).

After defoliation by *Cephalcia tannourinensis*, *C. libani* produces so called "emergency buds" during the month of July, these buds foliate the tree to compensate for the lost needles. Two species, *Ernobius libanensis* and *D. cedri* are the first to arrive to these new buds. Therefore, it is hypothesized that *E. libanensis* is dependent on the attacks of *C. tannourinensis* for its emergence and survival. Due to the competition between *E. libanensis* and *D. cedri*, it's possible that *D. cedri* is able to reach and colonize the buds first leaving *E. libanensis* without its primary and preferred colonization site. In the absence of the new emerging buds, the beetle is also able to attack the female cones of *C. libani*. In this case, populations of *E. libanensis* remain lower than expected with the emergency buds left intact (Nemer 2008).

*Ernobius* beetles are generally regarded as secondary parasites on most of their hosts (Roques 1983), however the damage to cedars had spread due to the abundance of *E. libanensis* populations and their specific utilization of cedar emergency buds (Nemer 2008). A cone of *C. libani* can be colonized by several individuals of *E. libanensis* while the emergency bud can

only be colonized by a single individual, the larvae therefore enter into competition as well in order to reach the center of a bud with only one being successful while the rest of the larvae die before reaching the center (Nemer 2008).

#### 4.1.7. *Leptoglossus* spp.

With 61 species and 1 subspecies, the genus *Leptoglossus* is one of the most complex and diversified taxa of Anisoscelini in the Western Hemisphere. It is widely distributed from southern Canada through the United States, México, the Antilles, Central America, and South America, including Chile and Argentina. The only *Leptoglossus* species found outside of the Western Hemisphere are *L. occidentalis* Found in Europe and parts of the Middle East, and *L. gonagra*, occurring in Africa, Southeast Asia, the Pacific Islands, and Australia (Brailovsky 2014). As a phytophagous insect, *L. gonagra* has been shown to feed on a variety of host plants, including fruit trees and vegetables, though it has been seen to do so most often on cucurbit plants. A sap sucker it is a pest that causes direct harm to the host plants and can be a vector for fungus and flagellates (Lee et al. 2020).

##### 4.1.7.1. *Leptoglossus occidentalis* Heidemann, 1910

The Western conifer seed bug, *Leptoglossus occidentalis*, is native to North America and has been recorded on almost 40 species of conifers, mostly pine trees (Hizal and Inan 2012). The species is an invasive alien species that has spread across Europe, first found in Italy in 1999 and later spread rapidly to many other European countries (Kment and Banar 2008) as well as in Morocco and Tunisia (Nemer et al. 2019). In 2016, it was recoded near Lebanon in eastern Turkey (Özgen et al. 2017) and prior to that its presence was confirmed on pine forests in Arsoun in Mount Lebanon (Nemer et al. 2019).

Since *L. occidentalis* colonizes the cones of Pines and causes them to dry out and become void of seeds, in 2012 this created a major threat to the production of Pine seeds in Lebanon of which the cause was not clear prior to the identification of the pest (Nemer et al. 2019). Although this conifer seed bug is originally hosted by *Pinus pinea* and *Pinus brutia* in Lebanon, some adult individuals were found on *Juniperus excelsa* and *Cedrus libani* in Ehden (Nemer et al. 2019). Despite its main establishment on *P. pinea*, this discovery on new hosts suggests that *L. occidentalis* might undergo a shift in hosts or expand its colonization to these new species affecting two of the most important trees in Lebanon, *Pinus pinea* and *Cedrus libani* (Nemer et al. 2021).

The strategy for managing this pest is still not fully developed in Lebanon and attention should be focused on preventing major outbreaks as well as rapid host shift. In some countries this pest completes only one generation per season such as in North America, however in Mexico it has been recorded to have 3 generations and this is mainly due to climatic conditions (Barta 2016).

4.1.8. *Megastigmus* spp.

The genus *Megastigmus* comprises around 130 species of seed chalcids that are present all over the world and have spread to a larger range than previously recorded. Most of the *Megastigmus* species are specialized in the colonization of seeds at the genus level, meaning species shifts occur under the same genus of trees and introductions of this chalcid to new countries follows the same logic. Only five species in conifers could attack more than one genus and in three of these cases the hosts belonged to the closely related genera *Abies* and *Cedrus*. Following its attack on *Cedrus*, *M. pinsapinis* from North Africa shifted to the native *Abies* species in Europe. Likewise, when introduced to southern France, *M. schimitscheki* from Minor Asia switched from *C. libani* to *Abies pinsapo*. Conversely, it was noted that the native *M. suspectus*, which attacks *Abies*, rarely moved on to target *Cedrus brevifolia* and the French-introduced *Cedrus atlantica* (Roques and Skrzypczyńska 2003).

Competitive advantage over local species and their establishment in unoccupied ecological niches gives invasive species a lead over native ones. The unintentional introduction of *M. schimitscheki* from the eastern Mediterranean in 1995 is one example of how the global trade of tree resources, especially seeds for plantations, facilitates the spread of forest insects (Fabre et al. 2004). *M. pinsapinis* is no exception, as it was brought to France from northern Africa most likely along the extensive *C. atlantica* plantations that started in southeast France at the end of the 1800s (Fabre et al. 2004).

The seed chalcid *Megastigmus schimitscheki* has invaded cedar woodlands in southeast France, thus posing a threat to the now native *Megastigmus pinsapinis* and using up the same resources. Despite this competition, *M. schimitscheki* has an advantage due to its earlier emergence and stronger reproductive capacity, which justifies its invasiveness (Fabre et al. 2004, Boivin et al. 2008). Because of their different emergence time*, M. schimitscheki* colonizes seeds before *M. pinsapinis*, what is more a female *M. schimitscheki*'s egg laying capacity is larger and occurs right after emergence (Boivin et al. 2008). Thus, the local abundance of both species and the availability of seeds related to the masting of cedars affects the competition between them.

4.1.8.1. *Megastigmus schimitscheki* Novicky, 1954

*Megastigmus schimitscheki*, a seed chalcid, is an insect pest specialized in the exploitation of cedar seeds and was first described in Turkey in 1954 from *Cedrus libani* seeds, and later spread to France with the importation of cedar seeds in the 1990s (Fabre 1994, Auger-Rozenberg et al. 2003). *M. schimitscheki* is now present in Cyprus, Greece, Lebanon, Syria, Turkey and France (Roques and Skrzypczyńska 2003). Hosts of this seed chalcid are *C. libani*, *C. brevifolia*, and in France this species has shifted to *C. atlantica* and *Abies pinsapo* (Fabre 1994, Roques and Skrzypczyńska 2003).

While several French entomologists had reported seeing this insect in cedar groves, it was not until 2001 that it was observed in the cedars of Tannourine, Bcharré, and Chouf in Lebanon. The cones are destroyed by this insect, and seeds die as a result (Fabre et al., 1994, Nemer 2008). With infestation percentages ranging from 1 to 5% in 2002, 0% in 2004, 13.5% in 2006, and 1.1% in 2007 in the Tannourine Hadath-El-Jebbeh cedar woodland, the insect's rate of infestation is still extremely low in Lebanese cedar forests (Nemer 2008).

4.1.9. *Barbara* spp.

*Barbara* is a genus of cone infesting moths comprising 5 species with few literature available. Distribution of the genus is in Europe, parts of Asia and North America. In Europe, *Barbara herrichiana* damages cones of fir trees, while *Barbara mappana* is present on Douglas fir in North America. Previously regarded as subspecies of *B. herrichiana*, *B. fulgens* is a species coined in China on spruce trees (Roques et al. 1994).

4.1.9.1. *Barbara osmana* Obraztsov, 1952

*Barbara osmana* is a leaf roller moth that is primarily hosted by *C. libani*. *B. osmana* is present on cones of *C. libani* in Asia Minor and is considered in Turkey as one of the important destructive pests feeding on cones and seeds. A study done by Çanakçioğlu (1969) indicated that *B. osmana* damaged *C. libani* cones in Kaş and Bozdağ areas (Antalya) about 10.7% and 36.2% respectively and became more severe (41%) in some areas in Bozdağ. This insect is also been found in cedar forests in Lebanon (Mouna and Fabre 2005).

4.1.10. *Dasineura* spp.

*Dasineura*, containing 490 species that are spread all over the world, is the largest genus of the family Cecidomyiidae with most species occurring in the Palaearctic Region. In Western

and Central Europe 230 species occur with most of them being associated with Fabaceae, Rosaceae, Asteracae, Brassicaceae and Lamiaceae (Skuhravá and skuhravý 2009).

Very few species of *Dasineura* are associated with conifers, they include *D. kellernii*, *D. rozhkovi*, *D. abietiperda* and *D. piceae*. *Dasineura kellerni* (listed under the name *Dasineura laricis*) is a pest of European larch (*Larix decidua*) that targets the cones hence reducing seed production. Another species that targets larch is *D. rozhkovi* which was found in Siberia and Kazakhstan on Siberian larch (*Larix sibirica*) and forms large galls (Fedotova and Averenskij 2016). *Dasineura abietiperda*, on the other hand, was historically widespread in Europe on spruce (*Picea abies*) trees and was characterized as occurring in blister galls down the length of twisted branches that had lost their needles, now this species appears to be scarce. Norway spruce that has been introduced to America from Europe has recently exhibited symptoms of swellings, bent shoots and needle drop and was later diagnosed to be damage from *Dasineura abietiperda* (Gagné and Graney 2014). *Dasineura piceae* was also described from Europe on Norway spruce as well as white spruce (*P. glauca*) and is characterized by blister galls that in aggregate cause the base of the branches to swell (Gagné and Graney 2014).

#### 4.1.10.1. *Dasineura cedri* Coutin, 2000

*Dasineura* is a genus of midges that often form galls on plant tissues, and lay eggs in the inflorescence. *Dasineura cedri* is a newly discovered species in Lebanon that was detected by chance in the cedar forest in the year 2000 (Coutin 2000, Nemer et al. 2021). Adults emerge early in Spring and attacks the summer buds of *C. libani* where it causes most damage. *D. cedri* is also found to be in competition with the anobiid *Ernobius libanensis* for the consumption of the buds (Nemer et al. 2021). Its distribution extends several cedar forests in Lebanon: Bcharré, Ehden, Tannourine – Hadath el Jebbeh (Nemer et al. 2021).

### 4.1.11. *Trisetacus* spp.

The genus *Trisetacus* comprises about 60 species of eriophyid mites that are mainly associated with coniferous plants (Pinaceae and Cupressaceae). Capable of causing various kinds of damage to conifers, some of these species are therefore considered economically important pests. The genus also includes many species that are rarely detected and difficult to collect, consequently, they are not sufficiently studied and descriptions of them have been short and incomplete (Chetverikov et al. 2019).

Shoot deformation and apical cell death are caused by the eriophyoid mite *Trisetacus juniperinus*, which has been observed on a variety of coniferous hosts in Europe and North

America, mainly *Juniperus communis* and *Cupressus*. In the Mediterranean, it can seriously harm *C. sempervirens*, particularly in nurseries and young stands (Simoni et al. 2004).

*T. pini* is found on pine forming bark galls on twigs, but also on spruce and larch. *T. silvestris* is found on Scots pine (*P. sylvestris*) as well as on *Pinus mugo*. *T. relocatus* is generally associated with fir and spruce, and *T. laricis* with larch. *T. floricolus* attacks cones of *Abies alba*, and *T. abietis* is found under the needle epidermis of *A. alba* causing necrosis (Lewandowski et al. 2014, Chetverikov et al 2019).

4.1.11.1. *Trisetacus cedri* (Nalepa 1920)

*T. cedri* is a species associated with the *Cedrus* genus and was first collected in 1913 and described in 1920 on *Cedrus atlantica* in Algeria but no publications have been made specifically on *T. cedri*. Later, this species was also determined on *C. deodara* in Abkhazia and South Africa (Chetverikov et al. 2019). In Lebanon, the cedar eriophyid mite was found on *C. libani* in Tannourine in 2012, visible through symptoms of needle and stem deformation. Some of the other symptoms by this pest include bud proliferation, needle discoloration and witches'-broom (Nemer at al. 2021).

Previous studies done by Chetverikov et al. (2019) on *C. libani* in Turkey and *C. brevifolia* in Cyprus found no trace of the eriophyid suggesting that the distribution of *T. cedri* remains unknown and thus problematic with the need of supplementary studies to be applied on this species concerning *Cedrus* trees.

4.1.12. *Callidium* spp.

The genus *Callidium* belongs to the Cerambycidae family commonly known as longhorn beetles. They are primarily associated with coniferous forests in Europe and parts of Asia. Known for their wood-boring patterns, they create galleries under the bark of dead, weakened, or dying conifer trees to serve as pupation chambers where later the larvae develop. Some species are quite common while others are considered rare or vulnerable exhibiting habitat preferences or specific hosts. Some of the rare species include: *C. cedri*, *C. libani*, *C. coriaceum*.

*Pinus*, *Picea*, *Larix* and *Abies* act as hosts for two species: *C. aeneum aeneum* and *C. violaceum*. Even in non-native conditions, *Callidium aeneum aeneum*, an oligophagous species, can be found in coniferous forests in Europe. Development occurs beneath the bark of recently fallen, weakened, or dying fir branches and thin trunks. The common polyphagous species *Callidium violaceum* is found in Eurasian coniferous woodlands, hedgerows, and areas

where unpeeled coniferous wood from man-made sources is present (wooden fences, roof frames, and fuel). Usually, the larvae develop beneath the bark of dead conifers, where they bore characteristic, broad, flat galleries. In the montane and sub-montane areas of central Europe, *Callidium coriaceum* is associated with Norway spruce (*Picea abies*) and is considered a rare species. Their preferred host is a dying or standing dead tree of rather large diameter.

In North Africa, *Callidium cedri*, described from Algeria in 1917, is considered a rare species as well and is assessed as vulnerable with an area of occupancy smaller than 1500 $km^2$ (Buse et al. 2016). *C. cedri* are "weakness inducing" species that have a marked preference for dry or drying wood. Their occurrence is closely associated with forests of *Cedrus atlantica* (Beghami et al. 2020). Droughts brought on by climate change may pose a threat to the long-term viability of Atlas Cedar woods that have already received an Endangered status. This saproxylic beetle species is highly dependent on the availability of cedars for larval development, hence any actions that aid in the protection of the *C. atlantica* populations are likely to be for their benefit (Buse et al. 2016).

*Callidium syriacum* is a species found in the Central-western Taurus Mountains and in the Amanus Mountains (now part of southeastern Turkey). Sama and Rapuzzi (2002) discuss the possibility that the specimens from these two areas could present two subspecies of *C. syriacum* yet to be confirmed. Additionally, *C. syriacum* inhabits the mountains of northern Syria, which is supported by observations of larval galleries in *Cedrus libani* near Slunfah on Jabal an-Nuṣayriyah, indicating the presence of this species in that region (Sama and Rapuzzi 2002).

#### 4.1.12.1. *Callidium libani* Sama and Rapuzzi, 2002

The cedar longhorn beetle, *Callidium libani*, is a rare species of beetle endemic to Lebanon. It is assessed as endangered since it has a restricted geographic range and a fragmented population due to the decline in host availability (Buse et al. 2016). It is a saproxylic species that lives off dead *Cedrus libani* and *Abies cilicica* branches. Thus far no damage was reported to *Cedrus libani*, rather this species presents an important role in the ecosystem as it helps with the decomposition of dead wood (Sama and Rapuzzi 2002, Nemer et al. 2021).

In Lebanon, this species is found in the relic Cedar forests of Bcharré, Ehden, Tannourine – Hadath El Jebbeh and on *Abies cilicica* in Fnaideq. *Callidium libani* holds the closest biological resemblance to *C. syriacum* that inhabits the mountains in northern Syria, as well *C. aeneum* from north-eastern Turkey (Sama and Rapuzzi 2002). Horsh Edhen Nature Reserve is one of the few remaining relic cedar forests, it hosts one of the subpopulations of *Callidium libani* and has 20% of all the remaining cedar trees in Lebanon. This makes it an important

area to be protected for habitat preservation of both *Callidium libani* and its main host, *Cedrus libani* (Buse et al. 2016).

4.1.13. *Phloeosinus* spp.

The genus *Phloeosinus* includes about 80 species of bark beetles distributed throughout all continents. Across Europe and Mediterranean regions, eight species are present, five of which are hosted by Cupressaceae, and the other three on *Cedrus* species (Faccoli and Sidoti 2013). A new bark beetle of this genus, *P. laricionis*, was recorded in Sicily, Italy, this species infests varieties of *Pinus nigra* in Southern Italy and is hypothesized to be dependent on Pine populations, where outbreaks occurred during the decline of the trees due to climatic conditions (Faccoli and Sidoti 2013). The newly found species bears resemblance to *Phloeosinus* species from the eastern Mediterranean, such as *P. pfefferi* from Cyprus and *P. acatayi* from Turkey, as well as *P. cedri* from North Africa, which are known to breed in cedars (respectively on *C. brevifolia*, *C. libani*, and *C. atlantica),* however *P. laricionis* can be easily distinguished by its larger size (Faccoli and Sidoti 2013).

*P. acatayi* from Turkey is found in forests of *Cedrus libani* and *Juniperus excelsa* (Selmi 1987), as well as in Morocco on *Cedrus atlantica* (Chauiyakh et al. 2023). Belhabib et al. (2009) found that *P. bicolor* in Tunisia was able to colonize indigenous as well as exotic species of *Cupressus* and reproduces more successfully on the exotic species *Cupressus arizonica*.

*Phloeosinus armatus* was first described in 1887 from specimens found in Syria (Reitter, 1887), its distribution mirrors that of its host *Cupressus sempervirens*, a tree native to the Middle East, Turkey, Greece, and Cyprus (Aljouri et al. 2018). It was in 1991 that this beetle was first recorded in Italy, and later in the summer of 2013 new outbreaks on this species were detected in the woodland areas of Tuscany (Pennacchio et al. 2013). Its potential to act as a vector for the canker causing fungal pathogen is of special concern. This species may potentially act as a harmful complement to *P. aubei*, the native beetle, in dispersing propagules of cypress canker (Pennacchio et al. 2013).

*Phloeosinus aubei*, native to the Mediterranean region, spread of Central Europe and is considered an invasive species that causes the death of *C. sempervirens* trees, its preferred host. Though *P. aubei* is also hosted by *Juniperus* spp. and *Thuja* spp. in parts of Europe (Fiala and Holuša 2019). A study done by Fiala et al. (2023) shows that it is possible to detect this bark beetle even at low population levels. With recommendations that baits, and traps should be set at the end of April and left exposed all of May in Central Europe, with possibility of catching other species of bark beetles which presents more monitoring opportunities.

4.1.13.1. *Phloeosinus cedri* Brisout, 1883

*Phloeosinus cedri* is the cedar bark beetle hosted by many species of *Cedrus*, mainly *C. atlantica* in North Africa, and *C. libani* in Lebanon and Turkey (Balachowsky 1969). It is likely that *Phloeosinus cedri* originated in the Aurès Mountains, as it was first described from Algeria's cedar forests on *C. atlantica*. The species is abundant and often hazardous in all of North Africa's cedar forests, where it sometimes invades young branches that are still fully sapped. The species is similarly widespread in the Near East (the Arabian Peninsula, Cyprus, Egypt, Iraq, Iran, Jordan, Lebanon, Palestine, Syria, and Turkey) and displays the same behavior as it does in North Africa (Balachowsky 1969).

The beetle forms galleries under the bark of healthy trees and make their way through branches that are dying or have been cut, eventually leading to the death of the branches (Balachowsky 2969, Nemer et al. 2021). *P. cedri* is a pioneer species that establishes itself on healthy cedar trees, preferring middle and top parts of the tree and branches with small diameters (Beghami et al. 2020). *P. cedri* has one generation per year, adults are observed in summer when their activity is at its highest (Beghami et al. 2020). At the entrance of primary tunnels, females lay eggs where the larvae will overwinter. The primary tunnels run along the length of the branches while secondary tunnels run perpendicular to them (Nemer et al. 2021).

***Table 2.*** *Insects hosted by all four* Cedrus *species (in bold are species on* C. libani *in Lebanon).*

| Guild | Order | Species | *C. atlantica* | *C. deodara* | *C. libani* | *C. brevifolia* |
|---|---|---|---|---|---|---|
| Sap feeder | Homoptera | ***Cinara (Cedrobium) laportei* (Remaudière, 1954)** | x | | x | |
| Sap feeder | Homoptera | ***Cinara cedri* (Mimeur, 1936)** | x | x | x | x |
| Sap feeder | Homoptera | *Cinara confinis* (Koch, 1856) | | | x | |
| Sap feeder | Homoptera | *Cinara curvipes* (Patch, 1912) | | | x | |
| Sap feeder | Homoptera | *Cinara indica* (Verma, 1970) | | | x | |
| Sap feeder | Homoptera | *Cinara intermedia* (Pasek, 1954) | | | x | |
| Sap feeder | Homoptera | *Cinara tellenica* (Binazzi and Strangi, 2020) | x | | | |
| Leaf feeder | Coleoptera | *Scythropus warioni* (Mars, 1876) | x | | | |
| Leaf feeder | Hymenoptera | *Acantholyda nemeri* n. sp. | | | x | |
| Leaf feeder | Hymenoptera | ***Cephalcia tannourinensis* (Chevin, 2002)** | | | x | |
| Leaf feeder | Hymenoptera | *Prionomeion gaullei* (Konow, 1906) | x | | | x |
| Leaf feeder | Lepidoptera | *Acleris undulana* (Walsingham, 1900) | x | | x | x |
| Leaf feeder | Lepidoptera | *Choristoneura murinana* (Hübner, 1796-1799) | x | | | |
| Leaf feeder | Lepidoptera | *Dendrolimus spectabilis* (Butler, 1877) | | x | | |
| Leaf feeder | Lepidoptera | ***Dichelia (Syndemis) cedricola* (Diakonoff, 1974)** | | | x | x |
| Leaf feeder | Lepidoptera | *Dichelia numidicola* (Chambon, 1990) | x | | | |
| Leaf feeder | Lepidoptera | *Ectropis deodarae* (Prout, 1926) | | x | | |
| Leaf feeder | Lepidoptera | ***Epinotia algeriensis* (Chambon, 1990)** | x | | | |
| Leaf feeder | Lepidoptera | ***Epinotia cedricida* (Diakonoff, 1969)** | x | | x | |
| Leaf feeder | Lepidoptera | *Lozotaenia cedrivora* (Chambon, 1990) | x | | | |
| Leaf feeder | Lepidoptera | *Thaumetopoea bonjeani* (Powell, 1922) | x | | | |
| Leaf feeder | Lepidoptera | ***Thaumetopoea libanotica* (Kiriakoff and Talhouk, 1975)** | | | x | |
| Leaf feeder | Lepidoptera | *Thaumetopoea pityocampa* (Denis and Schiffermüller, 1776) | x | x | x | |
| Cone and seed | Coleoptera | ***Ernobius libanensis* n. sp.** | | | x | |
| Cone and seed | Hemiptera | ***Leptoglossus occidentalis* (Heidemann, 1910)** | | | x | |
| Cone and seed | Hymenoptera | *Megastigmus pinsapinis* (Hoffmeyer, 1931) | x | | | |
| Cone and seed | Hymenoptera | ***Megastigmus schimitscheki* (Novicky, 1954)** | x | | x | x |
| Cone and seed | Hymenoptera | *Megastigmus suspectus* (Borries, 1895) | x | | | |
| Cone and seed | Lepidoptera | ***Barbara osmana* (Obraztsov, 1952)** | | | x | |
| Cone and seed | Lepidoptera | *Dioryctria peltieri* (De Joannis, 1921) | x | | | |
| Cone and seed | Lepidoptera | *Dioryctria peyerimhoffi* (De Joannis, 1921) | x | | | |
| Gall maker | Diptera | ***Dasineura cedri* (Coutin, 2000)** | | | x | |
| Gall maker | Prostigmata | ***Trisetacus cedri* (Nalepa 1920)** | | | x | |
| Wood borer | Coleoptera | *Anthaxia ludovicae* (Abeille, 1900) | x | | | |
| Wood borer | Coleoptera | *Anthaxia marmottani* (Bristout, 1883) | x | | | |
| Wood borer | Coleoptera | *Anthaxia nigritula* (Ratzeburg, 1837) | x | | | |
| Wood borer | Coleoptera | *Anthaxia pleuralis* (Fairmaire, 1883) | x | | | |
| Wood borer | Coleoptera | *Anthaxia salicis* (Fabricius, 1776) | x | | | |
| Wood borer | Coleoptera | *Anthaxia sepulchralis* (Fabricius, 1801) | x | | | |
| Wood borer | Coleoptera | *Anthaxia sepulchralis subsp. chobauti* (Abeille, 1894) | x | | | |
| Wood borer | Coleoptera | *Buprestis flavangulata* (Fairmaire, 1856) | x | | | |
| Wood borer | Coleoptera | ***Callidium libani* (Sama and Rapuzzi, 2002)** | | | x | |
| Wood borer | Coleoptera | *Carphoborus henscheli* (Reitter, 1887) | | | x | |
| Wood borer | Coleoptera | *Carphoborus minimus* (Fabricius, 1798) | | | x | |
| Wood borer | Coleoptera | *Cryphalus piceae numidicus* (Wood and Bright, 1992) | x | | | |
| Wood borer | Coleoptera | *Crypturgus cedri* (Eichhoff, 1868) | x | | | |
| Wood borer | Coleoptera | *Crypturgus numidicus* (Ferrari, 1867) | x | | | |
| Wood borer | Coleoptera | *Crypturgus pusillus* (Gyllenhal, 1813) | x | | | |
| Wood borer | Coleoptera | *Ergates faber* (Linnaeus, 1761) | x | | | |
| Wood borer | Coleoptera | *Hylastes batnensis anatolicus* (Brisout, 1883) | | | x | |
| Wood borer | Coleoptera | *Hylurgops bonvouloiri* (Wood and Bright, 1992) | x | | | |
| Wood borer | Coleoptera | *Ips sexdentatus* (Boerner, 1776) | x | | | |
| Wood borer | Coleoptera | *Kissophagus novaki* (Reitter, 1894) | x | | | |
| Wood borer | Coleoptera | *Magdalis leucopleura* (Fairmaire, 1883) | x | | | |
| Wood borer | Coleoptera | *Melanophila marmottani* (Fairmaire, 1868) | x | | | |
| Wood borer | Coleoptera | *Orthotomicus erosus* (Bright and Skidmore, 1997) | x | | x | |
| Wood borer | Coleoptera | *Orthotomicus robustus* (Knotek, 1899) | | | x | |
| Wood borer | Coleoptera | *Orthotomicus tridentatus* (Eggers, 1921) | | | x | |
| Wood borer | Coleoptera | *Phloeosinus acatayi* (Schedl, 1958) | | | x | |
| Wood borer | Coleoptera | ***Phloeosinus cedri* (Brisout, 1883)** | x | | x | |
| Wood borer | Coleoptera | *Pityogenes bistridentatus* (Eichhoff, 1878) | | | x | |
| Wood borer | Coleoptera | *Pityogenes calcaratus* (Wood and Bright, 1992) | | | x | |
| Wood borer | Coleoptera | *Pityogenes quadridens* (Hartig, 1834) | x | | | |
| Wood borer | Coleoptera | *Pityokteines curvidens* (Germar, 1823) | x | | x | |
| Wood borer | Coleoptera | *Scolytus carpini* (Wood and Bright, 1992) | | | | |
| Wood borer | Coleoptera | *Scolytus major* (Stebbing, 1903) | | | x | |
| Wood borer | Coleoptera | *Scolytus numidicus* (Brisout, 1883) | x | | | |
| Wood borer | Coleoptera | *Semanotus russica algericus* (Villiers, 1946) | x | | | |
| Wood borer | Coleoptera | *Stephanopachys quadraticollis* (Fairmaire, 1878) | x | | | |
| Wood borer | Coleoptera | *Tomicus minor* (Hartig, 1834) | | | x | |
| Wood borer | Coleoptera | *Xyleborus saxeseni* (Ratzeburg, 1837) | x | | | |
| Wood borer | Hymenoptera | *Urocerus augur* (Klug, 1803) | x | | | |

## *Chapter 5. Discussion*

### 5.1. Biogeography of *Cedrus* spp. and associated herbivorous arthropods

The history of host plants plays an important role in shaping the geographic distribution of the insect species associated with them. Influenced by climatic changes and geological events, the evolutionary trajectories of *Cedrus* species has likely impacted the distribution of insect communities currently present on different species of cedar. Global climate has oscillated between warm and cold extremes influencing biota dispersal and speciation given that climate tolerance greatly influences tree distribution (Qiao et al. 2007). Farjon (1990) suggested that the current disjunction between the closely related species of *Cedrus* could have been caused by migration along the Tethys Fold Belt, a sequence of mountain uplifts, and the shrinking of a previously widespread range. Later studies found that fossil evidence leads to a migration of the species from north to south and their origin being from the high latitude area of Eurasia, with climate fluctuation and population fragmentation resulting in the current distributions (Qiao et al. 2007). Molecular phylogenies place Himalayan cedar as sister to the Mediterranean clade, which was further divided into the two subclades of North Africa and the eastern Mediterranean (Qiao et al. 2007).

Considering that pests are also constrained by their host's geography and availability, this could suggest that they respond more to the composition of the host than to climate changes singularly. Host-specific species have been observed to follow their hosts when they alter their regions or shift their geographic range. Generalists with more diverse host ranges, on the other hand, can occupy larger geographic areas especially if their density increases and hosts become less suitable (Gougherty and Davies 2022b). Moreover, pests are capable of finding new host species that were previously inaccessible yet suitable, or they can adapt with time to conquer host defenses and accumulate hosts within their native ranges. Fittingly, climate change could speed up this process by leading to an extension of the pest's range and a wider host pool (Gougherty and Davies 2022a). In the case of *Cinara* species, they are presumed to have originated from eastern Asia about 50 Mya where their main hosts were pines and shifts to other conifers in Europe happened 23 Mya during the Miocene with intercontinental dispersal. The continuous conifer-dominated forests in Beringia likely promoted the diversification of *Cinara* with the emergence of new adaptive zones with less competition. Present day *Cinara* species are highly diverse due to the steady accumulation of lineages and hosts (Meseguer et al. 2015). *Cinara cedri* is highly specific to the genus *Cedrus* and is present on all four species, however its first discovery on *C. atlantica* presents us with the hypothesis that it is the original

host and later evolved to other *Cedrus* species. Whereas *C. laportei* is more constrained in its range and currently only identified on *C. atlantica* and *C. libani*, two species that have been proven to be closely related which could justify the presence of *C. laportei* on both of them. The discovery of a new *Cinara* species, *C. tellenica*, on *C. atlantica* in Algeria established that it coexists with *C. cedri*, and that speciation may have occurred due to past climate changes and complex aphid-host interactions (Ayache et al. 2020).

With the historic division of the *Cedrus* genus into several species that are now geographically dispersed it is only natural that they now host an array of insects that could overlap at times. However, there remains a few species that colonize only a specific species of cedar such as *Dasineura cedri* that is currently present in both populations of *C. libani* in Lebanon and Turkey. Likewise, many insects are split between these two populations of *C. libani* such as *Thaumetopoea ispartaensis* in Turkey and *Thaumetopoea libanotica* in Lebanon. This gap, therefore, could be due to the fragmentation of the *C. libani* range which led to the speciation of the cedar processionary moth given the similarities in their biology. *T. bonjeani* on the other hand, hosted by *C. atlantica* in Algeria, presents less biological likeness to the other two cedar processionary moths most likely due to their geographical distance.

The discovery of new species in Lebanon that have not been previously documented on cedars highlights the limited exploration, perhaps, of insects in the regions where cedars grow. It could also be due to the fact that some species are only discovered when their outbreaks occur, and they begin to pose threats to forests. The outbreak of *Cephalcia tannourinensis* in 1998 lead to its description as a new species not present in any other cedar forests, even the other fragmented cedar groves in Lebanon. This of course does not exclude the hypothesis that it has been present for a period of time unknown up until the outbreak, and neither does it exclude the fact that it could also be present elsewhere and has yet remained unnoticed. *Ernobius libanensis*, another species endemic to Lebanon, was discovered purely by accident after the *C. tannourinensis* outbreak, and it shares the same resources as *Dasineura cedri* which was also discovered by accident later in 2000. It is important to note that ongoing research has identified a potentially new species of *Acantholyda*, *A. nemeri*, hosted by Lebanon cedar. However, a formal description and publication are still forthcoming (Nemer, personal communication). These, mostly accidental, discoveries highlight the necessity for more extensive surveys of the entomofauna in Lebanese cedar forests that include all cedar groves seeing as most research has been done in Tannourine – Hadath El Jebbeh.

Understanding and protecting insect communities is important for maintaining a healthy forest ecosystem. Often viewed negatively as pests, mainly due to the economic losses they

cause, insects are part of many food webs participating in decomposition and nutrient cycling, pollination, predation, and bioindicators of ecosystem health. In fact, a decline in insect communities is an alarm signaling pollution and habitat loss, among others. The frequent discovery of new species endemic to Lebanon could be an indicator of species richness and diversity, which is a factor worthy of building on. So, we are presented with the need to expand taxonomic studies, such as phylogenetic research done on *Thaumetopoea* (Simonato et al. 2013), to identify and clarify the presence of more species associated with the already existing species specific to cedars in their natural range.

5.2. Current phytosanitary situation of cedar forests, specifically *C. libani*

The current *C. libani* distribution in Lebanon is limited, the species is assessed as vulnerable by the IUCN due to its restricted area of occupancy and declining habitat quality (Gardner 2013). Adding to that, the recent pest outbreaks and increase in mortality rates exacerbate their ecological state and put them on the brink of extinction should this pattern remain unchanged. A high percentage of the cedars in TNCFR were damaged due to the *C. tannourinensis* outbreak (70%) with 8% mortality, these numbers pose a serious threat given the already small number of cedar forests remaining in Lebanon. Moreover, pest management previously done to regulate the growth of this pest with IGR is no longer permitted in nature reserves in this region, therefore the risk of future sawfly outbreaks and consequential damages remain high. So far, the only measures taken have been the monitoring of the pest with little to no plan for outbreak prevention. Several studies have been done on the efficacy of EPNs against C. tannourinensis with successful in vivo and in vitro experiments using *S. feltiae* and *H. bacteriophora* (Rehayem et al. 2016, Rehayem et al. 2018), however implementations are yet to be made.

With the current and projected climate change effects, insects are expected to expand in range and density, and with the already present pests in Lebanese cedar forests, such as the Cedar processionary moth and the Cedar shoot moth, there is cause for concern vis-à-vis future outbreaks. In view of the cultural heritage and historical importance of this tree as the emblem of Lebanon, special attention ought to be given to its conservation and regeneration. At the same time, *C. atlantica* has been assessed as endangered by the IUCN (Thomas 2013) and has been in continuous decline due to increasing drought and severe attacks by pests such as *T. pityocampa*, *T. bonjeani* and the cedar bark beetle *Melanophila marmottani*. Recent studies pinpointed the presence of several natural enemies of *T. bonjeani* in Algeria which will prove effective in the control of the insect's population against outbreaks (Rahim et al. 2021b).

Despite the local efforts to conserve the current Cedar forests in Lebanon, they remain in danger due to past and current actions. The lack of suitable management plans implies a bigger issue relating to the authorities in charge and no clear stakeholder engagement. Moreover, the prohibition of proper silvicultural practices denotes a lack of knowledge and only short-term solutions that in fact hinder the attainment of healthy Lebanese cedar forests.

### 5.3. Prospects for the future

Land suitability analysis for the forests in Lebanon shows that *C. libani* is currently situated in moderately suitable land with the potential ecological niche being the slopes of the Anti-Lebanon Mountains. However, the projected land suitability is not very optimistic where unsuitable areas are predicted to increase by 2050 concluding that *C. libani* is in fact facing extinction risk with future climate change (Jezzini et al. 2023). Concern for the shrinking range of Cedar forest should be one of the top priorities of conservation initiatives and proper management plans. Studies also show that prescribed fire in combination with shelter-wood and strip clearcutting techniques can effectively restore Lebanon cedar forests (Boydak 2003). In some Turkish forests, prescribed fire is especially useful for increasing seedling survival and broadcast seeding has been shown to be 80% successful in reforestation of bare karstic terrain (Boydak 2003).

In the Atlas Mountains in Morocco, the situation of *C. atlantica* is dire. The resilience, migration rates, and capacity of *C. atlantica* to gradually recolonize new habitats should all be taken into consideration in long-term conservation efforts for the species. The Atlas cedar has traditionally adapted to shifting climates by living in micro-refugia, according to genetic and fossil evidence. But 70% of its existing woods will not be suitable in a scenario of climate change with a 2°C increase in temperature and a 20% decrease in precipitation (Cheddadi et al. 2022). The areas and populations that are most suited to adapt to changing conditions should be therefore given priority in effective conservation management. With the species assessed as endangered, efforts are directed towards the preservation of the remaining patched of cedar forests left and while present appropriate regions may eventually become unsuitable owing to continued climate change, expanding protected areas can help conserve biodiversity and endangered species (Cheddadi et al. 2022).

With several European countries utilizing *Cedrus* species for reforestation and commercial forestry purposes, attention should be given to land suitability and the risk of insect pests that exist locally to evolve to attack cedars as was already seen on *C. atlantica* in some areas in

France (Fabre et al. 1999). It might be that with the projected climate change effects areas that are now suitable for cedar plantations will shift upwards altitudinally and that factor should be also taken into consideration during reforestation, along with pest infestation risks also carried by warming temperatures. The common consensus thus far is that *C. libani* will most probably not pose a threat as an invasive species and does not have a highly competitive nature with other conifers in Europe (Messinger et al. 2015).

The two main forest laws in Lebanon are the Forest Code of 1949, which governs forest management under the Ministry of Agriculture (MOA), and Law 85 for forest protection, enacted in 1991 and amended by Law 558 in 1996. Under Law 558/1996, the MOA has designated over a dozen sites as national protected forests, where it prohibits various activities, such as camping, pruning, logging, grazing, and hunting, except for forest management and research activities (MOE/UNDP/ECODIT, 2011). With that in mind, silvicultural practices such as thinning, prescribed burning, and shelter-wood cutting could be integrated or made an exception to the law as it will benefit the regeneration and ultimately the overall health of cedar forests. The alarming state of the outbreak of *C. tannourinensis* in 1998 led to increased international awareness of the threats to relic forest ecosystems in Lebanon and the Mediterranean region. In 2003, a UNEP-GEF project funded an international and regional collaboration that aimed to protect newly identified insect pests from spreading and restore the Cedar forest reserve. The project, "Integrated Management of Cedar Forests in Lebanon in Cooperation with Other Mediterranean Countries," has enabled knowledge sharing and best practices for integrated forest management through scientific networks and is in line with the GEF Operational Program on forest ecosystems. The 36-month initiative covered Algeria, Cyprus, Morocco, and Turkey, and it was headed by the Lebanese Ministry of Environment in partnership with the American University of Beirut. The objectives were to preserve the biodiversity of Cedar forests and protect them from insect outbreaks (Sattout and Nemer 2008).

Albeit a redundant topic in the literature regarding Lebanon’s forests, one cannot stress enough the need to form an accord among stakeholder and begin the implementation of sustainable silvicultural measures and integrated pest management plans. Much more research needs to be done as well concerning the current knowledge of the entomofauna and potential new outbreaks in the future.

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