



## The entomofauna on *Eucalyptus* in Israel: A review

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**Key words.** *Eucalyptus*, Israel, invasive species, native species, insect pests, natural enemies

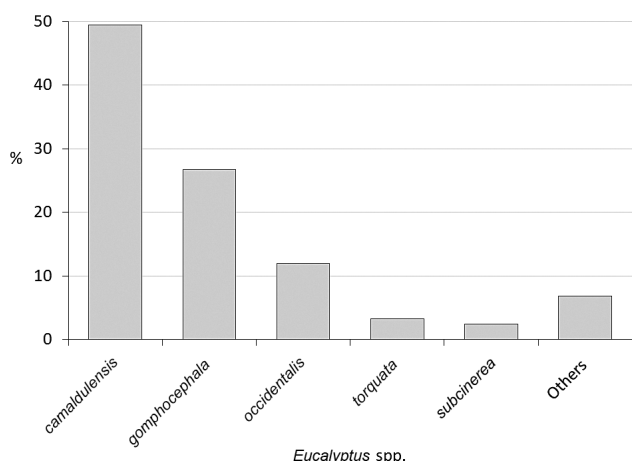
**Abstract.** The first successful *Eucalyptus* stands were planted in Israel in 1884. This tree genus, particularly *E. camaldulensis*, now covers approximately 11,000 ha and constitutes nearly 4% of all planted ornamental trees. Here we review and discuss the information available about indigenous and invasive species of insects that develop on *Eucalyptus* trees in Israel and the natural enemies of specific exotic insects of this tree. Sixty-two phytophagous species are recorded on this tree of which approximately 60% are indigenous. The largest group are the sap feeders, including both indigenous and invasive species, which are mostly found on irrigated trees, or in wetlands. The second largest group are wood feeders, polyphagous Coleoptera that form the dominant native group, developing in dying or dead wood. Most of the seventeen parasitoids associated with the ten invasive *Eucalyptus*-specific species were introduced as biocontrol agents in classical biological control projects. None of the polyphagous species recorded on *Eucalyptus* pose any threat to this tree. The most noxious invasive specific pests, the gall wasps (Eulophidae) and bronze bug (*Thaumastocoris peregrinus*), are well controlled by introduced parasitoids. Potential entomological hazards of *Eucalyptus* in Israel are most likely to originate from the Australian insect fauna.

### INTRODUCTION

The first *Eucalyptus* plants were brought from Australia to the West in 1770 (Doughty, 2000). The earliest eucalypt seeds that reached Israel (Palestine at that time) were those of the Tasmanian blue gum, *Eucalyptus globulus* Labill. Apparently none of these trees survived for long (Karschon, 1963). The first successful *Eucalyptus* stands were planted in Israel in 1884 at the Mikveh Israel agricultural school (near Tel Aviv), probably consisting only of river red gum *E. camaldulensis* Dehnh. In the following years this species became the main *Eucalyptus* used in the first large-scale plantations in Israel (Karschon, 1963). In the first decades of *Eucalyptus* planting in Israel, its role in draining swamps proved important in the struggle against malaria (Rosen, 1991) which at that time posed a major challenge in southern Europe, particularly around the Mediterranean (Bruce-Chwatt & Zulueta, 1980). In the last years of the 19<sup>th</sup> century 200,000 *E. camaldulensis* seedlings were planted in the Northern Sharon area (known as Hedera forest) to drain the local wetlands and manage the mosquito populations (Liphshitz & Biger, 2000). During those first 30 years, *Eucalyptus* comprised about a third of forest nursery production; its timber was harvested for agriculture and telephone poles and railway sleepers (El-Eini, 1999; Liphshitz & Biger, 2000). Subsequently, *Eucalyptus*, mainly *E. camaldulensis*, was extensively

planted in the Israeli low-altitude arid and semiarid lands. These stands form recreation areas, green belts surrounding neighbourhoods and agricultural areas, used for watershed management, sources of food for honeybees and a major source of timber and firewood. To date, *Eucalyptus* forests cover about 11,000 ha, half of which is planted with *E. camaldulensis* and much of the rest with *E. gomphocephala* DC (27%) and *E. occidentalis* Endl. (12%), the latter predominantly in desert or semi desert areas in the Negev (Fig. 1) (Anonymous, 2017). Some ninety-six species of *Eucalyptus* comprising between 2.5–5% of the total number of ornamental trees planted in public urban areas (about 25,000 ha) (Heller et al., 2017), 90% of which consist of *E. camaldulensis* (Nazarian, 2016).

A number of species of insects from the native range of *Eucalyptus* in Australia have been unintentionally introduced into *Eucalyptus*-growing regions throughout the world. An increasing number of insects native to the territories where *Eucalyptus* trees were planted outside Australia, especially in the southern hemisphere, have shifted onto these trees and achieved pest status (Paine et al., 2011). By the late 19<sup>th</sup> century, *Eucalyptus* forests were being planted in most of the Mediterranean Basin. Currently, three species, *E. camaldulensis*, *E. globulus* and *E. gomphocephala*, dominate the areas planted in the Western Mediterranean (Algeria, Italy, Morocco, Portugal, Spain



**Fig. 1.** Percentages of the different species of *Eucalyptus* planted in forests in Israel, which cover about 11,000 ha.

and Tunisia) which covers about 2.5 million ha. There is a lot of information about specific Australian invasive insects of *Eucalyptus* in the Mediterranean area (Kenis & Branco, 2010; Maatouf & Lumaret, 2012; Suma et al., 2018), but the presence of indigenous insects on *Eucalyptus* trees in these areas are rarely researched or reported.

Major threats to *Eucalyptus* plantations in Israel are posed by drought related to global warming, arson and invasive insect pests. By contrast, the overall damage to *Eucalyptus* in Israel caused by pathogens is limited and considered commercially insignificant. The present study reviews the information on the indigenous and alien invasive insects developing on *Eucalyptus* and their natural enemies in Israel.

**SOURCES OF DATA**

In this study, we processed and analysed both previous published records and the authors’ observations over the last thirty years.

**RESULTS**

Sixty-two phytophagous species of insects have been found on *Eucalyptus* in Israel, about 60% of which are indigenous; the remaining originate from different areas and of which 16% are Australian species (Fig. 2). Table 1 summarizes the information about fifty-two non-*Eucalyptus*-specific phytophagous insects occurring on *Eucalyptus* in Israel. None of these species are considered to be a major pest of this tree.

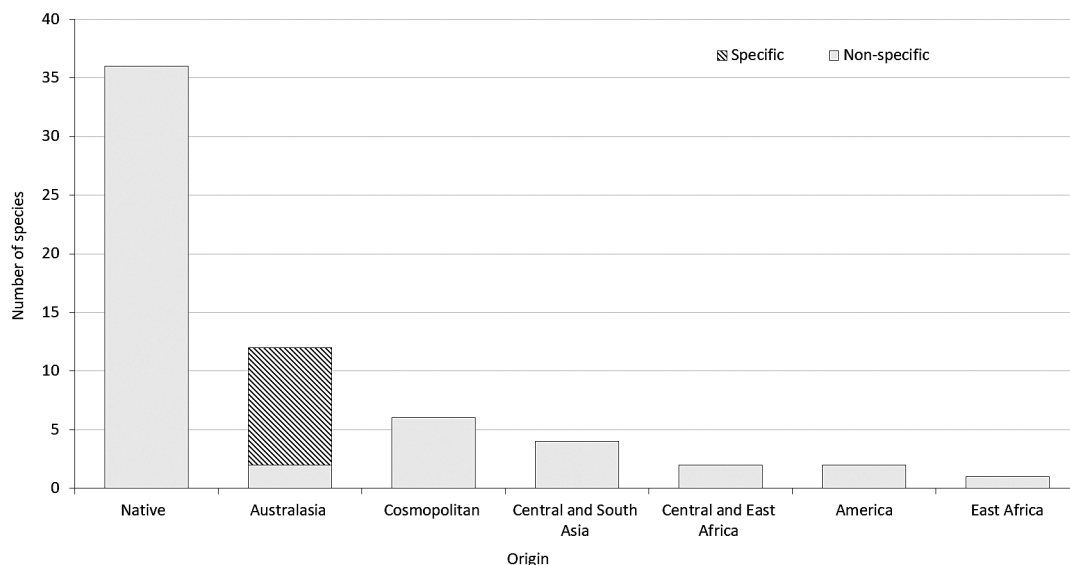
As expected, the insects living on *Eucalyptus* belong to different insect orders, with Hemiptera the major group and Coleoptera the second biggest group. Most of the Hemiptera are exotic, unlike the Coleoptera (Fig. 3).

Among feeding guilds, sap feeders constitute the largest group, followed by wood feeders (Fig. 4). Most of the insects were recorded from *E. camaldulensis* and it is very possible that those with no host record were also collected from this species of *Eucalyptus*. Few species were collected from several species of *Eucalyptus* and even fewer from species other than *E. camaldulensis* (Fig. 5).

Table 2 summarizes the specific invasive insects recorded on *Eucalyptus*. All ten species originated from Australia and seven of them were established in Israel in 2000. Among the eight phytophagous insect orders colonizing *Eucalyptus* there were no exotic species of Lepidoptera, Orthoptera or Isoptera (Fig. 3). Table 3 lists seventeen parasitoid species associated with the invasive *Eucalyptus*-specific species. Two species, *Rhoptrocentrus piceus* (Braconidae) (Halperin, 1976) and *Megastigmus leptocybus* (Torymidae) (Doganlar, 2015) are indigenous to Israel. Seven of the ten specific *Eucalyptus* insect species recorded in Israel are attacked here by one or more of their specific parasitoids (Table 3).

**DISCUSSION**

In Israel, as in many other countries, *Eucalyptus* trees are valued for their rapid growth and capacity for adapting

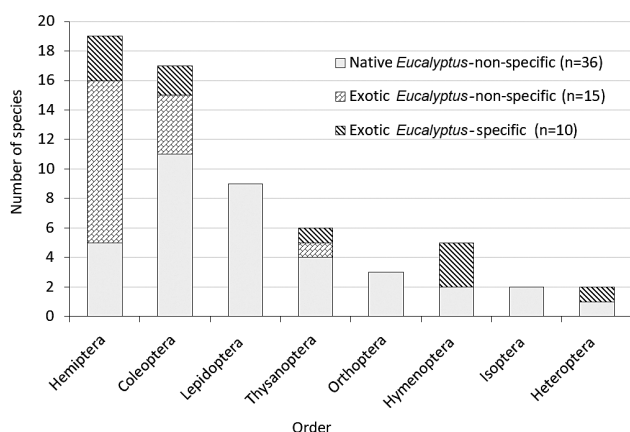


**Fig. 2.** Numbers of specific and non-specific species of the 62 phytophagous insects that occur on *Eucalyptus* in Israel according to their native area of origin.

**Table 1.** Native and invasive nonspecific phytophagous insects on *Eucalyptus* spp. in Israel.

Order	Family	Species	Origin	Feeding habit	<i>Eucalyptus</i> and <i>Corimbia</i> sp.	References
Coleoptera (15)	Curculionidae	<i>Achradidius milleri</i> (Tournier)	Native	Defoliator	<i>camaldulensis</i> + <i>gomphocephala</i>	Halperin, 1961a
		<i>Hypothenemus eruditus</i> Westwood	Cosmopolitan, invader	Wood feeder	<i>camaldulensis</i>	Authors' observ.
	Cerambycidae	<i>Prinobius myardi</i> (Mulsant)	Native	Wood feeder	spp.	Halperin & Holzschuh, 1993; Sama et al., 2010
		<i>Stromatium fulvum</i> Villers	Native	Wood feeder	sp.*	Halperin & Holzschuh, 1993
		<i>Penichroa fasciata</i> Stephens	Native	Wood feeder	<i>camaldulensis</i>	Sama et al., 2010
	Bostrichidae	<i>Apate monachus</i> Fabricius	Central and East Africa	Wood feeder	spp.	Peretz & Cohen, 1961
		<i>Scobicia chevrieri</i> (Villa & Villa)	Native	Wood feeder	<i>camaldulensis</i>	Halperin & Damoiseau, 1980
		<i>Trogoxylon impressum</i> (Comolli)	Native	Wood feeder	sp.	Halperin & Geis, 1999; A.-L. Fridman, pers. commun.
		<i>Lyctus africanus</i> Lesne	East Africa	Wood feeder	<i>gomphocephala</i>	Halperin & Geis, 1999
	Buprestidae	<i>Lyctus parallelocollis</i> Blackburn		Wood feeder	<i>maculata</i>	Halperin & Geis, 1999
		<i>Xyloperthella picea</i> Olivier	Native	Wood feeder	sp.	Halperin & Damoiseau, 1980
		<i>Acmaeodera pilosellae</i> (Bonelli)	Native	Wood feeder	<i>occidentalis</i>	Halperin & Argaman, 2000
	Tenebrionidae	<i>Anthaxia diadema</i> (Fischer)	Native	Wood feeder	<i>occidentalis</i>	Halperin & Argaman, 2000
		<i>Opatroides punctulatus</i> Brullé	Native	Wood feeder**	spp.	Halperin, 1961b; authors' observ.
	Hemiptera (16)	Aleyrodidae	<i>Aleurolobus marlatti</i> (Quaintance)	Native	Sucker	<i>camaldulensis</i>
Aphididae		<i>Aphis fabae</i> Scopoli	Native	Sucker	<i>camaldulensis</i>	Swirski & Amitai, 1999
		<i>Aphis gossypii</i> Glover	Native	Sucker	<i>camaldulensis</i> + <i>melliodora</i>	Swirski & Amitai, 1999
		<i>Myzus persicae</i> Sulzer	Native	Sucker	<i>camaldulensis</i>	Swirski & Amitai, 1999
		<i>Toxoptera aurantii</i> Boyer de Fonscolombe	Cosmopolitan, invader	Sucker	<i>camaldulensis</i> + <i>gomphocephala</i>	Swirski & Amitai, 1999
Coccidae		<i>Ceroplastes floridensis</i> Comstock	North America	Sucker	<i>camaldulensis</i> (greenhouse)	Authors' observ.
		<i>Parasaissetia nigra</i> (Nietner)	Africa	Sucker	<i>camaldulensis</i> (greenhouse)	Authors' observ.
Diaspididae		<i>Protospulvinaria pyriformis</i> (Cockerell)	Cosmopolitan, invader	Sucker	<i>camaldulensis</i> (greenhouse)	Authors' observ.
		<i>Aonidiella aurantii</i> (Maskell)	Central Asia	Sucker	<i>camaldulensis</i>	Avidov & Harpaz, 1969
		<i>Chrysomphalus aonidum</i> (Linnaeus)	South Asia	Sucker	sp.	Ben-Dov, 2012
Issidae		<i>Hemiberlesia lataniae</i> (Signoret)	Cosmopolitan, invader	Sucker	sp.	Ben-Dov, 2012
		<i>Agalmatium grylloides</i> (Fabricius)	Native	Sucker	sp.	Avidov & Harpaz, 1969
Monophlebidae		<i>Icerya purchasi</i> Maskell,	Australia	Sucker	<i>camaldulensis</i>	Authors' observ.
		<i>Icerya aegyptiaca</i> (Douglas)	South Asia	Sucker	<i>camaldulensis</i>	Authors' observ.
Pseudococcidae		<i>Planococcus citri</i> Risso	Southeast Asia	Sucker	<i>camaldulensis</i>	Authors' observ.
	<i>Pseudococcus viburni</i> (Maskell)	Australasia	Sucker	<i>camaldulensis</i>	Authors' observ.	
Heteroptera (1)	Pentatomidae	<i>Stenozygum coloratum</i> Klug	Native	Sucker	<i>camaldulensis</i>	Authors' observ.
Hymenoptera (2)	Megachilidae	<i>Megachile</i> sp.	Native	Defoliator	spp.	Halperin, 1961b
	Colletidae	<i>Hylaeus</i> sp.	Native	Pollen feeder	<i>ficifolia</i>	A. Dorchin, pers. commun.
Isoptera (2)	Rhinotermitidae	<i>Reticulitermes clypeatus</i> Lash	Native	Wood feeder	sp.	Halperin, 1973
	Termitidae	<i>Microcerotermes palestinensis</i> Spaeth	Native	Wood feeder	sp.	Halperin, 1973
	Erebidae	<i>Lymantria dispar</i> (Linnaeus)	Native	Defoliator	<i>camaldulensis</i>	Authors' observ.
	Geometridae	<i>Ascotis selenaria</i> (Denis & Schiffmüller)	Native	Defoliator	<i>camaldulensis</i>	Halperin & Sauter, 1991
	Lasiocampidae	<i>Pachypasa otus</i> (Drury)	Native	Defoliator	<i>camaldulensis</i> + <i>occidentalis</i>	Halperin & Sauter, 1991
Lepidoptera (8)		<i>Agrotis segetum</i> (Denis & Schiffmüller)	Native	Defoliator	sp.	Halperin, 1961b
		<i>Helicoverpa armigera</i> (Hübner)	Native	Defoliator	<i>camaldulensis</i>	Halperin et al., 1989
	Noctuidae	<i>Heliothis peltigera</i> (Denis & Schiffmüller)	Native	Defoliator	<i>camaldulensis</i>	Halperin, 1961b (as <i>Chloridea</i> ); Halperin & Sauter, 1991
		<i>Spodoptera exigua</i> (Hübner)	Native	Defoliator	<i>camaldulensis</i>	Halperin & Sauter, 1991
Orthoptera (3)	Acrididae	<i>Spodoptera littoralis</i> (Boisduval)	Native	Defoliator	<i>camaldulensis</i>	Halperin & Sauter, 1991
		<i>Anacridium aegyptium</i> (Linnaeus)	Native	Defoliator	<i>camaldulensis</i>	Halperin, 1961
		<i>Calliptamus barbarus palaestinensis</i> Ramme	Native	Defoliator	<i>camaldulensis</i>	Halperin, 1961
Thysanoptera (5)	Thripidae	<i>Dociostaurus maroccanus</i> (Thunberg)	Native	Defoliator	<i>camaldulensis</i>	Avidov & Harpaz, 1969
		<i>Florithrips traegardhi</i> (Trybom)	Native	Sucker	<i>camaldulensis</i>	Strassen & Kuslitzky, 2011–2012
	Phlaeothripidae	<i>Heliothrips haemorrhoidalis</i> (Bouché)	Tropic America	Sucker	<i>camaldulensis</i>	Halperin et al., 1989
		<i>Mycterotherrips acaciae</i> Priesner	Native	Sucker	<i>camaldulensis</i>	Strassen & Kuslitzky, 2012
		<i>Retithrips syriacus</i> Mayet	Native	Sucker	spp.	Strassen & Kuslitzky, 2012 and authors' observ.
		<i>Haplothrips gowdeyi</i> (Franklin)	Cosmopolitan, probably invader	Sucker	<i>camaldulensis</i>	Strassen & Kuslitzky, 2012

\* sp – single record, species of *Eucalyptus* was not indicated; \*\* feeds on rotten *Eucalyptus* wood.

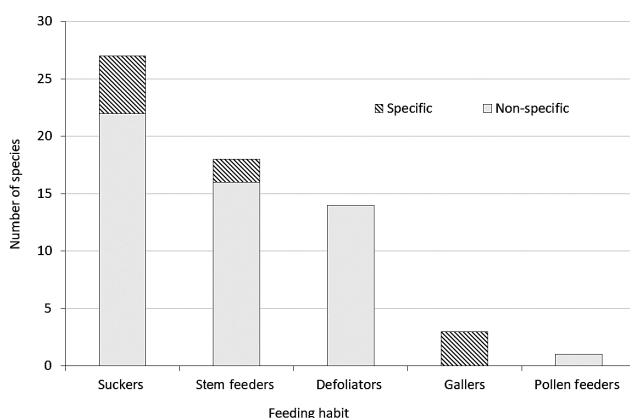


**Fig. 3.** Numbers of insects belonging to different orders of insects of the 62 phytophagous species of insects that occur on *Eucalyptus* in Israel according to their origin (indigenous vs exotic) and specificity to *Eucalyptus*.

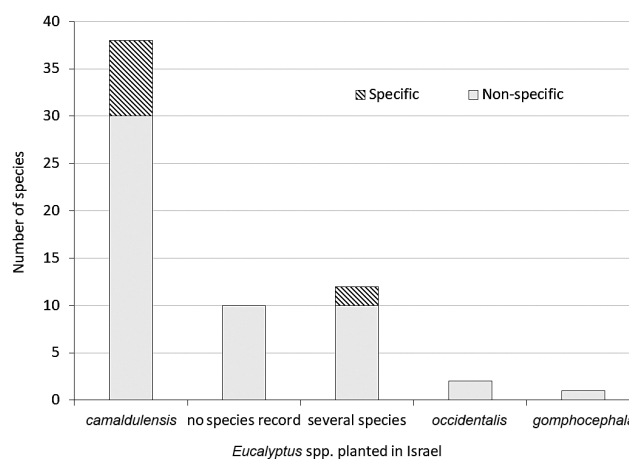
quickly to different climates. Generally, insect pests are not a major threat to *Eucalyptus* plantations in Israel. However, both invasive and indigenous species may become a problem in the future. Among the sixty-three phytophagous species of insects recorded so far on *Eucalyptus* in Israel, thirty-seven are native, twenty-six are invasive and ten of the latter are specific to *Eucalyptus*.

### Sapsuckers

Indigenous and invasive species of sapsuckers form the dominant group of insects on *Eucalyptus* in Israel. They are mostly found on *Eucalyptus* growing as ornamental trees in irrigated gardens, wetlands and along streams, which continue to grow during the long warm dry season. There are only slight changes in the cambial activity of *E. camaldulensis*, even under different climatic conditions or during different seasons of the year (Waisel et al., 1966). Water availability and an appropriate temperature regime are the main factors inducing seasonal changes in cambial activity (Kozłowski et al., 1991; Whitehead & Beadle, 2004). This may well account for the long growth period of *Eucalyptus* trees growing where the supply of water is adequate during the dry season and their suitability for sap-



**Fig. 4.** Numbers of the 62 phytophagous insect species that occur on *Eucalyptus* in Israel according to their feeding habit and specificity to *Eucalyptus*.



**Fig. 5.** Numbers of species of the 62 phytophagous insects that occur on *Eucalyptus* in Israel in terms of their recorded *Eucalyptus* host species in Israel and specificity to *Eucalyptus*.

suckers. In Israel, most of the sapsuckers are practically absent in planted forests where the trees only experience a short rainy season and consequently can only grow for a short period of time. Two of the *Eucalyptus*-specific sapsuckers, *Glycaspis brimblecombei* Moore and to a lesser extent *Thaumastocoris peregrinus* Carpintero and Dellapé are nevertheless still frequently recorded in forest plantations in the Northern and central areas in Israel (but see below for more about their biological control and pest status). The sapsuckers include six species of thrips, none of which are considered to be significant pests of *Eucalyptus*. Three are native; the invasive *Thrips australis* Bagnall (see below) is specific to *Eucalyptus*; *Heliethrips haemorrhoidalis* (Bouché) and *Retithrips syriacus* Mayet are minor pests of fruit trees.

The scale insects (10 species), thrips (5 species), aphids (4 species) and planthoppers (1 species) not specific to *Eucalyptus* (Table 1) are pests of many agricultural crops. However, their low frequency of occurrence on *Eucalyptus* indicate that these trees are not an important refuge for them or a significant source of these pests for agriculture. While the Hemiptera on *Eucalyptus* might constitute a refuge for their natural enemies, this possibility has yet to be studied.

### Stem borers

Coleoptera form the second largest group of *Eucalyptus* insects in Israel and includes the highest number of indigenous species. Most of the species are woodborers, which are polyphagous and develop in the dying or dead wood of *Eucalyptus* trees. Together with two termite species (Table 1), these wood feeders are common in *Eucalyptus* plantations, where they exploit an abundance of dying and dead wood. The invasive borers *Phoracantha semipunctata* (Fabricius) and *P. recurva* Newman occur in many other countries (Paine et al., 2010). Both borers are very common in Israel (Golan, 2011) and other Mediterranean countries (Rassati et al., 2016). The frequent occurrence of these borers is due to the abundance of reproductive substrate in the form of trees dying due to drought or forest

**Table 2.** Invasive *Eucalyptus*-specific phytophagous insects on *E. camaldulensis* in Israel.

Order	Family	Species	Feeding habit	Year of discovery	References
Coleoptera	Cerambycidae	<i>Phoracantha recurva</i> Newman*	Wood feeder	2001	Friedman et al., 2008
		<i>Phoracantha semipunctata</i> (Fabricius)*	Wood feeder	1945	Bytinski-Salz & Neumark, 1952
		<i>Blastopsylla occidentalis</i> Taylor	Sucker	2008	Spodek et al., 2015
Hemiptera	Aphalaridae	<i>Glycaspis brimblecombei</i> Moore	Sucker	2014	Spodek et al., 2015
		<i>Platyobria biemani</i> Burckhardt et al.	Sucker	2015	Burckhardt & Spodek, 2015
Heteroptera	Thaumastocoridae	<i>Thaumastocoris peregrinus</i> Carpintero & Dellapé	Sucker	2014	Mendel & Protasov, 2016; Novoselsky & Freidberg, 2016
Hymenoptera	Eulophidae	<i>Leptocybe invasa</i> Fisher & La Salle	Gall maker	2000	Mendel et al., 2004
		<i>Ophelimus maskelli</i> Ashmead	Gall maker	2003	Protasov et al., 2007a
		<i>Quadrastichodella nova</i> Girault	Seed gall maker	Before 1968	Boucek, 1977
Thysanoptera	Thripidae	<i>Thrips (Isoneurothrips) australis</i> Bagnall**	Sucker	1938	Strassen & Kuslitzky, 2012

\* Both *Phoracantha* spp. were also frequently collected from other species of *Eucalyptus* in Israel. \*\* In Australia, females feed primarily on the white flowers of various *Eucalyptus* species, and less commonly on those of other white-flowered Myrtaceae; adults may feed on plants of other families (Mound & Masumoto, 2005); first record in Israel was on flowers of *Prunus amygdali* (Halperin & Strassen, 1981).

fires, or fallen branches, the latter are frequently found beneath large *Eucalyptus* trees growing on wet sites. Neither these borers are primary pests of *Eucalyptus* in Israel and thus may serve as indicators of the physiological condition of the trees. There are many field studies on the resistance of *Eucalyptus* to *Phoracantha* (mainly *P. semipunctata*) (Chararas, 1969; Hanks et al., 1995), which indicate that the trees become susceptible to attack by these borers when they fail to cope with harsh environmental conditions, mainly as a result of drought. Dying *Eucalyptus* trees and dead wood are a refuge for polyphagous borers, e.g. the bostrichid *Apate monachus* Fabricius, which may switch to attack live trees of other genera, or the powder posts beetles *Lyctus* spp. and *Stromatium fulvum* Villers that damage timber and wood products. Generally, native Australian coleopteran borers have not become significant pests of *Eucalyptus* trees. However, a rather rich fauna of bark and ambrosia beetles have adapted to develop in *Eucalyptus* plantations in Brazil (Flechtmann et al., 2001), where many of these beetles are polyphagous and generalists, which is typical of many tropical species of scolytids. Lombardero and Fernández De Ana Magán (1997) report the presence of three native ambrosia beetles on *Eucalyptus* in Galicia (Spain), *Xyleborinus saxeseni* (Ratzeburg) and *Xyleborus dispar* (Fabricius) (Coleoptera: Scolytidae) and *Platypus cylindrus* (Fabricius) (Coleoptera: Platypodidae). Therefore, the rare occurrence of *Hypothenemus eruditus* Westwood on *E. camaldulensis* in Israel is not surprising (Table 1). Several species of cossid moths attack and breed on *Eucalyptus* in different areas outside Australia. *Polyphagozeira coffeae* Nietner and *Neurozerra conferta* Walker are recorded on *Eucalyptus* in south-eastern Asia (Yakovlev, 2011) and *Chilecomadia valdiviana* Philippi in Chile (Lanfranco & Dungey, 2001) and *Coryphodema tristis* (Drury) in South Africa (Gebeyehu et al., 2005) are serious pests of *Eucalyptus* in those areas. *Eucalyptus* trees are also frequently planted in deserts in the Northern Hemisphere (Teketay, 2000; Jeddi et al., 2009). Despite the fact that the Mediterranean is rich in species of cossids (Yakovlev & Dubatolov, 2013), there are no records of carpenter worms from *Eucalyptus* in this area. This is probably due to the absence of species of Myrtaceae that could serve as a source of species of cossids that could then develop on

*Eucalyptus*. The occurrence of Myrtaceae in the Southern Hemisphere probably facilitated the colonization of *Eucalyptus* there by cossids (Paine et al., 2010).

### Defoliators and Scarabaeidae

The defoliators form the third largest group with thirteen species, all of which are native. The eight species of Lepidoptera form the second largest taxonomic group of native species. None of the defoliators are serious pests of *Eucalyptus* in Israel and few are considered important pests of other crops. Minor damage caused by the weevil *Achradidius milleri* (Boheman) and a leaf cutting bee *Megachile* sp. to recently planted *Eucalyptus* in the Coastal Plain soon after planting in the Western Negev is reported by Halperin (1961a, 1973). *Megachile* spp. observed in late spring, during the nesting period of the bees, may also have caused some damage to young trees soon after planting (Halperin, 1961b). Two other native defoliators, the Moroccan locust *Doclostaurus maroccanus* (Thunberg) and the cypress false silk moth, *Pachypasa otus* (Drury), are considered minor pests in *Eucalyptus* stands in dry areas in Israel. Rarely, local small outbreaks of the Moroccan locust may affect pockets of *Eucalyptus* trees planted in the Jordan Valley. The locusts are attracted to these trees, which are planted in earthen constructions that collect floodwater by damming a gully or streambed along the roads. In this area, these trees are the sole green vegetation remaining during the summer months. The native area of the cypress false silk moth *P. otus* is between Italy, Armenia and Iran, with different tree hosts in the different environments (Battisti et al., 2016). In Israel, although *Cupressus sempervirens* L. is the main host it develops on *Eucalyptus* in semi-desert areas. The defoliation due *P. otus* often remains unnoticed. However, when the mature larvae descend in great numbers prior to pupation, they may cause public concern due to the sensitivity of some people to the urticating hairs that are on the first abdominal segment of the last instar (Battisti et al., 2016). Mansfield (2016) indicates that among the native colonizers, leaf chewers in particular, quickly colonize *Eucalyptus* trees. In Israel, aside from *D. maroccanus* and *P. otus*, other local defoliators are rarely found on *Eucalyptus*. There is only a single record of *Lymantria dispar* (L.) on *E. camaldulensis* in Hadera (central Coastal Plain of Israel). Rare outbreaks of this gypsy moth are reported here

on *Quercus calliprinos* Webb (Z. Mendel, unpubl. observ.). There are several reports of *Lymantria dispar* attacking *E. camaldulensis* in Italy (Roversi, 1995). Matsuki et al. (2001) also reports *Lymantria dispar asiatica* Vnukovskij feeding on a few species of *Eucalyptus*.

Although Scarabaeidae (Coleoptera) were not included in our survey, Ferreira et al. (1994) mention three species on *E. globulus* in Portugal; *Anoxia australis* (Gyllenhal), *Anoxia villosa* (Fabricius) and *Melolontha papposa* Illiger.

### Australian insects specific to *Eucalyptus*

Ten species of Australian insects specific to *Eucalyptus* are presently established in Israel. Most if not all occur in other Mediterranean countries and in other *Eucalyptus*-growing countries in the Americas and south Asia. *Thrips australis* was probably the first of this group to become established in this area. It is found both in Israel and elsewhere on many different plants and its females oviposit primarily on the white flowers of various *Eucalyptus* species (Mound & Masumoto, 2005). Until 2000 *P. semipunctata* was the best known *Eucalyptus* insect in Israel; it was unintentionally introduced from South Africa on shipments of *Eucalyptus* wood used for fortifications during the early 1940s (Bytinski-Salz, 1966). During the last two decades, eight other species became established in this country. *Phoracantha recurva*, three psyllid species and the bronze bug *T. peregrinus* arrived in Israel from the central area of the Mediterranean, but the route taken by two of the gall wasps and *T. australis* is not clear. *Leptocybe invasa* Fisher and La Salle was discovered here in 2000 (Mendel et al., 2004) and *Ophelimus maskelli* Ashmead in 2003 (Protasov et al., 2007b). The third gall wasp, *Quadrastichodella nova* Girault was collected in Israel before 1968 (Boucek 1977); Zdenek Boucek wrote: “In 1968, when visiting Dr Erdos in Hungary, I saw specimens which he collected in Israel.”; therefore, *Q. nova* could have been established here much earlier. Nine species develop on wide range of *Eucalyptus* species: *P. semipunctata* and *P. recurva* (Hanks et al., 1993), *G. brimblecombei*, *Blastopsylla occidentalis* Taylor (Luiz-Queiroz et al., 2012), *Platyobria biemani* Burckhardt et al. (Burckhardt et al., 2012), *T. peregrinus* (Wilcken et al., 2012), *L. invasa* (Mendel et al., 2004), *O. maskelli* (Protasov et al., 2007a) and *T. australis* (Mound & Masumoto, 2005). Similarly, while it is possible that *Q. nova* might develop on other genetically closely related congeners of *E. camaldulensis*, in reality, only *P. semipunctata* and *P. recurva* thrive on various *Eucalyptus* species growing in Israel. All other species mentioned above have been observed only on *E. camaldulensis*, including *L. invasa* and *O. maskelli* after the establishment of their natural enemies (Mendel et al., 2017).

### Management and natural enemies

In Israel, the management practices adopted, including chemical control and biological control, were directed against several species of the *Eucalyptus*-specific insects. The first management action was undertaken in the first half of the 20<sup>th</sup> century and aimed at preventing the damage caused by *P. semipunctata* to telephone poles, which

were then made of *Eucalyptus* trunks. To prevent damage by boring and powder post beetles (Lyctinae) the poles were impregnated with zinc chloride (Neumark, 1953). Later, a technique to protect fresh support poles made of *Eucalyptus* from damage by *P. semipunctata* was developed and extensively applied during the 1960s in fruit plantations in Israel. It consisted of spraying a 0.5% solution of lindane in a gasoil, which proved highly effective in eliminating or minimizing damage by borers (Chudnoff & Spetter, 1962). *Phoracantha semipunctata* was the first of the *Eucalyptus* pests for which classical biological control was used. Of the several species of parasitoids that were sent from Australia to Israel in 1982, three braconids, *Syngaster lepidus* Brullé, *Jarra phoracantha* Marsh & Austin and *Liodoryctes* sp., were released (Mendel et al., 1984b). For decades, there were no records of any of these parasitoids. In 2009 *Liodoryctes* sp. was recovered from a section of stem of *E. camaldulensis* colonized by both species of *Phoracantha* (Golan, 2011). *Closterocerus chamaeleon* (Girault), *Stethynium breviovipositor* Huber and *Stethynium ophelimi* Huber were collected in New South Wales, Australia for the control of *Ophelimus maskelli*; whereas *Quadrastichus mendeli* Kim & La Salle, *Selitrichodes kryceri* Kim & La Salle, *Megastigmus lawsoni* Doğanlar & Hassan and *M. zvimendeli* Doğanlar & Hassan were collected in Queensland, Australia, for use against *Leptocybe invasa*. Of these parasitoids six became established and successfully controlled the two gall wasps (Mendel et al., 2017). The establishment of *S. breviovipositor* is not yet confirmed. *Cleruchoides noackae* Lin & Huber, an egg parasitoid of the bronze bug, was sent to Israel from South Africa in 2017. It was released and subsequently high levels of parasitism of colonies of the bug were reported at several locations and very few bugs were observed in the summer of 2019 (Mendel & Protasov, in prep.).

Some of the most efficient Australian natural enemies fortuitously arrived and became established in Israel. *Phoracantha recurva* spread in the Mediterranean with its egg parasitoid *Avetianella longoi* Siscaro which was first reported in the central Mediterranean parasitizing *P. semipunctata* (Ben Jamaa & Dhahri, 2009; Longo et al., 1993). This wasp attacks the eggs of *P. semipunctata* (Luhning et al., 2004) more effectively than those of *P. recurva*. In Israel, it is frequently recovered from eggs of both *Phoracantha* species, with no apparent effect on their population density (Golan, 2011). Similarly, to what happened in other countries in the Mediterranean area, *Psyllaephagus bliteus* Riek establishment followed the arrival of *Glycaspis brimblecombei* Moore (Laudonia & Garonna, 2010; Boavia et al., 2016; Mendel et al., 2017). *Megastigmus zebrinus* Grissell was recorded recently together with its gall wasp host *Q. nova* (Mendel & Protasov, in prep.) but the time of their establishment is unknown. The list of parasitoids and the year of their initial discovery, or recovery in Israel, is detailed in Table 3. In general, native insect enemies have switched to attacking the Australian insects that develop on *Eucalyptus* in Israel, but usually their role in regulating their numbers is insignificant. Generalist predators that

**Table 3.** Parasitoids (Hymenoptera) of invasive specific phytophagous insects on *Eucalyptus camaldulensis*\* that were established in Israel by classical or fortuitous biological control ("a" indicates the year of discovery of both native and non-native species, "n" refers to native species, "b" indicates the year of recovery of the introduced species).

Family	Parasitoid	Host species*	Year of first discovery <sup>a</sup> or recovery <sup>b</sup> in Israel	References
Braconidae	<i>Liodoryctes</i> sp.	<i>P. recurva</i> , <i>P. semipunctata</i>	2010 <sup>b</sup>	Golan, 2011
	<i>Rhoproctentrus piceus</i> Marshall**	<i>P. semipunctata</i>	1983 <sup>a,n</sup>	Halperin, 1986
	<i>Syngaster lepidus</i> Brullé	<i>P. semipunctata</i>	1985 <sup>b</sup>	Mendel, 1987
Encyrtidae	<i>Avetianella longoi</i> Siscaro	<i>P. recurva</i> , <i>P. semipunctata</i>	2009 <sup>a</sup>	Golan, 2011
	<i>Psyllaephagus bliteus</i> Riek	<i>G. brimblecombei</i>	2018 <sup>a</sup>	Protasov et al., in prep.
Eulophidae	<i>Closterocerus chamaeleon</i> (Girault)	<i>O. maskelli</i>	2005 <sup>b</sup>	Protasov et al., 2007a
	<i>Selitrichodes kryceri</i> Kim & La Salle	<i>L. invasa</i>	2006 <sup>b</sup>	Mendel et al., 2017
	<i>Quadrastichus mendeli</i> Kim & La Salle	<i>L. invasa</i>	2006 <sup>b</sup>	Mendel et al., 2017
Mymaridae	<i>Stethynium breviovipositor</i> Huber***	<i>O. maskelli</i>	2006 <sup>b</sup>	Mendel et al., 2017
	<i>Stethynium ophelimi</i> Huber	<i>O. maskelli</i>	2006 <sup>b</sup>	Mendel et al., 2017
	<i>Cleruchoides noackae</i> Lin and Huber	<i>T. peregrinus</i>	2018 <sup>b</sup>	Protasov et al., in prep.
Torymidae	<i>Megastigmus lawsoni</i> Doğanlar & Hassan	<i>L. invasa</i>	2006 <sup>b</sup>	Mendel et al., 2017
	<i>Megastigmus zvimendeli</i> Doğanlar & Hassan	<i>L. invasa</i>	2006 <sup>b</sup>	Mendel et al., 2017
	<i>Megastigmus leptocybus</i> Doğanlar	<i>L. invasa</i> ****	2001 <sup>a,n</sup>	Mendel et al., 2017
	<i>Megastigmus zebrinus</i> Grissell	<i>Q. nova</i>	2019 <sup>a</sup>	Mendel et al., 2017

\* For more details see Table 2. \*\* Develops in various cerambycids. \*\*\* Recovery was recorded once, establishment was not confirmed. \*\*\*\* Not the original host.

typically prey on aphids and scale insects are frequently found in colonies of *G. brimblecombei* in Israel (Protasov et al., in prep.) and other areas (Erbilgin et al., 2004; Laudonia & Garonna, 2010). *Megastigmus leptocybus*, a local parasitoid has become fortuitously associated with *L. invasa* galls, but its rate of occurrence is low and it occurs in only one area in Israel (Protasov et al., 2008). Native *Megastigmus* spp. are frequently recovered from galls of *L. invasa* in almost every country where this insect has become established (Doganlar, 2015). Mendel et al. (1984a) report that the Syrian woodpecker is an important predator of larvae of *P. semipunctata* and *P. recurva*. Golan (2011) reports high levels of predation of adults of the latter borer by bats and aggregation of the adult borers on *Eucalyptus* trap trees.

To date, nine of the ten *Eucalyptus*-specific phytophagous insects are not considered significant pests of live trees. Both *Phoracantha* spp. are reported as secondary pests developing on dying trees, or cut timber. The psyllids, *B. occidentalis* and *P. biemani*, the thrips *T. australis* and the gall wasp *O. nova*, occur at very low densities and are usually undetectable. The two gall wasps *O. maskelli* and *L. invasa*, and the bronze bug *T. peregrinus* are controlled by introduced parasitoids. The red gum psyllid *G. brimblecombei* is still a nuisance on ornamental *E. camaldulensis* trees, as the level of parasitism is less than 5%, probably due to unfavourable climatic conditions during the main period of activity of the psyllid (Protasov et al., in prep.). *Psyllaephagus bliteus* was introduced into California in 2000 for the control of *G. brimblecombei* (Daane et al., 2005) and became established in Europe as a fortuitous biological control agent (Caleca et al., 2011; Perez et al., 2011). While in some tropical areas parasitism may be >90% (Filho et al., 2015), in the Mediterranean area *P. bliteus* has a minor role in regulating psyllid populations. Therefore, the biological control provided by *P. bliteus* is not sufficient to prevent outbreaks of *G. brimblecombei* (Daane et al., 2012; Boavia et al., 2016; Margiotta et al., 2017).

### Other *Eucalyptus*-specific species in the Mediterranean

Six other insects specific to *Eucalyptus* occur in the Mediterranean, but not in Israel. The potential hazard associated with these species is limited as they do not, or rarely attack the species planted here. *Ctenarytaina eucalypti* (Maskell) (Hemiptera: Aphalaridae) is narrowly host-specific, feeding only on a limited range of *Eucalyptus* spp. that originate from temperate Australia and Tasmania, and is unsuited to a warm Mediterranean climate. However, in Italy it was recorded in 1982 and was for almost 20 years the only psyllid species known to develop on *Eucalyptus* spp. (Suma et al., 2018). The parasitoid *Psyllaephagus pilosus* Noyes appears specific to *C. eucalypti* and was successfully introduced into California and Europe (Hodkinson, 1999). *Ctenarytaina spatulata* has been present in Europe since 2003 (Valente et al., 2004). Its favoured host trees are not common in Israel and its performance on *E. camaldulensis* is poor (Queiroz et al., 2010). Two species of *Eucalyptus* snout beetles occur in Europe. One of them, *Gonipterus platensis* Marelli is present on the Iberian Peninsula, where it mainly attacks *E. globulus* (Gonçalves et al., 2019) (an uncommon tree in Israel) and is well controlled by the egg parasitoid *Anaphes nitens* (Girault) in a warm Mediterranean climate (Valente et al., 2018). The second species is an undescribed *Gonipterus* sp. (*scutellatus* complex) (Mapondera et al., 2012), established in Sicily, recorded on *E. globulus* but not on *E. camaldulensis* trees growing nearby (Mazza et al., 2015). Three species of Australian gall wasps (Hymenoptera: Eulophidae) occur in the west Mediterranean. *Ophelimus mediterraneus* is exclusively associated with *Eucalyptus* species from the Maidenaria section and mainly found on *E. globulus* in Italy, France and Portugal (Borowiec et al., 2019). Another eulophid, *Epichrysocharis burwelli* Schauff was detected for the first time in 2015 in Almada, Portugal, causing leaf galls on *Corymbia* (formerly *Eucalyptus*) *citriodora* (Hook.) (Franco et al., 2016); *C. citriodora* is a common

ornamental tree in Israel. The third eulophid is *Leprosa milga* Kim & La Salle, a seed gall inducer found in 2006 in Apulia, Italy (De Marzo, 2008).

### Shift of local insects to *Eucalyptus* and *Eucalyptus*-specific species to local vegetation

Morphological classifications and molecular phylogenies suggest that the Myrtaceae family originated in Gondwana and most of its members naturally occur in the Southern Hemisphere and India (Thornhill et al., 2015). Native insects that have become pests on *Eucalyptus* outside Australia are generally either highly polyphagous, or have native Myrtaceae as their natural hosts. Insects in the latter group may be preadapted to shift to eucalypts as hosts (Paine et al., 2011). Brandle et al. (2008) suggest that after introduction the number of native species colonizing exotic plant species increases with time. However, as in California (Paine et al., 2011), the switch of a native herbivorous insect to becoming a serious pest of *Eucalyptus* in Israel is unlikely. Branco et al. (2015) examined 590 colonizations by native insects of exotic trees in Europe. These authors suggest that cases of major damage were positively correlated with the geographical extent of the exotic trees and the presence of congeneric native trees. The only Myrtaceae occurring in the Mediterranean basin are three *Myrtus* spp. that occur in the Mediterranean region of southern Europe, the Saharan mountains and Iran (Johnson & Briggs, 1981), none of which naturally occur in Israel. There is no information on the insect fauna of *Myrtus communis*, the most common native member of Myrtaceae in the Mediterranean area. About 12 insect species are listed on *M. communis* in Israel, including scale insects (7 species), thrips, aphids and whiteflies (Avidov & Harpaz, 1969; Y. Gottlieb, pers. commun.), all of which are polyphagous and most of them were also recorded on *E. camaldulensis* in our survey. None of the ten invasive species of insects specific to *Eucalyptus* (Table 2) are recorded occurring on *M. communis* in Israel. Furthermore, to the best of our knowledge, none of the specific phytophagous insects on *Eucalyptus* occur on members of tree genera other than *Eucalyptus* sensu lato in other areas. None of the *Eucalyptus*-specific species pose a threat to these trees in Israel, while the most noxious invasive species are well controlled by introduced parasitoids. Although the indigenous Australian insect fauna may constitute a potential threat to *Eucalyptus* in Israel, our experience suggests that their abundance can be controlled by the introduction of their specific natural enemies.

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