NOUREDDINE RAHIM[a] - GAHDAB CHAKALI[b] - ANDREA BATTISTI[c]

IMPACT OF NATURAL ENEMIES ON LARVAE OF *THAUMETOPOEA BONJEANI* (LEPIDOPTERA NOTODONTIDAE) IN ASSOCIATION WITH *THAUMETOPOEA PITYOCAMPA* IN NORTHERN ALGERIA.

[a] *École Nationale Supérieure de Biotechnologie, Ville universitaire Ali Mendjeli, BP E66, 25100 Constantine, Algeria.*
[b]*École Nationale Supérieure Agronomique, Avenue Hassan Badi, El Harrach 16030, Algiers, Algeria.*
[c] *University of Padova, DAFNAE Department, Via dell'Università 16. 35020, Legnaro (PD), Italy.*
Corresponding Author: Rahim Noureddine: n.rahim@ensbiotech.edu.dz or rahim.nouredine@gmail.com

Rahim N., Chakali G., Battisti A. - Impact of natural enemies on larvae of *Thaumetopoea bonjeani* (Lepidoptera Notodontidae) in association with *Thaumetopoea pityocampa* in northern Algeria.

The cedar processionary moth, *Thaumetopoea bonjeani* (Lepidoptera: Notodontidae), is a serious pest of the Atlas cedar *Cedrus atlantica* in north-western Africa and it is involved in the decline of this endangered tree species. Natural enemies of the cedar processionary moth are poorly known, especially for parasitoids, predators and pathogens of the larval-pupal life stages. Mature larvae were collected and examined in 2014 and 2015 in natural stands of Atlas cedar in the Djurdjura (northern Algeria), in occurrence with pine processionary moth *Thaumetopoea pityocampa*. The overall mortality rate of larvae of *Thaumetopoea bonjeani* ranged from 26.4% to 31.1%, with generalist predators and parasitoids being more effective than pathogens. Four primary parasitoid species were recorded, of which four tachinid flies and one braconid wasp, as well as four predatory beetles and one fungus. The most important species were the carabid *Calosoma sycophanta* and the tachinid *Compsilura concinnata*. The co-occurrence of *T. bonjeani* and *T. pityocampa* may offer to generalist natural enemies an extended period of availability of similar preys, as the two processionary moths have different life cycles. The sharing of natural enemies between the two species of *Thaumetopoea* can mitigate the outbreaks of both species.

KEY WORDS: *Cedrus atlantica*, processionary moth, Northern Algeria, parasitoid, predator, phenology

INTRODUCTION

The species of the genus *Thaumetopoea* (Lepidoptera: Notodontidae) are serious forest defoliators damaging cedar and pine plantations in the Mediterranean basin (ROQUES, 2015). Within the genus, there are two groups associated with conifers which are characterized by larval feeding in winter or in spring-summer, that is summer and winter processionary moths (BASSO *et al.,* 2016).

Two species of the genus *Thaumetopoea* occur In Algeria: The pine processionary moth *Thaumetopoea pityocampa* (Denis & Schiffermüller, 1775) and the cedar processionary moth *Thaumetopoea bonjeani* (Powell, 1922) (DEMOLIN, 1988).

Thaumetopoea pityocampa belongs to the group of winter processionary moths feeding on *Cedrus* and *Pinus* host plants (JACTEL *et al*., 2015). In Algeria, populations of this pest attack mainly, Aleppo pine (*Pinus halepensis* Mill.) in the semi-arid area and Atlas cedar (*Cedrus atlantica* Man.) in sub-humid elevation area stands causing considerable economic losses (SBABDJI *et al.,* 2009; SEBTI and CHAKALI, 2014; BATTISTI *et al.,* 2015). The expansion of this species in Algeria was favored by the Aleppo pine plantations along the Saharan Atlas as part of 'Barrage vert', established from 1965 to stop desertification (ZAMOUM *et al.,* 2015). *Thaumetopoea pityocampa* and *T. bonjeani* have a univoltine lifecycle (see Fig. I). In Algeria, the adults of *T. pityocampa* emerge, mate and lay eggs in a single clutch on pine needles or underside of cedar twigs in July at colder sites and in October at warmer sites (SEBTI and CHAKALI, 2014; ZAMOUM *et al.*, 2015). Embryonic development lasts for 30-45 days, the larvae live in aggregations and form a nest where they develop until springtime. In spring, late instar larvae make a procession to descend from the crown of pine trees before they bury into the soil and pupate. Some pupae have a prolonged diapause lasting 1-6 years (ZAMOUM, 1998; SALMAN *et al.*, 2019).

Thaumetopoea bonjeani is a major defoliator insect pest of cedars in the mountains of north-western Africa (Algeria and Morocco) (EL-YOUSFI, 1989; MOUNA, 2013; RAHIM *et al.*, 2016). This species is monophagous on the Atlas cedar *C. atlantica* whose populations are relictual and endangered in Algeria. Ecologically and phylogenetically, *T. bonjeani* belongs to the group of the summer processionary moths, such as *T. pinivora* (Treitschke) and *T. ispartaensis* (Doganlar & Avcı), which are adapted to high elevation/latitude (SIMONATO *et al.*, 2013; BASSO *et al.,* 2016). The adults emerge in August and September. After mating, females lay eggs which are covered with scales in a single clutch on the underside of *C. atlantica* twigs. First instar larvae are fully formed within the eggs by the end of autumn but the hatching occur in the following spring between March and April. All five larval instars live in aggregations with loose silk. Pupation occurs in June-July in the soil (RAHIM, 2016) and a prolonged diapause for several years may occur (GACHI, 1994).

The first outbreak of *T. bonjeani* was detected in Algeria in 1982 and since then extensive areas of cedar forests

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were defoliated (DÉMOLIN, 1988; GACHI *et al.,* 2005; RAHIM, 2016). These outbreaks reduce radial tree growth, lead to tree dieback after repeated defoliation, or make trees more vulnerable to secondary pests or pathogens (BATTISTI *et al.,* 2015). GACHI *et al*. (2005) reported that defoliation produced losses in total biomass up to 34% in moderately defoliated cedar trees and up to 50% in completely defoliated trees. The defoliation can contribute to the further decline of the relic stands of this conifer that are threatened by a shift to a drier climate (NAVARRO-CERRILLO *et al.,* 2019). In addition, *T. bonjeani* larvae have a social impact because of the release of microscopic urticating hairs (setae) present from L3 onwards. Contact with urticating setae can cause skin lesions of varying severity, respiratory problems and allergic reactions in both humans and other mammals (BATTISTI *et al.,* 2017; ROQUES, 2015; VASSEUR *et al.,* 2021).

Natural enemies are known to have great impacts on the population density of forest insect in various ecosystems (e.g., DUAN *et al*., 2014; ŽIKIĆ *et al*., 2017). Various natural enemies, including parasitoids (BONSIGNORE *et al*., 2015; TARASCO *et al*., 2015; ZAMOUM *et al.,* 2017; GEORGIEVA *et al.,* 2020; BOUZAR-ESSAIDI *et al.,* 2021; GEORGIEV *et al.,* 2021), predators, such as ants, beetles, spiders, insectivorous birds and pathogens (ZAMOUM *et al*., 2007; BATTISTI *et al*., 2000; BARTA *et al*., 2019; ERKAYA, 2020), might have a role in controlling processionary moth species. In the Mediterranean area, 18 parasitoids and approximately 14 predators have been reported as natural regulators of the most important forest pest, the pine processionary moth *Thaumetopea pityocampa* (BATTISTI *et al*., 2015). Nevertheless, information on the natural enemies of *T. bonjeani* in its natural range of distribution is mainly limited to egg parasitoids (RAHIM *et al*., 2016) and quantitative data on larval and pupal mortalities of the pest caused by parasitoids and predators is not available.

Given the recent increase in the frequency of *T. bonjeani* outbreaks in cedar forests of Algeria and the potential for more outbreak events to occur in the future (RAHIM, 2016), it is essential to quantify mortality caused by natural enemies. In this context, this work aims to (i) quantify mortality of mature larvae and pupae of *T. bonjeani* caused by natural enemies and (ii) understand how theses natural enemies could be affected by the co-occurrence of the two processionary moths (CPM and PPM) since they coexists together in cedar forest stands in an outbreak area of Djurdjura mountain in Algeria.

MATERIALS AND METHODS

SAMPLING SITES AND POPULATION DENSITY OF *T. BONJEANI* AND *T. PITYOCAMPA*

The study was carried out in 2014 and 2015 in two cedar stands located in the Djurdjura National Park (140 km southeast of Algiers, northern Algeria) under a sub-humid climate. Mean annual precipitation is approximately 1300 mm. The distance between the two forests is about 10 km. The first site, Tala-Guilef (36°29′N, 4°01′E, 1403-1825 m) is a natural stand of *C. atlantica* (age of trees: 20–150 years), where outbreaks of the summer processionary moth *T. bonjeani* are common. The second site, Tizi-Oujavoub (36°27'N 3°56'E, 1127-1219 m) is a planted stand of *C. atlantica* (age of trees: 32 years), where outbreaks of the winter processionary moth *T. pityocampa* are common.

The population density of *T. bonjeani* was estimated by counting the egg batches on 60 randomly selected trees along a linear transect as previously described by RAHIM *et al.* (2016). The population density of *T. pityocampa* was estimated by counting the number of winter tents (as previously described by FERRACINI *et al.,* 2020) on the same 60 trees used for the egg census of *T. bonjeani*

SAMPLING OF LARVAE OF *T. BONJEANI*

For each stand, mature larvae (fifth instar) of *T. bonjeani* searching for pupation into the soil were collected at Ca. biweekly intervals during June-July (corresponding to the pupation procession period and beginning of pupation phase).

Larvae were collected randomly along access roads to forests and at forest margins over 7-8 ha. In total, 3,468 larvae were collected with 1773 in 2014 and 1695 in 2015. In the laboratory, the larvae were divided in groups of 50 individuals in containers (15 x 10 x 12 cm) containing soil, covered with a net with a mesh of 1 mm and reared at 26±2°C until emergence of adult parasitoids or larval death or pupation. Pupal cocoons were removed from boxes and then pupae were placed individually in glass tubes (70 mm x 9 mm diameter) closed with cotton plugs, labeled and stored in the dark room at 24±2°C until parasitoids or adult moths emerged.

To determine the predation rate in the period of procession, mature larvae partially predated (chewing predators leave pieces of the skin, body and head capsule) were counted and removed every two weeks for the whole sampling area. Each predacious arthropod observed hunting or feeding on mature larvae during the sampling was collected carefully and transferred to laboratory for further rearing, to make sure that it was really associated with this stage of the pest.

STATISTICAL ANALYSIS

The percentage parasitism was calculated as number of insects in a sample from which parasitoids had emerged divided by the total number of insects in the sample. To compare the density of *T. bonjeani* (egg batches/tree), *T. pityocampa* (tents/per tree) and pupal mortality between sites and years, one-way ANOVA test was carried out after assessing for normality and homoscedasticity of the data. Chi-square (χ^2) test of the equality of distributions was used to compare the frequency of the parasitoid species between sites. All analyses were performed using SPSS v25 (IBM Corp., Armonk, N.Y., USA, 2017).

RESULTS

POPULATION DENSITY

During this study, the population density of *T. bonjeani* varied significantly between the two sites ($F_{1,\ 238}$ = 748.84, P<0.01), as revealed by the population census done on 60 randomly selected trees along the linear transect. The mean (±SD) density of egg batches of *T. bonjeani* per tree ranged from 7.2±2.5 to 11.2±3.1 in the natural stand of Tala-Guilef and from 0.3±0.1 to 0.5±0.1 in the planted stand of Tizi-Oujavoub (Table 1). By contrast, the population density of the winter pine processionary moth *T. pityocampa* occurring in the same area and on the same trees, was remarkably higher in the planted stand (range 2.2±0.7 to 2.4±0.8 tents/tree) than in the natural stand (0.3±0.1 to 0.4±0.2 tents/tree) (one-way ANOVA, $F_{1, 238}$ = 695.92, P<0.01) (Table 1).

Table 1 - Population density of *T. bonjeani* and *T. pityocampa* in the two study sites and years.

Site	Year	*T. bonjeani* Egg batches / tree	*T. pityocampa* Tents / tree
Tala-Guilef	2014	11.15±3.10	0.33±0.58
	2015	7.17±2.51	0.28±0.52
Tizi-Oujavoub	2014	0.47±0.65	2.35±0.61
	2015	0.33±0.60	2.20±0.66

MORTALITY FACTORS

Larval mortality was caused by several factors namely: (i) during larval-pupal-molt, (ii) diseases, (iii) parasitism, (iv) predation and (v) unknown factors. The overall mortality rate of larval-pupal molt of *T. bonjeani* ranged from 26.4% in 2014 to 31.1% in 2015 (mean 28.7%) in the natural stand of Tala-Guilef, and from 13.7% in 2014 to 17.1% in 2015 (mean 15.3%) in the planted stand of Tizi-Oujavoub. The difference was highly significant (one-way ANOVA, $F_{1, 72}$ = 102.06, P<0.01) (Table 2).

Fungal infections by *Beauveria* sp. (Deuteromycotina: Zygomycetes) varied from 4.1% to 5.8% (overall 4.9% of mortality) in Tala-Guilef, and from 2.3% to 3.0% (averaging 2.7%) in Tizi-Oujavoub, with not significant differences between the two forests sites (one-way ANOVA, $F_{1, 72}$ = 3.18, P =0.062).

Mortality of *T. bonjeani* caused by parasitoids decreased from 10.4% in 2014 to 8.3 % in 2015 (mean 8.3%) in the natural stand of Tala-Guilef and increased from 5.6% in 2014 to 6.9% in 2015 (mean 6.2%) in Tizi-Oujavoub, with highly significant difference between the two sites (one-way ANOVA, $F_{1, 72}$ = 30.44, P<0.01).

Predation was observed only in the natural stand of Tala-Guilef as from 4.2% to 6.8% (overall 5.5%) of sampled mature larvae were predated at the time of sampling.

Mortality of *T. bonjeani* caused by undetermined factors, which could not be attributed either to pathogens or parasitoids varied from 7.7% to 10.2% (averaging 8.9%) in Tala-Guilef, and from 5.1% to 7.9% (averaging 6.4%) in Tizi-Oujavoub, with significant differences between sites (one-way ANOVA, $F_{1, 72}$ = 21.33, P<0.01).

PARASITOID COMPLEX: SPECIES COMPOSITION AND RELATIVE ABUNDANCE

Five parasitoid species belonging to Hymenoptera (n=1) and Diptera (n=4) orders were identified: *Compsilura concinnata* (Meigen), *Exorista segregata* (Rondani), *Pales processioneae* (Ratzeburg), *Drino* sp. (near inconspicua) (Diptera: Tachinidae) and *Heterospilus* sp. (Hymenoptera: Braconidae). Other Diptera species were not yet identified (conserved as pupae). All parasitoid adults emerged in July to September in both of the studied years and sites (Table 3).

The frequency of the parasitoid species varied significantly between the two sites (χ^2=27.339, df=4, P<0.01) (Table 3). In the present study, parasitoids emerged only from prepupae, i.e. inside the cocoon and before the larval–pupal molt. Tachinid flies were the dominating parasitoids (95.3%) in both of the studied years and sites, with a total of 284 individuals emerged (Table 3). The parasitism for both sampled sites was largely driven by *C. concinnata*, accounting for about 50% of the total emerged parasitoids (range 48.9 to 52.8% in Tala-Guilef, and 44.5 to 54.1% in Tizi-Oujavoub), followed by *E. segregata*, accounting for 25.9 and 31.4% of all the parasitoids in Tala-Guilef and Tizi-Oujavoub, respectively. The tachinid *P. processioneae* was present only in the natural stand of Tala-Guilef, accounting for 12.1% of all the parasitoids (range 12 to 12.2%). *Drino* sp. (near *inconspicua*) was also more frequently recorded in Tala-Guilef, accounting for 8.1% (range 7.9-8.3%) of all the parasitoids. In Tizi-Oujavoub, *Drino* sp. (near *inconspicua*) was recorded only in 2015, accounting for 7.8% of all the parasitoids.

Parasitism by the braconid *Heterospilus* sp. was observed only in the planted stand of Tizi-Oujavoub in 2014, making up 12.1% of the total parasitoids. In addition, there were 2.8%-3.6% of unidentified dipterous parasitoids, which pupated but did not emerge as adults.

LARVAL PREDATORS

Four predators species were observed attacking and devouring mature processionary larvae of *T. bonjeani* during the larval procession: *Calosoma sycophanta* (Linnaeus) (Coleoptera: Carabidae), *Dermestes* sp. (Coleoptera: Dermestidae), *Hister thoracicus* (Paykull) (Coleoptera: Histeridae), *Ocypus olens* (Müller) (Coleoptera: Staphylinidae).

DISCUSSION

In our study, we found that the population density of *T. bonjeani* and *T. pityocampa* varied significantly between sites. The population density of the winter processionary moth *T. pityocampa* was higher in the artificial stand of Tizi-Oujavoub, which had a higher tree density, while the highest population density of the summer processionary moth *T. bonjeani* was found in the natural stand of Tala-Guilef. Forest parameters such as age, stand height and tree density are key factors affecting *T. pityocampa* densities. GÉRI *et al.* (1985) found that *T. pityocampa* tent density decreased with increasing tree density in pine forest. RÉGOLINI *et al.* (2014) showed that low densities of *T. pityocampa* are often associated with old natural forest sites that are often characterised by a greater tree height.

The pooled average parasitism from the two sites was less than 9%, but parasitism was the main known cause of mortality (33.7% of the overall mortality against 17.2% for pathogens, 16,5% for predation, and 32.7% for unknown factors, see Table 2). This mortality is similar to that reported on eastern cedar processionary moth *T. ispartaensis* in Turkey (9%, according to AVCI and KARA, 2002). The higher mortality observed in Tala-Guilef could be interpreted as a simple increase in probability of encountering the larvae by the parasitoid. According to Zovi et al. (2006), the effectiveness of parasitoids of the winter processionary moth *T. pityocampa* depends on the phase of the outbreak, with the highest percentages of mortality recorded at the high population density of the pest. A lower level of parasitism of several lepidopteran pests is commonly observed in non-outbreak periods (LESSELLS, 1985; MILLS and KENIS, 1991; QUAYLE *et al.*, 2003; CLEARY, 2004; PARITSIS *et al.*, 2012). At least five species of primary parasitoids (four Tachinidae and one Braconidae) were found associated with larvae of *T. bonjeani* in Northern Algeria. In the present study, the tachinids species were observed parasitizing *T. bonjeani* larvae in the last instar, when they leave the tree in a single file, head-to-tail procession, searching for soil sites suitable for pupation. In Morocco, only the tachinid fly *Exorista* sp. was obtained from the prepupating larvae of *T. bonjeani* (EL YOUSFI, 1994) while in Turkey, on the eastern cedar processionary moth *T. ispartaensis*, six species were listed. The most abundant parasitoid species in Algeria was *C. concinnata* and in Turkey *Blondelia nigripes*, both generalists. The specialist of summer processionary moths *P. processioneae* was found in both Algeria and Turkey, but with low frequency. However, it is commonly reported from Germany and Netherlands as dominant larval parasitoid of *T. processionea* (about 20% of mortality) (ZEEGERS, 1997). In Algeria, *E. segregata* and *C. concinnata* were also found to attack *T. pityocampa* (ZAMOUM *et al.*, 2017). The generalist parasitoids could be shared with the co-occurring *T. pityocampa*, although this species is characterized by a cohort of specific parasitoids in Algeria, causing higher mortality rates (14.1-45.7% according to locations and years) (ZAMOUM *et al.*, 2007). The braconid *Heterospilus* sp. is reported for the first time as parasitoid of *Thaumetopoea* species and it is likely to be shared with other hosts present in the planted stand (CHILETTO and PENTEADO-DIAS, 2016).

Predation was the factor determining the higher mortality in the natural stand, as predatory species were not observed in the planted stand of Tizi-Oujavoub. Predation of the larvae of *T. bonjeani* was caused by generalist beetles (carabid, dermestid, histerid and staphylinid) already known to feed on processionary moths (OĞURLU, 2000; ZAMOUM *et al.*, 2007; BATTISTI *et al.*, 2015; ZAEMDZHIKOVA and DOYCHEV, 2020). According to Caswell (2001), predation on advanced life stages of the lepidopteran pests can negatively affect population dynamics, given its immediacy to the reproductive stage. Predators of mature larvae or pupae can exert a strong control on forest Lepidoptera during endemic host densities maintaining populations at latency phase (TANHUANPÄÄ *et al.*, 1999, LIEBHOLD *et al.*, 2000). As the generalist predator *Calosoma sycophanta* was observed to prey on immature larvae of *Thaumetopoea* spp. (HALPERIN, 1990; BATTISTI *et al.*, 2015; DE BOER and HARVEY, 2020; CANDAN *et al.*, 2020) and it may control the population growth and prevent or delay outbreaks (OĞURLU, 2000). In Algeria, this carabid is known as larval predator of *T. pityocampa* (ZAMOUM *et al*., 2006) and *Lymantria dispar* (Lepidoptera: Erebidae) (MECELLEM, 2009). The occurrence of *T. pityocampa* with *T. bonjeani* may offer to predators an extended period of availability of similar preys, as the two species have different life cycles (Fig. I). It would be interesting to assess whether predators are equally effective against *T. pityocampa*, and if they respond efficiently to the host density. Temperature could also play a role, as *T. bonjeani* larvae are active during summer when temperatures are higher. According to PIMENTEL *et al.* (2006), invertebrate predators are expected to be more active on the summer than on the winter forms of *T. pityocampa* in Portugal.

Our study was carried out in areas where *T. bonjeani* and *T. pityocampa* coexisted and share the same host, suggesting that generalist parasitoids (e.g., *C. concinnata* and *E. segregata*) and predators (e.g., *C. sycophanta*) are able to exploit both species (Fig. I) and can play an important role in these areas in mitigating seasonal outbreaks of the two processionary species. The same can apply to other less frequent parasitoids, such as *Drino* sp. and *Heterospilus* sp., and to the entomopathogenic fungus *Beauveria* sp., which could be shared at the pupation sites in the soil (HALPERIN, 1990; BATTISTI *et al.*, 2000; ZAMOUM *et al.*, 2011; MIRCHEV *et al.*, 2012; MATEK and PERNEK, 2018; KOVAČ *et al.*, 2020). Under certain circumstances, one host species can sustain the community of natural enemies that may later exploit the other host species, given that the larvae of two species have different life cycles and different durations of the development (Fig. I).

In conclusion, the composition of natural enemy associated to *T. bonjeani* was rich in Algeria and composed mostly of generalists species. Ten species of natural enemies of the cedar processionary moth were found: five of parasitoids, four of predators and one species of fungus. Despite the limited spatiotemporal extent of our study, this research constitutes a first step towards understanding the potential role of natural enemies in regulating populations of this key herbivore of threatened Atlas cedar stands. Therefore, in order to understand the dynamics in population fluctuations of this pest in cedar forests, in our future work we will focus on assessing temporal variability in mortality caused by multiple natural enemies that attack eggs, larvae, pupae and adult stages across larger areas of the geographic distribution of *T. bonjeani*. Moreover, as *T. bonjeanii* coexists in the region with the winter pine processionary moth *T. pityocampa*, it would be very interesting to explore the species composition of both natural enemy complexes and the impact they may have on populations of their hosts and other native herbivores. Understanding these relationships could

Table 2 - Survival and mortality of *T. bonjeani* pupating larvae.

Site	**Year**	**Total number of individuals**	**Emerged adults % (N)**	**Pathogens % (N)**	**Parasitoids % (N)**	**Predators % (N)**	**Unknown % (N)**	**Total mortality % (N)**
Tala-Guilef	2014	1342	73.6 (988)	4.1 (55)	10.4 (139)	4.2 (57)	7.7 (103)	26.4 (354)
	2015	1303	68.9 (898)	5.8 (75)	8.3 (108)	6.8 (89)	10.2 (133)	31.1 (405)
	Total	2645	71.3 (1886)	4.9 (130)	9.3 (247)	5.5 (146)	8.9 (236)	28.7 (759)
Tizi-Oujavoub	2014	431	86.3 (372)	3.0 (13)	5.6 (24)	0	5.1 (22)	13.7 (59)
	2015	392	82.9 (325)	2.3 (9)	6.9 (27)	0	7.9 (31)	17.1 (67)
	Total	823	84.7 (697)	2.7 (22)	6.2 (51)	0	6.4 (53)	15.3 (126)
Overall		3468	74.5 (2583)	4.4 (152)	8.6 (298)	4.2 (146)	8.3 (289)	25.5 (885)

Table 3 - Insect parasitoids of *T. bonjeani* and their relative abundance.

			2014			**2015**			
Site	**Parasitoid**	**Emergence period**	**N**	**Frequency %**	**Mortality %**	**N**	**Frequency %**	**Mortality %**	**Overall mortality (%) (N)**
Tala-Guilef	*C. concinnata*	July-August	68	48.9	5.1	57	52.8	4.4	4.7 (125)
	E. segregata	July-August	38	27.4	2.8	26	24.1	2.0	2.4 (64)
	P. processioneae	July	17	12.2	1.3	13	12.0	1.0	1.1 (30)
	Drino sp.	July	11	7.9	0.8	9	8.3	0.7	0.8 (20)
	Diptera sp.	-	5	3.6	0.4	3	2.8	0.2	0.3 (8)
Tizi-Oujavoub	*C. concinnata*	July-August	13	54.1	3.0	12	44.5	2.8	0.7 (25)
	E. segregata	July-August	5	20.8	0.9	11	40.7	1.5	0.5 (16)
	Drino sp.	July	0	-	-	4	14.8	2.3	0.1 (4)
	Heterospilus sp.	September	6	25.1	1.4	0	-	-	0.2 (6)

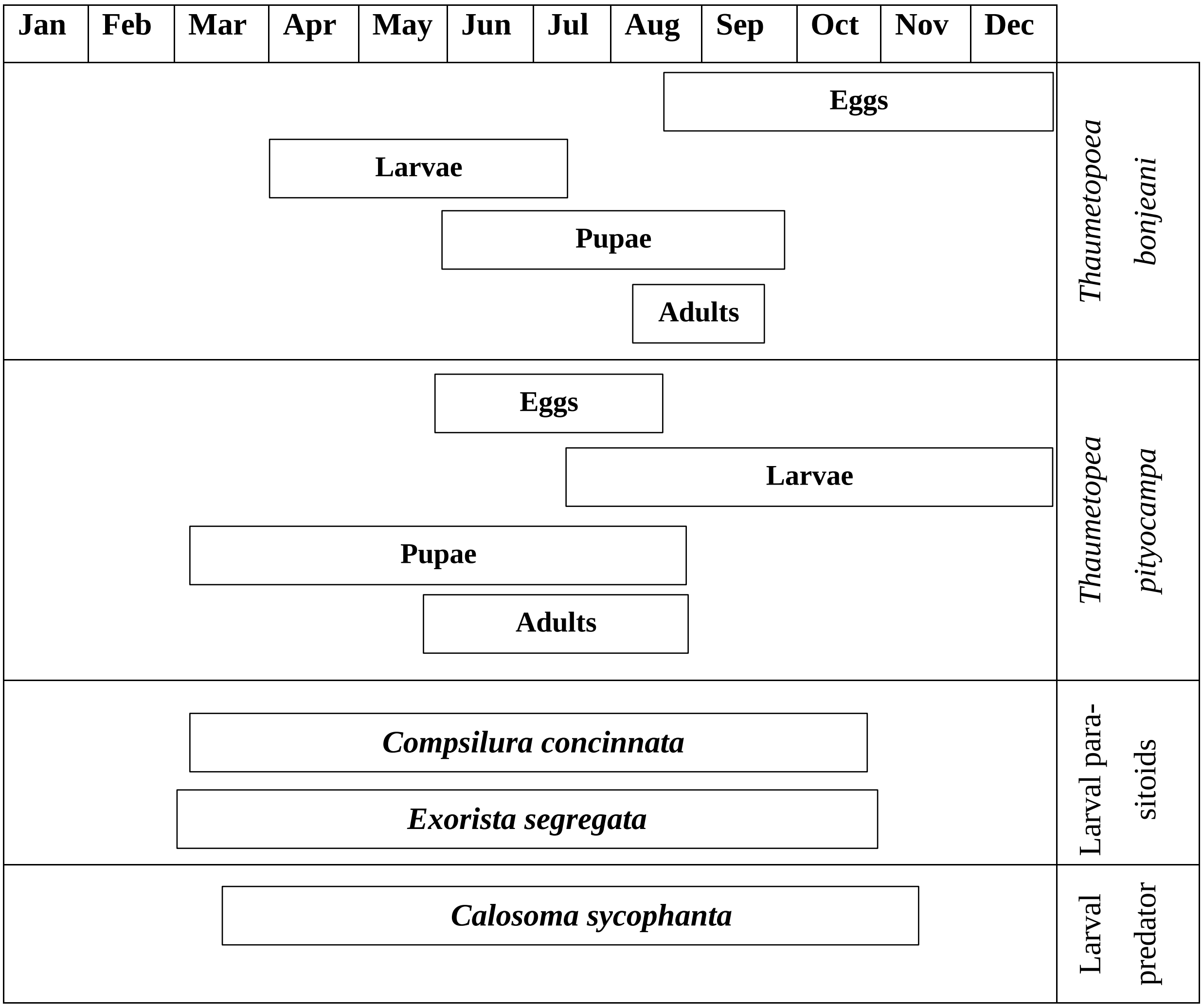

Fig. I - Life cycles of *T. bonjeani* and *T. pityocampa* in Atlas cedar stands of in Djurdjura and periods of activity of their larval parasitoids *C. concinnata* and *E. segregata*, and the predator *C. sycophanta*.

be a crucial step to improve the management of these economically and ecologically important pests.

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