Abundance and impact of egg parasitoids on the pine processionary moth (*Thaumetopoea pityocampa*) in Bulgaria

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We collected 2297 egg batches of the pine processionary moth (*Thaumetopoea pityocampa*) during the period 1991-2018 from 44 sites in Bulgaria. The sampling sites were classified into three groups according to *T. pityocampa* phenological form (early, late and both forms) as well as in two groups of its range (historical and newly colonized areas). Seven primary egg parasitoids were identified: *Ooencyrtus pityocampa*, *Baryscapus servadei*, *Pediobius bruchicida*, *Anastatus bifasciatus*, *Eupeplus (Macroneura) vesicularis*, *Eupelminus (Macroneura) vladimiri* and *Trichogramma* sp., and one hyper-parasitoid, *Baryscapus transversalis*. The average impact of egg parasitoids (the percentage of parasitized host eggs) on *T. pityocampa* in Bulgaria was 13.8%. The two main parasitoids, *O. pityocampa* and *B. servadei*, parasitized about 90% of the host eggs. The remaining parasitoids were of insignificant consequence to the parasitism of the *T. pityocampa* eggs, but in areas recently colonized by the pest, *A. bifasciatus* and *Trichogramma* sp. had a noticeable share (up to 33% of the impact). In old habitats of the host (areas colonized more than 10 years), the impact was almost two times higher than in new ones (15.3% vs. 8.6%). This could be attributed to *B. servadeii*, which was rare in newly colonized areas of *T. pityocampa* (impact 0.5%), but strongly dominant in old habitats (impact 7.2%). In contrast, *O. pityocampa* had a significant impact in new habitats (4.9%), which increased only slightly over time, reaching 6.0% in old habitats. There was no significant difference between the percentage of parasitism of the early and late form of the pine processionary moth (14.8% vs. 15.9%). However, there was a significant difference in the share of separate species in the parasitoid complex: in the early form,* B. servadei* definitely dominated (63% of the infested eggs), while in the late form *O. pityocampa* dominated, although not so strongly (52% of the infested eggs). This difference is most likely due to the phenological characteristics of the parasitoids and the two forms of *T. pityocampa*. *B. transversalis* secondarily infested about 5% of the eggs of *O. pityocampa* and *B. servadei*. This percentage was slightly lower for new habitats and habitats of the early form of pine processionary moth (3% and 4%, respectively). The impacts of the main parasitoids *O. pityocampa* and *B. servadei* as well as the total impact of the parasitoid complex as a whole decreased with altitude. Conversely, the impacts of *A. bifasciatus* and *Trichogramma* sp. slightly increased with altitude probably due to the reduced competition of the main parasitoids.

**Keywords**: *Thaumetopoea pityocampa*, Distribution, Habitats, Expansion, Phenological Forms, Egg Parasitism, Bulgaria

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**Introduction**

The pine processionary moth, *Thaumetopoea pityocampa* Denis & Schiffermüller, 1775 (Lepidoptera: Notodontidae) is among the most dangerous insect pests in pine forests. The northern border of its distribution passes through Bulgaria where two phenological forms of the species are widespread: the summer (early developing) and the winter (late developing – Tsankov et al. 1996, Mirchev et al. 2019). The abundance of *T. pityocampa* has been highly influenced by human activities. Since 1978, the annual size of its attacks in Bulgaria has increased five times as a consequence of the large-scale afforestation with black pine (*Pinus nigra* Arn.) and Scots pine (*P. sylvestris* L.) in the period 1950-1980 (Mirchev et al. 2011). Until the 1990s, the pest attacks remained limited to its historical range, where it has been known since the 1910s – southwestern and south central Bulgaria, both traditionally assigned to the Continental-Mediterranean and the European-Continental climatic zones (Savev & Stanev 1959). In 1991, economically significant attacks began in Central Bulgaria, northeast of the historical range. As a result, a stable expansion zone of *T. pityocampa* developed in Central Bulgaria, despite all control measures (Mirchev et al. 2018). The front of expansion is steadily moving east at a speed of about 2.5 km per year on the southern slope of the Balkan Range and in Sredna Gora Mt. Currently, the expansion zone coincides with Stara Zagora region (Zaemdzhikova et al. 2018). The egg parasitoids are the most signifi-
Table 1 - Characteristics of the studied localities of T. pityocampa and sampled biological material. (OH): old habitats; (NCA): newly colonized areas (new habitats).

| Habitat | N | Locality, District | Altitude (m a.s.l.) | No. sampling years | T. pityocampa range | Year of collection | Sampling (n) | Egg batches | Eggs |
|---------|---|---------------------|---------------------|---------------------|----------------------|-------------------|--------------|-------------|------|
| Early phenological form | | | | | | | | | |
| 1 | Dobrostan, Plovdiv | 850 | 1 | 2018 | NCA | | | 8 | 1740 |
| 2 | Dyulitsa, Kardzhali | 390 | 1 | 2016 | OH | | | 7 | 1815 |
| 3 | Domishhe, Kardzhali | 420 | 1 | 2016 | OH | | | 30 | 7164 |
| 4 | Drangovo, Kardzhali | 440 | 1 | 2016 | OH | | | 6 | 1348 |
| 5 | Dzherovo, Kardzhali | 460 | 1 | 2016 | OH | | | 20 | 4535 |
| 6 | Fotinovo, Kardzhali | 450 | 1 | 2018 | OH | | | 180 | 38202 |
| 7 | Kandilka, Kardzhali | 450 | 1 | 2018 | OH | | | 17 | 3780 |
| 8 | Kardzhali, Kardzhali | 400 | 1 | 1995 | OH | | | 67 | 13560 |
| 9 | Kayaloba, Kardzhali | 490 | 1 | 2016 | OH | | | 18 | 3337 |
| 10 | Medevtsi, Kardzhali | 470 | 1 | 2016 | OH | | | 30 | 6832 |
| 11 | Yanino, Kardzhali | 410 | 1 | 2016 | OH | | | 26 | 5428 |
| 12 | Hvoina, Smolyan | 950 | 1 | 1995 | NCA | | | 14 | 2350 |
| Late phenological form | | | | | | | | | |
| 13 | Asenovgrad, Plovdiv | 400 | 2 | 2016, 2017 | OH | | | 41 | 9455 |
| 14 | Banya, Plovdiv | 340 | 4 | 1992, 1993, 1996, 1999 | OH | | | 93 | 20565 |
| 15 | Garman, Blagoevgrad | 700 | 2 | 2016, 2017 | OH | | | 42 | 8839 |
| 16 | Gega, Blagoevgrad | 856 | 2 | 2017 | OH | | | 38 | 8226 |
| 17 | Gotse Delchev, Blagoevgrad | 830 | 2 | 2016, 2017 | OH | | | 51 | 11935 |
| 18 | Dikchan, Blagoevgrad | 900 | 3 | 2016, 2017, 2018 | OH | | | 107 | 24814 |
| 19 | Dupnitsa, Blagoevgrad | 725 | 2 | 1994, 1995 | OH | | | 56 | 13732 |
| 20 | Ilalovgrad, Haskovo | 285 | 5 | 2009-10, 2012, 2016, 2018 | OH | | | 145 | 39252 |
| 21 | Markostino, Blagoevgrad | 180 | 6 | 1991-1996 | OH | | | 329 | 76868 |
| 22 | Parvomai, Blagoevgrad | 450 | 3 | 2016, 2017, 2018 | OH | | | 90 | 20978 |
| 23 | Ploski, Blagoevgrad | 515 | 3 | 1991, 1992, 1994 | OH | | | 73 | 16211 |
| 24 | Satovcha, Blagoevgrad | 950 | 4 | 1994, 2000, 2002, 2008 | OH | | | 74 | 15890 |
| 25 | Sandanski, Blagoevgrad | 450 | 3 | 1994, 1997, 2017 | OH | | | 57 | 12792 |
| 26 | Maglizh, Stara Zagora | 365 | 2 | 2016, 2017 | NCA | | | 25 | 6529 |
| 27 | Klisura, Plovdiv | 710 | 3 | 2016, 2017, 2018 | OH | | | 96 | 22000 |
| 28 | Kurtovo, Plovdiv | 500 | 3 | 1991, 1995, 1996 | OH | | | 41 | 8979 |
| 29 | Kyustendil, Kyustendil | 1045 | 6 | 1994-95, 1997-99, 2014 | NCA | | | 96 | 14057 |
| 30 | Dilski Dozanastir, Kyustendil | 700 | 1 | 2016 | OH | | | 6 | 1478 |
| 31 | Vetren, Kyustendil | 680 | 3 | 2013, 2014, 2016 | NCA | | | 85 | 20950 |
| Common (both early and late phenological forms) | | | | | | | | | |
| 32 | Hisaria, Plovdiv | 415 | 2 | 2016, 2018 | OH | | | 59 | 15009 |
| 33 | Karlovo, Plovdiv | 535 | 1 | 2016 | OH | | | 8 | 2183 |
| 34 | Chirpan, Stara Zagora | 480 | 1 | 2017 | NCA | | | 13 | 2894 |
| 35 | Kazanlak, Stara Zagora | 475 | 1 | 2016 | NCA | | | 71 | 18010 |
| 36 | Dolno Sahrane, Stara Zagora | 450 | 2 | 2016, 2018 | OH | | | 40 | 9247 |
| 37 | Sladak kladenets, Stara Zagora | 400 | 1 | 2016 | NCA | | | 36 | 8279 |
| 38 | Lesichevo, Pazardzhik | 460 | 1 | 2016 | NCA | | | 11 | 2686 |
| 39 | Panagyurishte, Pazardzhik | 650 | 1 | 2016 | OH | | | 5 | 1418 |
| 40 | Peshtera, Pazardzhik | 640 | 1 | 2016 | OH | | | 10 | 2724 |
| 41 | Rakitovo, Pazardzhik | 1000 | 1 | 2016 | OH | | | 5 | 1242 |
| 42 | Momchilgrad, Kardzhali | 400 | 1 | 2018 | OH | | | 17 | 3639 |
| 43 | Zelenikovo, Plovdiv | 425 | 1 | 2016 | NCA | | | 20 | 5331 |
| 44 | Zhendam, Kardzhali | 400 | 2 | 2016, 2017 | OH | | | 34 | 8421 |
| | Total | | | | | | | 2297 | 509642 |

Significant biological factors regulating the number of the pine processory moth (Mirchev et al. 2005, Schmidt et al. 1999, Tsankov 1990). According to Masutti (1964), temperature is the major factor determining the favorable ecological niche of the main primary egg parasitoids – Ooencyrtus pityocampa Mercet (Hymenoptera: Encyrtidae) and Baryscapus servadei Domenichini (Hymenoptera: Eulophidae). In addition to temperature, a number of other biotic and abiotic factors are known to affect the impact of primary egg parasitoids: the hyperparasitoid Baryscapus transversalis Graham (Hymenoptera: Eulophidae – Bellin et al. 1990, Bellin 1995, Mirchev 2005), the vegetation diversity near the studied sites (Mirchev 2005), etc. Long-term studies have shown that adaptation time (i.e., the time after colonization of the area by the pine processionary moth) is also important for the development of host-specific parasitoids (Mirchev et al. 2017). The present work summarizes the case studies on T. pityocampa egg parasitoids made in Bulgaria. It is focused on the relative share and abundance of different species in the parasitoid complex, their impact on the pest and the peculiarities of the parasitism in new and old habitats, as
well as on the two different phenological forms.

Material and methods

The present work summarizes case studies made during 1991-2018 in 44 sites all over the range of the pine processionary moth in Bulgaria (Tab. 1, Fig. 1). The studied sites are located in an area of approximately 20,000 km². The distance between the southernmost site (Dzherovo) and the northernmost one (Klisura) is about 160 km, and between the westernmost and easternmost sites (Kyustendil and Maglizh, respectively) is 240 km.

The current range of the pine processionary moth in Bulgaria is outlined by the studied sites (Fig. 1). In the Sofia valley, the pine processionary moth occurs latently, in small numbers and without making attacks, due to the continental climate of the place. In the continental North of Bulgaria (i.e., the Danube plain, where pine plantations are rare) and on the northern slope of the Balkan Range, the pine processionary moth has not yet been reported. The pest is also absent to the east of the zone of expansion in South Bulgaria, including Burgas district on the Black Sea coast, strongly influenced by Mediterranean climate.

The biological material (2297 egg batches containing 524,724 eggs) included both single and multiple samples, with up to six generations of T. pityocampa (in Kyustendil and Marikostino). The egg batches collected at the individual sites ranged from 5 (Panagjurishte, Rakitovo) to 329 (Marikostino). The number of eggs in different sites varied from 1242 (Rakitovo) to 76,868 (Marikostino). Over the years, the material has been collected for different purposes. The predominant part of the studied biological material was collected in the historical range of T. pityocampa in Bulgaria. After the beginning of pest expansion, additional biological material was collected in the expansion zone. After establishing the early form, a number of studies were focused in these localities.

All sites were divided into three groups according to T. pityocampa phenological form: (i) early form habitats; (ii) late form habitats; (iii) both form habitats (i.e., where both early and late forms are present in the same area, sometimes on the same tree). In addition, in order to take into account the dynamics of the processes, the sampling sites were divided into: (i) old habitats (most of them), i.e., areas where T. pityocampa had been present for more than 10 years at the time of sampling; and (ii) new habitats, i.e., newly occupied areas where the pest had penetrated less than 10 years ago. For the same purpose, the sites were also divided into two other groups: (i) habitats from the historic range, where the pine processionary had been reported before 1991; and (ii) habitats from its expansion zone, which emerged in the Stara Zagora region in 1991 (Kazanlak, Sladak Kladenets, Chirpan, Dolno Sahrane, Maglizh). As the species has been expanding since the 1990s, it is important to note that there are new and old habitats in both the historic area and the area of expansion. The above subdivisions of the sampling sites were introduced to test for differences in the dynamics of the host and parasitoids in the different habitats.

Collected egg batches were transported to the laboratory of entomology at the Forest Research Institute in Sofia. The scales of the egg batches were removed, and the samples were analysed according to Tsankov et al. (1996). The egg batches were placed individually in test tubes covered by cotton stoppers and kept at room temperatures (20–22 °C). The samples were checked periodically and the emerged parasitoids were separated and identified under a stereomicroscope (40×). At the end of the experiments (10–12 months after sampling), the eggs were dissected and analyzed in detail.

The parasitoids that had emerged before sample collection were determined by their meconia and remains, according to Schmidt & Kitt (1994), Tanzen & Schmidt (1995) and Tsankov et al. (1996). The parasitoids emerged in the test tubes were identified by the following keys, according to the taxonomic group: Encyrtidae (Triapitzin 1978b, 1989); Eulophidae (Triapitzin 1978c, Graham 1987, 1991); Eupelmidae (Triapitzin 1978a, Fusui 2017); Trichogrammatidae (Nikolskaya & Triapitzin 1978). A part of the collected biological material was identified or confirmed by Dr. P. Boyadzhiev and Dr. M. Antov (Plovdiv University “P. Hilendarski”, Bulgaria) and Dr. E. Yegorenkova (Ulyanovsk State Pedagogical University, Russia).

In order to allow the comparison among different datasets, the average impact of the parasitoids (i.e., the rate of parasitism on T. pityocampa eggs) was chosen as the main indicator. In this way, the influence of different intensity of the research and the different number of repetitions in the different datasets is largely eliminated.

Statistical analysis was made using the package Statistica® v. 12.0 for Windows (StatSoft Inc., Tulsa, OK, USA). To compare the means, the t-test for independent samples was applied, with normality control.

Results

Seven primary egg parasitoids of the pine processionary moth were established in Bulgaria: Oencyrtus pityocampa Mertc, 1921 (Hymenoptera: Encyrtidae); Baryscapus servadei Domenichini, 1965; Pedilobius bruchicida Rondani, 1872 (Hymenoptera: Eulophidae); Anastatus bifasciatus Fonscolombe, 1832; Eupelmus (Macroneura) vesicularis Retzius, 1783; Eupelmus (Macroneura) vladimiri Fusui, 2017 (Hymenoptera: Eupelmidae) and Trichogramma sp. (Hymenoptera: Trichogrammatidae), and one hyperparasitoid, Baryscapus transversalis Graham, 1991.

The majority of the studied sites were dominated by O. pityocampa (19 sites, 43.2% – Tab. 2), followed by B. servadei (17 sites). A. bifasciatus was the dominant species in six localities (Dyulista, Hvoina, Garmen, Chirpan, Rakitovo, Vetren), and Trichogramma sp. in two (Dobrostan, Asenovgrad).

O. pityocampa had the highest impact (5.77%) on pine processionary moth, followed by B. servadei (5.69%), A. bifasciatus (1.23%) and Trichogramma sp. (0.52% – Tab. 3). The other three species of primary parasitoids (P. bruchicida, E. vladimiri and E. ves-
had a negligible impact on the host. They were found only in old habitats of *T. pityocampa* (Tab. 3).

The impact of egg parasitoids on the numbers of the pine processioneer moth varied within a fairly wide range in different localities, from 0.3% (Hvoina) to 31.6% (Dolno Sahrane - Tab. 2).

In old habitats, the greatest impact on *T. pityocampa* was due to *B. servadei* (7.20% - Fig. 2B), followed by *O. pityocampae* (6.03% - Fig. 2A), *A. bifasciatus* (11.2% - Fig. 2D) and *Trichogramma* sp. (0.30% - Fig. 2E). In newly occupied habitats, the most important was *O. pityocampae* (4.92% - Fig. 2A), followed by *A. bifasciatus* (1.62% - Fig. 2D), *Trichogramma* sp. (1.28% - Fig. 2E) and *B. servadei* (0.54% - Fig. 2B). The differences in the parasitoid impact in these two types of areas are statistically significant for *B. servadei* (p = 0.017) and *Trichogramma* sp. (p = 0.045), as well as for the hyperparasitoid *B. transversalis* (0.67% and 0.20%, respectively; p = 0.013 - Fig. 2C).

Significant differences of impact between early and late phenological forms of *T. pityocampa* were observed for two polyphagous species: *O. pityocampae* (3.12% and 8.27%, respectively; p = 0.012 - Fig. 3A) and *A. bifasciatus* (1.14% and 1.17%; p = 0.033 -
The relationship between the impact of parasitoids and the altitude of studied sites was established. The studies on the parasitoids were conducted with comparable fertility and habitat characteristics of pine processory moth. We found a small but significant difference in the average number of eggs per batch between early and late forms of T. pityocampa (209.16 ± 10.06 vs. 228.26 ± 5.79, respectively; p = 0.23), and between the new and old habitats of the species (225.64 ± 12.56 vs. 230.36 ± 4.80, respectively; p = 0.46 – Fig. 5). However, there was a significant difference in the average number of eggs of sites with both forms of pine processory moth (249.35 ± 5.82; p = 0.02) and the late form (p = 0.001) habitats.

The average altitude of the habitats in the expansion zone of T. pityocampa (429.00 ± 21.99 m a.s.l.) was lower than that of the habitats in its historical range (569 ± 35.28 m a.s.l.). This was expected, given that the

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**Tab. 3 - Average impact (%) of egg parasitoids of T. pityocampa in different zones of its range in Bulgaria.**

| Species            | Total (n=44) | Early form habitats (n=12) | Late form habitats (n=19) | Both early and late form habitats (n=34) | Old habitats (n=34) | New habitats (n=10) |
|---------------------|--------------|---------------------------|--------------------------|----------------------------------------|---------------------|---------------------|
| O. pityocampa       | 5.77 ± 0.78  | 3.12 ± 1.06               | 8.27 ± 1.34              | 4.56 ± 1.06                            | 6.02 ± 0.94         | 4.92 ± 1.32         |
| B. servadeii        | 5.69 ± 1.16  | 9.30 ± 2.95               | 5.04 ± 1.32              | 3.32 ± 1.88                            | 7.20 ± 1.40         | 0.54 ± 0.24         |
| B. transversalis    | 0.56 ± 0.09  | 0.40 ± 0.12               | 0.85 ± 0.16              | 0.28 ± 0.12                            | 0.67 ± 0.11         | 0.20 ± 0.10         |
| A. bifasciatus      | 1.23 ± 0.25  | 1.14 ± 0.66               | 1.17 ± 0.28              | 1.42 ± 0.44                            | 1.12 ± 0.27         | 1.62 ± 0.56         |
| Trichogramma sp.    | 0.52 ± 0.21  | 0.79 ± 0.74               | 0.54 ± 0.16              | 0.25 ± 0.12                            | 0.30 ± 0.09         | 1.28 ± 0.87         |
| P. bruchicida       | 0.0048 ± 0.0026 | 0.0025 ± 0.0018 | 0.0095 ± 0.0058 | 0 | 0.0062 ± 0.0033 | 0 |
| E. vladimiri        | 0.0068 ± 0.0068 | 0.0250 ± 0.0250 | 0 | 0 | 0.0088 ± 0.0088 | 0 |
| E. vesicularis      | 0.0032 ± 0.0024 | 0.0025 ± 0.0025 | 0.0053 ± 0.0053 | 0.0008±0.0008 | 0.0041 ± 0.0031 | 0 |
| All species         | 13.79 ± 1.25  | 14.79 ± 2.89              | 15.89 ± 1.35             | 9.81 ± 2.45                            | 15.33 ± 1.46         | 8.56 ± 1.52         |

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**Fig. 2 - Impact of egg parasitoids in different zones of T. pityocampa range. (A): O. pityocampa; (B): B. servadei; (C): B. transversalis; (D): A. bifasciatus; (E): Trichogramma sp.; (F): All parasitoid species.**
Fig. 3 - Impact of egg parasitoids on different phenological forms of *T. pityocampa*. (A): *O. pityocampae*; (B): *B. servadei*; (C): *B. transversalis*; (D): *A. bifasciatus*; (E): *Trichogramma* sp.; (F): All parasitoid species.

Fig. 4 - Influence of altitude on impact of egg parasitoids of *T. pityocampa*. (A): *O. pityocampae*; (B): *B. servadei*; (C): *B. transversalis*; (D): *A. bifasciatus*; (E): *Trichogramma* sp.; (F): All parasitoid species.
expansion zone is located more northwards than the historical zone, on average (Fig. 1). Such difference seems unlikely to be explained by the lack of sampling sites at high altitudes, as the expansion develops on the southern slope of Stara Planina, whose main ridges reach elevations not suitable to this pest.

The hyperparasitoid B. transversalis developed on O. pityocampaе and B. servadeii. Among the studied habitats, B. transversalis was not detected in nine locations (20.5%); four in sites with early form, and five in sites with both early and late forms (Tab. 2). The impact on primary parasitoids varied widely among sites from 0% up to 29.6% (Gotse Delchev). In nine localities, the impact on the number of primary parasitoids was above 10.0%, while it was between 5.1% and 10.0% in further nine localities, and below 5.0% in the remaining 26 localities. As for the relative share of polyphagous polyvotine generalist O. pityocampaе and A. bifiscatus in late phenological form of T. pityocampa, as well as Trichogramma sp. in newly colonized areas, could be explained with the possibility of gradual multiplication on alternative hosts in the studied habitats.

In recent decades, the expansion of T. pityocampa range to higher latitude and elevation due to climate change has been observed (Battisti et al. 2005, Auger-Rozenberg et al. 2015b). As for the two main parasitoid species of pine processionary moth (O. pityocampaе and B. servadeii), a decrease in parasitism rate with elevation has been established in a mountain range of Sierra Nevada (South-eastern Andalusia, Spain), with more severe decline for the specialist B. servadeii (Hödar et al. 2021). In Bulgaria, the impact of O. pityocampaе and B. servadeii also decreases at higher altitude, however it is not entirely negligible even near the upper limits of the host elevation range (about 1200 m a.s.l.). Conversely, the effectiveness of the other two significant parasitoids (A. bifiscatus and Trichogramma sp.) increases with increasing altitude, probably due to the reduced competition from O. pityocampaе and B. servadeii. This demonstrates their resilience and their ability to develop over a wider range of ambient temperatures.

In some habitats, the hyperparasitoid B. transversalis severely limits (up to 29.6%) the number of primary parasitoids O. pityocampaе and B. servadeii. The species is known from Greece (Schmidt et al. 1997, Tsankov et al. 1999) and other countries on the Balkan Peninsula: Bulgaria (Tsankov et al. 1996), Albania (Mirchev et al. 2000) and Bosnia and Herzegovina (Boyadzhiev et al. 2021). The higher impact of the polyphagous polyvotine generalist O. pityocampaе and A. bifiscatus in late phenological form of T. pityocampa is likely to have a major role in controlling the population of the pine processionary moth in the mountainous areas.
2015). It was also established on the Iberian Peninsula (López-Sebastián et al. 2003) and the Asian part of Turkey (Mirchev et al. 2000). Information that B. transversalis prefers B. servadei (Bellin et al. 1990, Bellin 1995) is not supported by other studies where no clear host selectivity has been established (Mirchev 2005). The impact of the hyperparasitoid on the two primary parasitoids is known to vary widely, from 0.5-3.0% (Tsankov et al. 1996, Schmidt et al. 1997) to 22.6% (Mirchev et al. 2000). These data are fully consistent with the results of this research and confirm the conclusion that there is great variability in the impact of the hyperparasitoid on the numbers of O. pityocampa and B. servadei in different habitats.

Conclusions

Our results confirmed O. pityocampa and B. servadei to be the two main egg parasitoids of pine processionary moth in Bulgaria. All the other parasitoids, mainly A. bifasciatus and Trichogramma sp., have a noticeable share (up to 33% of the parasitised eggs) only in areas recently colonized by T. pityocampa.

In old habitats of T. pityocampa (colonized more than 10 years ago), the impact of parasitoids is almost 2 times higher (15.2%) than in newly colonized areas (8.6%). This is due to the specialist B. servadei, which is rare in newly colonized areas (0.5%), but strongly dominates in long-established ones (7.2%). In new habitats of the host, the generalist O. pityocampa dominates (4.9%), B. servadei definitely dominates in the habitats of T. pityocampa early form (>50% of the parasitised eggs), while in the late form of the host, O. pityocampa dominates (>50% of the parasitised eggs). This difference is likely due to the phenological characteristics of the parasitoids and the host. The impact of the two most important species, O. pityocampa and B. servadei, and the parasitoid complex as a whole decreases with altitude. On the contrary, the impact of A. bifasciatus and Trichogramma sp. slightly increases with altitude, which might indicate their suppression by the main parasitoids.

In general, the parasitism of T. pityocampa eggs is a complex process that depends not only on the time of adaptation and the coincidence of the phenology of parasitoids to the phenology of the host, but also on many other factors such as population density of the pest, age and density of pine stands, local plant biodiversity, exposure, temperature conditions of the habitats, etc. Clarifying the complex influence of these factors is extremely important for the choice of silvicultural activities that would contribute to increasing the effectiveness of the parasitoids.

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