



# Flight of the Pine Processionary Moth *Thaumetopoea pityocampa* (Denis & Schiffermüller, 1775) (Lepidoptera: Notodontidae) in the Valley of Mesta, Bulgaria

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**Abstract:** In 2017 and 2018, the flight of the pine processionary moth (PPM) in the region of the town of Gotse Delchev (SW Bulgaria) was studied by pheromone traps. The flight period turned out to be long, 70-80 days. In the cooler summer of 2018, the flight of PPM was weaker in comparison to 2017. In both years, it began a week or two after the summer solstice on June 21 and ended on September 10. It took place during the hottest time of the year – July and August, and its peak preceded with a few days the annual culmination of local temperatures. From the observed flight times, a preliminary conclusion can be drawn that the area is occupied by the Mediterranean phenological form of the species, i.e. that the local population is winter-feeding. In both years of the study, a tri-modal distribution of flight over time was observed. There were three periods of 1–2 weeks of active flight with long breaks between them, during which only single males were captured. Various hypotheses that could explain tri-modality of PPM flight in the region are discussed. Of these, the most likely explanation remains the presence of populations with different phenological calendar near the sample area, which seems to be typical for high mountain regions.

**Key words:** *Thaumetopoea pityocampa*, phenology, ecology, Bulgaria

## Introduction

The pine processionary moth *Thaumetopoea pityocampa* (Denis & Schiffermüller, 1775) (Lepidoptera: Notodontidae) is reputed to be one of the most harmful needle-eating insects in pine ecosystems. The economic significance of the species is confirmed by the associated costs: in the period 2003-2019, about 60% of all treatment costs in coniferous forests in Bulgaria have been planned to control PPM (ZAEMDZHKOVA et al. 2019). The long-established range of the PPM covers southwestern and south-central Bulgaria, i.e. the lower parts of the Pirin and Rhodope Mountains and the neighbouring smaller mountains. In recent decades, under the influence of climate change (IPCC 2007, BATTISTI et al. 2005, 2006), PPM extends its range to the north – since 1995 in Central Bulgaria

(MIRCHEV et al. 2017, ZAEMDZHKOVA et al. in press), and more recently in the Sofia Valley in the central west part of the country (ZAEMDZHKOVA & DOYCHEV 2019). However, the majority (70.3%) of PPM attacks are still recorded in the old range in southwestern and south-central Bulgaria.

The present study area is the vicinity of the town of Gotse Delchev in the Mesta Valley, which is situated in the old range of PPM. The valleys of Struma (Strymon) and Mesta (Nestos) are the main habitats of the species in SW Bulgaria. PPM has been repeatedly studied in the Struma Valley (ZANKOV 1960, MIRCHEV et al. 2000, 2018). Although it is also widespread in the mountains along the Mesta Valley, on the east side of Pirin Mountain, it has not been the subject of study since Tsankov's work in the 1950s (ZANKOV 1960). Despite its importance as

**Table 1.** Monthly average air temperature in Gotse Delchev.

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Year	Monthly average temperatures, °C											
2017	2.5	11.6	17.0	18.6	22.6	27.2	29.6	32.3	27.4	21.0	12.2	9.5
2018	8.4	10.8	13.2	23.5	25.3	26.5	29.3	30.9	27.4	21.6	15.3	6.1

a pest, no contemporary studies have been conducted either on the biology and ecology of the species or on its distribution in the study area.

PPM is abundant in the Gotse Delchev region and occurs in the town itself. The town of Gotse Delchev is located in the south-eastern foothills of the Middle Pirin Mountains, at 545 m a.s.l. The climate of Mesta Valley is sub-Mediterranean. The area is considered vulnerable to climate change (RAEV et al. 2011). Pine forests near the town are mainly plantations (74%) of black pine and Scots pine (EFA 2015) planted in the 70's. At 545 m a.s.l., they are outside the natural range of both species (POPOV et al. 2018) and in poor health.

## Materials and Methods

In April-September of 2017 and 2018, Delta-type pheromone traps with adhesive bottom and pheromone dispenser were installed in the Gotse Delchev area. The site is a private property in the land of Borovo village, 3 km north of the town (41°35'34"N, 23°44'14"E, 538 m a.s.l.). Three pheromone traps were used in 2017 and two in 2018 (Table 1). The traps with the pheromone dispensers were installed on April 1<sup>st</sup> and removed on October 1<sup>st</sup>. The dispenser product used (Pityoprotect) contains the main component of PPM's sex pheromone (*Z*)-13-hexadecen-11-ynyl acetate. In normal weather conditions, the action of the dispenser lasts 120 days, i.e. 4 months. To be sure, we changed dispensers every 3 months. Traps' bottoms were changed when the number of caught specimens reached 20. The number of male moths caught was recorded daily.

To characterise the climate data, we used average monthly air temperatures provided by the weather station in the town of Gotse Delchev (Table 1).

## Results

In 2018, the flight of the pine processionary moth was weaker, with an average catch of 39 specimens per trap, while in 2017 we had 51 specimens per trap (Table 2).

The dynamics of the flight for the two years is presented in Figs. 1 and 2. It is seen that during the survey period the distribution of the caught specimens over time had multiple peaks, namely three.

**Table 2.** Males caught by year.

Year	Trap 1	Trap 2	Trap 3	Total	Mean
2017	69	37	48	154	51
2018	19	59	-	78	39

**Table 3.** Course of flight by years.

Observations	2017	2018	Mean
	Dates (day/month) or duration (days)		
1 <sup>st</sup> caught specimen	4/7	21/6	28/6
last caught specimen	10/9	10/9	10/9
absolute flight period	69	82	
1 <sup>st</sup> mass flight – beginning	6/7	30/6	
1 <sup>st</sup> mass flight – end	2/7	4/7	
1 <sup>st</sup> mass flight	7	5	
2 <sup>nd</sup> mass flight – beginning	5/8	20/7	
2 <sup>nd</sup> mass flight – end	13/8	31/7	
2 <sup>nd</sup> mass flight	9	12	
3 <sup>rd</sup> mass flight – beginning	3/9	20/8	
3 <sup>rd</sup> mass flight – end	9/9	2/9	
3 <sup>rd</sup> mass flight	7	14	
10 <sup>th</sup> percentile	8/7	30/6	4/7
90 <sup>th</sup> percentile	21/8	29/8	25/8
percentile-defined flight period	45	61	
50 <sup>th</sup> percentile (flight peak)	4/8	27/7	31/7

Three two-week active flying periods are observed, with two-week breaks between them, during which only single specimens are captured. Flight breaks give the characteristic step-like appearance of the cumulative distributions in Fig. 1 and 2.

The recapitulation of the flight dynamics over the two years is presented in Table 3: the absolute flight period, the three periods of mass flight and the percentile-defined flight period are presented. The absolute flight period is defined by the date of the first and the last insect caught for the season. The beginning and the end of the intermediate periods of mass flight were read from Fig. 1 and 2. In parallel, a flight period is defined using the 10<sup>th</sup> and the 90<sup>th</sup> percentiles of the cumulative distributions (Figs. 1 and 2). Flight culmination (the peak of the flight) was determined by the 50<sup>th</sup> percentile.

Fig. 3 is a graphical representation of Table 3, in which the periods are shown as intervals on the

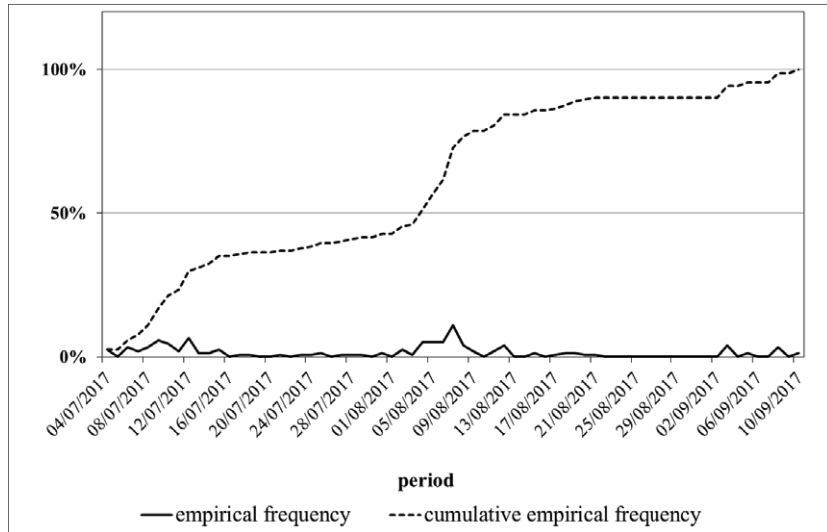


Fig. 1. Flight distribution by days in 2017.

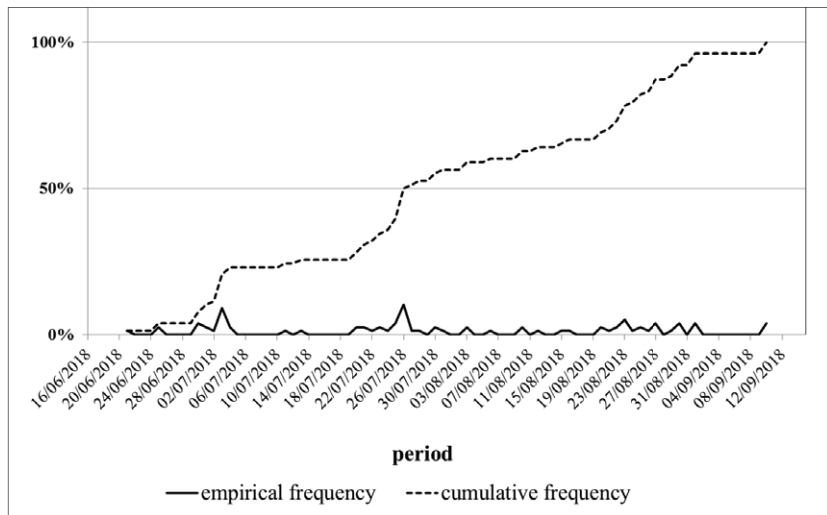


Fig. 2. Flight distribution by days in 2018.

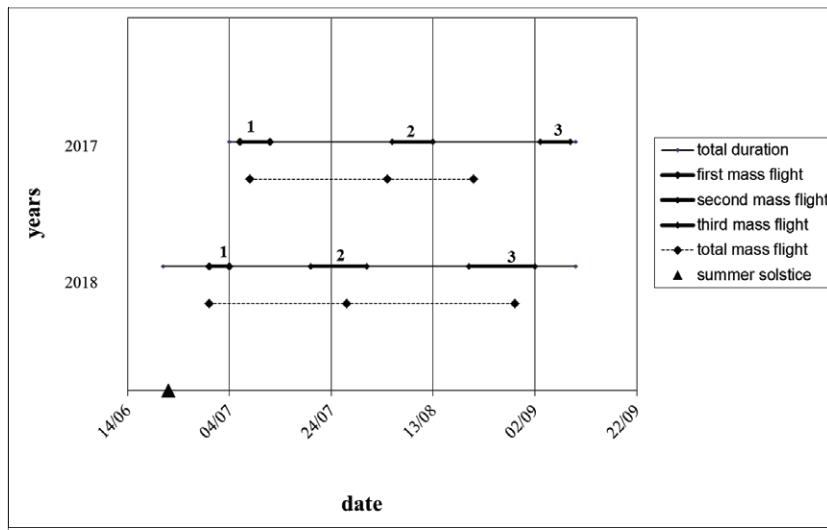


Fig. 3. Course of flight by years.

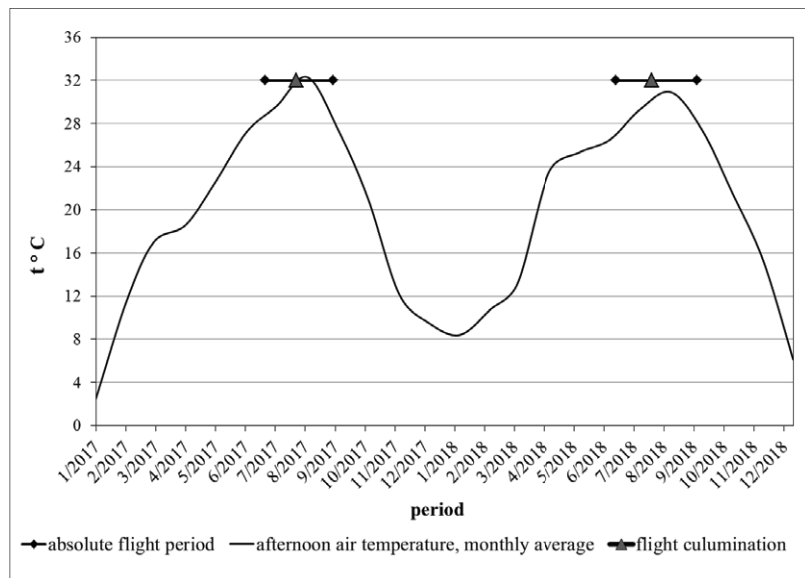


Fig. 4. Comparison of the flight period and the peak of flight with the temperature profile.

numerical axis. For the sake of clarity, the percentile-defined flight period, defined by the 10<sup>th</sup> and 90<sup>th</sup> percentiles, is shown on second parallel axes. The figure shows that in both years, the flight of the pine processionary moth began after the summer solstice. In both years the flight ended on September 10. Besides, Fig. 3 illustrates some difficulties associated with the presentation of multimodal distributions. For 2017, the 90<sup>th</sup> percentile inadequately determines the end of the flight period, placing it in the middle of a flight pause and ignoring the last flight activation.

In Fig. 4 the flight period has been plotted together with the air temperature profile of the region after Table 1. The flight period is given by the capture of the first and the last insect for the season, as well as by its peak. Fig. 4 shows that the flight invariably took place during the hottest time of the year, and also that its peak invariably preceded the annual culmination of local temperatures by several days.

## Discussion

According to our observations, the PMF flight in the study area occurs mainly from the beginning of July to the end of August, culminating on 31 July. In the cooler summer of 2018, the flight began and ended one week earlier than in 2017. These results are close to TSANKOV's observations made in Southwestern Bulgaria in the late 1950s using another method. Based on observations in laboratory conditions of cocoons collected in the Southwest Bulgaria (at Razlog in the valley of Mesta and Velingrad on the northern slope of the Rhodopes), TSANKOV

found that PPM flied in Southwestern Bulgaria from the second half of June to the beginning of August (ZANKOV 1960). These flight times are one or two weeks ahead than the observed by us. It is tempting to explain this difference with the climate warming, which would most likely delay the flight of the PPM. However, the later flight times observed may be also due to annual fluctuations in temperature, local temperature differences and differences in applied methods.

The flight times recorded by the present study are an indirect indication that the Gotse Delchev neighbourhoods are occupied by the winter (Mediterranean) form of PPM.

Similarly to Portugal (SANTOS et al. 2013), there are two phenological forms of PPM in Bulgaria (ZANKOV, 1960), i.e. the winter form (also known as Mediterranean) and the summer form (also known as continental form). Worldwide, much more widespread and long known is the winter form, which emerges and flies in late summer and continues its larval development in winter – the caterpillars remain in the nests and continue to feed. The relative rare summer form flies earlier in summer (in June), completes its larval development towards early autumn, leaves the nests and pupates in the soil and winters there. This behaviour saves it from extreme temperatures of winter that kill caterpillars in the branches but exposes it to extreme temperatures of mid-summer. It is unknown whether this different behaviour is genetically anchored. Because of this, the neutral terms „summer population” and „winter population” of PPM are also used.

In Bulgaria, the summer form is thought to fly in June, while the winter form flies in July and the following months (ZANKOV 1960). It follows that the population of the pine processionary moth in the vicinity of the town of Gotse Delchev is most likely to have winter feeding and larval development. In support of this assumption, it can be stated that the winter form is established in the Sandanski area in the Struma Valley, which is also characterised by sub-Mediterranean climate. Besides, it was a winter-feeding population found in Razlog in the Mesta Valley (ZANKOV 1960). So far, the pine processionary moth phenological form in the area of the town of Gotse Delchev is only judged by the flight time. It can be definitely proven by tracking the processions or dissecting the nests to determine if they were left before winter.

The late flight of PPM observed in the Bulgarian half of Mesta Valley is typical of the Mediterranean phenological form inhabiting areas with dry and hot summers. Like other insects adapted to this climate, PPM avoids high summer temperatures by postponing adult emergence until late summer (BATTISTI et al. 2015). The details are disputed and might prove regionally specific. According to DÉMOLIN (1969), temperatures above 32°C perturb physiological processes in eggs and larvae and cause epizootics. He considered that these effects are certain when the monthly mean of maximal temperatures is above 25°C. Recent studies on northern French populations showed that eggs are not affected by temperatures over 32°C (ROBINET et al. 2013), while studies in Portugal found that survival of L1 and L2 is reduced by temperatures of 36°C and 40°C, respectively (SANTOS et al. 2011). However, it is undisputed that heat-vulnerable larvae tend to hatch

after the highest summer temperatures (ROBINET et al. 2015). Taking into account the 30-45 days of egg development (HUCHON & DÉMOLIN 1970), the hatching of caterpillars in the Gotse Delchev area should have started in late August and early September with air temperatures well below 32°C. In September, when the mass appearance of L1 and L2 caterpillars is to be assumed, the average monthly temperatures were below 28°C.

An interesting detail is that the flight of the pine processionary moth in the Mesta Valley begins around the date of the summer solstice. This seems to be common to all winter populations of the pine processionary moth. Figure 5 and Table 4 provide an overview of the flight period of the pine processionary moth in countries with Mediterranean and oceanic climate (HUCHON & DÉMOLIN 1970, BOUHOT-DELDUC 2005, cited after BATTISTI et al. 2015). In all the populations depicted, flight begins around or shortly after summer solstice. An exception is the only summer population represented, the summer population of the pine processionary moth in Portugal, whose mass flight ends on that date. This astronomical attachment of the phenological calendar of PPM seems to be related to the culmination of sunshine around the date, which is the major factor controlling temperature. Averaged representative data on PPM flight duration in Bulgaria have not been published yet, but our results at the Gotse Delchev area show also a flight period starting after the summer solstice. Moreover, TSANKOV and MIRCHEV's opinion that the mass flight of the summer (continental) form of PPM in Bulgaria occurs essentially in June, is also in line with the flight of the summer form in Portugal (Fig. 5).

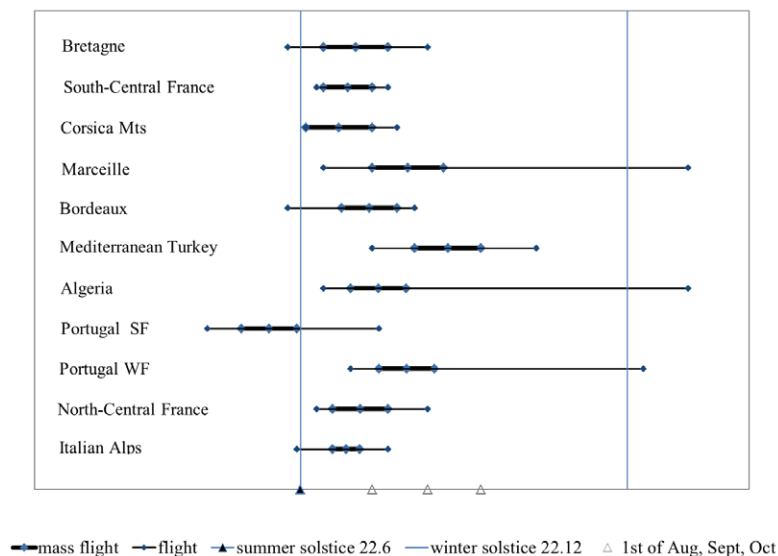


Fig. 5. Flight calendar of the pine processionary moth in different climatic conditions.

**Table 4.** Typical flight period of the pine processionary moth (BATTISTI et al. 2015).

Biogeographic zones	Flight beginning	Mass flight beginning	Mass flight end	Flight end
	Dates (day/month)			
Italian Alps	20/6	10/7	25/7	10/8
NC France	1/7	10/7	10/8	1/9
Portugal WF	20/7	5/8	5/9	1/10
Portugal SF	1/5	20/5	20/6	5/8
Algeria	5/7	20/7	20/8	25/10
Turkey	1/8	25/8	30/9	1/11
Aquitania	15/6	15/7	15/8	25/8
Provence	5/7	1/8	10/9	25/10
Mt. Corsica	25/6	25/6	30/7	15/8
SC France	1/7	5/7	30/7	10/8
Bretagne	15/6	5/7	10/8	1/9

The trimodal flight of the pine processing moth in 2017 and 2018 is likely to be a permanent feature in the Gotse Delchev area. This hypothesis is corroborated by the fact that some of the distributions established by TSANKOV are also trimodal. According to our unpublished data, multimodal distribution was observed in 2018 by MIRCHEV et al. for the Sandanski population.

There are various hypotheses that can explain tri-modality observed. Fluctuations in the flight may be related to fluctuations of summer heat. Adult emergence should be disturbed by unusually high temperatures since heat waves increase mating failures and decrease the overall reproduction success (ROBINET et al. 2013). According to literature, the factors triggering the end of pupal diapause are unknown. Nevertheless, the ability to postpone emergence during a hot wave would be an evident tool to improve the chances of leaving progeny and corresponds to the known plasticity of the species by which it insures itself against variability in temperature throughout the year in order to produce successful offspring.

Another factor that may be related to the periods of flight activation and decrease is that the males of the pine processionary moth travel considerable distances. For this reason, specimens from populations with different phenological calendars may be caught in the same trap. In this case, the multimodality of the flight distribution over time reflects the complexity of the habitat of the pine processionary moth near the traps. In favor of this assumption is the abundance of pine plantations in the vicinity of the town and the change in altitude from 500 to 2000 m within a radius of 15 km from the traps installed.

Two flight peaks are mandatory in areas where summer and winter populations of the pine processionary moth coexist, which occurs quite often in Bulgaria (MIRCHEV et al. 2019). This factor is unlikely to play a role in the case under study, however. As stated above, there is probably no summer (continental) population of the species near the studied area, because no massive June flight of the pine processionary moth is observed.

A possible reason for a separate early flight peak may also be a significant number of pupae that have undergone perennial diapause. The pupae remaining in the ground for several years have more time to develop and may be ready to emerge earlier than the others. Particularly significant is the number of pupae remaining in a perennial diapause in mountain habitats (SALMAN et al. 2016). However, this factor would rather result in a bimodal distribution rather than the observed tri-modal one.

## Conclusions

The flight of the pine processionary moth in the Gotse Delchev region in 2017 and 2018 took place mainly in July and August, culminating in the end of July or the beginning of August. From this, a preliminary conclusion can be drawn that the area is occupied by the winter-developing Mediterranean form of the species. In both years of observation, the flight distribution by time was tri-modal, with clearly distinguished activation periods at the beginning, the middle, and the end of the period and pauses between them. The most likely explanation of tri-modality observed is the presence of populations with a different phenological calendar within the range of the traps.

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