AN INDICATOR SPECIES OF GLOBAL WARMING IN BULGARIA

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Abstract

The pine processionary moth *Thaumetopoea pityocampa* (Denis & Schiffermüller, 1775) (Lepidoptera: Notodontidae) is one of the main pests in pine forests and an indicator species for global warming. Its expansion in Europe is considered one of the signals for changing climate. While other countries in the species range have a Mediterranean or oceanic climate, Bulgaria has a predominantly continental climate, which allows to see the pine processionary in a different light. For example, in Bulgaria, climate change is not causing expansion, but rather a habitat shift.

Key words: *Thaumetopoea pityocampa*, pine processionary moth, habitat shift, altitude, aspect, summer populations

Introduction. The pine processionary moth (PPM) is commonly sighted in the form of an awful hairy caterpillar, poisonous to animals and humans. In the wild, only tits and cuckoos feed on it. Unlike most insect pests, PPM caterpillars are social creatures – after hatching, they remain together, build a common silk filament nest (“a tent”) in the pine branches and leave it only at night for feeding (they feed on the pine needles). When they complete their development, they leave the tent in a procession to which the species owes its name, each caterpillar

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hiding its head in the hairs of the tail of the caterpillar in front of it. They search for a section of open ground where they disperse, burrow underground and pupate. The adults emerge from the pupae after a few months, at least two, in the early or mid-summer. They fly for one-two days during which they manage to copulate and lay eggs. The eggs hatch after a month and a half and the cycle repeats.

Like in Portugal [1], there are two phenological forms of PPM in Bulgaria: the winter (or Mediterranean) form and the summer (or Continental) form. The difference is that one flies a month or two earlier – in May-June, it manages to complete its development in the fall of the same year and goes down to earth before the cold. Its nourishment and growth take place in the summer and it is therefore called summer form. The other flies later, the cold finds it in the tents, where it vegetates until spring – its development slows down – and manages to pupate in April. It continues to feed in winter, and is, therefore, called winter form. The early development saves the summer form from extreme temperatures of winter, but exposes it to extreme temperatures of summer. It is unknown whether this different behaviour is genetically anchored. Because of this, the neutral terms “summer” and “winter population” of PPM are often preferred. Worldwide, the winter form is much more widespread and has long been known. Bulgaria is unique with the high occurrence of the summer form – about 1/3 of the sites investigated.

In recent decades, a worldwide vertical and horizontal expansion of PPM range to the north and to higher altitudes is being reported [2], also in Bulgaria [3]. Until 1995, economically significant attacks of PPM occurred in Bulgaria only in its sub-Mediterranean southernmost regions (“the old range”), which covers the low parts of the Rila, Pirin and Rhodope Mountains in South Bulgaria. In 1995, economically significant attacks began in sub-continental Central Bulgaria. An expanding new habitat emerged (“the expansion zone”), which currently coincides with the Stara Zagora Province [4]. The PPM range is depicted in Fig. 1. The colour of the pixels denotes the presence or the absence of the species. The boundary between the old range and the area of expansion corresponds to the Kalofer hills that stopped the PPM spread for decades (at least from 1950 to 1995).

The original aim of this work was to study in detail the professional archival data in order to plan a field study of this indicator species for global warming. It turned out that interesting results were obtained even at this preliminary stage. Bulgarian forest authorities have been keeping statistics on PPM attacks since 1950. Although they do not contain all the details, they are extensive and very serious data, tested in practice, which allows us to examine both the distribution and the history of the species in Bulgaria.

Other indicator species of global warming are also observed in Bulgaria, such as the cypress groundling *Gelechia senticetella* (Staudinger, 1859) (Gelechiidae) [5] and the oak processionary *Thaumetopoea processionea* (Linnaeus, 1758) (Thaumetopoeidae) [6]. PPM is a particularly suitable object for global warming study

Fig. 1. *T. pityocampa* in Bulgaria; old range – green, expansion zone blue

because of the long series of professional data on it, which are due to its status of a primary pest of pines.

Material and methods. Data. For the expansion zone, we created a geo-referenced database that allows detailed analysis. It is an excerpt from the primary reporting documents. It was made based on 6644 signal sheets recording all PPM attacks in Stara Zagora province since their beginning in 1995 kindly provided by the Forestry Protection Station in Plovdiv. The inventory data on the attacked forest stands were extracted from the electronic models of the forest management plans (<http://www.iag.bg/>). Signal sheets and forest description sheets were compiled into the database.

So far, attacks outside the province of Stara Zagora are not covered by the database. Such required data were read from EFA aggregated data (Forest Pathology Inventories, <http://www.iag.bg/docs/lang/1/cat/6/index>) and publications [7].

Unfortunately, the above official data do not provide any information on the phenological form. As a data source on the altitudinal distribution of phenological forms, the publication of MIRCHEV et al. [8] was used, which is based on 21 sample plots representative of the entire range of PPM in Bulgaria. In each sample plot, the phenological form has been identified by collecting tents in winter and dissecting them to determine if the caterpillars were still in the tent.

Evaluation. The official data used is comprehensive: it covers all pine forests and all PPM attacks in the study area. Accordingly, only descriptive statistics were applied to it. The IBM SPSS 20 software was used to evaluate sampling data.

Fig. 2. Attacks of *T. pityocampa* in Bulgaria in 1995–2017

Results. Opposite decennial trends. The attacks of the pine processionary moth in its expansion zone and in the old range are presented in Fig. 2. The heavily attacked area is presented, i.e. the area requiring treatment. The graphs show a clearly increasing trend in the expanding zone and a decreasing trend outside it. The curves of attacked area are fitted quite well with exponential functions. From their coefficients it is read that the attacks in the old range decrease by an average of 5.7% on annual basis, while in the expansion zone they increase by 11.27%.

Optimal altitude. The annual frequency of attacks depending on altitude in the expansion zone is shown in Fig. 3. Frequency was calculated as the ratio of yearly number of signal sheets to the number of forest description sheets of pine forests.

The attacks start at a low frequency at 250 m a.s.l., they reach a maximum at 600 m and then weaken again. The graph evidences that PPM finds optimal conditions for its development at 600 m. In a relatively narrow range of 400 to 800 m attacks occur 2–3 times more often than outside of it, reaching 5× at 600 m.

Figure 3 is a local result, reliably established in Central Bulgaria. It allows us to formulate the working hypothesis that in non-maritime climates, the spread of PPM is characterized by an expressed optimal altitude, on both sides of which the frequency of attacks rapidly decreases. If this distribution is due to the temperature regime, further global warming is likely to cause the optimum to move to a higher altitude.

An important detail seen in Fig. 3 is the existence in Central Bulgaria of a lower limit for the spread of PPM at 300 m. This limit should be attributed to

Fig. 3. Attacks frequency in the expansion zone by elevation

climate factors since the absence of attacks lower than 300 m is not due to a lack of pine forests there [4].

Preference for shady habitats. Shady habitats are mainly the north, northeast, northwest and east slopes. In narrow gorges, all the habitats are shady, but this terrain shape is rare. Conversely, south, southeast, southwest and west slopes are sunny habitats. In the plains and on the hilltops all habitats are sunny, however. In Fig. 4, the frequency of attacks in shady habitats is given as a percentage of that in sunny ones (relative frequency of attacks). It shows that at the lower altitudes, the species prefers the shady habitats and re-orientates to the sunny habitats with increasing altitude. The relative frequency is 167% at 300 m a.s.l., which means that at this altitude, attacks in a shady habitat are 67% more likely than in a sunny one. The relative frequency is 36% at 800 m, which means that attacks in a shady habitat are almost 3 times less likely at this altitude than in a sunny one.

Distribution of phenological forms in Bulgaria. The percentage of tents abandoned before winter as a function of altitude is shown in Fig. 5 according to Mirchev et al. [8].

This percentage indicates the phenological form. The value of 100% indicates summer populations (all tents empty), the value of 0% indicates winter populations (all tents full) and intermediate values indicate mixed populations, i.e. sites where both forms coexist. They often coexist in the same place although pure populations are more common.

The average elevation of the habitats of the winter populations is 376 m a.s.l. and that of the continental ones is 701 m. The 95% confidence interval of

Fig. 4. Relative frequency of attacks in shady habitats in Central Bulgaria

Fig. 5. Distribution of winter and summer populations by altitude

the difference between these average altitudes is (57.8, 590 m), hence it is quite certain that the habitats of the continental summer form are located on average and typically higher than those of the Mediterranean winter form. Interestingly, there is no correlation between phenological form and affiliation of the sample plot to the continental or the Mediterranean climate.

The transition zone in Fig. 5 – the interval (400, 550), is the range of altitudes

where both forms occur. It also comprises all mixed populations. To its left there are only winter populations, with rare exceptions, and to its right there are only summer populations, also with rare exceptions. It is outlined by the 1-sigma limits – the lower limit of summer feeding (412 m) and the upper limit of winter feeding (567 m).

Given that the altitude distribution of the Mediterranean form is normal with a standard deviation of 191 m, the upper limit of the spread of Mediterranean form can be estimated at 950 m a.s.l. by the 3-sigma-rule. Standard deviation of altitude is much higher for the continental form – 289 m. This asymmetry is likely to be due to the impact of orography, i.e. of kettles with a harsh winter due to cold air trapping.

Discussion. *Habitat shift or expansion.* Available data evidences a habitat shift of PPM in Bulgaria, because PPM's well studied expansion to the north is accompanied by habitat losses in the south or at least by habitat deterioration. This is somewhat surprising in Bulgaria, which is located on the northern border of the pine processionary moth, but far away from the southern. Nevertheless, this conclusion is based on comprehensive well documented professional data and should be considered certain. Interestingly, the dynamics of *T. pityocampa* attacks in Bulgaria are accompanied by its dynamic displacement by the *T. pityocampa* ENA clade in Greece [9]. From the data we use here, it is not possible to determine details about the fate of the PPM in the area where its attacks decrease. From preliminary field observations made in the South, we tend to think that it retains a reduced presence there. Figure 3 suggests that the decline in PPM attacks in southern Bulgaria is most likely due to the shift of their centre of gravity to greater altitudes. Such movement is less spectacular than a massive attack in a new area, but it can also have significant consequences.

Habitat shift and global warming. In the case of Bulgaria, PPM habitat shift can hardly be explained by anything other than global warming.

An alternative explanation for shifting the species attacks to the north could be a possible selectivity in pest control activity of forest authorities, such as systematic treatment in its main range and neglect in the expansion zone. Knowledge of the rules and practice of the agency does not support this hypothesis – all mass propagation of the pest is treated, without any geographical selectivity (<http://www.iag.bg/data/docs/Naredba12.pdf>). If there are counter-examples, they are in the opposite direction – in 2000, there was an attempt to stop the progressing of the pine processionary moth in the Stara Zagora Province through intensive treatment of its outbreaks [7].

Another alternative explanation for pest attacks dynamics could be nutrient base dynamics. Most pine forests in the reach of PPM in Bulgaria are artificial plantations. Pine plantations area in Bulgaria decreases for various natural and economic reasons by about 1% yearly. However, their country-wide reduction cannot explain the reduction in pine processionary moth attacks, which is 6 times

faster. Moreover, in Stara Zagora province the reduction rate of pine plantations area (2% yearly) is higher than the national average, but the attacks there are multiplying.

Lower limit of PPM. Due to the use of comprehensive data, the observed absence of attacks by the PPM at altitudes below 300 m is certain. For 25 years, no attacks have been recorded in Central Bulgaria at altitudes of 100 or 200 m, although the pine forests are well represented there at such altitudes. From our data, it is not clear, however, whether the PPM is completely absent there or latent, i.e. present with very low population density. The existence of a lower limit for the PPM spread may be a feature of continental climate, because in Greece PPM occurs and is quite abundant in coastal forests at 0 m a.s.l. This could explain why this limit has not been observed and reported so far, since developed countries in the PPM range have Mediterranean and ocean climate.

Phenological form and altitude. The conclusion that in Bulgaria the Mediterranean winter form occurs at an average altitude lower than the continental summer form is a natural consequence of PPM's climatic requirements [10] and might be confirmed in other countries. Because of its caterpillars crawling and feeding in winter, winter populations are obviously restricted to southern areas and low places, while larval hatching and feeding in the heat of summer restricts summer populations to more northerly or higher habitats.

Preference for shady habitats. Worldwide, PPM attacks are known to be more frequent on the southern habitats which receive more sunlight [11]. As an average, this has been confirmed in Central Bulgaria, too. Figure 4 shows, however, that the preference for sunny habitats is not absolute but depends on altitude.

Conclusions. 1. Global warming is manifested in Bulgaria rather in a habitat shift of PPM (the pine processionary moth *T. pityocampa*), since its expansion in Central Bulgaria is accompanied by a decrease in attacks in its old habitat in the South. Therefore, the study of global warming effects should cover the whole range of the species, not just the expansion zone.

2. In Central Bulgaria, the PPM habitat is a narrow belt with a clear lower limit at about 300 m a.s.l., a pronounced maximum of attacks at 600 m and a more fuzzy upper limit at 900 m. The existence of a lower limit of PPM attacks might be a feature of continental climate. If this structure of the PPM habitat is confirmed in most of its range in Bulgaria, this might explain the reduction of PPM attacks in South Bulgaria with the retreat of the species to higher places.

3. Near its lower limit, PPM clearly prefers shady sites in spite of known usual preference for sunny ones. However, near its upper limit, it strongly prefers the sunny ones.

4. In Bulgaria, winter populations of PPM are located on average lower than summer populations.

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