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Research Article

Factors Influencing the Expansion of the Pine Processionary Moth in Central Bulgaria

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Abstract: Stara Zagora Province in Central Bulgaria is a dynamic new range of the pine processionary moth (PPM) *Thaumetopoea pityocampa* (Denis & Schiffermüller, 1775) (Lepidoptera: Notodontidae), which arose 25 years ago and continues to expand. PPM attacks in Central Bulgaria are most frequent in Black Pine (*Pinus nigra*) forests, at elevations of 500-600 m a.s.l., sunny slopes and stocking rate (relative density) of 70%. Attacks are limited to elevations up to 900 m a.s.l. on shady slopes and up to 1300 m a.s.l. on sunny slopes. They do not depend on slope, terrain and site productivity but depend to certain extent on forest age.

Key words: *Thaumetopoea pityocampa*, elevation, slope aspect, forest density, pine plantations, Bulgaria.

Introduction

Until 1995, the range of the pine processionary moth (PPM) in Bulgaria was restricted to the relative small "Southern-Frontier Forest-Vegetation Province", which has a transitional Mediterranean climate. Historically, some reports of the pine processionary moth outside this range were made in the 1900s and 1950s (Zankov 1960) but until 1995 there were no economically significant attacks requiring treatment there. In 1995, however, economically significant attacks began in Stara Zagora Province in Central Bulgaria, where this pest had never been reported before. For the last 25 years, the pine processionary moth spread throughout the province, going from W to E at an average speed of 2.6 km/year (Zaemdzhikova et al. 2018). Despite pest control activities, the attacks continue to unfold and the affected zone expands (Zaemdzhikova et al. 2019). Currently, the expansion zone covers the territory of the Stara Zagora Regional Forest Directorate, which coincides with the Stara Zagora Province. This territory has always been considered to have a transitional continental climate (Sabev & Stanev 1959). Therefore, the spread of PPM there may be considered as one of the indicators signalling for climate change in Bulgaria (Zaemdzhikova et al. 2018).

Stara Zagora Province comprises part of Sredna Gora Mt. (the southern foothills of the Balkan Mountains) and part of the southern slope of the Main Balkan Range. Pine forests in the province are exclusively plantations (99.2%) of Scots pine (*Pinus sylvestris* L.) and black pine (*Pinus nigra* Arn.), with a 3:2 predominance of black pine (EFA 2015), planted mainly in the 60's and early 70's (Dimitrov 2000, Popov et al. 2018). The majority (70%) have been situated at altitudes below 900 m, i.e. outside the natural range of conifers in this country. Unfortunately, this is also the vulnerability zone of climate change (Raev et al. 2011).

The total area of pine forests in the territory of the study area is 44,458.8 ha. According to the signal sheets, the sum of the attacked areas since 1995 is even greater, 48,184.9 ha. This is explained by repeated attacks – once appearing in a forest, PPM usually continues to be recorded there for many consecutive years (Zaemdzhikova et al. 2018). The average annual attacked area is 2,095.0 ha, the average frequency of attacks is 4.71%. About 10% of the attacked area is heavily attacked, i.e. area requiring treatment.

In general, the factors that determine the spread of PPM are known from numerous studies (Mirchev et al. 2000). The purpose of the present work was to use the available database to check the list of these factors and their impact in the species expansion zone.

Materials and Methods

The main data sources of the present investigation were the archive of the Forest Protection Station (FPS) in Plovdiv and the electronic models of the Forest Management Plans published by the Executive Forest Agency (http://www.iag.bg/). A number of 6659 signal sheets provided by the FPS were processed and a number of 49,404 forest description sheets, incl. 14,042 with pines, were compiled into a database. On the basis of this information, a preliminary factor analysis was made.

The main technique for identifying the influencing factors was to compare the distributions of attacks and pine forests. The identity of the two distributions was considered an indication of neutrality or insignificance of the studied factor. Otherwise the factor was considered relevant to the spread of PPM. In this case, comparison of the distributions was used to identify favourable and unfavourable conditions: under favourable conditions, the incidence of attacks is higher than the frequency of pine forests, i.e. it is disproportionately high, and vice versa.

In this study, the number of signal sheets (i.e. the number of pine plantations attacked) was taken as a measure of the size of the attacks. Accordingly, the distribution of this number was compared with the distribution of the total number of pine plantations.

Based on the above distributions, the relative probability p_x of attacks under different conditions x can be calculated:

$$\frac{p_x}{p_{\text{average}}} = \frac{a_x}{f_x} \tag{1}$$

$$\frac{p_x}{p_y} = \frac{a_x}{a_y}\frac{f_y}{f_x} \tag{2}$$

$$\frac{p_x}{p_{\text{other}}} = \frac{a_x}{f_x}\frac{1-f_x}{1-a_x} \tag{3}$$

wherein x and y are two factors, e.g. Scots pine and black pine, a_x and a_y are the attacks in Scots pine and black pine stands as a percentage of the total amount of attacks, f_x and f_y are the Scots pine and black pine stands as a percentage of the total amount of pine forests.

Our study was done by summarising public data, which have the advantage of being complete. It covers *all* pertaining forests and registered attacks and does not have the character of a sample study. Therefore, data processing is limited by descriptive statistics. No ANOVA is made, because in the case of comprehensive data, there is no risk that the data will not be representative of the study object.

Results

The data indicate a preference of PPM attacks for black pine over Scots pine (Fig. 1). Attacks in black pine forests (69% of all attacks) are more frequent than black pine forests themselves (59% of all pine stands). From Fig. 1, it can be calculated that, at least in Central Bulgaria, the probability of an attack in a black pine forest is 55% higher than in a Scots pine forest:

$$\frac{\text{Black pine}}{\text{Scots pine}} = \frac{69}{59} : \frac{31}{41} = 1.55$$

The preference of PPM for sunny slopes (South, Southeast, Southwest, West) is visible in Fig. 2. Only 42% of the forests are located on sunny slope but most attacks (59%) occur there. From the figure 2, it can be calculated that on sunny slopes the probability of a PPM attack is almost exactly twice as high (1.99 times) as on shady ones.

Attacks of the pine processionary moth occur mainly at altitudes of 500-600 m a.s.l, where most pine forests are located (Fig. 3). In the distribution of attacks, however, these altitudes are well more frequent than in the distribution of forests. This indicates that altitudes of about 500-600 m a.s.l., where PPM is disproportionately frequent, are optimal for its development in Central Bulgaria. Above 700-800 m a.s.l. the incidence of attacks falls sharply below the level of available food base which indicates unfavourable conditions. Attacks are limited to altitudes up to 900 m a.s.l. on shady slopes and up to 1300 m a.s.l. on sunny slopes (Fig. 3a, Fig. 3b).

Data indicate the dependence of PPM spread on relative forest density (stocking rate). In the low-density range (stocking rates below 60%), the distribution of attacks by stocking rate strictly follows the distribution of forests (Fig. 4). However, in the upper range of stocking rate, a pronounced preference for less dense forests and an avoidance of the densest ones is observed. The optimal conditions for the development of PPM seems to give the stocking rate of 70% because this stocking rate occurs fairly more frequently (1.7 times) in signal sheets than in pine forests.

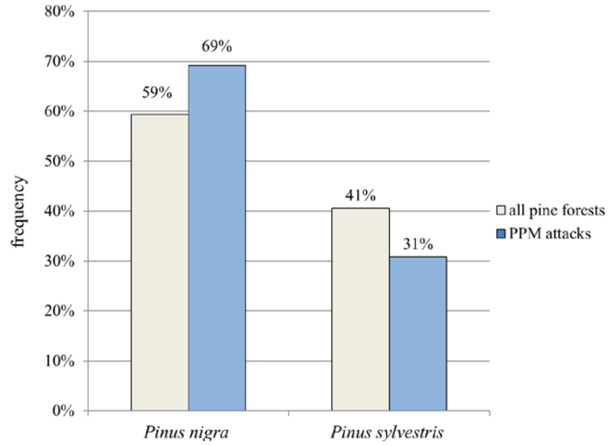

Fig. 1. Distribution of attacks and forests by tree species.

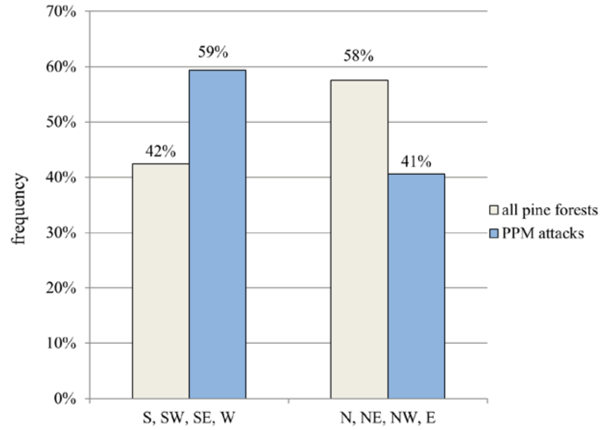

Fig. 2. Distribution of attacks and forests by exposure to sun.

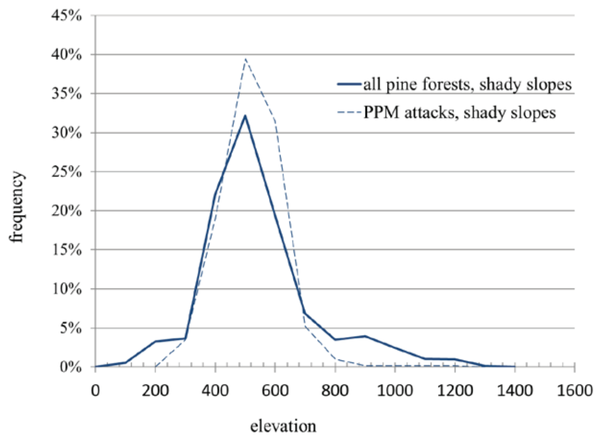

Fig. 3a. Distribution of attacks and forests by elevation, shady slopes.

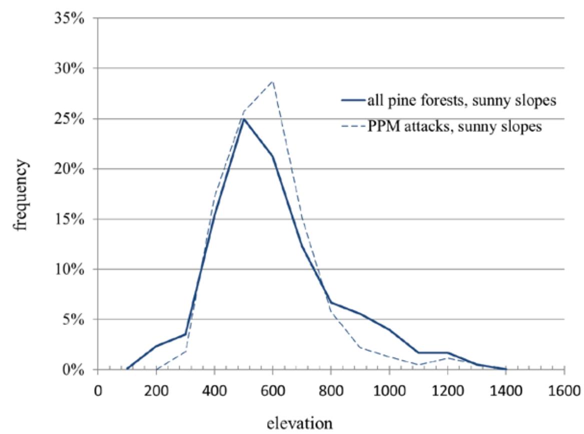

Fig. 3b. Distribution of attacks and forests by elevation, sunny slopes.

Attacks occur most frequently in forests at the age of 40 (Fig. 5), which is the most common in the pine forests studied. The attacks, however, show a certain preference of PPM for older forests, which are reported more often (1.4 times at 50 y.) on the signal sheets than are encountered in the mountains and also an avoidance of younger ones, which, on the opposite, appear more often in forest description sheets than in signal sheets (1.4 times at 30 y.). This may be explained by the gradual decrease in average stocking rate of pine plantations with advancing of age which is observed in Bulgaria.

The attacks distribution by site index is almost the same as the distribution of pine forests (Fig. 6). This indicates a lack of correlation between forest productivity and the spread of PPM. (Site index 1 denotes the most productive stands and site index 5 denotes the most poor).

PPM attacks are not affected by terrain configuration or slope. The distribution of attacks according to these parameters is almost the same as the distribution of pine forests (Fig. 7, 8).

Attacks occur most frequently in forests at the top of the hillside and at a slope inclination of about 15º apparently because these are the most common conditions in the studied pine forests. However, in Fig. 7, the attacks show a certain preference for the lower concave part of the slope (the bottom part). Similarly, in Fig. 8, there is a clear avoidance of the steepest terrain (above 32º).

Discussion

This paper reports the results of a graphical data analysis, which is the preparation for fitting a model. Some interesting results have been obtained already at this stage, such as the PPM's preference for black pine and other results cited in the Conclusion section. Fitting a model will allow refinement of the established parameter values.

The factors influencing the spread of PPM have been studied by a number of authors and the main

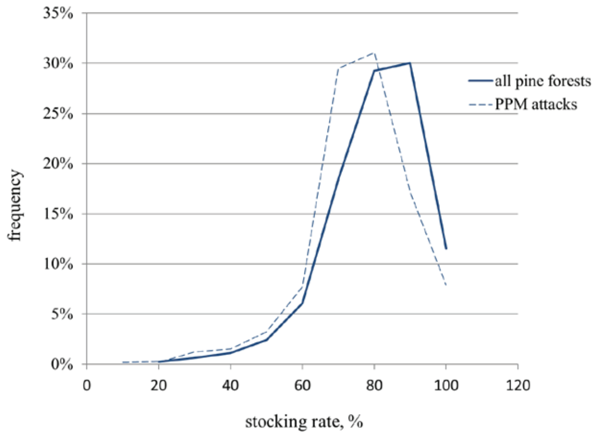

Fig. 4. Distribution of attacks and pine forests by stocking rate.

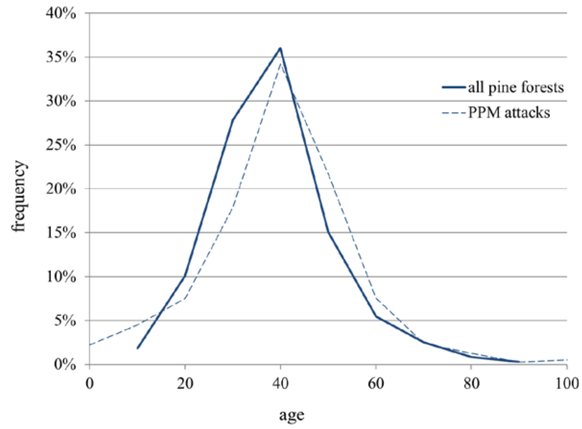

Fig. 5. Distribution of attacks and pine forests by age.

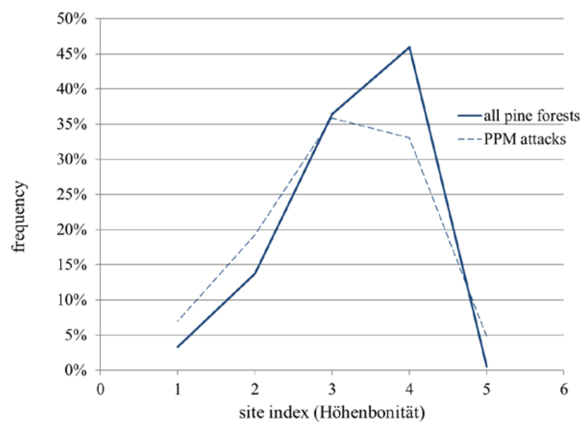

Fig. 6. Distribution of attacks and distribution of forests by site index.

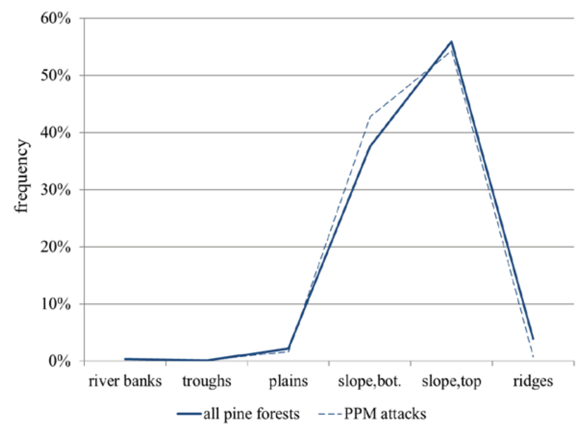

Fig. 7. Distribution of attacks and forests by orography.

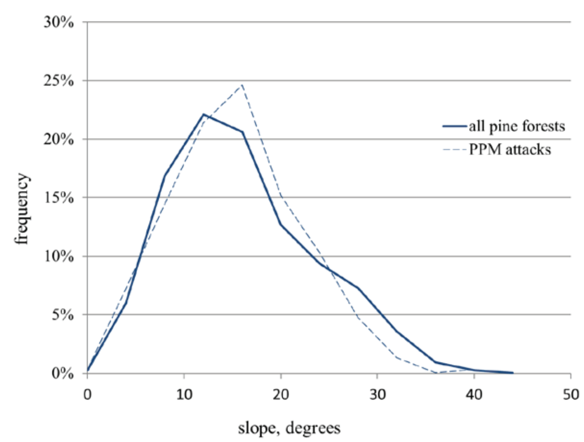

Fig. 8. Distribution of attacks and forests by slope.

facts are known. Nevertheless, there are still discussion topics and many details remain unclear. Régolini et al. (2014) found that PPM population density (number of nests/ha) did not differ significantly between stands and was not correlated with stand density. By contrast, Geri & Miller (1985) observed a larger number of infested trees in less dense pine stands. The PPM preference to thinner forests is usually explained by the fact that its larvae search for sunny parts of the tree crown to make their nests on, where they achieve a more favourable microclimate inside the nests (Geri 1980, 1984, Buffo et al. 2007, Hoch et al. 2009, Battisti et al. 2005, 2013). In addition, in thinner forests, open areas are more likely to occur which PPM caterpillars need to pupate (Dulaurent et al. 2012). Same reasons explain the observation of Geri & Miller (1985) that trees located at the edge of stand are more likely to be infested. Higher rates of infestation at forest edges have also been reported by Dulaurent et al. (2012), Barbaro et al. (2013), Régolini et al. (2014). Our results suggest a reconciliation of the above two competing opinions on density impact: both can be considered valid, but for different density ranges. PPM obviously avoids the most dense plantations, which is a confirmation of the study of Geri & Miller (1985) at high stocking rate (relative density), but at stocking rate 50% and lower, PPM attacks become independent of density, which is rather in agreement with Régolini et al et al. (2014). It is interesting to note that the arguments, which are cited to corroborate PPM preferences to a lower density, do not contradict this concept. With a stocking rate of 50%, all crowns are already well-lit and the presence of bare spots is ubiquitous, so further reducing of density does not create additional benefits for PPM.

Our conclusion that the spread of PPM does not depend on the height of the pine forest can be easily reconciled with the observation of Régolini et al. (2014) that within a forest stand PPM prefers thicker and taller trees. This observation is most likely explained by the fact that PPM prefers dominant trees because of their well-lit crown, which tend to be thick and tall. PPM, however, finds dominant trees at any average height of the forest stand. In Bulgaria, PPM is often seen in forests with a height of no more than 2 m.

As stated above, the preference of PPM for sunny slopes observed in Fig. 2 is fully consistent with the known facts and is one of the tests for the reliability of our data. PPM attacks are known to be more frequent on the southern slopes which receive more sunlight especially important with winter feeding of caterpillars. Within a stand, attacks are concentrated on its W and SW edges, whereas shady edges (N and NE) have the lowest rates of infestation (nests/ha) and edges facing SE and NW have intermediate levels of infestation (Barbaro et al. 2013, Régolini et al. 2014).

The aspect (N, E, S, W) is a factor relevant to temperature regime. However, the most important factor that determines temperature regime is elevation, the impact of which varies from region to region. In Bulgaria, PPM has been found up to 1200 m a.s.l. on shady slopes and up to 1350 m a.s.l. on sunny slopes (Zankov 1960, Mirchev et al. 2000). Fig. 3 reads that in the studying area, the attacks of the pine processionary moth are limited to altitudes up to 900 m a.s.l. on shady slopes and up to 1300 m a.s.l. on sunny slopes. Due to the comprehensive data we use, these are reliable estimates. These values are within the range determined for the first time by Tsankov (Zankov 1960). However, it is noteworthy that the estimates on sunny slopes are close (1300 versus 1350 m a.s.l.), while the big difference on shady slopes (900 versus 1200 m a.s.l.) remains unclear for now. It may be due to the peculiarities of the spread of PPM in the area of expansion. Another possible explanation is that the upper limit of the species in Bulgaria is underestimated, i.e. that on sunny slopes the species also occurs at altitudes above 1350 m a.s.l., but perhaps with low concentration, so that it has remained unnoticed for the time being. This is possible due to the distribution of pine forests, which occur at altitudes up to 2000 m a.s.l.

As Tsankov (1960) presented his observation on altitude, it is tempting to compare them with the modern ones in order to look for a climate change effect since this time. For the time being, we refrain from such a comparison because Tzankov's research was not done in the area of expansion, to which our data are related.

It is difficult to say for now whether the trend of PPM to be more frequent in black pine forests is due to preference for black pine or to random factors not taken into account. However, PPM preference for black pine is the most likely explanation given the preference for black pine established for *Thaumetopoea wilkinson* Teams by feeding experiments (İpekdal & Çağlar 2012). If the increased incidence of attacks is a permanent black pine property, any future PPM research in Bulgaria should treat Black pine separately from Scots pine.

The slight preference of PPM for the lower concave part of the slope at first sight contradicts the observation of Mirchev et al. (2000) that the valley location is unfavourable to PPM due to the frequent fogs that deprive it of sunshine. In fact, Mirchev is referring to smaller details of terrain than the ones seen in Fig 7.

Observations on the influence of age, forest height, terrain shape and slope are not known in the available literature. This indirectly confirms the insignificance of these parameters in this study.

Most of our findings are confirmation in the particular case of already known relationships and dependencies. This can serve as a test of the data used. Official inventory data used here have the advantage to be complete, unlike case studies and sample studies. Therefore, they can be very useful for finding mean values and limit values and for establishing frequencies, incl. frequencies of rare events. However, they do not give an idea of important details, such as the distribution of attacks within forests. Based on them, causal relationships are difficult to establish. Nevertheless, they can be recommended as a means of preliminary study and for planning experiments and observations.

Conclusions

In Central Bulgaria, the attacks of the pine processionary moth are limited to altitudes up to 900 m a.s.l. on shady slopes and up to 1300 m on sunny slopes. The optimal altitude is about 500-600 m a.s.l., Black pine forests are 1.55 times more often attacked then Scots pine forests. Sunny sites are 2 times more often attacked than shady ones. Stocking rate of 70% seems to be the most favourable for the development of PPM. The data from Central Bulgaria suggest a reconciliation of two competing opinions on density impact: the first is that PPM prefers lower densities (Geri & Miller 1985) and the second is that density does not matter (Régolini et al. 2014). They seem to be valid for different density ranges: respectively above and below the stocking rate (relative density) of 60%.

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