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THE IMPORTANCE OF SOIL IN THE SPREAD OF THE PINE PROCESSIONARY MOTH IN CENTRAL BULGARIA

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Abstract

Available geo-referenced data about the pine processionary moth (PPM) attacks in Stara Zagora province in Central Bulgaria were used to study the relationships between the frequency of attacks and soil conditions. It was established that the PPM prefers fresh, deep and fertile soils.

KEY WORDS: *Thaumetopoea pityocampa*, soil conditions, pupation, emergence

Introduction

Habitat selection is especially important for the pupae of holometabolous insects because at this stage they are usually immobile and largely unable to react to the world around them. Therefore, they are more vulnerable to parasitoids, predators, temperature fluctuations, etc. (Hawkins *et al*., 1997). The pine processionary moth *Thaumetopoea pityocampa* (Denis & Schiffermüller, 1775) (Lepidoptera: Notodontidae), which is an important forest pest (Régolini *et al*., 2014; Mirchev *et al*., 2003; Zaemdzhikova *et al*., 2019a), pupates in the soil, selecting a protected site that offers shelter and camouflage (Zheng *et al*., 2011). In the soil, its pupae are protected against temperature fluctuations and most predators (Hogdson *et al*., 1998; Zheng *et al*., 2011), but the danger of flooding remains, as well as rotting by the action of fungi and bacteria and attacks of specialized parasitoids (Hogdson *et al*., 1998). The pupal stage of the PPM is characterized by significant variability of duration. It includes a pupal diapause, which lasts from 1 month (at higher altitudes) to 5 months (at lower altitudes) (Démolin, 1969), but in some cases PPM remains in an extended diapause up to 8 years (Salman *et al*., 2016). For these reasons, the soil conditions should play a significant role for the survival of PPM in its pupal stage.

Our study was conducted in Stara Zagora province in central Bulgaria. It is a continental region in the foothills of the Balkan mountain range and its south slope with altitudes from 100 m to 2000 m. The coniferous forests in the province are exclusively artificial plantations (99.2%), mainly of Scots pine and black pine, in a ratio 2:3 (EFA, 2015), with a total area of 44,458.8 ha. They were established mainly in the 1960s and early 1970s (Popov *et al*., 2018), most of them at altitudes below 900 m a.s.l (70%), i.e. outside the conifers' natural range, and are considered vulnerable to climate change (Raev *et al*., 2011). The spread of PPM in the Stara Zagora province has been studied in detail because it is considered one of the indicators signaling climate change in Bulgaria. PPM appeared there 25 years ago (Mirchev *et al*., 2017) and continues to expand from West to East by 2.5 km/year (Zaemdzhikova *et al*., 2019b). The long-term (23-year) average of PPM attacks frequency is 4.7% of the pine plantations per year. The PPM Attacks are very often repeated – once appearing in a forest, the PPM usually continues to be reported there for consecutive years (Zaemdzhikova *et al*., 2019b).

The purpose of the present work was to use the available detailed data about PPM attacks in central Bulgaria to find a correlation between attacks and soil conditions.

Materials and methods

The main data source of the present investigation was a geo-referenced data bank of PPM attack records (the "signal sheets") and the pine forests (the "forest description sheets"). In this study, public data were summarized, which have the advantage of being complete. The study covers *all* pertaining forests and registered attacks and does not have the character of a sample study (Dimitrov, 2000). The main technique for identifying the favorable conditions was to compare the distribution of attacks by the investigated parameter with the distribution of pine forests by the same (Zaemdzhikova, 2020). This allows to distinguish visually the favorable, the unfavorable and the neutral conditions for the spread of PPM. It is assumed that if a parameter value occurs more frequently in signal sheets than in forest description sheets, its presence must be a favorable condition. For quanititative evaluation of important conclusions, the average annual probability of attacks p_x under condition x was calculated

$$p_x = \frac{S_x}{F_x},$$

wherein S_x is the yearly average number of signal sheets pertaining to condition x and F_x is the number of forest description sheets.

Results

The distribution of attacks by soil type is shown on Fig. 1. The data indicate a preference of PPM attacks for plantations growing on cinnamonic forest soils (chromic luvisols, FAO). Most attacks (91%) occur in forests on such soils which dominate the pine forests in the study area, with a smaller share of 70%. From Fig. 1, it can be calculated that at least in central southern Bulgaria, the probability of an attack in a pine forest on cinnamonic soil is 2.9 times higher than in a pine forest on brown soil (dystric/eutric cambisols, FAO).

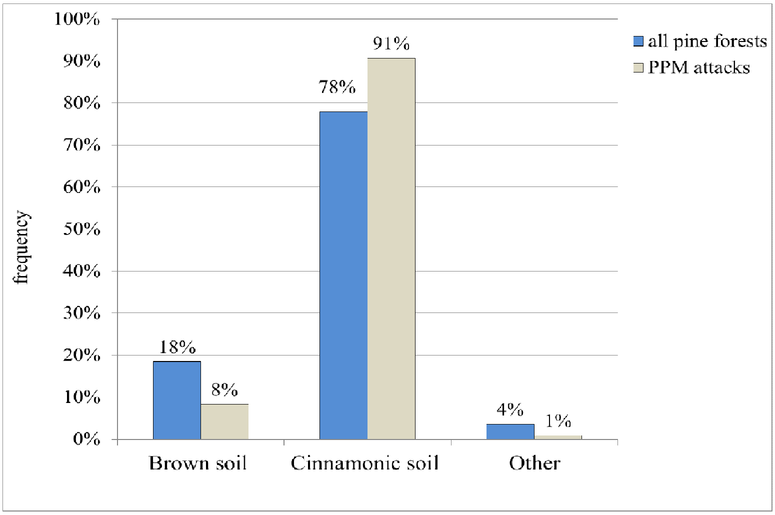

Figure 1. Distribution of attacks and distribution of plantations by soil type.

Figs. 2, 3 and 4 show that fresh, medium-deep and medium-rich soils are favorable for the PPM, because the frequency of encountering such soils in the signal sheets is higher than in the forest description sheets.
From Fig. 2 it is seen that dry soils, whose share is not small in central southern Bulgaria, are unfavorable for PPM – they occur more often in the forest description sheets than in the signal sheets. It can be calculated that on a dry soil, an attack 1.5 times less probable than on a fresh soil. Finally, fresh soils are definitely favorable for the spread of *T. pityocampa* in Stara Zagora.

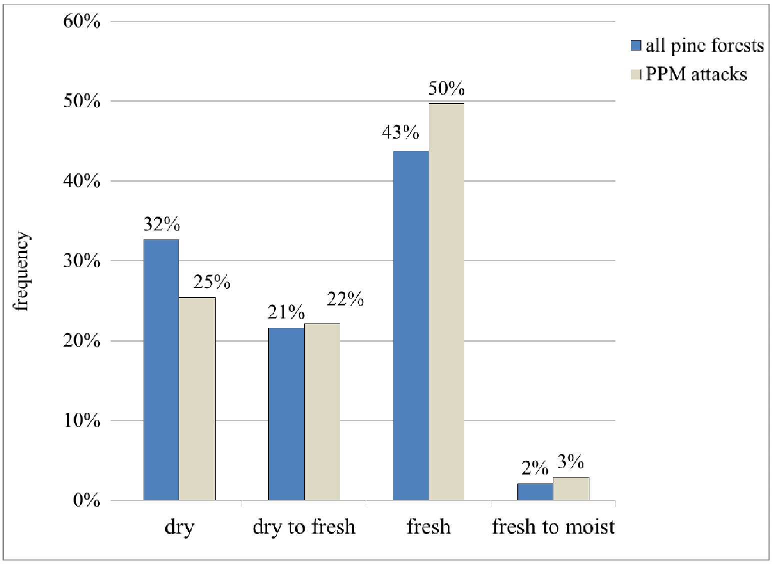

Figure 2. Distribution of attacks and distribution of plantations by soil moisture.

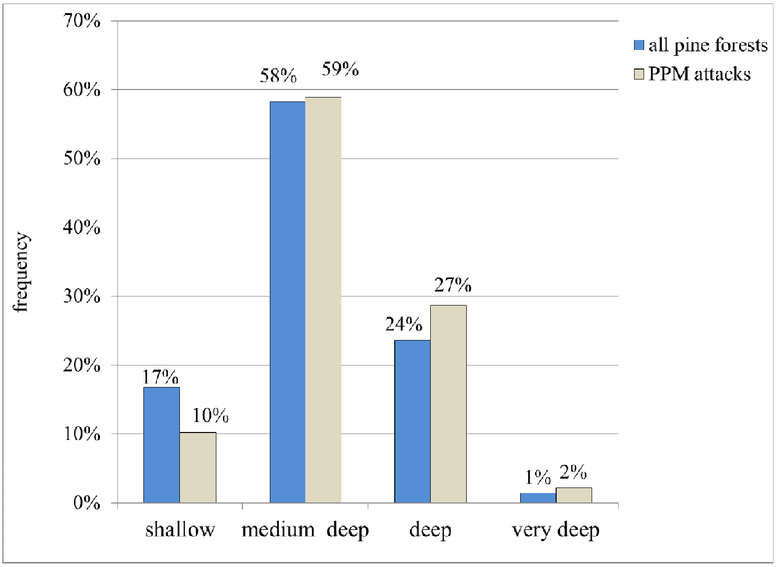

Figure 3. Distribution of attacks and distribution of plantations by soil depth.

The preference of PPM for deep soils is visible in Fig. 3, shallow soils are unfavorable and medium deep are neutral. It is calculated that in a pine plantation on a deep soil an attack is on average 2 times more probable than on a shallow soil.

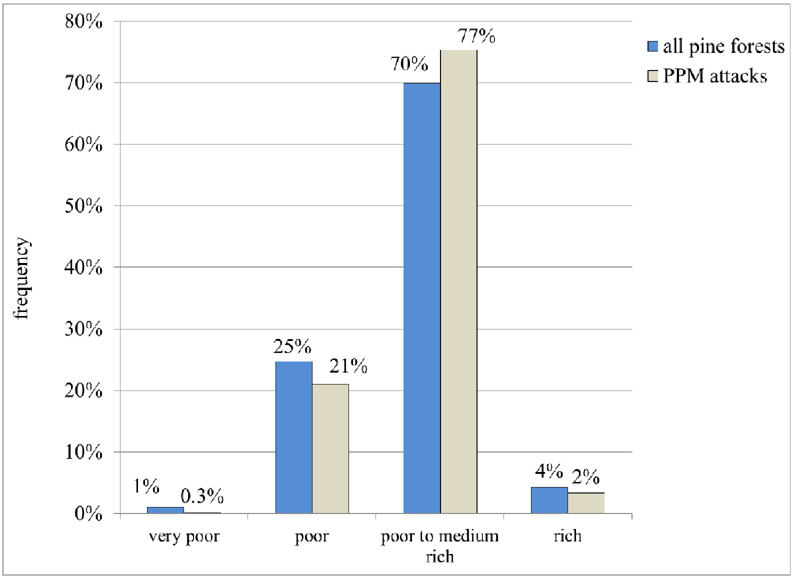

Figure 4. Distribution of attacks and distribution of plantations by soil fertility.

The distribution of attacks by soil fertility is shown on Fig. 4. From the graph it is seen that PPM prefers rich soils. It is calculated that a plantation on a medium-rich soils is attacked 1.3 times more often than on a poor one.

There is a strong correlation between these factors, as rich soils are usually deep and fresh and poor soils are shallow and dry. For this reason, the relatively equal impact of depth, fertility and moisture is not surprising.

Surprisingly, there is a quite clear preference of PPM attacks for magmatic silicate bedrock (Fig. 5). It can be calculated that a stand on granite and rhyolite bedrock is attacked 2.4 times more frequently than a pine forest growing on limestone, sandstone or shists. As the development of PPM has no direct relation to bedrock, its influence on PPM attacks is certainly indirect, through its impact on soil conditions and site productivity.

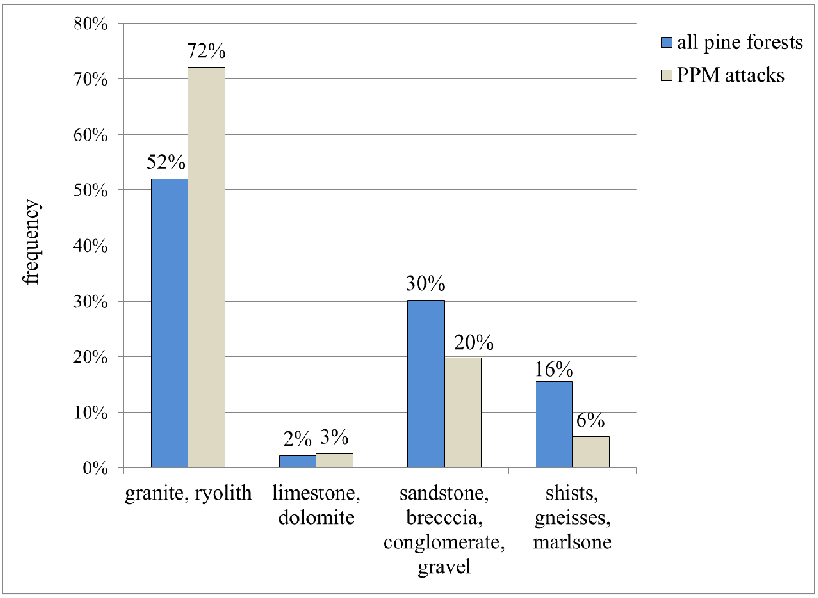

Figure 5. Distribution of attacks and distribution of plantations by bedrock.

Discussion

Cinnamonic forest soil types cover the largest area in Bulgaria. They are located in southern Bulgaria up to 700 m a.s.l. Brown forest soil types are also well-represented there but they are located at higher altitudes – above 700 m (Koynov *et al.*, 1997). Zaemdzhikova (2020) determined that in central southern Bulgaria, PPM attacks are concentrated between 400-700 m a.s.l. and decrease outside this belt. This may explain the correlation of the attacks to the cinnamonic forest soil type, as well as the low frequency with which the attacks are present in plantations there with brown forest soil types.

A specific feature of cinnamonic soils is that the humus horizon (A, 0-20 cm) has a lighter mechanical composition, unlike the illuvial – B horizon, which is strong and composed of clay. This is particularly well expressed in the transitional Bt horizon. Usually, clay soils contain more nutrients and moisture

(Bogdanov, 2012). This could probably explain the relationship of the attacks with soil moisture and fertility. It is known that in this area, cinnamonic soils are characterized by a medium-to-acidic reaction, which is strongly contributed to by the granite rocks (Koynov *et al.*, 1997; Bogdanov & Glogov 2006).

Given that the pupae are buried to a depth of 20 cm, this means that they only inhabit the surface soil layer (the humus horizon). According to Montoya & Hernández (1998), the depth of pupating depends on the soil structure, and Battisti *et al*. (2015) set the depth at 5-20 cm, regardless of soil type. Deeper soils will provide better protection for the pupae from natural enemies, but on the other hand, this can make it more difficult for moth emergence (Capinera, 2008), especially in hard clay soils. The light loose soils will have a good effect on the emergence of the moths. In shallow soils, the variations in temperature caused by heat exchange during the day and night can also be a problem, which is otherwise well-pronounced only in the surface-soil layer of deep soils. At greater depths (10-20 cm), these fluctuations should be less since temperature and humidity there are relatively stable. Thus, deeper soils offer more choice of places for the caterpillar to pupate.

The thermal conductivity of soil is not irrelevant. Soil is a poor conductor of heat, so when the soil is dry, it heats up quickly, but the heat transfer in it is slow. On the other hand, moist soils heat up slowly, which is due not only to evaporation, but also to the faster transfer of heat to the deeper layers. Therefore, their slow cooling at night is due to the offset of heat from the deeper layers. In other words, in moist and deep soils, lower fluctuations in temperature and water regime are expected, which seems to be a preferred condition of the PPM. On the other hand, the higher thermal conductivity of deep soils favors the pupae located in deeper soil layers, where it is expected that they will receive the required amount of heat needed for the normal flow of their vital activity faster, especially if they are there for a longer period of time. The negative effect of moist soils is related to the development of pathogenic microorganisms and fungi. A moist environment favors the development of phytopathogenic fungi, which can cause epizootics of the pupae (Dejoz, 2000).

According to literature sources, soil moisture does not affect the caterpillars' behavior when choosing soil for pupating. It is also unlikely that it will affect the duration of the pupal diapause, with the exception of pupae with prolonged diapause. However, soil moisture affects the emergence of adults. On dry soils, an earlier emergence of adults has been identified, which means that rising temperatures over the decades will also lead to the earlier emergence of caterpillars (Torres-Muros *et al.,* 2016). Also, dry soils are often hard. The density of the soil hinders the caterpillars, which tunnel into them to pupate. On dry and hard soils, pupae are likely to be located at a shallower depth, and the rapid heating of these soils will enhance metabolism and accelerate their development.

It is known that PPM pupae are eaten by various bird species (Battisti *et al.,* 2000). When caterpillars are buried at shallower depths, especially when this is limited by soil texture, the pupae on the surface will be easy prey for birds.

The favorable influence of silicate rocks remains unclear, but it is also probably due to an accidental coincidence with another factor. For now, the only assumption to be made is that the acidic environment created may be a favorable condition for the development of the pupae. A study of *Cochliomyia hominivorax* (Coquerel) (Diptera: Calliphoridae) determined that soil acidity affects the size of the pupae. There is an inverse correlation between the two, i.e. at higher soil pH, the size of the pupae is smaller (Meneguz *et al*., 2018). If this also applies to the PPM, the smaller size of the pupae would be more convenient for pupae in prolonged diapause. It could be a way of saving the energy needed for the normal functioning of the physiological processes of individuals, especially when the state of prolonged diapause continues for years.

Conclusions

Soil characteristics have a limited impact on the spread of the pine processionary moth. It was shown that the PPM prefers fresh and moist soils, which use to be deep and fertile. An attack in a plantation on such soils proved to be 50% more probable than on a dry soil.

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ЗНАЧАЈ ТЛА У ШИРЕЊУ БОРОВОГ ЧЕТНИКА У ЦЕНТРАЛНОЈ БУГАРСКОЈ

Гергана Заемджикова

Извод

Доступни гео-референтни подаци о нападима боровог четника у провинцији Стара Загора у централној Бугарској коришћени су за проучавање односа између учесталости напада и стања тла. Утврђено је да боров четник преферира свежа, дубока и плодна тла.

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