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THE IMPACT OF SPECIFIC ECOLOGICAL CONDITIONS ON THE FLIGHT OF THE PINE PROCESSIONARY MOTH (*Thaumetopoea pityocampa* Schiff.) IN THE ORJEN MOUNTAIN AREA

SUMMARY

This paper presents research conducted to determine the most important ecological conditions that influence the onset and course of the flight of male pine processionary moths (*Thaumetopoea pityocampa* Schiff.) in the Orjen Mountain area, which belongs to Bosnia and Herzegovina. The ecological conditions monitored in the study area were air temperature and relative humidity, which are correlated with the flight of the imago of this harmful species. The onset of adult emergence and the duration of the flight period were determined using pheromone traps with lures and by counting the captured male pine processionary moths. The research showed that higher average daily temperatures led to a much more intense male flight activity in this area. The most intense flight, with the highest number of captured adults (1,336), was recorded on August 22, i.e., during the period from July 31 to August 22, when the average daily temperature was 23 °C. Based on the determined values of ecological conditions and the bionomy of the imago, the pine processionary moth population in this area is characterized as a winter population, i.e., an early type of pine processionary moth.

Keywords: pine processionary moth, *Thaumetopoea pityocampa*, Orjen, ecological conditions.

INTRODUCTION

The presence of the pine processionary moth in Europe has been known since the Tertiary period (Molotkov and Patlaj, 1991). Its range is subject to changes in both altitude and geographical latitude during the interglacial periods of the Pleistocene (Bennet *et al*., 1991; Willis *et al*., 1998). Climatic conditions have a significant impact on the biology of insects, the speed of development, the number of generations, the timing, and the duration of migrations.

An increase in temperature and climate changes can lead to shifts in phenological phases. Current trends in climate change may encourage the spread

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of the pine processionary moth (Hodar *et al*., 2001). Oligophagous is a species that is trophically linked to various species of pines (*Pinus nigra, P. sylvestris, P. pinea, P. halepensis, P. pinaster, P. canariensis, P. heldreichii, P. radiata, P. ponderosa, Cedrus atlantica, C. libani, Abies concolor, Pseudotsuga menziesii*), however, it can occasionally be found on species from the genus *Larix* (Roques *et al*., 2015). Due to the increase in temperature, the lifespan of adult individuals may shorten Species with a short life cycle are considered to be highly endangered (Harvey *et al*., 2020.). The rise in temperature may affect the expansion of their range and phenology (Hill *et al*. 2002, Wilson *et al*., 2005, Stefanescu *et al*., 2003).

Thaumetopoea pityocampa is one of the most significant pests of pines in the sub-Mediterranean region of Bosnia and Herzegovina. Due to the fact that the hairs from their caterpillars cause serious allergic reactions in humans and animals, this species is of public concern (Vega *et al*., 2004.). *Thaumetopoea pityocampa* is a species that is widely distributed in the western Mediterranean (Huchon and Démolin, 1971). Thanks to the warmer period, especially higher winter temperatures, this species successfully expands its range to higher geographical latitudes (Battisti *et al*., 2005.; Robinet and Roques, 2010).

According to Androić (1957), the range of the pine processionary moth in Croatia overlaps with the northern boundary of the growth zone of *Quercus pubescens*, which is also the southern boundary of *Abies alba* and *Fagus sylvatica* in Croatia. Describing in detail the boundaries of the pine processionary moth's range, Androić (1957) mentions its presence in the areas of Drvar, Mostar, Konjic, Prozor, Nevesinje, Bjelašnica, Orjen, and Trebinje. The height of pine trees and their position in the stand, especially the proximity to the edge of the stand where there is more sunlight, create favorable conditions for the appearance of the pine processionary moth. The emergence of the pine processionary moth in our areas depends on altitude and air temperature. According to Androić (1957), the emergence lasts from the first half of July to the first half of August. In the northern part of Italy, emergence lasts from the end of June to the beginning of September, reaching its peak in mid-July (Battisti *et al*., 2006.). In their research, Battisti *et al*. (2006) state that due to extremely warmer summers and pronounced climate changes, the pine processionary moth is expanding to higher altitudes, over 1000m, inhabiting the new host, *Pinus mugo*. After defoliation caused by the pine processionary moth, the attacked trees rarely die, but as a result of defoliation, reduced growth occurs (Linares *et al*., 2014).. According to Castagneyrol *et al*. (2014), young pine trees are more susceptible to attacks by the pine processionary moth, but the level of infestation is higher in older trees. Investigating the sensitivity of two pine species to the pine processionary moth, it was found that *Pinus nigra* is susceptible, while *Pinus pinea* is highly resistant (Buxton, 1983; Masutti and Battisti, 1990; Stastny *et al*., 2006; Hodar *et al*., 2012). The pine processionary moth has been registered as the most important pest of pines in many countries (Devkota and Schmidt, 1990).

It is widespread mainly in the Mediterranean region, while in the continental part it is very rare, and its range is limited by the July isotherm of 22 ºC.

Androić and Opalički (1965) state that two ecotypes of the pine processionary moth have been identified in domestic regions, one with an earlier and one with a later appearance of moths and caterpillars. In warmer areas and in the coastal part of the Mediterranean, moths and caterpillars appear later, while in continental and colder areas, the 'early' type predominates. In the spring of 1952, several locations in the Trebinje Forest Administration area were identified where the pine processionary moth was present: Kučino Brdo, Klobuk, Struge, and Mahala (Lastva), Mokro Korito and Oblat (Ravno), Troglav near Ubla, and Ivanica (Fitze, 1953).

This research aims to provide a more comprehensive overview of specific ecological factors that influence the bionomics of the pine processionary moth. Additionally, by considering three different locations and integrating ecological conditions, the study seeks to determine the timing and duration of the adult flight period, as well as the flight capability of males as an important factor in the spread of this harmful insect. Understanding these factors that affect the bionomics of the pine processionary moth is of great importance for forest and plantation management in this area, as well as for the development of protection plans and the implementation of control measures against this pest.

The stronger influence of air temperature on the onset and course of the pine processionary moth's flight, in comparison to air humidity, was tested as the main hypothesis.

MATERIAL AND METHODS

The research was conducted during the summer of 2024 in the Orjen Mountain area, which belongs to Bosnia and Herzegovina. Orjen Mountain is located on the border between Bosnia and Herzegovina and Montenegro, and it is considered the rainiest area in Europe. Different altitudes were used in the study along the Lastva-Dubovac profile on the northeastern slopes of Orjen (Figure 1). The study area is home to black pine stands at various elevations and exposures. The ecological conditions at all research sites, defined by air temperature and relative humidity, were determined over a 24-hour period using automatic weather stations of the PCE-FWS20N type (Figure 2). Data on the locations of the used automatic weather stations are presented in Table 1.

Table 1. Locations of automatic weather stations

	Coordinates		Altitude
	Y	X	
Lastva	18°29'36"	42°41'38"	382 m
Orovac	18°29'43"	42°40'41"	710 m
Dubovac	18°31'42"	42°39'50"	987 m

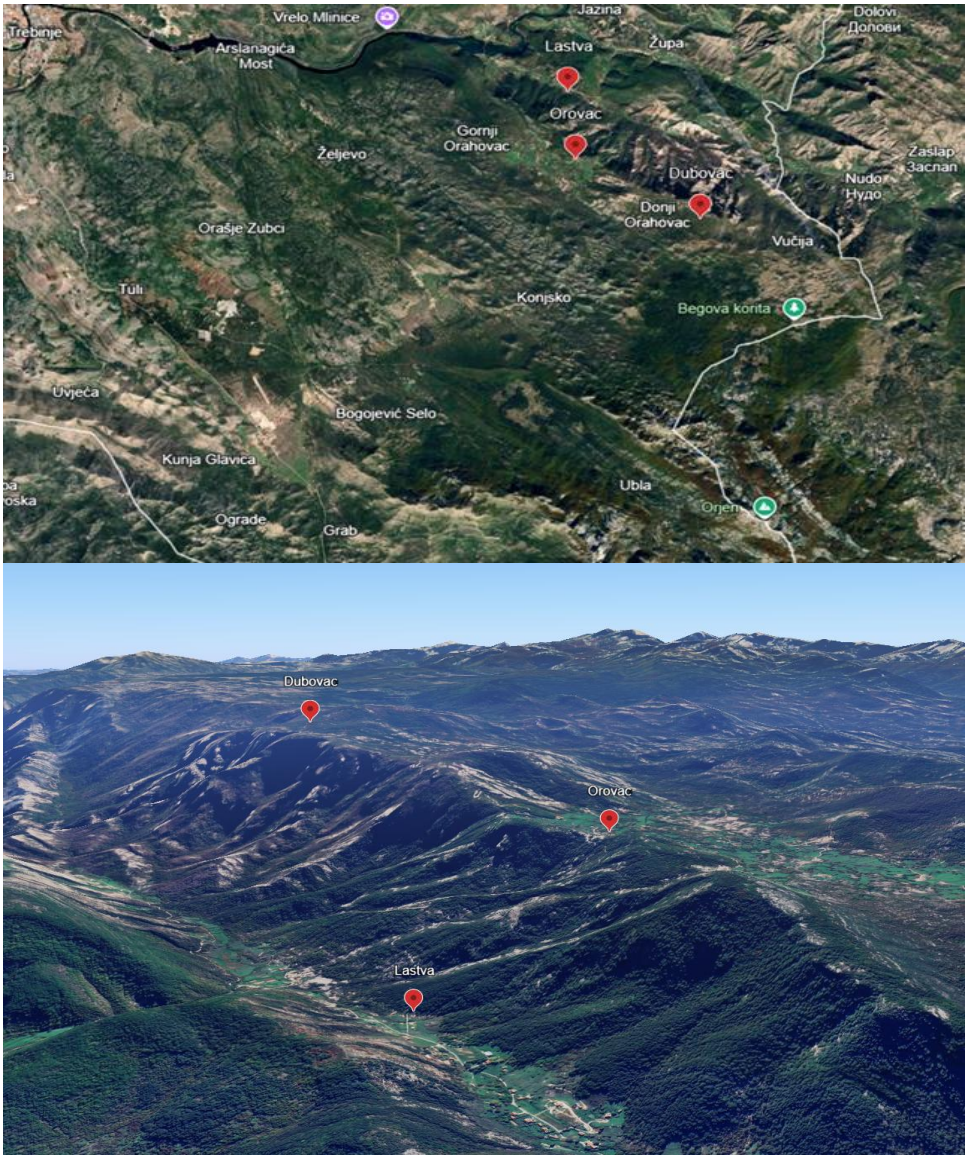

Figure 1. Research area

In order to determine the onset, duration, and end of the flight of the pine processionary moth imago, male moths were captured using pheromone traps and pheromone baits (Figure 3). Two types of pheromone traps were used: ECONEX G TRAP (Spain) and WitaTrap (Austria), along with two types of pheromone baits: ECONEX THAUMETOPOEA PITYOCAMPA 200 DAYS Thaumatowit

The duration of the experiment, in which the capture of male pine processionary moths was monitored under appropriate ecological conditions, lasted from June 19, 2024, to October 1, 2024 (Table 2). Trap checks and catch

counting were performed at 15-day intervals (twice a month). The data processing and statistical analysis were performed using the software programs MS Excel and IBM® SPSS® Statistics (version 20). The influence of ecological conditions on adult pine processionary moths and the strength of these relationships were presented using Pearson's correlation, expressed through positive and negative coefficients, as well as the statistical significance of these correlations.

Figure 2. Automatic weather station at the Dubovac site

Figure 3. Pheromone traps ECONEX G TRAP, and captured imago

Table 2. Pheromone trap control and catch counting deadlines

Term	Period
I	19.6. - 02.7.2024.
II	03.7. - 15.7.2024.
III	16.7. - 30.7.2024.
IV	31.7. - 22.8.2024.
V	23.8. - 01.9.2024.
VI	10.9. - 17.9.2024.
VII	18.9. - 01.10.2024.

Figure 4. Witatrap

RESULTS AND DISCUSSION

The life cycle of the pine processionary moth varies significantly depending on the climate and is controlled by two main temperature limitations, which also determine the distribution area and population dynamics. Table 3 presents the results of the correlation analysis between the flight of male individuals and the measured ecological conditions.

Table 3. Correlation between ecological conditions and the flight of individuals

		Temperature	Humidity	Locality
PPM	Pearson correlation	.393	-.433	-.018
	Sig.	.000	.000	.755

Air temperature is moderately positively correlated with the flight of male individuals, while relative humidity is also moderately correlated but in a negative direction. The correlations of these variables are statistically significant. The sites represented by the elevation element show a weak and negative correlation. Furthermore, Ferracini *et al*. (2022) also determined a negative correlation between altitude and other components in their research.

Depending on the geographical area, significant differences in the adult flight period may occur due to their sensitivity to cold winter and high summer temperatures. The flight of male individuals is weaker at higher humidity and lower air temperatures, while it is much more intense at higher temperatures and lower humidity (Chart 1). The evolutionary development of the pine processionary moth allows it to develop within a specific range of environmental temperature conditions (Georgiev *et al*., 2023). The effect of air temperature should not be considered in isolation, but in combination with other environmental factors. During the emergence period of the imago, the average daily air temperature ranged from 12.5 to 24.7 ºC. The average daily air temperature for the entire research area during the experiment period was 20.4 ºC (Chart 2). It is known that summer air temperature positively affects insect activity and is indeed a limiting factor that stimulates the flight of males (Bonsignore and Manti, 2013). Battisti *et al*. (2006) state that the rapid spread of the pine processionary moth is facilitated by warm summer nights, which contribute to the dispersal of female moths over long distances (more than 2 km). Insect flight occurs when body temperature is within a certain range. It can be said that unfavorable temperatures affect the flight of male pine processionary moths precisely because body temperature depends on environmental conditions. The relative humidity during the monitoring period of the imago flight ranged from 57.3% to 85%. The average relative humidity for the entire research area during the experiment period was 70.4% (Chart 3).

If environmental conditions are unfavorable, the insects can remain in the pupal stage for several years, which leads to butterflies from multiple generations emerging simultaneously when favorable conditions occur, causing severe outbreaks and possible population surges (Vega *et al.,* 1999). According to Malamel, J.J. (2021), the population dynamics of ectothermic organisms are strongly influenced by environmental parameters, and outbreaks of harmful forest insects are major causes of changes and degradation of forest ecosystems worldwide. Ongoing changes in climatic conditions can directly lead to modifications in the distribution, development, reproduction, and mortality of insects.

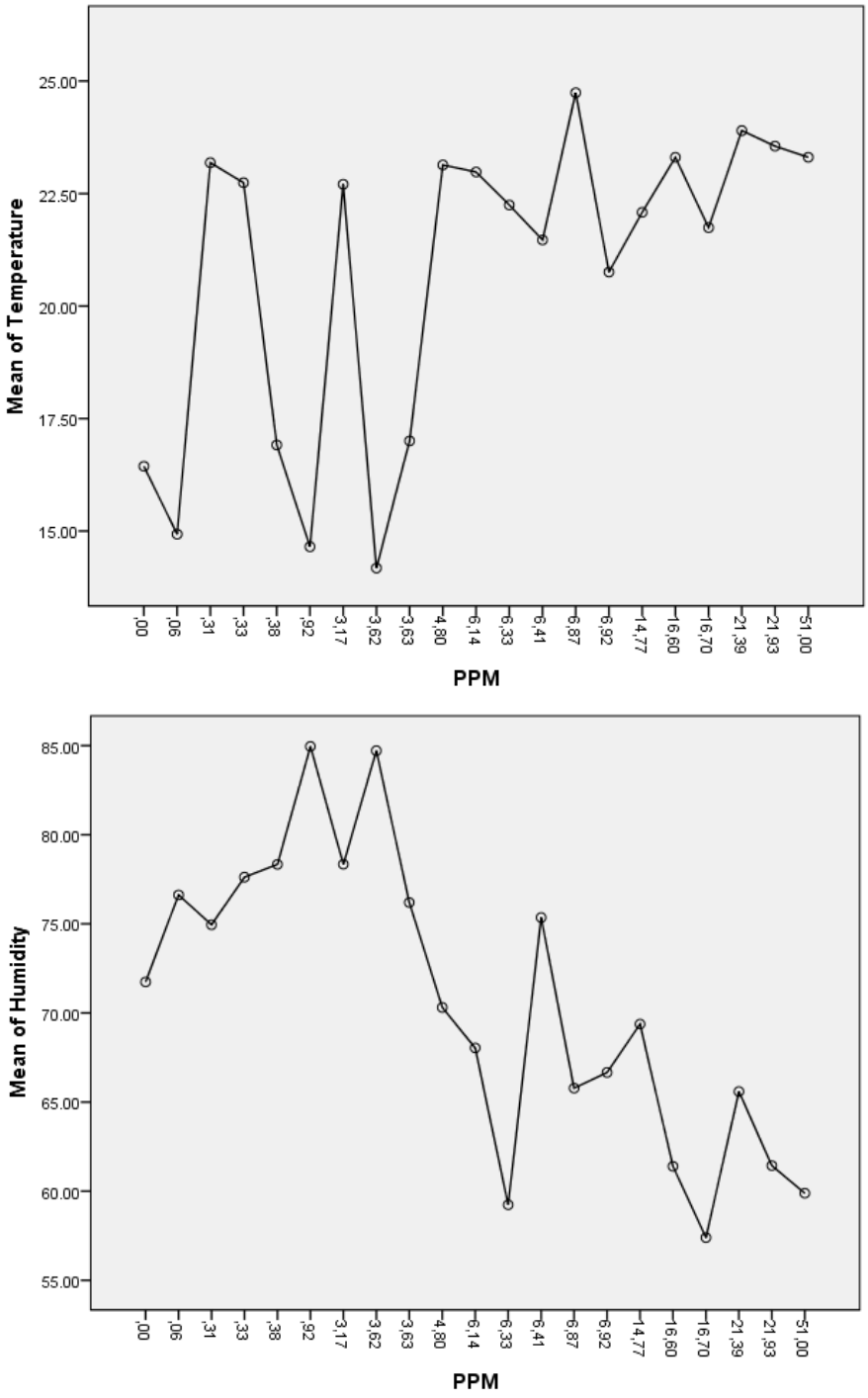

Chart 1. Dependence of the pine processionary moth flight on ecological conditions in the research area

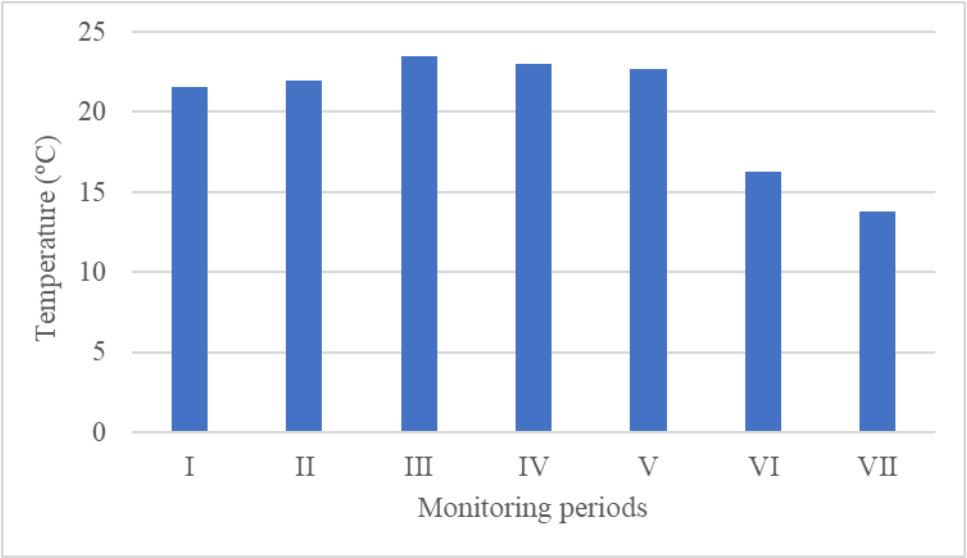

Chart 2. Air temperature during the monitoring period

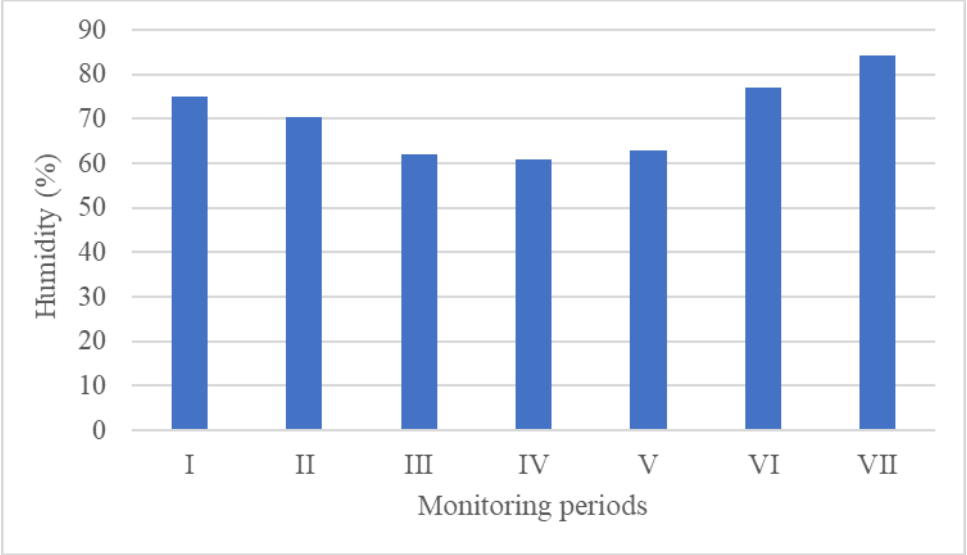

Chart 3. Relative humidity during the monitoring of imago flight

The most intense flight and the highest number of captured adults, 1,336 (44%), in the study area were recorded on August 22 (IV), when the average daily air temperature was 23 °C, while the lowest number of captured adults (41 individuals) was recorded on July 2, at an average daily temperature of 21.6 °C (see Graph 4). During the entire duration of the experiment, a total of 3,054 adult pine processionary moths were captured across the study area.

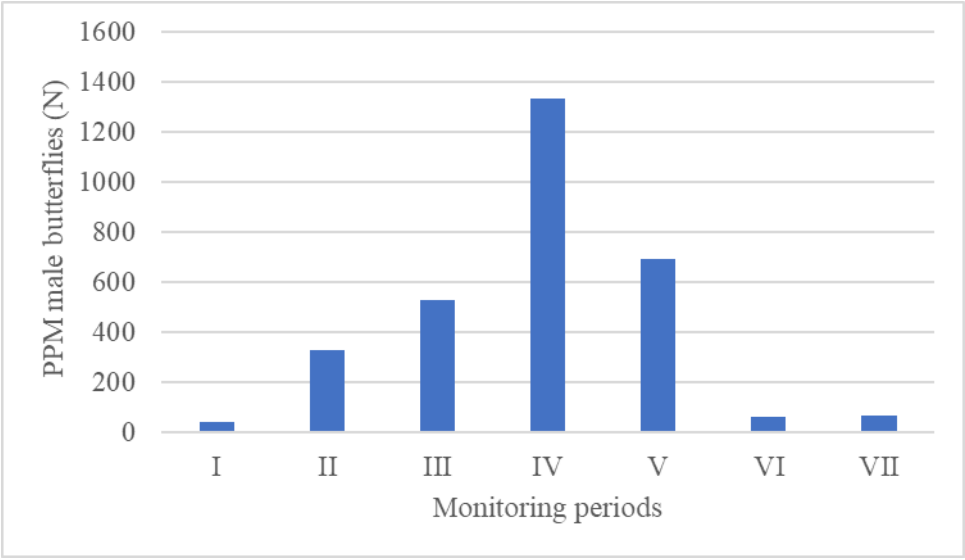

Chart 4. Capture of imago during the monitoring

Zaemdzhikova and Zaevski (2023) refer to populations of the pine processionary moth, whose larvae develop during the winter and whose imago appear in the summer, as 'winter' populations. These populations are characterized by earlier imago flight, as well as some other atypical processes in different bioclimatic regions. The first observed flight of males was recorded on June 22 in the Lastva area, when the average daily air temperature was 25.6 ºC, while the cessation of imago flight across the entire research area was recorded in the last week of September, when the average daily air temperature was 13.8 ºC. Mirchev *et al*. (2013) established the same period and duration of the pine processionary moth flight in central Bulgaria. Ferracini *et al*. (2020) also determined, through six years of monitoring, that the male flight period lasts from mid-June to mid-September. Based on the time of the first male capture in the research area, it can be said that this population belongs to the early type of pine processionary moth.

CONCLUSIONS

Based on the conducted research, it can be concluded:

- The conducted research provides results that contribute to a better understanding of the influence of ecological conditions on the bionomy of the pine processionary moth in the area of the Orjen mountain in Bosnia and Herzegovina,

- During the research, ecological conditions (air temperature and relative humidity) were determined over a 24-hour period using automatic weather stations,

- Statistical analysis of the data revealed a moderate correlation between the measured elements and the flight of male pine processionary moths, which is statistically significant,

- The average daily air temperature during the imago flight ranged from 12.5 to 24.7 ºC,

- Unfavorable temperatures affect the flight of male pine processionary moths because body temperature depends on environmental conditions,

- The appearance of adults and their flight are most intense at higher temperatures and lower air humidity,

- The first observed male flight was recorded on June 22 in the Lastva area, and the cessation of imago flight occurred during the last week of September,

- The highest number of captured adults, 1,336 (44%), in the study area was recorded on August 22, at an average daily air temperature of 23 °C.

- Based on the bionomics and timing of adult flight observed in the study area, it can be concluded that an early population type of the pine processionary moth is present in this region,

- Due to their ecological significance, the collected data can be useful for predicting the occurrence, monitoring the potential spread of the pine processionary moth, as well as for the timely, efficient, and effective implementation of control measures against this pest,

- It is important to control the population status of this insect due to future climate change, as well as to conduct further research on population dynamics

- Future research must be conducted in relation to ecological conditions, as the appearance of the imago itself, changes in seasonal and daily activities are linked to global climate change and may be influenced by weather conditions.

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