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Climate-Induced Shifts in the Population Dynamics of *Synanthedon myopaeformis* in Apple Orchards

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Abstract

Synanthedon myopaeformis (Borkhausen, 1789) (apple clearwing moth) has traditionally been classified as a secondary pest in Bulgarian apple orchards. However, consistent annual captures using pheromone traps, combined with recent studies from 2025, indicate a shift in population dynamics. During peak flight periods, the average number of captured individuals exceeds 25, suggesting increased pest pressure. This study presents preliminary results from the first year of a scientific project focused on the impact of climate change on entomofauna development. A strong correlation has been established between species activity and rising temperatures, supporting the hypothesis that changes in climatic factors accelerate emergence and intensify infestation levels. The findings underscore the need to reassess the pest's phytosanitary status and to adapt integrated pest management systems for apple cultivation.

Keywords: *Synanthedon myopaeformis*; apple orchards; climate change; pest dynamics; integrated pest management.

1. Introduction

The apple clearwing moth (*Synanthedon myopaeformis* Borkhausen, 1789) is a univoltine species belonging to the family Sesiidae. It overwinters as a seven-instar larva, residing in the cambial zone between the bark and wood, where it creates characteristic winding galleries. These galleries are typically formed in response to mechanical injuries or pruning wounds, with the larvae showing a marked preference for callus tissue—particularly in trees grafted on M9 rootstock. The resulting damage compromises the structural integrity of the tree, reduces nutrient flow, and can lead to significant yield losses and shortened orchard lifespan [4].

Historically, *S. myopaeformis* has been classified as a secondary pest in apple orchards, primarily due to its sporadic occurrence and limited economic impact. However, recent observations indicate a shift in its pest status. In both Bulgaria and other parts of Europe, the species is gaining economic importance, with an increasing number of reports of infestation and damage [1,5]. This trend is supported by long-term monitoring data, which reveal consistent annual presence, an extended adult flight period, and a gradual rise in population density. A previous study conducted in Bulgarian orchards confirmed the species' persistence across seasons and highlighted its potential to become a primary pest under favorable conditions [3]. Interestingly, while infestation levels vary across orchards, there is still no conclusive evidence linking tree age or cultivar to pest abundance, suggesting that other environmental or physiological factors may be at play.

One of the most compelling drivers of this shift appears to be climate change. In recent years, the region has experienced a pattern of rising average temperatures, earlier onset of spring phenophases, and prolonged growing seasons. These climatic shifts are known to influence insect development rates, voltinism, and synchronization with host plant phenology. For *S. myopaeformis*, warmer conditions may accelerate larval development, advance adult emergence, and extend the reproductive window. Moreover, international studies have demonstrated that trees subjected to climate-induced stress undergo biochemical changes — such as altered volatile emissions and reduced defensive capacity — which may enhance their susceptibility to pest colonization [2].

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In this context, the present study aims to investigate the climate-induced changes in the population dynamics of *S. myopaeformis* in Bulgarian apple orchards. It presents preliminary findings from the first year of a multi-year scientific project focused on entomofaunal responses to climate variability. Specifically, the study seeks to establish a quantitative relationship between temperature conditions and the flight activity of the species during the 2025 growing season. The results aim to inform the refinement of integrated pest management (IPM) strategies, with a focus on climate-adaptive monitoring, forecasting, and control measures tailored to the evolving behavior of this emerging pest.

2. Material and Methods

The research was conducted during the 2025 growing season at a commercial apple orchard located at the Fruit Growing Institute in Plovdiv, Bulgaria. This orchard reflects the typical production systems of the region, featuring trees mostly grafted onto M9 rootstock and maintained under standard horticultural practices. The location was chosen due to its documented presence of *S. myopaeformis* and its closeness to a meteorological station, which facilitates accurate collection of climatic data.

Monitoring of the pest *S. myopaeformis* was carried out using Delta pheromone traps (CSALOMON, Hungary), which are well-known for their ability to capture clearwing moths effectively. Traps were set up in early April, ahead of the anticipated emergence of adults, and they were placed at a height of around 1.5 meters within the tree canopy. A total of six traps were deployed across the orchard, spaced evenly to ensure representative sampling. Trap inspections were conducted at regular intervals (every 3–4 days), and the number of captured individuals was recorded systematically throughout the flight period.

Climatic data for the 2025 season were obtained from the official meteorological station in Plovdiv, located within 2 km of the orchard. The dataset included average daily temperatures, relative humidity, precipitation levels, and temperature anomalies. Particular attention was given to identifying periods of extreme weather events, such as heatwaves or heavy rainfall, which could influence pest behavior.

For statistical processing of the data, the open-source software environment “R” [6] was used. Descriptive statistics were calculated to summarize trap catches and climatic variables. A Pearson correlation analysis was performed to assess the relationship between the number of individuals caught and temperature values. Additionally, a nonparametric Kruskal–Wallis’s test was applied to evaluate differences in species activity across distinct flight phases (initial, peak, and final). The significance threshold was set at $p < 0.05$. Graphical representations of flight dynamics were generated to visualize temporal patterns and their alignment with climatic trends.

3. Results and Discussion

During the 2025 growing season, the flight activity of *Synanthedon myopaeformis* was monitored continuously, revealing a distinct temporal pattern. The first adult was captured on 16 May, marking the start of the flight period, with an average of 0.5 individuals per trap (Figure 1). This early emergence coincided with a brief period of elevated temperatures following rainfall, suggesting that microclimatic fluctuations may trigger initial adult activity. The peak flight occurred between 13 June and 1 July, with average trap catches of 23, 24, and 35 individuals, respectively. The highest single-day activity was on 1 July, with 70 individuals captured across two traps. This intense activity aligned with stable daily mean temperatures between 24.5°C and 27.9°C, representing the optimal thermal window for emergence and flight. The final capture was recorded on 25 August, with an average of 1.5 individuals per trap, concluding a 102-day flight period. Population dynamics followed a clearly defined single-peaked curve, with a plateau during the peak phase. This unimodal distribution suggests synchrony in adult emergence, likely driven by the accumulation of thermal units and favorable conditions. The extended flight duration indicates developmental plasticity, possibly reflecting microhabitat variability or asynchronous larval development. Correlation analysis between the average daily temperature (Tave) and trap catches revealed a strong positive relationship ($r = 0.81$, $p < 0.01$), confirming the temperature dependence of the trap catches. These findings align with previous studies [3] and international data on Sesiidae species, which typically exhibit optimal flight behavior between 24 °C and 28°C. Relative humidity also influenced flight dynamics (Figure 2). The highest activity occurred under moderately low humidity (52.3%–56.7%), which is likely optimal for pheromone dispersion and mating. Excessive humidity may inhibit the release of volatiles and reduce flight efficiency. Precipitation showed no consistent relationship with catches, though intense rainfall—such as 44.3 l/m² on 16 May—temporarily suppressed activity, likely due to mechanical disruption (Figure 3). The Kruskal–Wallis's test confirmed significant differences in trap catches across the three flight phases ($H = 14.62$, $p < 0.05$), with peak activity notably higher than early and late phases. This reinforces the importance of precise timing in pest monitoring and control. Overall, the 2025 data underscore the critical role of temperature and humidity in shaping the phenology of *S. myopaeformis*. The findings support the hypothesis that climate change—through its impact on thermal regimes and seasonal timing—may enhance the pest's biological performance. These results underscore the need for adaptive pest management strategies that incorporate climatic indicators and phenological models to optimize intervention timing and enhance control efficacy.

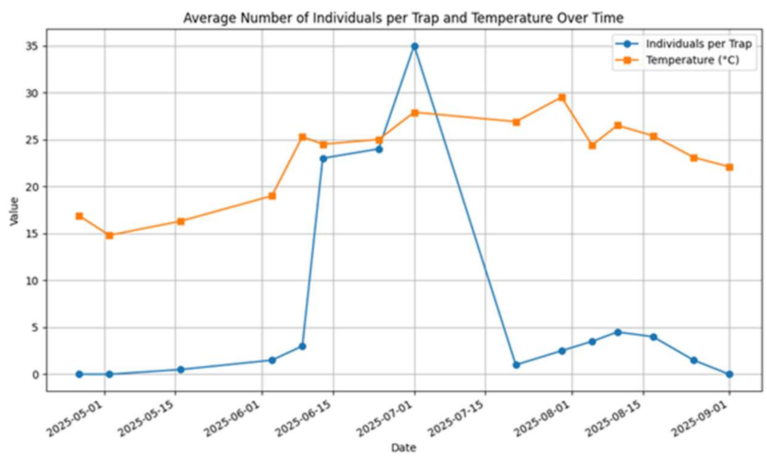

Figure 1. Flight activity of *Synanthedon myopaeformis* and temperature trends during the 2025 season. The graph shows the average number of individuals per trap (blue line) and the average daily temperature (°C; red line) across the monitoring period. A distinct flight peak is observed between mid-June and early July, coinciding with temperatures above 24°C.

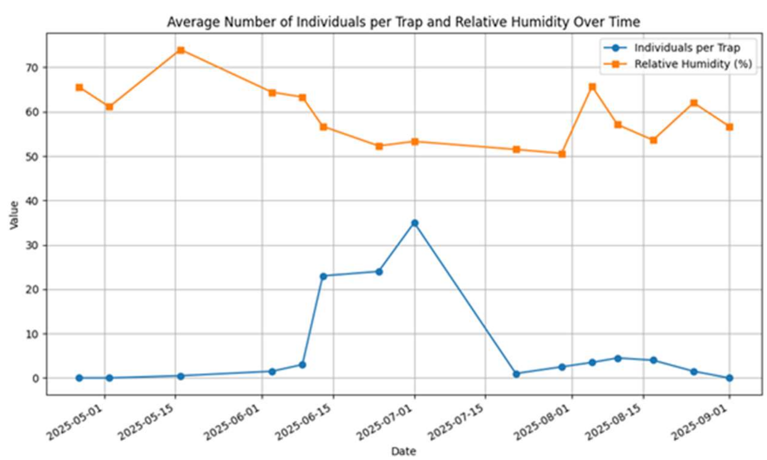

Figure 2. Flight activity of *Synanthedon myopaeformis* and relative air humidity during the 2025 season. The graph illustrates the relationship between average trap catches (blue line) and average relative humidity (%) (green line). Peak activity occurred under moderately low humidity conditions (52–56%), suggesting optimal flight conditions in drier periods.

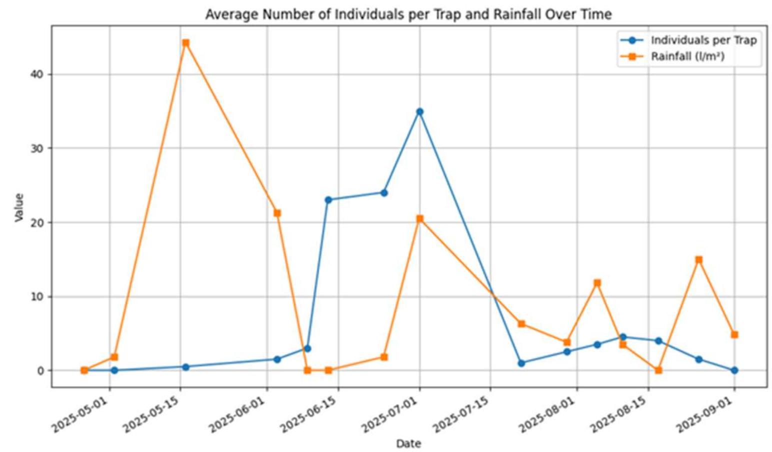

Figure 3. Flight activity of *Synanthedon myopaeformis* and rainfall dynamics during the 2025 season. This figure compares the average number of individuals per trap (blue line) with rainfall amounts (orange line, in liters per square meter). Heavy rainfall events (e.g., 44.3 l/m² on May 16) correspond to suppressed flight activity, while moderate precipitation appears to have a limited impact.

The 2025 results confirm that the flight activity of *Synanthedon myopaeformis* is strongly influenced by temperature, with peak emergence coinciding with periods when the daily mean temperature exceeds 24°C. This thermal threshold appears to be critical for adult activation. It is consistent with both previous local observations [3] and international data indicating increased activity of Sesiidae species under warm, dry conditions [2], [5]. The alignment of peak flight with stable temperature intervals suggests that the species' phenology is tightly coupled with climatic cues, particularly thermal accumulation.

The extended flight window of 102 days, combined with the clearly defined single-peaked curve and plateau, indicates a high degree of adaptive plasticity. This pattern suggests that *S. myopaeformis* can adjust its emergence timing in response to environmental variability, a trait that may be increasingly advantageous under shifting climate regimes. The elevated population density observed in June and July likely reflects accelerated larval development and synchronized adult emergence, phenomena well-documented in other clearwing moths [1]. Such synchrony enhances mating success and may contribute to localized outbreaks if not detected in a timely manner.

Air humidity also emerged as a key ecological factor. Peak activity was recorded at relative humidity levels between 52% and 56%, a range that likely facilitates optimal pheromone dispersion and sustained flight. These conditions may enhance the efficacy of mating communication, while excessively high humidity could suppress volatile release or reduce flight efficiency. Rainfall, on the other hand, did not show a consistent correlation with activity levels. Only extreme precipitation events — such as intense downpours — appeared to disrupt flight, likely through mechanical interference rather than physiological inhibition. This suggests that short-term rainfall may not significantly impact the species' reproductive cycle or dispersal.

Statistical analyses, including the Kruskal–Wallis's test, revealed significant differences in trap catches across the defined flight phases, with peak activity being markedly higher than both the initial and final stages. These findings underscore the importance of precise temporal targeting in pest control programs. In particular, they emphasize the importance of synchronizing pheromone trap deployment and insecticide applications with the most vulnerable stages of the pest's life cycle.

Given ongoing climate trends — characterized by rising temperatures, altered precipitation patterns, and extended growing seasons — *S. myopaeformis* demonstrates clear potential for increased biological activity and expanded impact. These dynamics necessitate a reassessment of current economic-harm thresholds and call for the integration of climate-based indicators into pest forecasting and early warning systems. Incorporating phenological models and real-time weather data into Integrated Pest Management (IPM) frameworks will be essential for maintaining effective control and minimizing crop losses in future seasons.

4. Conclusions

The data from the 2025 growing season clearly demonstrate that *Synanthedon myopaeformis* exhibits temperature-dependent flight activity, with peak emergence occurring when the daily mean temperature exceeds 24°C. This thermal sensitivity, combined with the prolonged flight period and increasing population density, suggests that the species is exhibiting climate-driven adaptability. Such plasticity may enhance its survival and reproductive success under warming conditions, potentially elevating its pest status in apple orchards.

Environmental factors such as relative humidity and rainfall further modulate flight behavior. Dry, moderately humid conditions (52–56%) were found to be optimal for pheromone communication and sustained flight, while intense rainfall events temporarily suppressed activity. These findings underscore the importance of integrating microclimatic variables into pest monitoring protocols.

Statistically significant differences between flight phases, confirmed through nonparametric analysis, highlight critical windows for intervention. This reinforces the need to refine Integrated Pest Management (IPM) strategies by aligning trap deployment and control measures with phenological patterns driven by climate.

Looking ahead, future research should prioritize multi-year monitoring to capture interannual variability, biochemical profiling of host–pest interactions under stress conditions, and the development of predictive population models. Incorporating climate indicators into early warning systems will be essential for proactive and sustainable pest management in the face of ongoing environmental change.

5. Acknowledgements

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