



## Prevalence and Distribution of Pine Processionary Moth (*Thaumetopoea pityocampa*) in Shahat's Aleppo Pine (*Pinus halepensis*) Plantations, Al-JabalAl-Akhdar, Libya

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**Abstract:** The current study aims at investigating the spatial distribution of pine processionary moth (PPM) in parts of Al-Jabal Al-Akhdar region in Libya (in Shahat area). Two *Pinus halepensis* stands in the area (in Al-Mansurra and the ancient city of Cyrene) were chosen for field data collection. Growth parameters for pine trees including; tree height, crown height, diameter at breast height, stand density level, location within the stand, health condition, in addition to the observed number of PPM nests per tree were recorded. Pearson correlation coefficient analysis and variance analysis were applied to assess the relationship between obtained variables, and evaluate growth conditions for both stands. Results revealed relatively better growth conditions at Al-Mansurra site compared to Cyrene site. Moreover, PPM nests occurrence was positively correlated with trees growing isolated or on the stand edge ( $r = 0.54$ ,  $P$  value  $< .001$ ), and negatively correlated with tree height ( $r = - 0.4$ ,  $P$  value  $< .001$ ) emphasizing more dispersal rate among young pine trees. Crown height, dbh, and tree's health condition showed no significant effect on PPM spread in the area. In-depth investigations of the population dynamics of PPM are highly recommended to provide insights into their spatial distribution in the region.

انتشار فراشة جادوب الصنوبر (*Thaumetopoea pityocampa*) وتوزيعها في مشجرات الصنوبر الحلبي (*Pinus halepensis*) في منطقة شحات، الجبل الأخضر، ليبيا

### الكلمات المفتاحية :

فراشة جادوب الصنوبر الحلبي، *Thaumetopoea pityocampa*، التوزيع المكاني، الصنوبر الحلبي، منطقة شحات، الجبل الأخضر، ليبيا.

**المستخلص :** تستهدف الدراسة الحالية معرفة التوزيع المكاني لفراشة جادوب الصنوبر (PPM) في أجزاء من منطقة الجبل الأخضر في ليبيا (تحديداً في منطقة شحات). تم اختيار مشجرتين للصنوبر الحلبي في المنطقة (قرية المنصورة وموقع المدينة الأثرية في شحات) لإجراء الدراسات الحقلية. خصائص النمو لأشجار الصنوبر بما فيها: ارتفاع الأشجار، وارتفاع التاج، والقطر عند مستوى الصدر، وكثافة المشجر، وموقع الأشجار من المشجر، والحالة الصحية، فضلاً عن عدد أعشاش آفة PPM لكل شجرة تم تسجيلها. استخدم معامل الارتباط بيرسون وتحليل التباين لتقييم العلاقة بين البيانات المعطاة، ولتقييم ظروف النمو ولكلا المشجرتين. النتائج أوضحت - إلى حد ما - وجود ظروف نمو أفضل لمشجر المنصورة مقارنة بظروف النمو الموحدة بمشجر الموقع الأثري بشحات. كما أوضحت النتائج أن وجود أعشاش آفة PPM وانتشارها ارتبط بشكل إيجابي مع الأشجار النامية بصورة معزولة أو موجودة على حافة المشجر ( $r = 0.54$   $P$  value  $< .001$ ) وبشكل سلبي مع ارتفاع الأشجار ( $r = - 0.4$ ,  $P$  value  $< .001$ ) وهذا يدل على وجود معدلات انتشار أعلى بين الأشجار الصغيرة في العمر. لم تسجل بيانات ارتفاع التاج، والقطر عند مستوى الصدر، والحالة الصحية للأشجار أي تأثير معنوي على انتشار آفة PPM في منطقة الدراسة. يُصح بشدة بإجراء دراسات مفصلة عن ديناميكية وسلوك مجتمعات آفة جادوب الصنوبر؛ لمعرفة المزيد عن سلوكها وتوزيعها المكاني في المنطقة.

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## INTRODUCTION

The pine processionary moth (PPM) *Thaumetopoea pityocampa* (Denis & Schiff-ermüller)(Lepidoptera, Thaumetopoeidae) is one of the most harmful pests to conifer species in the world (Kesdek et al., 2020; Otsu et al., 2018; Sevim et al., 2010), and one of the main pine defoliators in the Mediterranean region (Camarero et al., 2022; Devkota & Schmidt, 1990; Régolini et al., 2014; Sangüesa-Barreda et al., 2014). PPM distribution is usually controlled by the significant drop in temperature during winter seasons (Battisti et al., 2005). However, evidences were documented for the expansion of PPM in the upper northward of the Mediterranean as a consequence of climate change (Battisti et al., 2005; Robinet et al., 2007; Rosenzweig et al., 2007). This pest causes severe damage throughout the autumn, but especially in the winter when larvae feed on pine needles (Castagneyrol et al., 2014). By that time, they can be easily distinguished on pine trees with conspicuous white silky nests on the upper and lower branches that face the sunlight. They feed mostly during nighttime and hide in their nests during daytime away from their natural predators (Huchon & Demolin, 1970). Even when the percentage of defoliation is relatively low, PPM outbreak might decrease the annual growth rate of infected trees in the short term and interrupt the growth of newly emerging saplings (Hóðar et al., 2003; Jacquet et al., 2013; Jacquet et al., 2012). The severe defoliation caused by PPM as well as other abiotic agents may have a negative impact on the economic value of pine stands (Sangüesa-Barreda et al., 2014). Furthermore, it may increase the susceptibility to other pine pests such as bark and wood boring beetles (Masutti & Battisti, 1990; Zamoum, 2002). In spring, caterpillars make a head-to-tail procession in which they march down from the crown of trees to bury themselves into selected sunny exposed soils for pupation. They remain buried until the moth's emergence in the next summer or for a longer time in what is known as "semi-voltine cy-

cle" (Martin et al., 2021) where they stay for prolonged pupal diapause for one or more years. The emergence of an adult moth occurs in summer, and the life cycle continues after reproduction when the short-lived female moth searches for a prospective host tree for oviposition (Castagneyrol et al., 2014). Besides the severe defoliation effect, the urticating hairs "setae" which PPM caterpillars release as a defensive mechanism might lead to serious allergic reactions in humans and animals such as dermatitis and anaphylactic reactions (Moneo et al., 2015; Vega et al., 2003).

As a Mediterranean basin country, the distribution of pine processionary moth in Libya was briefly described in literature (El Mokhefi et al., 2016; Kerdelhué et al., 2009; N Avtzis et al., 2016) with limited sufficient details regarding their distributional range and current outbreak status. (Kerdelhué et al., 2009) classified the PPM found in Cyrenaica into one of the sub-clades derived from the ENA clade. The existing similarities between Greek and Libyan mitochondrial DNA haplotypes might indicate the original source of PPM in Greece according to (N Avtzis et al., 2016).

The scarcity of information about the origin, distribution, and impact of PPM on pine trees, in addition to the raised public-health awareness due to the approximation of pine plantations to urban areas, were among the drivers of this work. Therefore, the objectives of the current study are set to evaluate the distributional range and patterns of PPM infestation on pine trees in Shahat area in Al-Jabal Al-Akhdar region. Moreover, we examine whether tree height, size, and location have an impact on the degree of severity and spread of PPM in pine trees in the subjected area of study.

## MATERIALS AND METHODS

**The Study Site Description:** This study was carried out in two pine plantations in Shahat

municipality, Al-Jabal Al-Akhdar region in eastern Libya (Cyrenaica). The first site is a pine plantation in Al-Mansurra town (N= 320. 83' 74'', E= 210. 84' 14''), (Altitude = 405m). The site was established in 1958 surrounding Shahat Hospital of Chest and Respiratory Diseases. It is classified as a pure pine plantation (more than 95% of the basal area is *P. halepensis*) and covers an area of approximately 13 ha. The second site is a mixed conifer and broad-leaf plantation that was established in the early 1940s during the Italian colonization era in the ancient city of Cyrene (N= 320 49' 12'', E= 210 51' 48''), (Altitude = 620m). *P. halepensis* compresses the majority of the stocking area (around 75% of the total number of species) followed by *Cupressus sempervirens*, *Eucalyptus camaldulensis*, and other evergreen species. The forested area around the ancient city of Cyrene is estimated to be between 70- 80 ha and was established mainly to protect the archaeological ruins and heritage sites in the city. Both study sites are located in one of the most humid and cold places in Al-Jabal Al-Akhdar region with an average annual precipitation of 600 mm and an average temperature of 20 C<sup>0</sup> (OMU report, 2005). The predominant soil types in the study areas are the red Mediterranean soils of Ferrisiallitic Red (Rhodoxeralfs) and shallow calcareous Rendzinas (Rendolls Lithic) soils (Mahmoud, 1995).

**Sampling and methodology:** Field work for this study took place in April 2022 at the later instar of larvae phase, right before the procession started. At each of the study sites, five quadrat sampling plots (15x15m) were established and measurements were recorded for each pine tree included in the study design. The parameters measured were as follows; tree height (using Silva Clinometer at a fixed distance from the tree trunk) (Avalos et al., 2005; Wright et al., 1997), crown height (the total foliar part of the sampled tree using also Silva Clinometer), Diameter at breast height (dbh) (using diameter tape at 1.3m), presence of PPM nests (visual observation), number of total PPM nests per sampled tree, and notes of the current health status of the sampled tree and its loca-

tion (inside, on the edge, or away from the stand centre). Additionally, 3 core samples were extracted from three different pine trees within each sampling plot using Pressler's increment borer to estimate the average age of each site following standard dendrochronological procedures (Stokes & Smiley, 1968). Among the 10 plots sampled, two plots (one on each plantation) were established in young *P. halepensis* stands (less than 10 years old) to estimate the infestation percentage among young pine cohorts. The young pine stand in Al-Mansurra plantation was self-regenerated in a protected open area on the site, while the ancient city of Cyrene site was established in a reforestation project by the City Coordination Association (NGO) back in 2013. Data collected in this project were grouped and extrapolated to give a better representation of the whole study area. Descriptive statistics and graphs were generated to illustrate the current stand outstanding.

**Statistical Analysis:** Variance analysis (ANOVA) was performed and Pearson correlation coefficients were calculated for nest occurrences and stand variables of height, crown height, dbh, tree location, and health condition to investigate the relationship between PPM distribution and these growth parameters. All statistical analyses were performed using IBM SPSS Statistics software 28.0.

## RESULTS

**Current stands condition:** As illustrated in (Table 1, Fig.1), Al-Mansurra pine plantation expands on an area of 13 ha and is classified as a pure *P. halepensis* stand (more than 95% of basal area). The average number of trees/ha is estimated at around 506.6 tree/ha. Mean tree height is 13.2 m, mean crown height is 6.5m, and mean diameter at breast height is 38.1 cm. In general, the site is in good condition (arguably better than Cyrene site) in terms of density, tree height, size, vigour, and health condition. Emerging seedlings of pines are observed, more concentrated in low-dense and open areas since the site is protected against invaders and

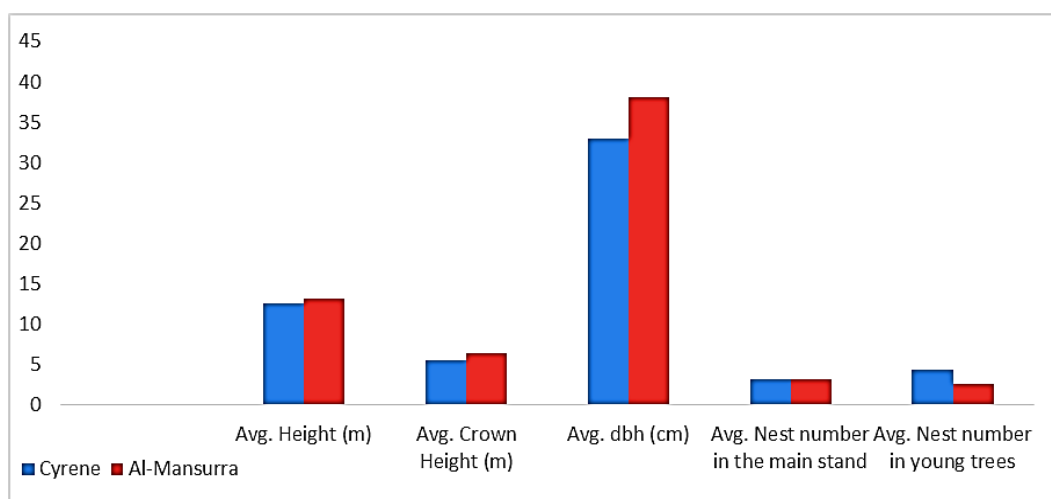
livestock. PPM is considered the only pest affecting pine trees on the site with no evidence of other disturbing biotic agents.

In the ancient city of Cyrene site, *P. halepensis* is the predominant species with 75% of the basal area and expands on an area of around 75 ha. The density of the plantation is relatively low compared to Al-Mansurra site with an average number of trees/ha of 311, mean tree height is 12.6 m, mean crown height of 5.6 m, and mean diameter at breast height of 33 cm. Several biotic and abiotic factors have a deteriorative effect on the growth of pine trees on the

site. For instance, the Mediterranean pine engraver beetle (*Orthotomicus erosus* Wollaston) is responsible for the death of many pine trees, and combined with PPM outbreak and other abiotic agents are causing severe damage resulting in the increasing number of fallen and dead logs on the site. Both stands of Al-Mansurra and Cyrene are classified as unmanaged stands, where there are no signs of silvicultural treatments or any sort of management approaches (thinning, clearcutting, pruning, etc.) applied since the establishment date.

**Table (1):** Description of current pine status in both sites in the study area. Younger pine cohorts (less than 10 years old) in both stands were excluded from the given results

Plantation name	Coordinates	Altitude(m)	Percentage of <i>P. halepensis</i> in the stand	No of trees/ha	Stand age	Average PPM nest occurrence per tree	Density level	Stand health condition
Al-Mansurra	N= 32. 83 E= 21. 84	400-412	95%	506.6	62 ± 3	3.22	High dense stand	Good
Cyrene	N= 32. 49 E= 21. 51	560-625	75%	373.3	49 ± 19	3.25	Moderate dense stand	low



**Figure (1):** Stand characteristics in both study sites of Cyrene and Al-Mansurra

**T. pityocampa distribution:** PPM silky white nests were observed on a large scale in both plantations (Fig. 3). Descriptive analysis of the obtained data showed similar distributional patterns in both sites in the number of nests per pine tree (3.25 and 3.22 for Cyrene and Al-

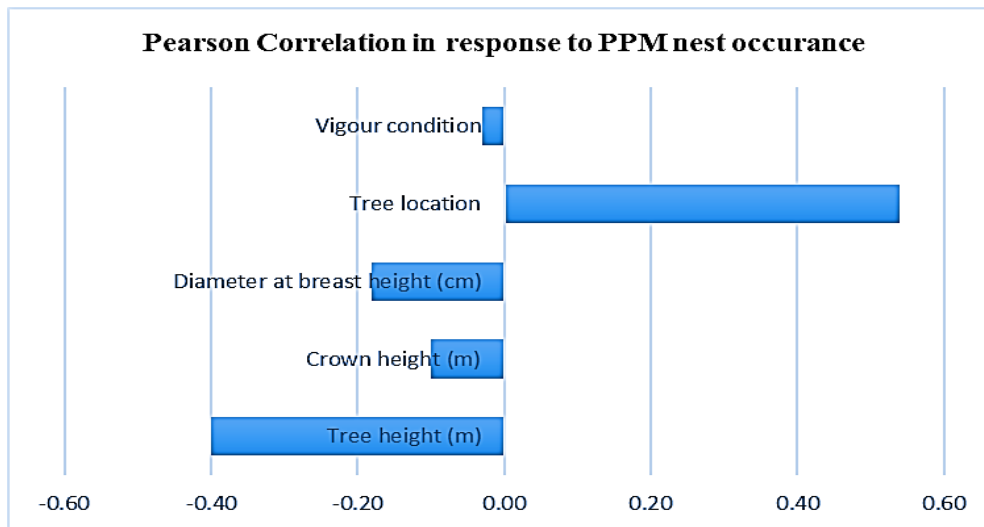
Mansurra sites, respectively). For younger pine cohorts, the dispersal of PPM in Cyrene was significantly higher than that of Al-Mansurra site (4.42 and 2.61 nests per tree, respectively). The infection rate of spread differs greatly between both sites on stand level. In Al-Mansurra

site, around 38% of pine trees have at least one observed PPM nest while in Cyrene site, on the other hand, more than three-quarters of pine trees (75%) are affected by PPM outbreak. Moreover, younger pine trees in both sites exhibited more PPM nests spread compared to older cohorts, with infection percentages of 100% and 85% for both Al-Mansurra and Cyrene sites, respectively. Linear regression and bivariate correlation were applied to investigate possible relationship between the percentage of nest existence and stand parameters such as tree height, crown height, diameter at breast height, tree location within the stand, and vigour condition. The results (Table. 2) suggest a significant positive correlation between the

presence of PPM nests and the tree location within the stand ( $r = 0.54$ , P value  $<.001$ ). Pine trees on the stand edge or in areas where they are exposed to full sunlight are more vulnerable to PPM attack, while inside-stand trees have a better chance of surviving PPM spread. On the contrary, a significant negative correlation was found between PPM nest's presence and the height of trees ( $r = -0.4$ , P value  $<.001$ ), which indicates a high infestation rate among young and small-size trees compared to dominant and co-dominant trees in both stands. No significant correlations were found among the effect of crown height, diameter at breast height (dbh), or vigour condition on nest occurrence in pine trees as shown in (Table.2, Fig. 2).

**Table:(2):** Descriptive statistics of some of the trees and stand parameters in correlation with PPM occurrence in the study area

Trees parameters in relation to PPM nest occurrence	Mean	Std. Deviation	Pearson Correlation	Sig. (2tailed)
Tree height (m)	10.2	4.064	-0.4	<.001
Crown height (m)	4.14	2.762	-0.1	.323
Diameter at breast height (cm)	24.42	14.885	-0.18	.069
Tree location	1.616	0.488	0.54	<.001
Vigour condition	3.05	0.896	-0.03	.731



**Figure (2):** Correlation significance between PPM nest occurrence and some of the studied stand variables.



**Figure (3):** (A) shows *T. pityocampa* spread among young *P.halepensis* trees. (B) shows *T. pityocampa* nest a few hours before the procession starts. Both images were taken in Cyrene site, Shahat, Libya.

## DISCUSSION

Despite the limited information available regarding the origin and distribution of PPM in Libya, this pest has a history of negatively affecting the growth of pine trees (mainly *P. halepensis*) in many forested areas in the country, especially in Al-Jabal Al-Akhdar region, where the species is the most favored in reforestation projects. The expansion of PPM toward higher latitudes and altitudes in areas that previously were unaffected by the pest (Stastny et al., 2006) as a consequence of climate change (Battisti et al., 2005; Benigni & Battisti, 1999; Goussard et al., 1999; Robinet et al., 2007; Rosenzweig et al., 2007) has led to more comprehensive studies investigating population distributional patterns and infestation mechanisms of the insect. On the contrary, different distributional patterns and surviving rates were observed in the southern edge of PPM distribution (in North Africa). Climate warming may contribute to increasing mortality rates of the pest's early life stages in Tunisia (Bourougaaoui et al., 2021). Moreover, PPM nests have disappeared from areas

in the far southern-edge range of Tunisia where it was previously proven to exist. One of the observed impacts that climate change has on PPM populations is the change in the usual timing at which larval procession starts (Bonsignore et al., 2015). For instance, field data for this study took place in April right before the start of the larval procession. Usually, this process happens much earlier in late February or early March in the region. However, the rainy season of this year (2022) lasted longer than usual and led to a delay in the procession time of this pest.

PPM outbreak tends to be higher near the forest edge or in isolated trees (Démolin, 1969). The ideal preference for this pest is selecting taller and edge-located trees for colonization (Démolin, 1969). The findings of this study were in parallel with PPM preference, where the highest and only positive nest occurrence correlation found was with *P.halepensis* trees growing on the stand edge ( $r = 0.54$ ). Higher solar radiation and warmer temperatures might be responsible for such observed spatial

distributions (Buffo et al., 2007). The density level of pine trees in Al-Mansurra site (506.7 tree/ha) was relatively higher than that of Cyrene site (373.3 tree/ha). This might explain the higher infestation rate, especially in younger pine cohorts, in Cyrene Plantation. These results were in agreement with (Geri et al., 1985) who found that PPM tent density declined with increasing density levels in *P. nigra* and *P. sylvestris*, and (Régolini et al., 2014) who reported similar results with *P. pinaster* growing in parts of France. However, (Lombardero et al., 2012) found no significant impact of thinning on PPM density in young *P. pinaster* stands in Spain. The distribution of PPM was notably higher in younger pine trees in both study sites. The percentage of PPM nest occurrence was negatively correlated with tree height ( $r = -0.4$ ). Observations of PPM nests are common among young pine trees in the study area as well as in nearby places since the species is extensively used in reforestation programs, shelter belts, and road-sides plantations. These findings were in contrast with (Régolini et al., 2014) who reported a significant increase in PPM attack with increasing tree height, and (Dulaurent et al., 2012) who stated that PPM infestation was not common among young *P. pinaster* stands. A long-term outbreak of PPM may cause a decrease in both height and size of affected trees compared to healthy unaffected pine trees (Carus, 2004; Jacquet et al., 2012).

The expansion of PPM in both natural and artificial pine plantations, more specifically during the last decade in the study area and the whole region of Al-Jabal Al-Akhdar, has raised concerns among researchers regarding the potentially harmful effect of this pest on pine populations. Its vast dispersal among young trees might be the trigger for more cautious approaches to prevent its expansion. However, scientific works regarding the subject in the region have not been published so far, and this study might highlight the importance of more investigation to be carried on. Proper management approaches might be a key factor in maintaining stand density at

beneficial levels to help decrease PPM infestation. The outcome of this work can be applied to all pine plantations in Al-Jabal Al-Akhdar region since they are homogeneous and share the same growth and climatic conditions. *P. halepensis* is an important tree species in the region (OMU report, 2005; Alsanousi & Ali, 2018), and its ability to survive drought and the semi-arid harsh environments (Quézel, 2000) makes it the most favourable species in afforestation projects (Schiller, 2000). Indeed, the species compresses more than 60% of Libya's total plantation basal area. Maintaining pine stands in the country at sustainable and historical levels is essential for future conservation approaches.

## CONCLUSION

*T. pityocampa* populations were found in many of the natural and artificial *P. halepensis* stands in Al-Jabal Al-Akhdar region, in eastern Libya. This pest has a long history of affecting pine trees in the study area, although no scientific works have documented its dispersal and impact on these pine stands. Ecologists, foresters, and local references declared that PPM populations had increased rapidly especially during the last decade. Despite that the severe defoliation damage of this moth has not been observed or documented on a large scale in the region, cautious and protective measures should be applied since the majority of pine stands in the area are under stress either by biotic or abiotic agents. This study found a high prevalence of PPM nests among isolated and stand-edge pine trees compared to inner stand trees. Most of pine trees in the region are in pure, moderate to low, dense stands which make them more susceptible to PPM infestation. Interestingly, the most alarming finding in this study is the spread of PPM nest among young pine trees even those within high-dense stands. This may negatively affect the growth of these young pine cohorts and threaten their survival capability to replace old stands. Practical management approaches to sustain and protect these young stands are needed now more

than ever in order to achieve long-term sustainability of *P.halepensis* stands in the region.

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