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Assessing the climatic impacts on abundance of *Mansonia annulifera*, *Ma. indiana*, and *Ma. uniformis* (Diptera: Culicidae) in Central Thailand

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Abstract. *Abdulloh A, Chaiphongpachara T, Laojun S. 2024. Assessing the climatic impacts on abundance of* Mansonia annulifera, Ma. indiana, *and* Ma. uniformis *(Diptera: Culicidae) in Central Thailand. Biodiversitas 25: 4736-4744.* *Mansonia* mosquitoes (Diptera: Culicidae) are important vectors for transmitting filarial nematodes, including *Brugia malayi* and *Wuchereria bancrofti*, which cause lymphatic filariasis in humans. In this study, we used a Poisson regression model to evaluate the impact of climatic variables atmospheric pressure, rainfall, relative humidity, temperature, and wind speed on the abundance of three *Mansonia* mosquito species, including *Ma. annulifera*, *Ma. indiana*, and *Ma. uniformis* in Central Thailand. Over the period from November 2021 to October 2022, we collected the mosquitoes in three villages: Rua Village, Wat Khok Ket Village, and Khlong Bang Kae Village using BG-Pro CDC-style traps equipped with dry ice, BG-lure, and an ultraviolet light system, operating from 6:00 PM to 6:00 AM for three consecutive days each month. Our analysis revealed significant associations between several climatic factors and mosquito abundance. For *Ma. annulifera*, each unit increase in temperature and relative humidity significantly increased mosquito abundance by 83.2% and 16.2%, respectively (p<0.05). In contrast, increases in wind speed, atmospheric pressure, and rainfall correspondingly decreased abundance by 57.6%, 10.3%, and 0.7% (p<0.05). For *Ma. indiana*, rises in temperature, atmospheric pressure, and rainfall notably increased mosquito counts by 119.3%, 30.1%, and 0.6%, respectively (p<0.05). Conversely, an increase in wind speed led to a significant reduction of 43.2% (p<0.05). In the case of *Ma. uniformis*, temperature, and rainfall positively influenced mosquito abundance by 114.5% and 0.7%, respectively (p<0.05), while a rise in relative humidity resulted in a 3% reduction (p<0.05). These findings have significant practical implications, providing crucial insights into predicting future shifts in mosquito populations in response to climatic changes, thereby empowering the surveillance and control of mosquito-borne diseases in this region.

Keywords: *Mansonia* mosquitoes, Poisson regression model, public-health, vector surveillance, vectors of filariasis

INTRODUCTION

Mansonia mosquitoes (Diptera: Culicidae) play a critical role in transmitting filarial nematodes such as *Brugia malayi* (Brug, 1927) and *Wuchereria bancrofti* (Cobbold, 1877), which cause lymphatic filariasis in humans (Famakinde 2018; Amorim et al. 2023). Within the genus *Mansonia*, there are two subgenera: *Mansonioides* and *Mansonia*, comprising 25 officially recognized species (Harbach 2023). Lymphatic filariasis, commonly known as elephantiasis, has been prevalent since ancient times and causes permanent disabilities. The World Health Organization (WHO) indicates that over 657 million people in 39 countries still require preventive chemotherapy to combat this parasitic disease (World Health Organization 2023). Among the populations affected by filariasis, men are the most impacted, with 25 million suffering from hydrocele and more than 15 million from lymphedema. At the same time, at least 36 million continue to experience chronic disease symptoms. The global efforts under WHO's global program to eliminate lymphatic filariasis reduced the number of infected individuals to 51 million by 2018—a 74% decrease since the program's inception in 2000 (World Health Organization 2023). Additionally, local mosquito vector control has proven to be an effective strategy for disease management, providing reassurance about our ability to combat this disease (van den Berg et al. 2013; Golding et al. 2015).

In Thailand, *Mansonia* mosquitoes are widely recognized for their role in transmitting lymphatic filariasis (Rattanarithikul et al. 2005). Six species, all from the subgenus *Mansonioides*-*Mansonia annulata* (Leicester, 1908), *Ma. annulifera* (Theobald, 1901), *Ma. bonneae* (Edwards, 1930), *Ma. dives* (Schiner, 1868), *Ma. indiana* (Edwards, 1930), and *Ma. uniformis* (Theobald, 1901) are found in Thailand (Rattanarithikul et al. 2006). These mosquitoes are primarily associated with the southern region, characterized by swamp forests and an abundance of floating and aquatic plants (Rattanarithikul et al. 2006). *Mansonia* mosquitoes use specialized breathing tubes to extract oxygen from aquatic plants during their immature stages. However, some species *Ma. annulifera*, *Ma. indiana*, and *Ma. uniformis* have also been observed in the central region of Thailand (Laojun et al. 2024). Lymphatic filariasis was once a major health issue in Thailand. In 1950, the Department of Health, Thailand Ministry of Public Health, conducted its first survey on filariasis and identified patients in 10 of the 15 provinces surveyed: Pattani, Narathiwat, Phatthalung, Nakhon Si Thammarat, Surat Thani, Chumphon, Yala, Krabi, Trang, and Ranong. The provinces with many patients included Chumphon, Surat Thani, Nakhon Si Thammarat, Phatthalung, Pattani, and Narathiwat (Rojanapanus et al. 2019). In 2017, the WHO validated Thailand as having eliminated lymphatic filariasis, but strict disease surveillance, including the monitoring and tracking of mosquito vectors, should be continued (Meetham et al. 2023).

Climatic factors, including variations in rainfall, temperature, wind speed, and humidity, play a significant role in the dynamics of mosquito-borne diseases (Giesen et al. 2020). These environmental variables directly impact mosquito vector distribution, survival, reproduction, and even resistance to pesticides, which are crucial for effective control measures (Chaiphongpachara and Moolrat 2017; Chaiphongpachara and Laojun 2019a; Ma et al. 2021). Specifically, these factors influence the abundance and distribution of mosquitoes across different regions (Mazarire et al. 2024). Our understanding of these relationships is essential for predicting and managing changes in mosquito populations due to climatic variations (Chaiphongpachara and Laojun 2019b; Sumruayphol et al. 2020; Dalilah et al. 2024). For instance, a previous entomological study in Central Thailand demonstrated that meteorological factors such as temperature and atmospheric pressure significantly influence the populations of *Mansonia* mosquitoes (Laojun et al. 2024). Insights from such data are crucial for developing predictive models that estimate mosquito population dynamics in response to ongoing environmental changes.

Therefore, to understand the influence of climatic variations on *Mansonia* mosquitoes in Central Thailand, this study aimed to assess the abundance of three species *Ma. annulifera*, *Ma. indiana*, and *Ma. uniformis* relative to atmospheric pressure, rainfall, humidity, temperature, and wind speed. The findings will provide insights into predicting shifts in mosquito vector populations due to climatic impacts, aiding efforts to enhance mosquito-borne disease surveillance in the region.

MATERIALS AND METHODS

Ethical approval

The research protocols involving the use of mosquitoes in this study were reviewed and approved by the Institutional Animal Care and Use Committee (IACUC) of Suan Sunandha Rajabhat University (Reference No. IACUC 64-005/2021).

Mansonia mosquito collection

Mansonia mosquito habitats are commonly found in the central region of Thailand, particularly within the coconut plantations of Samut Songkhram Province, an area characterized by numerous watercourses and dense aquatic vegetation (Laojun et al. 2024). Although no filariasis outbreaks have been reported in Central Thailand, previous research indicated that *Mansonia* mosquitoes in this region can transmit nocturnally subperiodic *B. malayi*, more commonly found in Southern Thailand (Saratapeian et al. 2002). *Mansonia* species were collected using BG-Pro CDC-style traps (BioGents, Regensburg, Germany) equipped with dry ice, BG-lure, and an ultraviolet light system, as recommended by prior research (Wilke et al. 2022; Chaiphongpachara et al. 2024). This study focused exclusively on adult *Mansonia* mosquitoes due to their role in disease transmission. Understanding the abundance of adult mosquito populations is essential for developing effective vector control strategies and preventing disease.

The collection was performed over 12 months, from November 2021 to October 2022, in three villages: Rua Village (13°22'016.6" N, 99°53'029.4" E), Wat Khok Ket Village (13°23'018.7" N, 99°55'034.7" E), and Khlong Bang Kae Village (13°24'036" N, 99°55'007.4" E). As *Mansonia* mosquitoes are predominantly nocturnal (Galardo et al. 2022), in each village, three traps were set up and operated nightly from 6:00 PM to 6:00 AM over three consecutive days each month. The collected mosquitoes were euthanized at -20°C each morning. Subsequently, they were transported to the College of Allied Health Sciences, Suan Sunandha Rajabhat University, Samut Songkhram Campus, Thailand, for species identification.

Species identification

Species identification was conducted on all female mosquito specimens using a Nikon AZ 100 M stereo microscope (Nikon Corp., Tokyo, Japan). Specimens of *Mansonia* with incomplete or damaged morphological features were excluded from the study. Identification relied on morphological characteristics, employing taxonomic keys (Rattanarithikul et al. 2006). The identified specimens were then individually placed in 1.5 mL microcentrifuge tubes containing 95% ethanol and stored at -20°C in a freezer for preservation at the laboratory of the College of Allied Health Sciences, Suan Sunandha Rajabhat University, Samut Songkhram Campus.

Climate data

Monthly climate data for Samut Songkhram Province in Central Thailand including atmospheric pressure (millibars), rainfall (mm), relative humidity (%), temperature (°C), and wind speed (knots) from November 2021 to October 2022 were obtained from the local weather station of the Thai Meteorological Department and are presented in Table 1. This region experiences three distinct climatic periods: the cool season (November-February), the hot season (March-May), and the rainy season (June-October), based on patterns observed in a previous mosquito survey in Samut Songkhram Province (Laojun et al. 2024). Therefore, to elucidate the seasonal variations in climate data, Grouped Principal Component Analysis (GPCA) was employed using Past software version 4.03.

Statistical analyses

Monthly climate data and mosquito counts were analyzed to investigate the correlation between mosquito abundance and climatic factors and to predict changes in mosquito populations caused by climatic variations. The distribution data for the *Mansonia* species showed consistent non-zero counts each month without any over-dispersion. Based on these characteristics, a Poisson regression model was used to assess how various climatic variables (atmospheric pressure, rainfall, relative humidity, temperature, and wind speed) influenced mosquito abundance. The thoroughness of our analysis is evident in the use of the Poisson regression model, which is particularly suitable for count data as it assumes that the response variable (mosquito count) follows a distribution where the mean is equal to the variance. The absence of over-dispersion indicating that the variance does not exceed the mean confirmed the appropriateness of this model, negating the need for alternatives like the negative binomial regression, which is typically employed in cases of over-dispersion. Additionally, the Kolmogorov-Smirnov test was conducted to verify the normality of these variables, further validating the use of Poisson regression for our analysis.

All statistical analyses were performed using Jamovi software (version 2.6.2), available at https://www.jamovi.org. A significance level of α = 0.05 was used, with *p*-values of >0.05 indicating no significant statistical relationships. Next, to calculate the percentage change in mosquito abundance due to climatic variables, the following approach was used: if the exponentiation of the coefficient (Exp (B)) was >1, the mosquito count was expected to increase, and the percentage increase was calculated as (Exp (B) - 1) × 100. Conversely, if Exp (B) was <1, the mosquito count was expected to decrease, with the percentage decrease calculated as (1 - Exp (B)) × 100.

RESULTS AND DISCUSSION

Seasonal variations in climate data

To analyze the influence of climatic factors across different seasons, GPCA was employed. The GPCA resolved five components, with the first two accounting for 83.71% of the total variance (component 1 represented 44.19%, and component 2 contributed 39.52%). The scatter plot derived from these components (Figure 1) depicted distinct clusters for each season, demonstrating the unique climate profiles of each. According to the climate data presented in Table 1, the rainy season was characterized by high humidity, increased rainfall, and elevated temperatures. In contrast, the cool season exhibited lower humidity and cooler temperatures. Additionally, the hot season, encompassing the pre-monsoon period of March and April, was marked by higher temperatures and elevated wind speeds, highlighting significant climatic activity leading into the monsoon.

Abundance of three *Mansonia* species

The survey conducted in Samut Songkhram Province, Central Thailand, from November 2021 to October 2022, captured a total of 3,533 *Mansonia* mosquitoes, comprising three species: 1,494 *Ma. annulifera*, 636 *Ma. indiana*, and 1,403 *Ma. uniformis*. Monthly distribution data, presented in Figure 2, displayed fluctuations in both the total and individual species counts throughout the study period. The highest numbers were recorded with counts of 555 for *Ma. annulifera*, 109 for *Ma. indiana*, and 342 for *Ma. uniformis*. Conversely, the lowest counts were observed in March 2022 for *Ma. annulifera* with only 14 individuals, in January 2022 for *Ma. indiana* with 8, and in November 2021 for *Ma. uniformis* with 34 individuals.

Correlations between mosquito abundance and climatic data

Before analyzing the data, we applied the Kolmogorov-Smirnov test to check the normality of the variables. The results were not significant ($p>0.05$), indicating that the data did not deviate from a Poisson distribution. Table 1 showed the results of the Poisson regression model that climate factors have a significant effect on the abundance of *Mansonia* mosquitoes. Notably, each unit increase in temperature approximately doubled mosquito numbers (Exp (B) = 1.995; $p<0.001$). Similarly, each unit increase in relative humidity led to a 4.9% increase in mosquito numbers (Exp (B) = 1.049; $p<0.001$). In contrast, wind speed had a negative effect, reducing mosquito counts by about 32.1% per unit increase (Exp (B) = 0.679; $p<0.001$). Rainfall marginally increased mosquito numbers by 0.2% per unit (Exp (B) = 1.002; $p<0.05$). However, atmospheric pressure showed a negligible and non-significant impact on mosquito abundance (Exp (B) = 0.998; $p>0.05$). These results are summarized in Figure 3, which illustrates the predicted impact of climatic conditions on the total abundance of *Mansonia* species.

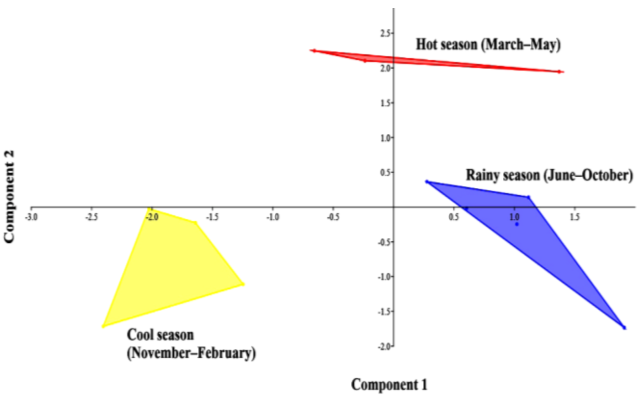

Figure 1. Grouped Principal Component Analysis (GPCA) of three distinct climatic periods: the cool season (November-February), the hot season (March-May), and the rainy season (June-October). The analysis is based on five climate variables: atmospheric pressure, rainfall, relative humidity, temperature, and wind speed. This analysis highlights the significant variation in weather conditions across seasons, a key finding of our study. The first two principal components explain 44.19% and 39.52% of the total variation, respectively

Table 1. Results of the Poisson regression model for the total of *Mansonia* species

Parameter	B	SE	95% Confidence interval		Exp (B)	95% Exp (B) Confidence interval		z score	p
			Lower	Upper		Lower	Upper		
(Intercept)	5.316	0.023	5.270	5.361	203.536	194.346	212.964	227.806	<.001*
Atmospheric pressure	-0.002	0.024	-0.048	0.044	0.998	0.953	1.045	-0.075	0.940
Rainfall	0.002	0.001	0.000	0.003	1.002	1.000	1.003	2.6777	0.007*
Relative humidity	0.047	0.007	0.033	0.062	1.049	1.033	1.064	6.378	<.001*
Temperature	0.691	0.041	0.610	0.771	1.995	1.840	2.162	16.773	<.001*
Wind speed	-0.387	0.029	-0.444	-0.330	0.679	0.641	0.719	-13.270	<.001*

Abbreviations: B: Coefficient estimate; SE: Standard Error; Exp (B): Exponentiation of the coefficient estimates. *Statistically significant (p<0.05)

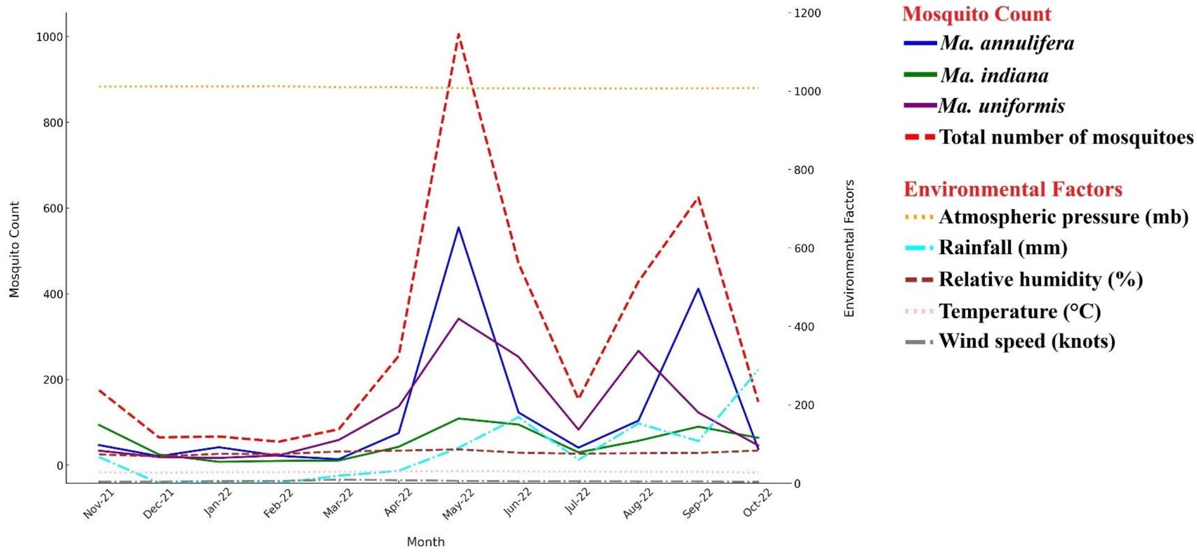

Figure 2. Monthly trends of mosquito count and environmental factors during the study period from November 2021 to October 2022

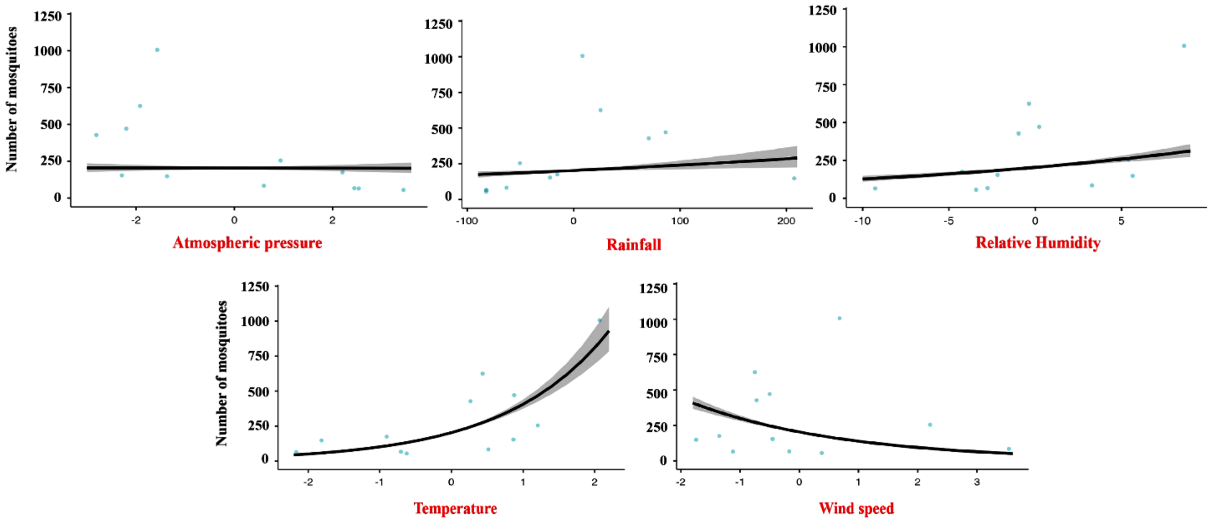

Figure 3. Prediction of climatic impacts on the abundance of the total of *Mansonia* species, showing the influence of atmospheric pressure, rainfall, relative humidity, temperature, and wind speed. The model explains 85.2% of the variance in mosquito abundance (R^2 = 0.852)

When analyzing the impact of climatic factors on different species of *Mansonia* mosquitoes, the Poisson regression model results vary. For *Ma. annulifera*, all climatic variables-atmospheric pressure, rainfall, relative humidity, temperature, and wind speed-significantly influenced mosquito abundance, with p-values less than 0.05 (Table 2). Temperature and relative humidity had positive impacts on mosquito abundance, as indicated by positive z-scores, increasing the numbers by approximately 83.2% (Exp (B) = 1.832; *p*<001) and 16.2% (Exp (B) = 1.162; *p*<001), respectively. Conversely, increases in wind speed and atmospheric pressure resulted in reductions of about 57.6% (Exp (B) = 0.424; *p*<001) and 10.3% (Exp (B) = 0.897; *p*<05), respectively. Rainfall, although having a minor effect, negatively affected abundance, reducing it by 0.7% (Exp (B) = 0.993; *p*<001) per unit increase. These climatic effects on the abundance of *Ma. annulifera* are illustrated in Figure 4.

The Poisson regression analysis for *Ma. indiana* indicated significant climatic impacts on mosquito abundance, as reflected in Table 3. A one-unit increase in temperature and atmospheric pressure resulted in significant increases in mosquito abundance by 119.3% (Exp (B) = 2.193; *p*<0.01) and 30.1% (Exp (B) = 1.301; *p*<0.01), respectively. Conversely, wind speed exhibited a notable negative influence, reducing abundance by 43.2% (Exp (B) = 0.568; *p*<0.01) with each unit increase. Rainfall, although having a minor effect, significantly increased mosquito counts by 0.6% (Exp (B) = 1.006; *p*<0.01) per unit increase. However, relative humidity, which resulted in a 1% change in mosquito counts (Exp (B) = 1.01), did not significantly affect *Ma. indiana* abundance, as its *p*-value of 0.570 suggests a lack of meaningful impact. These results are visually detailed in Figure 5, providing a clear and concise summary of the findings.

The Poisson regression analysis for *Ma. uniformis* revealed that climatic factors such as rainfall, relative humidity, and temperature significantly impacted mosquito populations (*p*<0.05, Table 4). A one-unit increase in temperature was associated with a substantial rise in mosquito counts, approximately 114.5% (Exp(B) = 2.145; *p*<0.001). Rainfall contributed to a modest increase, raising mosquito counts by 0.7% per unit (Exp(B) = 1.007; *p*<0.001). Conversely, relative humidity was linked to a slight decrease in abundance, reducing mosquito counts by about 3% (Exp (B) = 0.970; *p*<0.05), indicating a minor yet significant effect. However, atmospheric pressure and wind speed did not show significant impacts in this analysis (*p*>0.05). The climatic effects on the abundance of *Ma. uniformis* are visually depicted in Figure 6.

Table 2. Results of the Poisson regression model for *Ma. annulifera*

Parameter	B	SE	95% Confidence interval		Exp (B)	95% Exp (B) Confidence interval		z score	*p*
			Lower	Upper		Lower	Upper		
(Intercept)	4.276	0.041	4.194	4.355	71.969	66.299	77.882	104.150	< .001*
Atmospheric pressure	-0.109	0.040	-0.188	-0.031	0.897	0.828	0.970	-2.710	0.007*
Rainfall	-0.007	0.001	-0.009	-0.005	0.993	0.991	0.995	-6.080	< .001*
Relative humidity	0.150	0.013	0.125	0.177	1.162	1.133	1.193	11.330	< .001*
Temperature	0.606	0.076	0.457	0.754	1.832	1.579	2.125	8.010	< .001*
Wind speed	-0.859	0.059	-0.978	-0.745	0.424	0.376	0.475	-14.440	< .001*

Abbreviations: B: Coefficient estimate; SE: Standard Error; Exp (B): Exponentiation of the coefficient estimates. *Statistically significant (*p*<0.05)

Table 3. Results of the Poisson regression model for *Ma. indiana*

Parameter	B	SE	95% Confidence interval		Exp (B)	95% Exp (B) Confidence interval		z score	*p*
			Lower	Upper		Lower	Upper		
(Intercept)	3.733	0.051	3.630	3.831	41.802	37.706	46.111	72.78	< .001*
Atmospheric pressure	0.263	0.051	0.164	0.363	1.301	1.178	1.437	5.203	< .001*
Rainfall	0.006	0.001	0.003	0.009	1.006	1.003	1.009	4.286	< .001*
Relative humidity	0.010	0.017	-0.024	0.043	1.01	0.977	1.044	0.568	0.57
Temperature	0.785	0.088	0.613	0.959	2.193	1.845	2.608	8.898	< .001*
Wind speed	-0.566	0.079	-0.725	-0.415	0.568	0.484	0.66	-7.159	< .001*

Abbreviations: B: Coefficient estimate; SE: Standard Error; Exp (B): Exponentiation of the coefficient estimates. *Statistically significant (*p*<0.05)

Table 4. Results of the Poisson regression model for *Ma. uniformis*

Parameter	B	SE	95% Confidence interval		Exp (B)	95% Exp (B) Confidence interval		z score	*p*
			Lower	Upper		Lower	Upper		
(Intercept)	4.288	0.042	4.203	4.369	72.824	66.906	78.980	101.380	< .001*
Atmospheric pressure	-0.057	0.038	-0.132	0.017	0.944	0.876	1.017	-1.510	0.130
Rainfall	0.007	0.001	0.005	0.009	1.007	1.005	1.009	7.680	< .001*
Relative humidity	-0.031	0.012	-0.053	-0.008	0.970	0.948	0.992	-2.700	0.007*
Temperature	0.763	0.061	0.643	0.884	2.145	1.902	2.420	12.440	< .001*
Wind speed	0.064	0.039	-0.012	0.140	1.067	0.988	1.150	1.670	0.096

Abbreviations: B: Coefficient estimate; SE: Standard Error; Exp (B): Exponentiation of the coefficient estimates. *Statistically significant (*p*<0.05)

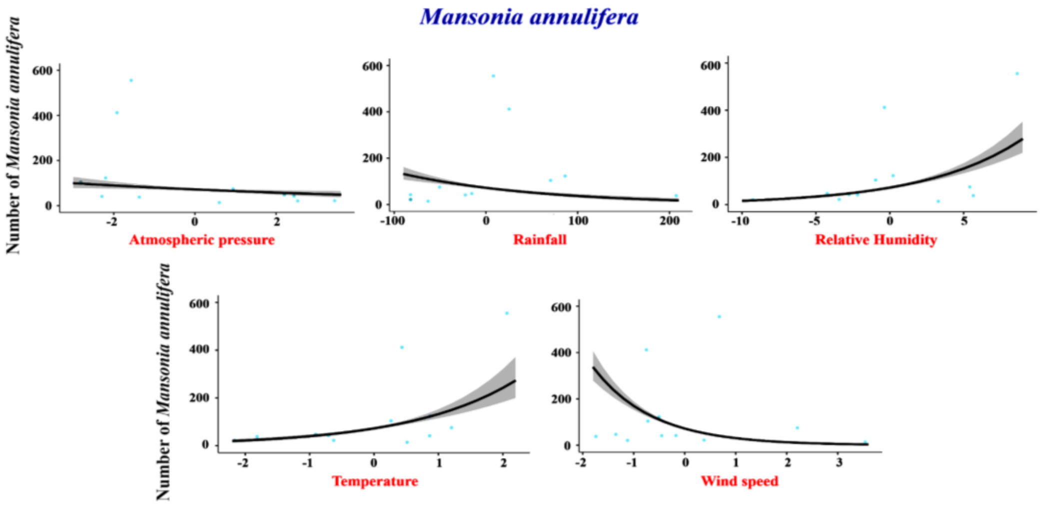

Figure 4. Prediction of climatic impacts on the abundance of *Ma. annulifera*, showing the influence of atmospheric pressure, rainfall, relative humidity, temperature, and wind speed. The model explains 77.6% of the variance in mosquito abundance (R^2 = 0.776)

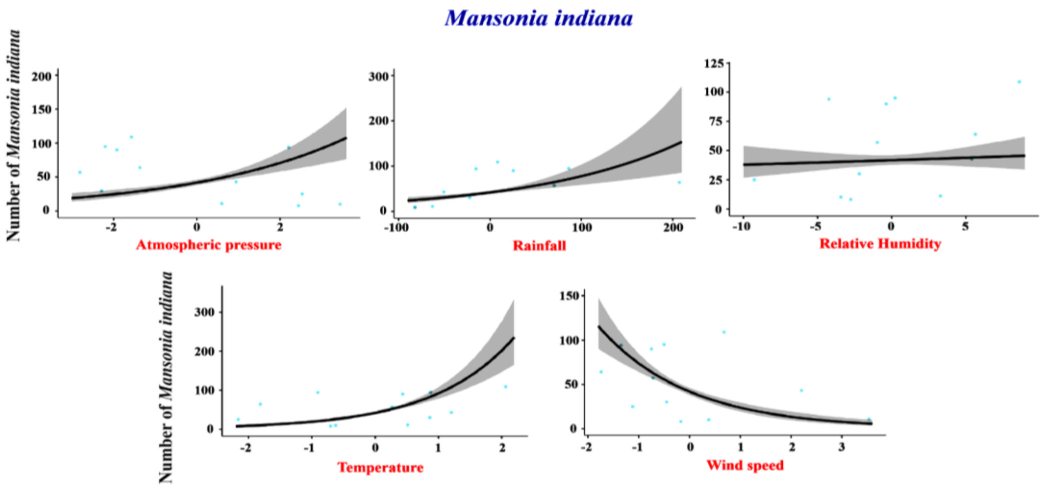

Figure 5. Prediction of climatic impacts on the abundance of *Ma. indiana*, showing the influence of atmospheric pressure, rainfall, relative humidity, temperature, and wind speed. The model explains 74.4% of the variance in mosquito abundance (R^2 = 0.744).

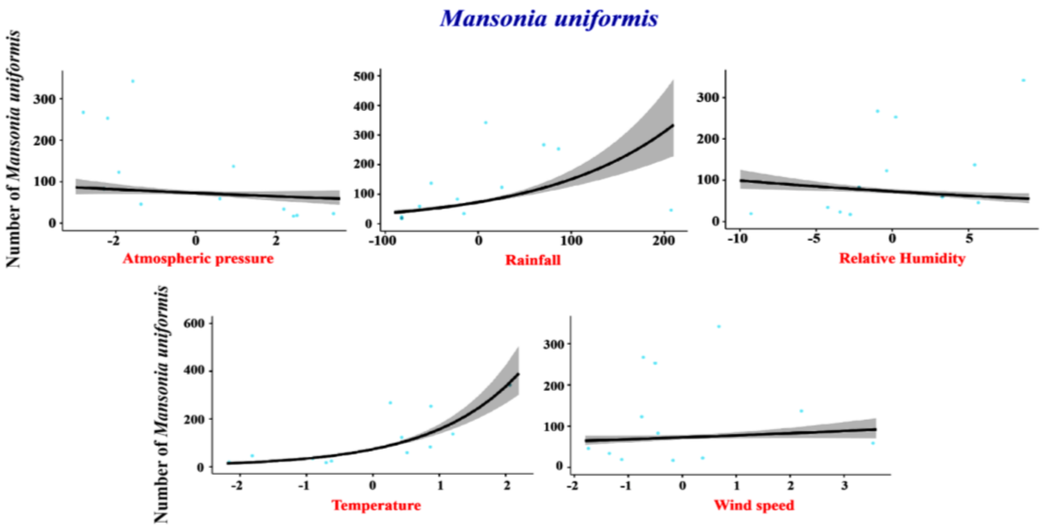

Figure 6. Prediction of climatic impacts on the abundance of *Ma. uniformis*, showing the influence of atmospheric pressure, rainfall, relative humidity, temperature, and wind speed. The model explains 90.4% of the variance in mosquito abundance (R^2 = 0.904)

Discussion

This study collected *Mansonia* mosquitoes over one year in the central region of Thailand, identifying three species: *Ma. annulifera, Ma. indiana,* and *Ma. uniformis*. Seasonal differences in weather conditions, as demonstrated by the GPCA, prompted year-round sampling to assess the impact of these changes. Our results in this study indicated that various climatic factors significantly influenced the abundance of these *Mansonia* species, although the impact varied by species. This variability may reflect the unique biological and behavioral characteristics of each species, aligning with findings from previous studies in the Republic of Korea (Hwang et al. 2020) and Qatar (Tahir et al. 2023), which noted species-specific responses to climatic conditions.

Although the climatic impacts on abundance varied among species, temperature consistently had a positive correlation on all three: each unit increase in temperature significantly raised abundance by 83.2% for *Ma. annulifera*, 119.3% for *Ma. indiana*, and 114.5% for *Ma. uniformis*, highlighting its critical role in mosquito population dynamics (Tables 2-4). These observations align with studies from other regions, such as central Iran, where a strong positive correlation between temperature and mosquito abundance was noted (Asgarian et al. 2021). Higher temperatures accelerate mosquito larval growth and maturation, increasing population sizes, survival rates, and feeding behaviors, which in turn enhance mosquito activity and potential disease transmission (Lim et al. 2021).

Wind speed significantly negatively impacted the populations of *Ma. annulifera* and *Ma. indiana*: each unit increase in wind speed resulted in a decrease in abundance by 57.6% for *Ma. annulifera* and 43.2% for *Ma. indiana* (Tables 2-4). Strong winds may disrupt their flight. Previous studies suggested that high wind speeds reduce mosquito host-seeking activities due to their influence on flight range and patterns (Drakou et al. 2020), similar to those observed in species like *Aedes albopictus* (Skuse, 1894) (Adeleke et al. 2022). However, our results indicated that not all mosquito species are affected by wind speed, which may be due to different flight behaviors and capabilities, as no significant impact was observed in *Ma. uniformis*. These observations are consistent with a study on *Mansonia* species, including *Ma. annulifera*, *Ma. indiana*, and *Ma. uniformis* in Southern Thailand, which demonstrated varied flight patterns and behaviors among the species (Gass et al. 1983).

Rainfall is a crucial climatological variable for predicting the abundance of mosquitoes, particularly for the genus *Culex*, as its volume and distribution directly impact the production and size of mosquito breeding sites (Yan et al. 2021). However, excessive rainfall can negatively affect other species by destroying their breeding grounds, as seen with *Anopheles minimus* (Theobald, 1901), which relies on slow-flowing streams (Fansiri et al. 2024). This study found that rainfall significantly correlated with all three *Mansonia* species, though the effects varied: it negatively impacted *Ma. annulifera*, with each unit increase resulting in a 0.7% decrease in abundance, while positively affecting *Ma. indiana* and *Ma. uniformis*, increasing their abundance by 0.6% and 0.7% respectively (Tables 2-4). The increased rainfall likely enhances habitat availability for the larval stages of *Ma. indiana* and *Ma. uniformis*, aligning with findings from a previous study in the Amazon that demonstrated rainfall's influence on the density and dispersal of *Mansonia* mosquitoes (de Mello et al. 2022). Conversely, for *Ma. annulifera*, high rainfall disrupts the breeding environment, causing excessive water flow that makes it difficult for them to roost on aquatic vegetation and reduces the availability of suitable plants, leading to a decline in this species population (de Mello and Alencar 2021).

Relative humidity significantly influenced two *Mansonia* species, causing a 16.2% increase in the abundance of *Ma. annulifera* and a 3% decrease in *Ma. uniformis* for each unit increase (Tables 2-4). Generally, relative humidity affects mosquito survival by influencing desiccation tolerance, development, and lifespan, which in turn impacts population dynamics (Asgarian et al. 2021; Baril et al. 2023). However, the effects of relative humidity vary among mosquito species. The negative impact on *Ma. uniformis* corresponds with findings from previous studies, such as in Estonia, where a negative correlation between mosquito abundance and humidity was reported (Kirik et al. 2021). Similarly, research in Bangladesh demonstrated a strong negative correlation between relative humidity and the abundance of several *Anopheles* species, including *An. karwari* (James, 1903), *An. annularis* (Wulp, 1884), *An. jeyporiensis* (James, 1902), and *An. minimus* (Bashar and Tuno 2014).

Atmospheric pressure, the force exerted by Earth's atmosphere on its surface, is closely associated with changes in temperature, wind, and precipitation. Insects may adjust their behaviors in response to variations in atmospheric pressure. Increases in atmospheric pressure can enhance mating, flight, and feeding behaviors, whereas decreases may reduce activity levels due to unstable weather conditions and heightened mortality risks (Azevedo et al. 2023). Furthermore, Haufe (1954) reported that atmospheric pressure directly impacts mosquito flight activity, a finding echoed by Fimia-Duarte et al. (2020), who observed its effects on mosquito population density in Cuba. In this study, atmospheric pressure significantly correlated with mosquito populations: it positively affected *Ma. indiana*, leading to a 30.1% increase in abundance per unit increase and negatively impacting *Ma. annulifera,* resulting in a 10.3% decrease per unit increase. These findings suggest varying sensitivities among species to changes in atmospheric pressure. Some insect species might perceive an increase in pressure as an indicator of favorable weather, thus ramping up activities that boost their survival and reproduction chances. In contrast, others may reduce activities to conserve resources in response to perceived adverse conditions (Azevedo et al. 2023).

A previous entomological study in Thailand that used Pearson's product-moment correlation test to assess the relationship between *Mansonia* species and meteorological factors showed significant positive correlations between *Ma. annulifera* and *Ma. uniformis* with temperature. Additionally, *Ma. uniformis* showed a significant negative correlation with atmospheric pressure. However, *Ma. indiana* did not demonstrate any significant correlations with climatic factors (Laojun et al. 2024). In comparison, the Poisson regression model used in this study provided more detailed insights, revealing relationships that were not detected in the Pearson correlation test. The Pearson test measures the linear relationship between two variables (e.g., a single climatic factor and mosquito abundance) but does not account for the influence of other variables or their interactions (Drakou et al. 2020; Ha et al. 2021). In contrast, the Poisson regression model accounts for multiple independent variables and their interactions, offering a more comprehensive analysis of how climatic factors influence mosquito populations (Lim et al. 2021; Muñoz-Pichardo et al. 2021).

In conclusion, our findings provide robust evidence that climatic factors influence the abundance and dynamics populations of *Ma. annulifera*, *Ma. indiana*, and *Ma. uniformis*. Rising temperatures and fluctuations in other climatic patterns may contribute to increase these mosquito population densities, thereby heightening the risk of filariasis transmission. This understanding is vital for monitoring the spread of mosquito-borne diseases. Accurate forecasting of mosquito population trends is vital for strategic planning in vector control.

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