Analysis of *Scirpophaga incertulas* Population Dynamics in a Single Rice-Growing Season Influenced by Climatic Factors in Sei Bingei, North Sumatra

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Abstract

This study aimed to analyze the relationship between climatic factors (temperature, humidity, and rainfall) and the population dynamics of *Scirpophaga incertulas* in Sei Bingei, Langkat, North Sumatra, using regression analysis and a logistic growth model. The population was monitored using an LED SMD light trap with an intensity of 500 lumens (50 W), operated daily from 6:00 PM to 6:00 AM (Western Indonesian Time) in a 600 m² (20 × 30 m) paddy field, with a container of soapy water placed below the lamp to capture moths. Correlation analysis showed that temperature had a strong positive relationship with the population ($r = 0.795$), while humidity ($r = –0.491$) and rainfall ($r = –0.535$) had weak negative relationships. Linear regression results indicated an R^2 value of 0.75, meaning that 75% of population variation could be explained by climatic factors, with a Significance F value of 0.0085, showing that climatic factors collectively had a significant effect. The regression coefficients revealed that temperature had a significant positive effect (coefficient = 4.375; $p = 0.014$), while humidity and rainfall were not significant ($p > 0.05$). Simulation of the population dynamics of *S. incertulas* with the logistic growth model produced a MAPE value of only 3.15%, indicating that the model has a high level of accuracy in predicting the population dynamics of *S. incertulas* in Sei Bingei. These findings imply that temperature changes play a dominant role in influencing *S. incertulas* population fluctuations in rice ecosystems.

***Keywords**: Climate, Linear Regression, Logistic Model, Population Dynamic, Scirpophaga Incertulas*

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Introduction

Rice is one of the world's staple food crops, and its productivity is increasingly threatened by climate variability and pest infestations [1]. Among the major pests, *Scirpophaga incertulas* (yellow stem borer) causes substantial damage to rice yields in Asia by attacking stems and causing "dead-heart" and "white-ear" symptoms [2], [3]. Climate factors like temperature, relative humidity, and rainfall are known to influence insect pest population dynamics, phenology, and outbreak risk in rice ecosystems [4], [5], [6]. Understanding how these abiotic factors correlate with pest abundance is critical for developing prediction models and management strategies to reduce crop losses [7], [8]. However, empirical studies that integrate logistic growth models, correlation, regression, and error estimation (such as MAPE) for *S. incertulas* under specific microclimates are relatively limited.

Recent field studies demonstrate that temperature often has a strong positive effect on *S. incertulas* incidence, while excessive rainfall or high humidity may reduce or delay infestation peaks [9], [10]. For example, Anandhi et al (2023) found a positive correlation between maximum temperature and stem borer damage during certain meteorological weeks, but negative relationships with high humidity during other periods [11]. Another recent study in Uttar Pradesh, India, reported that relative humidity and rainfall explained much of the variability in yellow stem borer incidence depending on planting dates and methods [12]. Studies on stem borer complexes also show that abiotic factors such as morning relative humidity, minimum temperature, and occasional rainfall events significantly affect pest composition and dynamics [13]. These findings suggest that a multifactorial approach combining temperature, humidity, and rainfall data with statistical modelling can better explain population trends.

In modeling pest population dynamics, logistic growth models are useful because they account for density-dependent effects and carrying capacity changes over time [14]. Such models, when linked with climatic covariates, allow prediction of population growth under differing environmental scenarios, which is valuable for pest forecasting and management [15]. Regression analysis, R^2 statistics, and ANOVA help quantify how much of the variation in pest population can be explained by climatic factors and whether those factors collectively have statistically significant influence [16]. Additionally, using error metrics like Mean Absolute Percentage Error (MAPE) permits evaluation of the model's predictive precision [17], an aspect often under-reported in pest dynamics literature. Applying these tools in a context-specific field setting (e.g. Sei Bingei, North Sumatra) can yield insights into pest management under local climate conditions.

This study aims to address these research gaps by analyzing the relationship between climatic factors (temperature, relative humidity, and rainfall) and the population dynamics of *Scirpophaga incertulas* during a single growing season in Sei Bingei, Langkat, North Sumatra. Specifically, correlation and multiple linear regression methods were employed to evaluate the extent to which climatic variables influence population dynamics, as indicated by the coefficient of determination (R^2), followed by ANOVA to test overall significance. The simulation of *S. incertulas* population dynamics based on climatic factors using a logistic growth model was also evaluated with MAPE to assess its predictive accuracy. The results are expected to inform local pest management policies by identifying which climatic variables are most critical and by guiding the timing of appropriate interventions.

Literature Review

Recent studies have consistently shown that climatic variables play a critical role in determining the incidence and severity of *Scirpophaga incertulas* (yellow stem borer) infestation in rice [18]. Sanyal et al. (2025) examined seasonal occurrence of *S. incertulas* across multiple planting seasons and found strong positive correlations with maximum temperature, alongside negative associations with afternoon relative humidity and minimum temperature during particular weeks [19]. Devi and Varma (2022) demonstrated that planting dates and weather-dependent methods influence incidence patterns: for instance, maximum and minimum temperature, morning relative humidity and rainfall explained significant variability in dead-heart and white-ear damage in Bihar, India [20]. Sarkar et al. (2022) studied aromatic rice under staggered planting in Odisha and observed that temperature extremes (maxima) combined with low rainfall periods contributed to peak yellow stem borer infestation in early cropping stages. These findings reinforce that temperature, rather than humidity or rainfall alone, often emerges as the dominant abiotic factor influencing yellow stem borer population dynamics.

Experimental work focusing on developmental rates under different temperatures supports the field observations. Sharmitha et al. (2021) found that increasing constant temperatures led to shorter developmental times for eggs and larvae, implying more generations per season under higher temperature regimes [21]. Such physiological acceleration under warmer conditions suggests that even moderate increases in temperature due to climate change might substantially increase *S. incertulas* population growth. In contrast, high humidity or excessive rainfall sometimes delayed infestation peaks or reduced survival, possibly through increased pathogen pressure or reduced adult activity, as shown in the Mandya studies [22]. Thus, both laboratory and field studies agree that temperature exerts strong control over population growth, with humidity/rainfall exerting more variable, sometimes negative, influence [23].

Modeling studies and statistical analyses incorporating climatic covariates have become more frequent in recent years to forecast pest outbreaks and estimate the extent of variation explained by weather. Ela et al. (2023) used correlation analyses between meteorological variables and pest incidence, finding that temperature variables explained a significant portion of variation in infestation rates [24]. Dasari et al. (2024) used regression techniques to evaluate how combinations of temperature, humidity, and rainfall influence damage metrics, with some models showing high explanatory power for certain growth stages or damage types [25]. Hatwar et al. (2021) similarly correlated weather parameters with yellow stem borer incidence under different planting dates, helping to identify critical periods when climatic conditions favor pest build-up [26]. However, few studies have combined logistic growth modelling with error-estimation metrics like MAPE to both model dynamics and assess predictive accuracy.

There is also increasing attention in studies from Indonesia and nearby regions to pest control and resistance in relation to climate. For example, inventory surveys of parasitoids in Northern Sumatra indicate that natural enemies may respond to climate-induced shifts in pest populations, potentially impacting biological control efficacy [27]. Research on rice genotype resistance shows variation in yellow stem borer damage among cultivars, emphasizing the potential for breeding climate-resilient varieties [28]. Studies on biochemical defense mechanisms (e.g. via silicon amendments) suggest options to mitigate damage under conditions favorable to pest growth [29]. These lines of work underscore the multifactorial nature of pest management under changing climatic conditions, combining modelling, genetics, biocontrol, and agronomic practices.

Despite these advances, there remain gaps in the literature. Many studies focus on correlation or incidence patterns but do not quantify precisely how much of population variation is explained by climatic factors (i.e. R^2) or assess the predictive precision (e.g. via MAPE) of growth models under local climate conditions. There is also relatively little research in Sumatra or similar equatorial rice ecosystems combining logistic growth models with climatic covariates. The effects of short-term lags (weeks) between climatic changes and population growth phases are underexplored in many field studies. Finally, the integration of local weather measurements with standardized trapping methods for estimating population dynamics remains somewhat rare, making comparative studies more difficult. Addressing these gaps is essential for improving pest forecasting and for guiding management interventions tailored to local environmental conditions.

Research Methodology

Time and Location

This research was conducted from June 1 to August 31, 2025, during a single rice growing season. The experimental site was located in Sei Bingei Subdistrict, Langkat Regency, North Sumatra, Indonesia, at geographic coordinates 3.5246° N (latitude) and 98.5005° E (longitude). The field used for data collection had an area of 600 m² (20 × 30 m) and was cultivated under a monoculture rice cropping system. The study area represents a typical lowland rice ecosystem with clay-loam soil texture and a humid tropical climate. Weekly observations of pest populations and climatic variables were recorded throughout the study period.

Materials and Methods

The main tool used for monitoring adult *Scirpophaga incertulas* populations was a light trap installed at the center of the rice field. The trap consisted of an LED SMD light source with an intensity of 500 lumens (50 W), positioned approximately 1.5 meters above the ground surface. Beneath the lamp, a container filled with soapy water was placed to capture adult moths attracted to the light. The trap was operated daily from 6:00 PM to 6:00 AM Western Indonesian Time to collect nocturnal insects. Climate parameters, including temperature (°C), relative humidity (%), and rainfall (mm), were obtained as secondary data from the international open-access climate database, NASA's Prediction of Worldwide Energy Resources (POWER). A total of 91 days of daily climatic observations during the study period were downloaded and averaged into weekly means, resulting in 13 weeks of summarized climate data. The collected specimens were identified and counted weekly to determine population abundance per observation period.

Figure 1. Light traps at the rice field research site

Data Analysis

The relationship between climatic factors and the population of *S. incertulas* was analyzed using Pearson's correlation analysis to determine the strength and direction of linear relationships [30]. A multiple linear regression analysis was then applied to evaluate the combined effect of temperature, relative humidity, and rainfall on population abundance. The regression model was statistically tested using the coefficient of determination (R^2) to assess how much variance in population could be explained by climatic factors, ANOVA (Significance F) to test overall model significance, and Coefficients and p-values to evaluate the contribution of each independent variable.

Population growth dynamics were further modeled using a logistic growth model [31], expressed as :

$$N_{t+1} = N_t + r_t \cdot N_t \cdot \left(1 - \frac{N_t}{K}\right)$$

where N_t is the population at week t_1, N_{t+1} is the population at week $t+1$, $r_t = ln(N_{t+1}/N_t)$ is the intrinsic growth rate, and K is the carrying capacity, defined as the maximum observed population size ($K = Max\ N_t$).

To assess the predictive accuracy of the logistic model, the Mean Absolute Percentage Error (MAPE) was calculated using the formula [32]:

$$MAPE = \left(\frac{|Actual - Predicted|}{Actual}\right) \cdot 100$$

Results

The relationship between climate factors and the population dynamics of *S. incertulas*

The correlation analysis indicated that temperature had a strong positive relationship with the population dynamics of *S. incertulas* (r = 0.795), suggesting that higher temperatures tend to increase pest abundance. In contrast, relative humidity (r = –0.491) and rainfall (r = –0.535) exhibited weak negative correlations with the pest population. These results imply that while temperature promotes population growth, excessive humidity and rainfall may suppress the pest's activity or disrupt its life cycle. Table 1 explains the analysis of the correlation results (Pearson) between climate factors and the *S. incertulas* population.

Table 1. Correlation (Pearson) matrix between climate factors and S. incertulas population

	Temperature (°C)	Relative Humidity (%)	Rainfall (mm)	Population (individuals)
Temperature (°C)	1	-0.233	-0.494	0.795
Relative Humidity (%)	-0.233	1	0.181	-0.491
Rainfall (mm)	-0.494	0.181	1	-0.535
Population (individuals)	0.795	-0.491	-0.535	1

The multiple linear regression analysis provided further insight into the combined effect of climatic factors. The model produced an R^2 value of 0.75 (Table 2), meaning that approximately 75% of the variation in *S. incertulas* population could be explained by temperature, relative humidity, and rainfall. The ANOVA test yielded a Significance F of 0.0085 (Table 3), confirming that the regression model was statistically significant at the 95% confidence level.

Table 2. Statistical description of research data

Statistical Description	
Multiple R	0.866
R Square	0.750
Adjusted R Square	0.657
Standard Error	1.745
Observations	12

Table 3. ANOVA statistical results

	df	SS	MS	F	Significance F
Regression	3	73.30	24.43	8.02	0.0085
Residual	8	24.37	3.05		
Total	11	97.67			

The regression coefficients in Table 4 showed that temperature had the strongest positive influence on pest population (Coefficient = 4.375, *P* = 0.014), followed by relative humidity (Coefficient = –0.658, *P* = 0.125) and rainfall (Coefficient = –0.106, *P* = 0.451). This indicates that temperature significantly affects the increase of *S. incertulas* population, whereas the effects of humidity and rainfall were not statistically significant. The positive coefficient for temperature implies that every one-degree Celsius increase could result in an average rise of approximately 4.38 individuals in the pest population, under constant conditions of other factors.

Table 4. Regression statistical results

	Coefficients	Standard Error	t Stat	P-value
Intercept	-43.917	52.701	-0.833	0.429
Temperature (°C)	4.375	1.403	3.119	0.014
Relative Humidity (%)	-0.658	0.384	-1.712	0.125
Rainfall (mm)	-0.106	0.134	-0.792	0.451

These findings align with previous studies reporting that *S. incertulas* thrives in warm environments where high temperature accelerates larval development and adult emergence [33], [34]. Figure 2 explains that the spike in population growth that occurred in the 9th week was accompanied by an increase in temperature. Meanwhile, excessive rainfall and humidity can reduce egg viability and larval survival due to fungal infection or submersion of host plants [35], [36]. Therefore, temperature acts as the dominant climatic driver regulating the seasonal fluctuation of *S. incertulas* in the Sei Bingei region.

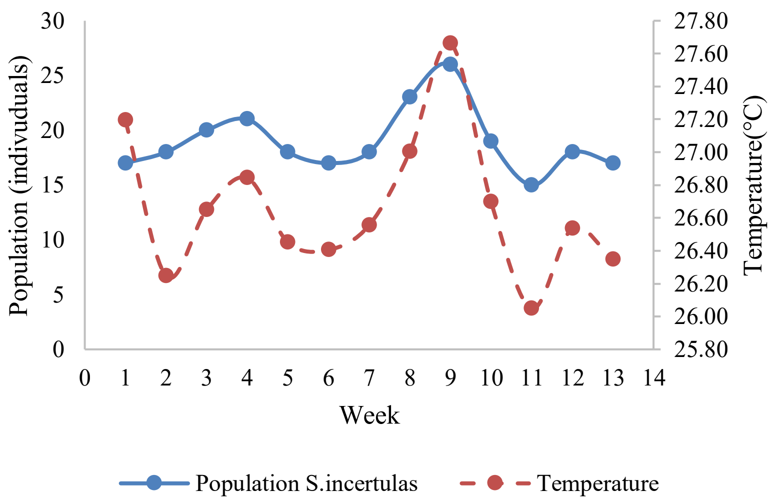

Figure 2. The relationship between the population dynamics of *S. incertulas* and temperature

Logistic growth model of population dynamics

The logistic growth model was developed to describe the temporal population changes of *S. incertulas* based on observed field data and climatic influences. The model successfully represented the sigmoidal pattern of pest growth, characterized by an initial lag phase, rapid exponential increase, and stabilization at the carrying capacity. Figure 3 explains the population dynamics of S. incertulas based on actual observation data and the results of logistic growth model simulations. The model evaluation produced a Mean Absolute Percentage Error (MAPE) of 3.15%, which indicates a very high level of accuracy between predicted and observed population data (Table 5).

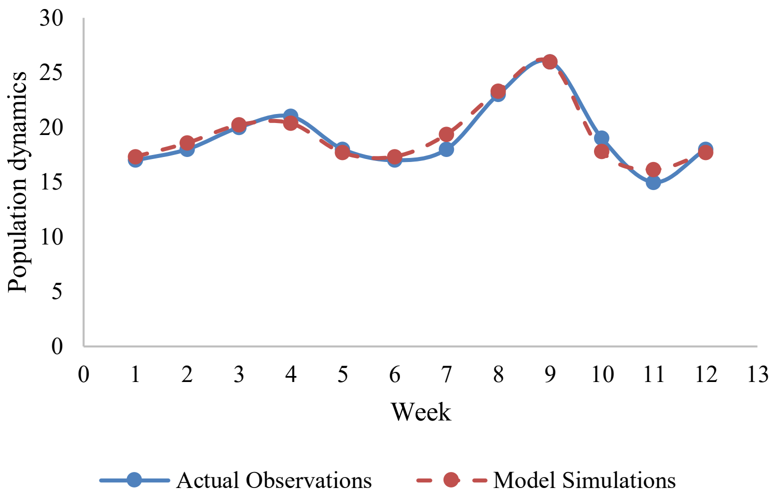

Figure 3. Comparison of the population dynamics of *S. incertulas* from observations with the results of logistic growth model simulations

Table 5. MAPE analysis of logistic growth model simulation for *S. incertulas* population dynamics

Week	Populasi		Error	MAPE
	Actual	Predicted		
1	17	17.34	1.98%	3.15%
2	18	18.58	3.24%	
3	20	20.23	1.13%	
4	21	20.38	2.96%	
5	18	17.68	1.76%	
6	17	17.34	1.98%	
7	18	19.36	7.54%	
8	23	23.33	1.41%	
9	26	26.00	0.00%	
10	19	17.79	6.36%	
11	15	16.16	7.71%	
12	18	17.68	1.76%	

This small MAPE value demonstrates that the logistic growth model effectively captures the biological behavior of *S. incertulas* population dynamics in Sei Bingei. It reflects the pest's tendency to grow rapidly during favorable climatic periods, followed by stabilization as resource limitations or natural enemy pressures increase. Thus, the developed model can be applied as a reliable predictive tool for anticipating population outbreaks under local climatic conditions.

Recommendations for Integrated Pest Management (IPM)

Based on the findings, temperature was identified as the primary climatic factor influencing the population dynamics of *S. incertulas* in the Sei Bingei agroecosystem. Therefore, climate based monitoring and integrated management strategies should be prioritized to ensure effective pest control under changing environmental conditions. Regular monitoring of temperature and rainfall data is essential to anticipate potential population surges, as predictive models incorporating climatic variables can serve as early-warning systems for pest outbreaks [37]. Adjustments to cultural practices, such as modifying planting schedules to avoid synchronization between the rice reproductive stage and peak *S. incertulas* activity, can help minimize infestation risks. In addition, proper irrigation management can prevent overly humid conditions that favor pest development [38].

The enhancement of biological control agents, including parasitoids such as *Trichogramma spp.* and predators like *Cheilomenes sexmaculatus*, can also contribute significantly to reducing pest populations when supported by habitat manipulation or refugia planting [39], [40]. Rational chemical control should only be employed when pest densities exceed economic thresholds to minimize pesticide resistance and preserve ecological stability [41]. Integrating climatic data analysis with biological and cultural control measures can thus optimize pest suppression while maintaining environmental sustainability [42]. The developed logistic model demonstrates high predictive accuracy and provides a valuable scientific foundation for designing climate-adaptive integrated pest management (IPM) programs tailored to the specific agroclimatic conditions of Sei Bingei and other similar rice-growing regions [43].

Conclusion

The present study concluded that temperature was the most influential climatic factor affecting the population dynamics of *S. incertulas* in the Sei Bingei rice agroecosystem, North Sumatra. Correlation and multiple linear regression analyses demonstrated that temperature had a strong positive relationship ($r = 0.795$, $p = 0.014$) with pest population growth, whereas relative humidity and rainfall showed weak negative correlations. The regression model yielded an R^2 value of 0.75 and a significant ANOVA result (Significance F = 0.0085), indicating that the combination of climatic factors could explain 75% of the variation in *S. incertulas* population dynamics. Moreover, the logistic growth model developed based on climatic factors achieved a very low MAPE of 3.15%, confirming its high accuracy and suitability for simulating pest population behavior in the study area.

The findings emphasize that temperature variations play a pivotal role in regulating *S. incertulas* abundance, suggesting that climate based monitoring and predictive modeling should be incorporated into pest management programs. Integrating climatic data with cultural, biological, and rational chemical control strategies offers a more effective and sustainable approach to minimizing pest pressure. The implications of this study extend to developing early warning systems and adaptive Integrated Pest Management (IPM) frameworks under local climate conditions. Future research should focus on validating the logistic model across different cropping systems and regions to enhance its predictive reliability and support broader applications in climate-smart pest management.

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