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Demographic Responses of Insect Pest Populations to Climate Variability: A Regional Study of Jharkhand

Dr. Sushil Kumar Yadav
Radha Govind University, Ramgarh, Jharkhand
Email: dranshumangal@gmail.com

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Abstract: *Climate change has emerged as one of the most critical drivers reshaping the population dynamics and demographic profiles of insect pest communities worldwide. Jharkhand — a state nestled in the tribal heartland of eastern India — presents a compelling case study, where shifting monsoon patterns, rising mean temperatures, and increasingly erratic rainfall regimes are quietly rewriting the ecology of agricultural pest species. This study investigates the age-specific life table parameters, intrinsic rate of natural increase (rm), net reproductive rate (R_0), doubling time (DT), and finite rate of increase (λ) of four economically significant insect pest species: the rice leaf folder (Cnaphalocrocis medinalis), the stem borer (Scirpophaga incertulas), the fall armyworm (Spodoptera frugiperda), and the brown planthopper (Nilaparvata lugens), under three distinct thermal regimes mirroring observed and projected climate scenarios in Jharkhand. Laboratory bioassays conducted at 25°C, 30°C, and 35°C over two agricultural seasons (kharif 2023 and rabi 2023–24) revealed significant temperature-dependent modulation of all demographic parameters. The rm values increased substantially from 25°C to 30°C for all species, with the most dramatic response noted in N. lugens (rm = 0.187 d^{-1} at 30°C vs. 0.143 d^{-1} at 25°C), indicating accelerated population build-up under projected warming. Field validation conducted across six agro-ecological zones of Jharkhand corroborated these laboratory findings, with pest pressure indices correlating positively with deviation from historical mean temperatures ($r = 0.78$, $p < 0.01$). These findings underscore the urgent need for climate-responsive integrated pest management (IPM) strategies and predictive pest forecasting systems tailored to the unique agro-climatic context of Jharkhand.*

Keywords: *Life table parameters, Climate variability, Integrated pest management, Thermal biology, Rice pests*

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Introduction

The relationship between climate and insect population dynamics is ancient, intricate, and — as we are now beginning to fully appreciate — profoundly consequential for food security. Insects are ectotherms: their metabolic rates, developmental timelines, reproductive capacities, and survival

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probabilities are all tightly coupled to ambient temperature and humidity. As the Earth warms, this biological dependency is translating into measurable, sometimes alarming shifts in pest population behavior across the globe. India, with its vast and varied agricultural landscape, is particularly vulnerable. Within this diversity, Jharkhand occupies a unique position — a state of paradoxes. Carved out of Bihar in November 2000 to honor the aspirations of its predominantly tribal population, Jharkhand is rich in mineral wealth and forest cover, yet agriculture remains the livelihood of over 70% of its rural households. The state's agricultural economy rests heavily on rainfed rice cultivation, supplemented by pulses, oilseeds, and vegetables. This dependence on the monsoon makes it uniquely sensitive to climate variability.

Over the past two decades, Jharkhand has witnessed a consistent warming trend, with mean annual temperatures rising by approximately 0.4–0.6°C, alongside increasing variability in rainfall distribution. The Chota Nagpur Plateau, which forms the topographic backbone of the state, is experiencing more frequent dry spells interspersed with intense rainfall events — a pattern consistent with model projections for central-eastern India under the RCP 4.5 and RCP 8.5 scenarios. These shifts are not merely meteorological abstractions; they have tangible consequences for the agricultural pest complex that farmers in Ranchi, Khunti, Giridih, Dhanbad, and Palamu districts contend with every kharif season. Demographic parameters — derived from age-specific life tables — provide the most rigorous quantitative framework for understanding how climate mediates insect population growth. The intrinsic rate of natural increase (rm), introduced by Birch (1948) and elaborated by Southwood & Henderson (2000), captures the per-capita rate of population growth under specific environmental conditions. Alongside rm, the net reproductive rate (R_0), mean generation time (T), doubling time (DT), and finite rate of increase (λ) together paint a comprehensive picture of a pest population's potential trajectory under any given thermal regime. This research aims to fill that gap — not merely as an academic exercise, but as a necessary step toward building climate-smart pest management protocols for one of India's most food-insecure states.

Objectives of the Study

1. To determine the age-specific life table parameters of four major insect pest species under three temperature regimes representative of current and projected climate scenarios in Jharkhand.
2. To analyze the effect of temperature on key demographic indices — rm, R_0, T, DT, and λ — and establish quantitative temperature–response relationships for each species.

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3. To validate laboratory findings through field surveys across representative agro-ecological zones of Jharkhand, correlating pest incidence with observed climate variables.
4. To project potential shifts in pest population dynamics under future climate scenarios and recommend adaptive IPM strategies for Jharkhand's farming communities.

Study Area and Agro-Climatic Profile of Jharkhand

Jharkhand, spanning approximately 79,716 km² between latitudes 21°58' to 25°18'N and longitudes 83°22' to 87°57'E, is geographically defined by the ancient metamorphic and igneous rocks of the Chota Nagpur Plateau. The state shares borders with Bihar to the north, West Bengal to the east, Odisha to the south, and Chhattisgarh and Uttar Pradesh to the west. This central position in the Indian peninsula gives Jharkhand a climate that is transitional — neither fully continental nor fully coastal — making it particularly susceptible to shifts in large-scale atmospheric circulation patterns.

For the purposes of this study, six representative agro-ecological zones (AEZs) were identified:

- Zone I – Chota Nagpur Plateau Highland (Ranchi, Khunti): Mean annual temp 24.2°C; Rainfall 1,350 mm
- Zone II – North Chotanagpur Plateau (Hazaribagh, Ramgarh): Mean annual temp 25.1°C; Rainfall 1,180 mm
- Zone III – South Chotanagpur Plateau (Gumla, Simdega): Mean annual temp 26.3°C; Rainfall 1,420 mm
- Zone IV – Santhal Pargana (Dumka, Deoghar): Mean annual temp 26.8°C; Rainfall 1,280 mm
- Zone V – Kolhan Division (West Singhbhum, East Singhbhum): Mean annual temp 27.5°C; Rainfall 1,550 mm
- Zone VI – Palamu Division (Palamu, Latehar): Mean annual temp 27.9°C; Rainfall 1,060 mm

The principal crop of Jharkhand is kharif rice (Oryza sativa), cultivated on approximately 1.5 million hectares during the monsoon season. Rabi crops include wheat, pulses, and winter vegetables, though their coverage is significantly smaller due to limited irrigation infrastructure. It is in this rainfed, single-crop-dominated landscape that the pest species under study cause their most significant economic damage.

Materials and Methods

Four insect pest species were selected based on their economic importance, prevalence across Jharkhand's rice-growing districts, and differential sensitivity to temperature observed in preliminary screening:

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Cnaphalocrocis medinalis (Guenée) — Rice Leaf Folder (Order: Lepidoptera; Family: Crambidae)

Scirpophaga incertulas (Walker) — Yellow Stem Borer (Order: Lepidoptera; Family: Crambidae)

Spodoptera frugiperda (J.E. Smith) — Fall Armyworm (Order: Lepidoptera; Family: Noctuidae)

Nilaparvata lugens (Stål) — Brown Planthopper (Order: Hemiptera; Family: Delphacidae)

Insect Culture and Rearing Conditions

Founder colonies were established from field-collected specimens from rice fields in Ranchi and Khunti districts during kharif 2022. Insects were reared on freshly harvested rice seedlings (variety Swarna/MTU-7029) under controlled conditions at the Entomology Laboratory, Birsa Agricultural University, Ranchi. Three thermal treatments were maintained in Biological Oxygen Demand (BOD) incubators:

- T_1: 25°C ± 0.5°C (representing baseline current temperature)
- T_2: 30°C ± 0.5°C (representing near-future projected warming)
- T_3: 35°C ± 0.5°C (representing end-century extreme scenarios)

Relative humidity was maintained at 70 ± 5% and a photoperiod of 14L:10D was provided using fluorescent lighting. All bioassays were replicated across three generations to ensure colony stability before demographic data collection commenced.

Life Table Construction

Age-specific cohort life tables were constructed following the methodology of Carey (1993) and Chi & Liu (1985). For each temperature treatment and each species, a cohort of freshly laid eggs (n = 150 per replicate; three replicates) was followed from oviposition to death. Daily observations were recorded for:

- lx: Age-specific survivorship (probability of surviving from birth to age x)
- mx: Age-specific fecundity (mean number of female offspring produced per female at age x)
- lxmx: Contribution to net reproduction at each age class

Calculation of Demographic Parameters

The following demographic indices were computed using the TWO-SEX-MSChart software (Chi, 2015) and verified using age-stage, two-sex life table analysis:

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Net Reproductive Rate (R_0): The expected number of female offspring produced by a female over her lifetime. $R_0 = \Sigma\, lx \cdot mx$

Intrinsic Rate of Natural Increase (rm): Derived iteratively by solving the Euler-Lotka equation: $\Sigma\, e^{-rx} \cdot lx \cdot mx = 1$

Mean Generation Time (T): The average time from birth of a female to the birth of her offspring. $T = \ln(R_0) / rm$

Doubling Time (DT): The time required for a population to double in size. $DT = \ln(2) / rm$

Finite Rate of Increase (λ): The per-capita rate of population increase per unit time. $\lambda = e^{rm}$

Field Validation

Field surveys were conducted across the six identified agro-ecological zones during kharif 2023 and kharif 2024 at three growth stages of rice (tillering, panicle initiation, and flowering). At each site, 25 randomly selected hills were assessed for pest incidence. Meteorological data (temperature, relative humidity, rainfall) were obtained from the nearest Automatic Weather Station (AWS) maintained by the Jharkhand State Council of Agricultural Research (JSCAR). Pearson's correlation analysis and regression modeling were performed using SAS 9.4 to establish relationships between climate variables and pest population indices.

Results

The developmental periods of all four pest species were significantly influenced by temperature, following a general inverse relationship — higher temperatures accelerating development across most life stages. Table 1 summarizes the mean duration (days) of key life stages across the three thermal treatments.

Life Stage	**C. medinalis 25°C / 30°C / 35°C**	**S. incertulas 25°C / 30°C / 35°C**	**S. frugiperda 25°C / 30°C / 35°C**	**N. lugens 25°C / 30°C / 35°C**
Egg	5.8 / 4.2 / 3.6	7.1 / 5.3 / 4.8	3.9 / 2.8 / 2.4	6.2 / 4.9 / 4.1
Larva/Nymph	18.4 / 14.6 / 13.2	28.3 / 22.7 / 20.1	16.8 / 13.5 / 12.3	12.6 / 9.8 / 8.9

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Life Stage	C. medinalis 25°C / 30°C / 35°C	S. incertulas 25°C / 30°C / 35°C	S. frugiperda 25°C / 30°C / 35°C	N. lugens 25°C / 30°C / 35°C
Pupa	8.2 / 6.8 / 6.1	9.6 / 7.9 / 7.4	8.1 / 6.4 / 5.9	—
Pre-oviposition	2.6 / 2.1 / 2.4	3.2 / 2.6 / 3.1	2.8 / 2.3 / 2.7	3.1 / 2.4 / 2.9
Total (Egg–Adult)	35.0 / 27.7 / 25.3	48.2 / 38.5 / 35.4	31.6 / 25.0 / 23.3	21.9 / 17.1 / 15.9

Table 1. Mean developmental periods (days) of four insect pest species under three temperature regimes (mean ± SE; n = 3 replicates × 150 eggs each)

Notably, at 35°C, developmental acceleration was accompanied by increased mortality in egg and early larval stages of S. incertulas, suggesting that this species is approaching its upper thermal threshold. The egg-to-adult survival was 82.4% at 25°C, 78.9% at 30°C, and dropped significantly to 61.3% at 35°C for the stem borer, while N. lugens maintained relatively higher survival (71.2%) even at 35°C, indicating broader thermal plasticity.

The core demographic indices computed from two-sex life table analysis are presented in Table 2. These numbers tell a story that goes beyond mere statistics — they reveal the latent biological capacity of these pests to respond to a warming climate.

Parameter	Temperature	C. medinalis	S. incertulas	S. frugiperda	N. lugens
Net Reproductive Rate (R_0)	25°C	68.4 ± 3.2	112.6 ± 8.4	184.3 ± 11.2	42.8 ± 2.6
	30°C	82.1 ± 4.6	138.7 ± 9.8	216.9 ± 14.7	58.4 ± 3.9

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Parameter	Temperature	C. medinalis	S. incertulas	S. frugiperda	N. lugens
	35°C	61.3 ± 5.1	98.4 ± 7.2	172.6 ± 13.1	44.2 ± 4.1
Intrinsic Rate (rm) (d^{-1})	25°C	0.112 ± 0.003	0.096 ± 0.004	0.143 ± 0.005	0.143 ± 0.006
	30°C	0.138 ± 0.004	0.124 ± 0.005	0.171 ± 0.006	0.187 ± 0.008
	35°C	0.119 ± 0.005	0.101 ± 0.006	0.156 ± 0.007	0.162 ± 0.009
Doubling Time (DT, days)	25°C	6.19	7.22	4.85	4.85
	30°C	5.02	5.59	4.05	3.71
	35°C	5.83	6.86	4.44	4.28
Finite Rate (λ) (d^{-1})	25°C	1.119	1.101	1.154	1.154
	30°C	1.148	1.132	1.186	1.206
	35°C	1.126	1.106	1.169	1.176
Mean Generation Time T (days)	25°C	38.4	49.7	36.2	26.1
	30°C	32.1	40.8	31.4	22.3
	35°C	34.7	45.2	33.8	23.9

Table 2. Demographic parameters of four insect pest species under three temperature treatments (Values are mean ± SE)

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The data reveal several key patterns. First, the rm values for all species peak at 30°C, confirming that the intermediate temperature treatment most closely aligns with the thermal optimum for population growth. Second, the doubling time at 30°C is notably shorter — implying faster population escalation — with N. lugens showing the most dramatic response (DT reduced from 4.85 days at 25°C to just 3.71 days at 30°C). This means that under a scenario where mean temperatures rise by 2–3°C over the next two to three decades (a projection well within current IPCC estimates for the region), BPH populations in Jharkhand's rice fields could double in under four days during peak infestation periods.

The decline in demographic fitness at 35°C across most species — while still representing population growth — signals that extreme heat stress begins to impose physiological constraints. However, this should not be interpreted as a silver lining: the increased temperature variability projected for Jharkhand, with hot-day extremes above 40°C followed by moderate periods around 28–32°C, may actually create pulse-exploitation dynamics where pest populations rapidly expand during thermally favorable windows.

The age-stage-specific survivorship curves (lx) demonstrated characteristic Type II mortality patterns (relatively constant hazard rate) for N. lugens at all temperatures, while the Lepidopteran species showed Type III patterns (high early mortality) that became more pronounced at 35°C. The age-specific fecundity curves (mx) showed a characteristic hump-shaped distribution, with peak oviposition occurring earlier in the adult lifespan under elevated temperatures — a pattern that could lead to more synchronized pest outbreaks during critical crop growth stages. At 30°C, S. frugiperda females initiated oviposition significantly earlier (mean pre-oviposition period: 2.3 days) compared to 25°C (2.8 days), and peak fecundity (up to 380 eggs per female per day) occurred 4–5 days earlier in the adult lifespan. This compression of the reproductive timeline, when superimposed on the shortened generation time, means multiple overlapping generations can occur during a single kharif season.

Field monitoring data from the six agro-ecological zones across kharif 2023 and 2024 are summarized in Table 3. Pest pressure was quantified using a standardized Pest Pressure Index (PPI) calculated as the mean number of insects per hill (for BPH) or percent infested hills (for stem borer and leaf folder).

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AEZ / District	Mean Temp (Jun-Sep,^{0}C)	Total Rainfall (mm)	BPH (nymphs/hill)	Stem Borer (% DH)	Leaf Folder (% IL)	FAW (larvae/hill)
Zone I – Ranchi	27.8	1,342	6.4 ± 0.8	12.3 ± 1.4	18.7 ± 2.1	1.2 ± 0.3
Zone II – Hazaribagh	28.6	1,178	8.1 ± 1.1	14.8 ± 1.9	22.4 ± 2.6	1.8 ± 0.4
Zone III – Gumla	29.2	1,418	9.6 ± 1.3	11.6 ± 1.2	24.8 ± 3.1	2.1 ± 0.6
Zone IV – Dumka	29.8	1,264	10.8 ± 1.6	15.3 ± 2.2	27.1 ± 3.4	2.6 ± 0.7
Zone V – Singhbhum	30.4	1,548	13.2 ± 2.1	13.9 ± 1.8	31.6 ± 4.2	3.4 ± 0.9
Zone VI – Palamu	31.1	1,062	11.4 ± 1.9	17.8 ± 2.6	28.9 ± 3.8	3.9 ± 1.1

Table 3. Field pest incidence across six agro-ecological zones of Jharkhand (Pooled mean of kharif 2023 and 2024; DH = Dead Heart; IL = Infested Leaves)

The data exhibit a clear spatial gradient: higher mean temperatures during the monsoon season correlate positively with greater pest pressure across all species. Pearson's correlation coefficients between June–September mean temperature and pest incidence were: BPH ($r = 0.87$, $p < 0.01$), Leaf Folder ($r = 0.82$, $p < 0.01$), FAW ($r = 0.91$, $p < 0.01$), and Stem Borer ($r = 0.64$, $p < 0.05$). These field data provide robust empirical support for the laboratory-derived demographic findings.

Notably, Palamu (Zone VI), despite receiving the lowest rainfall (1,062 mm) and experiencing periods of moisture stress unfavorable for rice production, recorded the highest FAW pressure (3.9 larvae/hill). This paradox is explained by the warming effect: drier conditions with higher temperatures accelerate FAW larval development and reduce natural enemy effectiveness, allowing populations to build up rapidly on whatever crop is available.

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Discussion

The results of this study confirm what insect ecologists have long theorized but regional entomologists in Jharkhand have rarely quantified: temperature is the master variable governing insect pest population dynamics, and the trajectory of climate change in this region is creating conditions increasingly favorable to the species we studied. The finding that rm values peak at 30°C for all four species is consistent with the broader thermal performance literature. Interestingly, however, the degree of sensitivity to temperature increment differs markedly between species — a finding with significant practical implications.

N. lugens (brown planthopper) showed the greatest proportional increase in rm between 25°C and 30°C (30.8% increase), suggesting this species is the most thermally responsive of the four and, by implication, the most likely to exhibit dramatic population explosions under even modest warming. This is particularly concerning given that BPH-induced hopperburn has caused catastrophic yield losses in Asian rice systems historically, and the species is already documented in Jharkhand's districts bordering West Bengal and Odisha.

The fall armyworm (S. frugiperda), which invaded South Asia only around 2018, is already demonstrating rapid adaptation to local agro-climatic conditions. Its high baseline fecundity (>400 eggs per female) combined with marked temperature responsiveness (rm increase of 19.6% between 25°C and 30°C) makes it a particularly formidable challenger in a warming Jharkhand. The species' polyphagous nature — attacking maize, sorghum, millet, and even rice under food-stressed conditions — amplifies its threat as crop diversification efforts expand in the state.

Perhaps the most important demographic finding from this study is the compression of generation time under elevated temperatures. As T decreases from 38.4 days (25°C) to 32.1 days (30°C) for C. medinalis, the number of generations that can be completed within a 120-day kharif season increases from approximately 3.1 to 3.7 generations. For N. lugens, this shift is even more dramatic — from 4.6 generations at 25°C to approximately 5.4 generations at 30°C. Each additional generation represents a multiplicative amplification of population size, compounding the per-generation reproductive potential.

This generational compression phenomenon may help explain a pattern increasingly reported by farmers and extension agents in Jharkhand — that pest outbreaks are now occurring earlier in the

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season, reaching damaging thresholds before natural enemy populations have had time to build up, and showing second or third infestation peaks that were historically uncommon in this region. What farmers are observing as 'new pest behavior' may, in significant measure, be the demographic arithmetic of generation time compression.

An aspect of climate-pest interactions that this study, by design, does not fully capture — but which deserves emphasis — is the differential thermal response of pest species versus their natural enemies. It is well-established in the ecological literature that parasitoids and predators often have narrower thermal optima and lower thermal tolerance ceilings compared to their herbivorous hosts. If this pattern holds for the natural enemy complex of Jharkhand's rice pests — including egg parasitoids like Trichogramma spp., larval parasitoids like Cotesia flavipes, and predatory spiders — then warming may disproportionately benefit the pests relative to their natural regulators, eroding the biological control services that currently suppress pest populations below economic threshold levels.

This demographic mismatch hypothesis deserves dedicated investigation through future research. Preliminary observations from our field surveys found significantly lower parasitism rates (measured as percentage of collected larvae with parasitoid emergence) in Zones V and VI (the warmest zones), averaging 8.3% compared to 18.7% in Zone I (Ranchi), lending tentative support to this concern.

Conclusion

The four pest species studied — *C. medinalis, S. incertulas, S. frugiperda,* and *N. lugens* — all demonstrate significant temperature-dependent acceleration of population growth within the 25–30°C range, with demographic parameters pointing toward shorter doubling times, more generations per season, and higher net reproductive rates as Jharkhand's climate continues to warm. Field data from six agro-ecological zones corroborate these laboratory findings with high statistical confidence, establishing the real-world relevance of theoretical demographic models.

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