

Tracking the Crop-Insect Calendar: Seasonal Abundance, Weather Associations and the Timing of Pests and Natural Enemies in Hanumangarh District, Rajasthan

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Abstract:

In double-cropped irrigated agriculture, insect abundance follows both the weather and the crop calendar, and the relative timing of pests and their natural enemies decides when pest management can work. We analysed 24 fortnightly samples from six sites in Hanumangarh district, Rajasthan (18,742 individuals, 96 species) together with fortnightly weather records. Abundance was bimodal, with a principal peak of 271.7 individuals per site per fortnight in the second half of August and a lower peak of 206.3 in early February. Kharif held 49.7 percent of all individuals, Rabi 41.7 and Zaid 8.6. Pests peaked in rounds 10 and 22, pollinators in the pre-monsoon weeks and mid-winter, and the ratio of natural enemies to pests rose from 0.13 in Zaid to 0.57 in Rabi. Relative humidity was positively associated with pests, predators and parasitoids (Spearman $\rho = 0.52$ to 0.66), whereas maximum temperature was negatively associated with predators ($\rho = -0.59$). Natural enemies tracked pests with no detectable delay at fortnightly resolution ($\rho = 0.90$ at zero lag). We convert peak windows for six key pests into a scouting calendar and flag a conflict between the mustard aphid peak and the pollinator peak in late January.

Keywords: seasonal abundance; insect phenology; Zaid, Kharif and Rabi; natural enemies; integrated pest management; Hanumangarh.

I. INTRODUCTION

Farmers in irrigated north-western Rajasthan plan their year around the crop calendar, and the insects keep a calendar of their own. Whitefly arrives with the cotton canopy, mustard aphid with the cold-season flowering, and the pod borer turns up twice, once in each cropping season. Seasonality of this kind is among the oldest observations in entomology, and its causes (temperature, moisture, host availability, natural enemies) have been argued over for decades.¹ For pest management the question is practical.

¹Henk Wolda, *Insect Seasonality: Why?*, 19 ANN. REV. ECOLOGY & SYSTEMATICS 1 (1988).

Knowing when a pest builds up, and whether its natural enemies are present at the same time, tells a farmer when to look, when to wait and when a spray would do more harm than good.

Weather acts on insects through direct effects on development rate, survival and fecundity, and a warming climate is expected to shift those effects in ways that differ among species and feeding guilds.² A recent synthesis argues that insects respond to climate change not only in abundance but also in the timing of their life cycles, with consequences for synchrony between insects, their host plants and their enemies.³ In hot, semi-arid regions with canal irrigation, however, the crop calendar and the weather move together through the year, and teasing them apart is hard.

Little quantitative work describes this calendar for Hanumangarh. This paper uses a year of fortnightly sampling at six sites in the district to answer four questions. How does insect abundance change through the Zaid, Kharif and Rabi seasons, and which orders drive the change? How are the abundances of pests, natural enemies and pollinators associated with temperature, humidity and rainfall? Do natural enemies track pests closely, or trail behind them? And can the answers be turned into a monitoring calendar that extension workers could use? Community composition and site-level diversity, drawn from the same dataset, are treated in a companion paper.

II. MATERIALS AND METHODS

A. Sampling and weather records

Six sites in six tehsils of the district (Hanumangarh, Pilibanga, Nohar, Bhadra, Rawatsar and Sangaria) were each visited twice a month for twelve months, from April to March, giving 24 fortnightly rounds. The rounds fall into three cropping seasons: Zaid (April–June, rounds 1–6), Kharif (July–October, rounds 7–14) and Rabi (November–March, rounds 15–24). Every round applied the same five methods, namely sweep netting, pitfall traps, yellow sticky traps, a light trap and visual counts on plants, which are described with the sampling design in the companion paper. Specimens were identified to species, and each species was assigned to a guild: herbivorous pests, predators, parasitoids, pollinators, or other. Fortnightly mean maximum and minimum temperature, mean relative humidity and total rainfall were taken from the weather record for the study area. The sites span the district's main cropping systems: paddy and wheat at Hanumangarh, cotton and wheat at Pilibanga and Bhadra, mustard, gram and guar at Nohar, guar, pearl millet and mustard at Rawatsar, and cotton with vegetables at Sangaria. Farmers managed all fields in the usual way, and no practice was altered for the study.

B. Analytical framework

The analysis is organised around the framework in Figure 1, which treats weather as acting on insects both directly and through the crop calendar, and treats the monitored abundance of pests and their natural enemies as the information on which a timing decision rests. Seasonal summaries pooled the fortnights of each season, and seasons were compared on individuals and Shannon diversity per site-by-fortnight

²J.S. Bale et al., *Herbivory in Global Climate Change Research: Direct Effects of Rising Temperature on Insect Herbivores*, 8 GLOBAL CHANGE BIOLOGY 1 (2002).

³Jeffrey A. Harvey et al., *Scientists' Warning on Climate Change and Insects*, 93 ECOLOGICAL MONOGRAPHS e1553 (2023).

sampling unit (144 units) with the Kruskal–Wallis test.⁴ Weather associations were measured as Spearman rank correlations⁵ between the six-site total for each guild in each fortnight and each weather variable ($n = 24$). To test timing, cross-correlations were computed between pest abundance and the abundance of natural enemies (predators plus parasitoids) at lags from -3 to $+4$ fortnights. The seasonal window of a pest was defined as the run of fortnights in which its abundance was at least half its maximum, and its peak as the single highest fortnight.

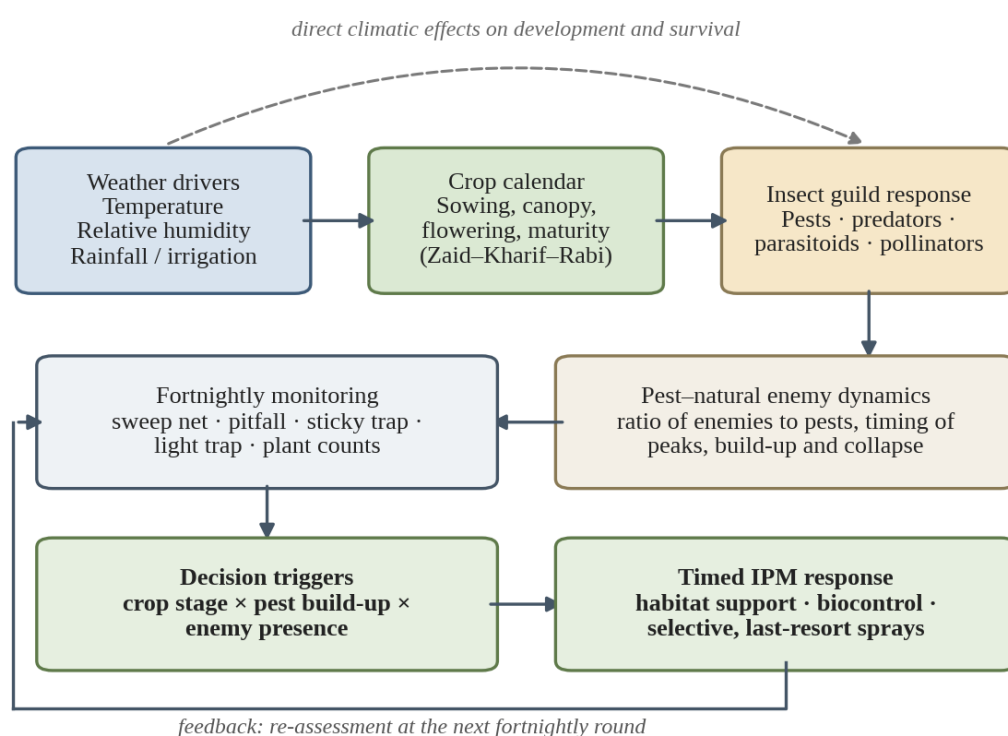


Figure 1. Conceptual framework: weather and the crop calendar shape guild abundance, which is monitored fortnightly and feeds timing decisions and re-assessment.

Two cautions apply to all of the inference that follows. Fortnightly series from a single year are strongly autocorrelated, so nominal p-values overstate the strength of evidence, and the weather variables follow the same twelve-month cycle as the crop calendar, so a correlation cannot distinguish a weather effect from a crop-stage effect. The p-values reported here are therefore descriptive and not confirmatory, and none was adjusted for the number of comparisons.

⁴William H. Kruskal & W. Allen Wallis, *Use of Ranks in One-Criterion Variance Analysis*, 47 J. AM. STAT. ASS'N 583 (1952).

⁵C. Spearman, *The Proof and Measurement of Association Between Two Things*, 15 AM. J. PSYCHOL. 72 (1904).

III. RESULTS

A. The weather of the study year

The year (Figure 2) showed the usual shape of the district's climate. Total rainfall was 276 mm, of which 214 mm (77.5 percent) fell in the Kharif rounds and only 27 mm in the five months of Rabi. Maximum temperature peaked at 43.8 °C in the first half of June and fell to a seasonal mean of 25.1 °C in Rabi, and the lowest minimum, 4.0 °C, came in the first half of January. Mean relative humidity was 39 percent in Zaid and about 65 percent in both Kharif and Rabi. Zaid was therefore hot and dry (mean maximum 41.5 °C), Kharif warm and humid (35.9 °C, 66 percent), and Rabi cool, with little rain but humidity as high as in Kharif.

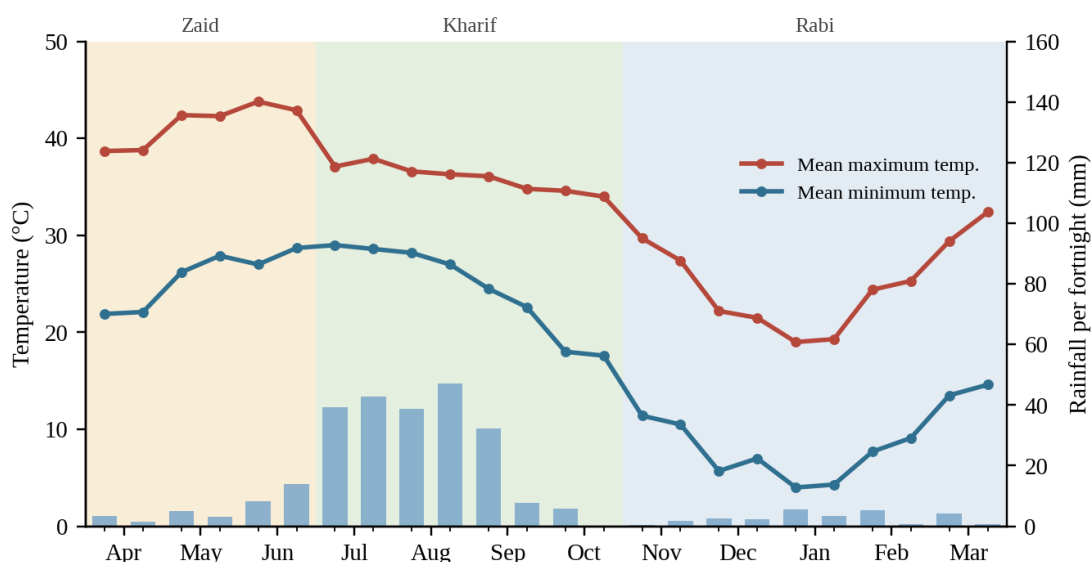


Figure 2. Fortnightly maximum and minimum temperature (lines) and rainfall (bars) over the 24 sampling rounds, with the three cropping seasons shaded.

B. The annual cycle of abundance

Abundance was strongly bimodal (Figure 3). Mean numbers of insects per site per fortnight rose from 14.8 in the first half of April to a principal peak of 271.7 in the second half of August (round 10), an eighteen-fold increase in five months. They then fell to a trough of 54.8 in the second half of November (round 16), climbed to a lower second peak of 206.3 in the first half of February (round 21), and declined towards the end of March. Every site showed the same two-peaked shape. The principal peak fell in round 10 at four sites and in round 11 at the other two, Pilibanga and Sangaria, the two cotton-centred sites.

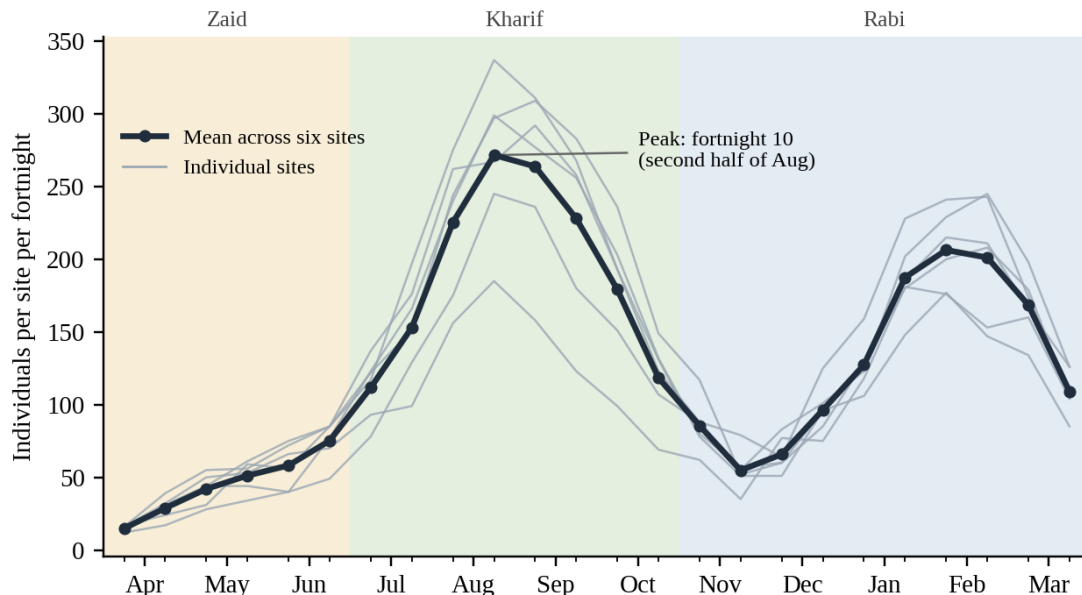


Figure 3. Mean number of insects per site per fortnight (bold line) and the six individual site series (grey), with seasons shaded.

Seasonal contrasts were large (Table 1). Kharif, with eight rounds, contained 49.7 percent of the year's 18,742 individuals, Rabi, with ten, contained 41.7 percent, and Zaid, with six, only 8.6 percent. Individuals per sampling unit averaged 45.0 in Zaid, 193.9 in Kharif and 130.2 in Rabi, and the seasons differed significantly in both abundance (Kruskal–Wallis $H = 80.66$, $p < 0.001$) and unit-level Shannon diversity ($H = 74.73$, $p < 0.001$). Richness followed abundance. The average unit held 15.3 species in Zaid, 36.1 in Kharif and 24.0 in Rabi, and the district-wide species count per round rose from 24 in round 1 to 68 in round 11 (first half of September). Seventeen species were recorded in only one season and 54 in all three.

Table 1. Seasonal summary of weather, abundance, diversity and guild balance.

Season (rounds)	Max. temp. (°C)	Rain (mm)	Individuals (share)	Species	H'	Indiv. per unit	Pests (%)	Enemies per pest
Zaid (1–6)	41.5	35	1,621 (8.6%)	67	2.980	45.0	61.3	0.13
Kharif (7–14)	35.9	214	9,307 (49.7%)	86	3.318	193.9	70.7	0.36
Rabi (15–24)	25.1	27	7,814 (41.7%)	76	3.111	130.2	54.0	0.57
Year	–	276	18,742	96	3.654	130.1	62.9	0.42

Species and H' are pooled over sites within each season. Enemies per pest = (predator + parasitoid individuals) / pest individuals.

C. Which orders drive the cycle

Hemiptera was the largest order in every season, but its dominance was greatest in Kharif, when it contributed 4,747 of 9,307 individuals (51.0 percent) (Figure 4). Coleoptera supplied a further 2,456 (26.4 percent), and Lepidoptera 1,117. Hymenoptera were proportionally most prominent in Zaid (449 of 1,621 individuals, 27.7 percent), mostly bees working the pre-monsoon bloom. Diptera changed most between seasons: only 25 individuals in Zaid and 40 in Kharif, but 507 in Rabi, when hoverflies follow the cold-season aphids. Neuroptera were scarce in Zaid (7), then numerous in Kharif (217) and Rabi (276). Orthoptera and Odonata were almost confined to the warm half of the year, with 49 of 67 grasshoppers and crickets and 21 of 27 dragonflies and damselflies caught in Kharif.

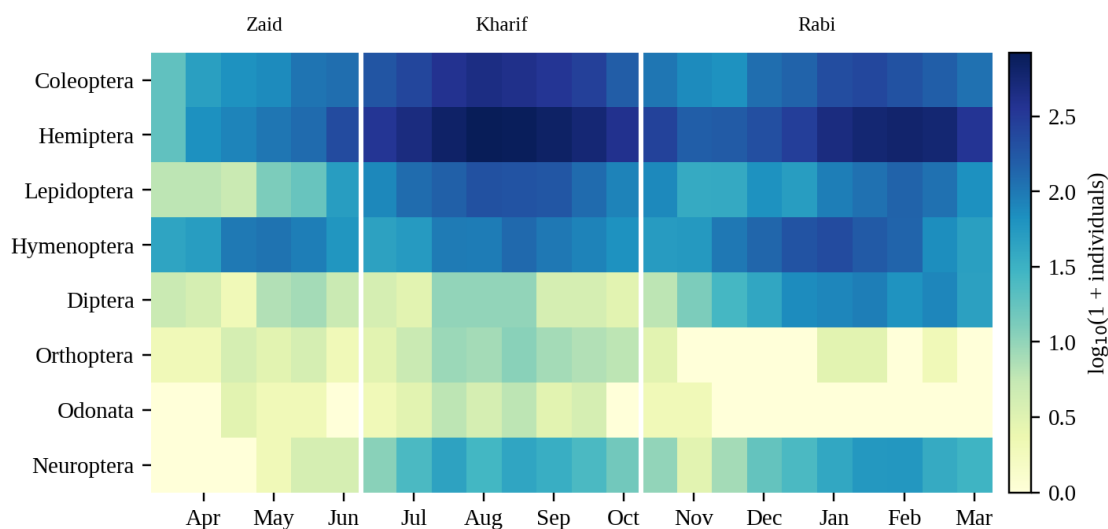


Figure 4. Abundance of each order by fortnight (log-scaled counts, all sites pooled). White vertical lines mark season boundaries.

D. Guild phenology

Guilds peaked at different times (Figure 5). Pests reached their maximum (1,152 individuals across the six sites) in round 10 and a second, lower maximum (720) in round 22; they made up 70.7 percent of individuals in Kharif and 54.0 percent in Rabi. Predators had their larger peak in Rabi (410 in round 21, against 346 in round 10), whereas parasitoids peaked in Kharif (117 in round 11) and were thin in Rabi (130 individuals over the whole season, against 563 in Kharif). Pollinators were the mirror image of pests. They peaked in the pre-monsoon weeks (106 in round 4) and again during the Rabi flowering (211 in round 20), and nearly vanished in Kharif, where they made up 0.9 percent of individuals, against 26.3 percent in Zaid and 13.5 percent in Rabi.

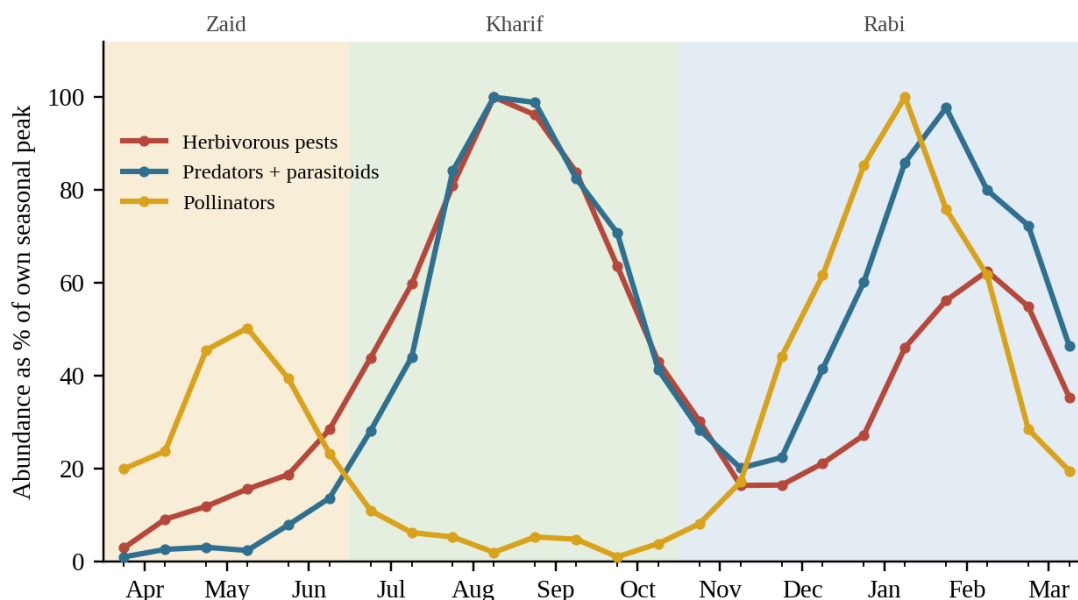


Figure 5. Phenology of pests, natural enemies (predators plus parasitoids) and pollinators, each expressed as a percentage of its own seasonal maximum.

The ratio of natural enemies to pests rose steadily through the year, from 0.13 in Zaid to 0.36 in Kharif and 0.57 in Rabi (0.42 overall). Zaid therefore stands out as the season when pests, though still few, have the fewest enemies relative to their numbers.

E. Associations with weather

Relative humidity was the variable most consistently associated with abundance (Figure 6). It correlated positively with total insects (Spearman $\rho = +0.63$, $p < 0.001$), pests ($+0.52$, $p = 0.009$), predators ($+0.66$, $p < 0.001$) and parasitoids ($+0.52$, $p = 0.010$), and not at all with pollinators ($+0.03$). Rainfall showed weaker positive associations with pests ($+0.48$), parasitoids ($+0.43$) and all insects ($+0.43$), and none with predators ($+0.23$, $p = 0.27$). Maximum temperature was negatively related to predator abundance ($\rho = -0.59$, $p = 0.002$) and only weakly to the other guilds. Pollinators alone were associated with minimum temperature, negatively (-0.51 , $p = 0.011$), which reflects their abundance in the cool Rabi months. Pests showed no detectable association with either temperature variable ($\rho = -0.20$ and $+0.13$).

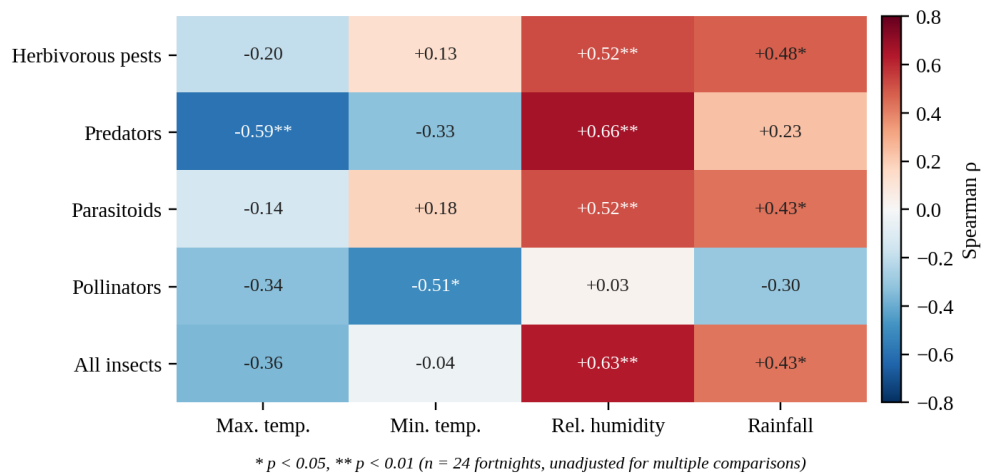


Figure 6. Spearman rank correlations between fortnightly guild abundance and weather variables ($n = 24$).

F. Timing of natural enemies relative to pests

Predators and parasitoids tracked pests closely (Figure 7). The cross-correlation was highest at zero lag ($\rho = 0.90$) and nearly as high when enemies lagged by one fortnight (0.78) or led by one (0.83). Correlations at lags of ± 2 were lower (0.56 and 0.64), and those at ± 3 were not significant. At fortnightly resolution there is no evidence of the delay classically expected in predator–prey cycles, since the two series rise and fall together. The only hint of a delay lies in the parasitoids, whose peak (round 11) fell one fortnight after the pest and predator peaks (round 10).

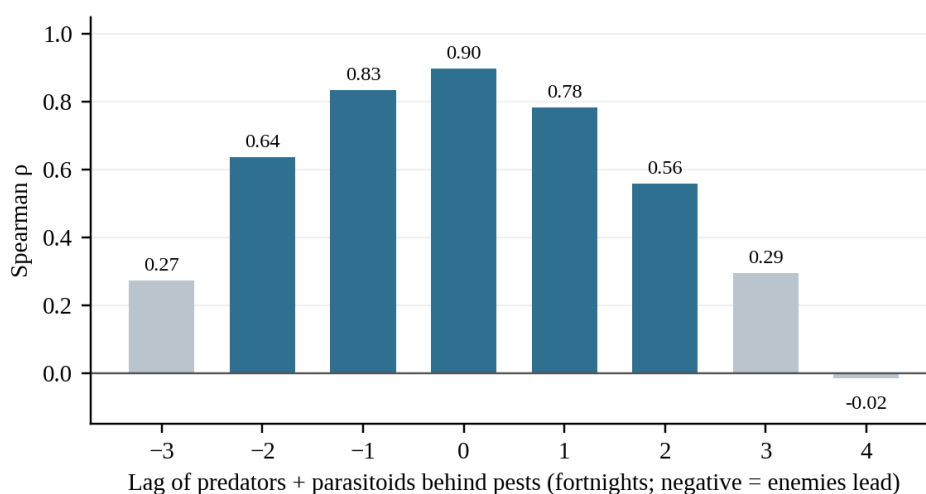


Figure 7. Cross-correlation between pest abundance and natural-enemy abundance at lags of -3 to $+4$ fortnights. Dark bars are significant at $p < 0.05$.

G. Seasonal windows of key pests

Windows for six key pests are given in Table 2 and Figure 8. The Kharif sap-feeders came first: the cotton jassid *Amrasca biguttula* (rounds 7–11, peak in round 10), then whitefly (rounds 9–13, peak in round 10), with the brown planthopper *Nilaparvata lugens* following later in paddy (rounds 10–14, peak in round 13). Whitefly was overwhelmingly a Kharif insect, with 1,670 of 1,906 individuals (87.6 percent) caught then. In Rabi, the mustard aphid *Lipaphis erysimi* had a window from round 19 to 23 with its peak in round 20, and 1,022 of its 1,050 individuals (97.3 percent) were caught in that season. The wheat aphid *Sitobion avenae* built up later still (rounds 21–24, peak in round 23). The pod borer *Helicoverpa armigera* alone was active in both seasons, with 392 individuals in Kharif and 493 in Rabi and a window running from round 10 to round 23. The cotton aphid *Aphis gossypii* peaked in Kharif (round 9) but showed a distinct early-season rise in Zaid, which supplied 352 of its 1,016 individuals (34.6 percent).

Table 2. Seasonal windows of six key pests (window = fortnights at or above half of the peak; peak counts are totals for six sites).

Pest	Main crop	Window (rounds)	Window (months)	Peak round	Peak count
<i>Amrasca biguttula</i>	Cotton	7–11	Jul – early Sep	10	153
<i>Bemisia tabaci</i>	Cotton	9–13	Aug – early Oct	10	313
<i>Nilaparvata lugens</i>	Paddy	10–14	Late Aug – Oct	13	66
<i>Lipaphis erysimi</i>	Mustard	19–23	Jan – early Mar	20	186
<i>Helicoverpa armigera</i>	Cotton, gram	10–23	Late Aug – early Mar	22	124
<i>Sitobion avenae</i>	Wheat	21–24	Feb – Mar	23	184

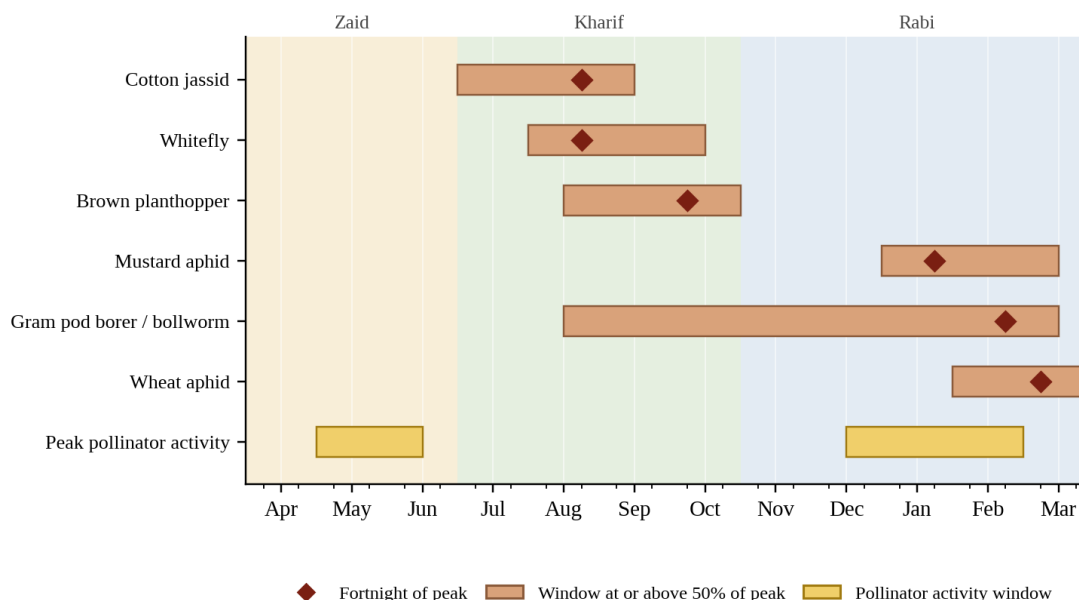


Figure 8. Seasonal windows of six key pests and of peak pollinator activity across the 24 rounds. Diamonds mark the peak round of each pest.

H. Seasonal profiles at individual sites

The balance between seasons shifted with the cropping system. The two cotton-centred sites placed most of their catch in Kharif (52.5 percent at Pilibanga and 55.1 percent at Sangaria), as did Hanumangarh (52.3 percent) and Bhadra (50.9 percent). Nohar, where mustard and gram dominate, was the only site in which Rabi supplied the larger share (50.5 percent, against 43.5 percent in Kharif), and Rawatsar tilted the same way (47.3 percent in Rabi, 40.7 percent in Kharif). Rawatsar also had the largest Zaid share (11.9 percent, against 6.0 percent at Nohar), which fits a site whose pearl millet and guar are sown early. The peak round itself barely moved among sites, which is why the pooled calendar in the figures above is a fair summary of all six.

IV. DISCUSSION

The two-peaked cycle is what a double-cropped irrigated system should produce, and it is sensible to read it as a joint product of weather and crop calendar. The Kharif peak coincides with the warm, humid months in which cotton and paddy canopies are fullest, and the Rabi peak with mustard and wheat. The valley between them, in the second half of November, falls after the harvest of the monsoon crops and before the winter crops close their canopy, when hosts are scarce and nights are cooling quickly. Heat, by contrast, appears to hold insects down more than it drives them. Zaid has the district's highest temperatures and its lowest abundance, and the one significant association with maximum temperature was negative (predators). Direct thermal effects on insect development are well documented,⁶ and temperatures above

⁶Bale et al., *supra* note 2.

40 °C may plausibly suppress foliage-dwelling predators, but those same fortnights also have the fewest hosts, and this design cannot say which matters more.

The synchrony between pests and enemies is the most encouraging result in the dataset. If natural enemies arrived late, a monitoring calendar would have to guard against a long window of unchecked pest growth, and early intervention would be easier to justify. The data point the other way. The ratio of enemies to pests was 0.36 in Kharif and 0.57 in Rabi, and the two groups rose together. This is the pattern that conservation biological control aims for, in which habitat and refuges keep predators on site so that they are present when pests arrive.⁷ Two cautions apply. A fortnight is too coarse to resolve a delay of a few days, which is the time scale of many aphid–ladybird interactions, and the Zaid ratio of 0.13 shows that an early-season window with few enemies per pest does exist, even though pest numbers are low then. The pollinator pattern deserves its own note. Pollinators peak in the weeks before the monsoon (rounds 3 to 5) and again through the mustard flowering (rounds 18 to 22), and are nearly absent in Kharif. In late January the mustard aphid and the pollinators peak in the same fortnight (round 20), so any spray aimed at the aphid falls in the week when bees are most active. Because insect pollination improves the yield or quality of most major food crops,⁸ that overlap is directly relevant to the choice and timing of products.

The site profiles add a practical nuance. Because the peak round hardly shifted among sites while the Kharif–Rabi balance did, a district-wide calendar will serve for timing, but the weight to give each season in a scouting plan should follow the local cropping system: Kharif first at the cotton sites, Rabi first in the mustard and gram belt around Nohar. This is a pattern observed at six sites, with cropping system confounded with location, and it should be read as a lead for extension workers to check locally and not as an established rule.

The limits of the evidence are plain. One year gives one realisation of the weather, so we cannot say how much of the cycle is stable. Fortnightly sampling smooths short-lived events. The correlations are drawn from autocorrelated, seasonally structured series, and crop stage and spray records, which probably explain much of the variation that weather does not, were not part of the dataset. A multi-year series that includes crop-stage and pesticide-use data would allow these confounded effects to be separated.

V. IMPLICATIONS FOR MONITORING AND INTEGRATED PEST MANAGEMENT

The calendar in Figure 8 suggests a monitoring schedule built around windows and not fixed dates. Scouting for jassid and whitefly should begin in the first half of July and run to mid-October, mustard aphid needs close attention from early January and wheat aphid from early February, and the pod borer deserves watching in both seasons, from late August to March. In Zaid, when enemies are thin relative to

⁷Douglas A. Landis, Stephen D. Wratten & Geoff M. Gurr, *Habitat Management to Conserve Natural Enemies of Arthropod Pests in Agriculture*, 45 ANN. REV. ENTOMOLOGY 175 (2000).

⁸Alexandra-Maria Klein et al., *Importance of Pollinators in Changing Landscapes for World Crops*, 274 PROC. ROYAL SOC'Y B 303 (2007).

pests, the early rise of *A. gossypii* in May suggests that vegetable and early-cotton plots merit particular scouting. Sprays aimed at the Rabi aphids should avoid the pollinator peak in the second half of January, which coincides with the mustard aphid's own peak, and that is where selective compounds, spot treatment and timing within the day matter most.

A window tells a farmer when to look, not when to spray. The decision to spray rests on the economic injury level, the density at which damage equals the cost of control, and treating only above an economic threshold is the foundation of integrated control.⁹ Thresholds depend on crop, stage and market, and none can be derived from this dataset;¹⁰ they should come from validated local trials and the recommendations of the state agricultural university. The stakes are real, since insects are among the largest causes of crop loss worldwide.¹¹ The legal setting counsels the same care. The Insecticides Act, 1968 regulates the sale and use of insecticides with a view to preventing risk to human beings and animals,¹² so use in line with registered labels is the minimum the law asks, while the finer matter of timing around beneficial insects is left to agronomic advice.

VI. CONCLUSION

A year of fortnightly sampling shows that insect abundance in Hanumangarh's farmland follows a two-peaked calendar, with half of all individuals in Kharif and most of the rest in Rabi. Humidity, more than temperature, was associated with the build-up of pests and their natural enemies, and enemies rose and fell with pests at the resolution of a fortnight. The windows of six key pests can be turned into a scouting calendar, and the collision between the mustard aphid peak and the pollinator peak in late January is a concrete case in which timing matters. Whether these patterns repeat from year to year, and how much of them is weather and how much is crop stage, are questions only a multi-year record can answer.

⁹V.M. Stern, R.F. Smith, R. van den Bosch & K.S. Hagen, *The Integrated Control Concept*, 29 HILGARDIA 81 (1959).

¹⁰David Dent, *INSECT PEST MANAGEMENT* (2d ed. 2000).

¹¹E.-C. Oerke, *Crop Losses to Pests*, 144 J. AGRIC. SCI. 31 (2006).

¹²Insecticides Act, 1968, No. 46, Acts of Parliament, 1968 (India), pmbl.