Monitoring Population Dynamics of Leafhoppers and Planthoppers in Paddy Fields in the Subtropical Region of Bhutan Using Light Trap

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ABSTRACT

Rice is an important cereal crop for food security in Bhutan, but its production is threatened by many insect pests including planthoppers and leafhoppers. This study monitored and analyzed the population dynamics of green leafhopper, brown planthopper, white-backed planthopper, and zigzag leafhopper using commercial light traps in two Gewogs of Sarpang Dzongkhag: Chuzergang Gewog (Dawathang in 2018, 2020, and 2021; Karbithang in 2018) and in Samtenling Gewog (ARDC Samtenling in 2020, 2021, and 2022; farmer's field in Samtenling in 2022. The results showed variation in hopper populations between monitoring sites and time period. Green leafhopper was consistently the most abundant species across all sites and years, with mean trap counts ranging from 182 to 1,736 individuals per trap. In contrast, brown planthopper showed fluctuating trends, peaking at 608 per trap in some sites and declining to below 100 in others. White backed planthopper and zigzag leafhopper remained relatively low, with trap means ranging from near zero to 331 and 258, respectively. Relative abundance data showed these similar patterns, with green leaf hopper dominating the hopper composition, comprising 52.7%–69.1% of populations across sites. In contrast, white backed planthopper and zigzag leafhopper represented the least abundant species. Across rice growth stages at four monitoring sites, mean hopper counts were lowest during tillering, increased significantly during booting, and peaked at grain-filling. The highest pest pressure occurred during grain-filling, with green leafhopper and brown planthopper being the most abundant. Populations declined at maturity. These findings underscore the importance of monitoring hopper populations across different sites and time periods to better understand their dynamics. Additionally, it is important to implement targeted pest management strategies during critical growth stages, particularly booting and grain-filling, to effectively mitigate hopper pressure and reduce crop losses.

Keywords*:* *Rice; Planthoppers; Leafhoppers; Population Dynamics; Monitoring*

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1 Introduction

Rice (*Oryza sativa* L.) is an important food source and a key component of global food security, as it sustains over half of the world's population (Maurya, Dwivedi, Khan, Giri, & Dixit, 2022). This staple food crop is integral to the diets of billions of people, particularly in Asia where it is a primary source of carbohydrates and nutrition. In 2022, global rice production reached approximately 780 million tonnes, making it the fourth-most-produced cereal, following maize, wheat, and barley (Food & Agriculture Organisation [FAO], 2023). This huge production capacity reflects rice's important role in meeting the dietary needs of a rapidly growing global population. In Bhutan, rice is the most widely grown cereal, with 40,563 metric tons (mt) of irrigated paddy and 241 mt of upland paddy harvested in 2023, highlighting its vital role in the nation's food production (National Statistics Bureau [NSB], 2023). Despite its relatively small scale compared to global production, Bhutan's focus on rice underscores its importance in maintaining local food supply.

Insect pest attacks significantly limit rice yields, causing annual losses of up to 20-30% (Haider, Akhtar, Noman, & Qasim, 2021). Major insect pests include stem borers like the yellow stem borer in the Philippines (Bandong & Litsinger, 2005), and leaf folder in Pakistan (Haider, Akhter, & Sabir, 2014). Sucking pests, such as planthopper and leafhopper, cause severe damage to paddy, resulting in reduced yields and poor grain quality. Rice planthoppers are especially destructive, damaging about 20 million hectares annually (Hu et al., 2014). The common leaf and plant hopper in the rice ecosystem is the rice green leafhopper, brown plant hopper, and white-backed plant hopper (Deshwal et al., 2019; Kumar et al., 2023). Adults and nymphs of these pests cause 'hopper-burn' by sucking sap from tillers, leading to chlorosis, wilting, and yield losses of 10 to 70% (Dey, Das, & De, 2024)

Hopper burn has led to significant yield and economic losses globally (Horgan et al., 2018; Quayum, Hossain, & Sharmin, 2023). In addition to physical damage, hoppers are vectors for viral diseases like rice tungro virus, rice ragged stunt, rice grassy stunt viruses, and southern rice black-streaked dwarf virus, causing stunted growth, yellowing, and reduced grain yield (Lu, Zhang, He, & Zhou, 2016). Hoppers can migrate long distances, leading to outbreaks in rice-growing areas (Hereward et al., 2020; Huang et al., 2022), such as the migration of brown plant hoppers and white-backed planthoppers from northern Vietnam to southern China in the spring (Otuka, Matsumura, Watanabe, & Van Dinh, 2008).

Early detection and effective monitoring are crucial to mitigate the impact of insect pest infestations. Light traps have gained attention as a promising tool for monitoring seasonal fluctuations of insect pests (Abbas et al., 2019). These traps, which attract nocturnal insects using light sources, offer a non-invasive and environmentally friendly means of tracking pests (Rashid, Ridoy, Rahman, Rahman, & Mondal, 2022). Light trap catch data can show peak insect activity periods (Dadmal & Khadakkar, 2014), enabling precise timing of control measures, and early detection of outbreaks. Additionally, light traps can directly reduce populations by capturing significant numbers of pests (Patidar, Vaishampayan, Band, & Sahu, 2019). Ali et al. (2020) reported that light traps captured approximately 94% more insects compared to field sampling, demonstrating their higher effectiveness.

In Bhutan, research on planthoppers and leafhoppers is limited, particularly regarding the identification, abundance, and population dynamics in the paddy ecosystem. This study aimed to fill this research gap by conducting a systematic investigation into the diversity, abundance, and population dynamics of hopper species in paddy fields using a light trap. Such findings will not only enhance the understanding of hopper ecology in the subtropical region but also support the development of precise and sustainable pest management strategies tailored to local conditions. The study is expected to have practical implications for local farmers, extension agents, and policymakers. The data presented here can support tailored integrated pest management programs, potentially improving rice production practices and mitigating crop losses due to hopper infestations.

2 Materials and Methods

2.1 Monitoring sites and period

The study was conducted across multiple years in two Gewogs of Sarpang Dzongkhag. In Chuzergang Gewog, monitoring was carried out at Dawathang (26.8631°N, 90.5275°E; 245 m asl) during 2018, 2020, and 2021, and at Karbithang (26.8662°N, 90.5104°E; 227 m asl) in 2018. In Samtenling Gewog, monitoring was conducted at ARDC Samtenling (26.9047°N, 90.4309°E; 381 m asl) in 2020, 2021, and 2022, and at a farmer's field in Samtenling (26.9081°N, 90.4267°E; 389 m asl) in 2022.

2.2 Light trap

A commercial insect light trap manufactured by Physilab and marketed by S.K. Appliances, Ambala, Haryana, India, was used in the study. The trap was made of mild steel and a 100 W incandescent bulb was used (Figure 1). It contains a box at the bottom measuring 40 cm (length)

× 40 cm (breadth) × 25 cm (height) for placing an insect collection tray and a funnel (30 cm in length, 5 cm diameter at the tail end) that directs trapped insects into the collection tray. The trap is equipped with a roof covering the entire setup. The trap was placed in the center of the paddy field, with a shelter to protect it from rain. The traps were raised 2 meters above the ground. They were turned on at 6:30 AM and turned off at 6:30 PM.

Figure 20. Light trap installed in a paddy field for hopper monitoring

2.3 Data collection

Hopper counting commenced at the tillering stage, approximately one month after transplanting, and continued weekly until the paddy reached maturity. The number of adult green leaf hoppers, brown plant hoppers, white-backed plant hoppers, and zigzag plant hoppers were collected weekly from August to November. Segregation of the light trap catches was done in the laboratory, as the traps contained many non-target species. In the laboratory, the hoppers were morphologically identified based on key characteristics described by Wilson & Claridge (1991).

2.4 Data analyses

Data visualization and exploratory summaries were performed using RStudio version 4.4.2 (2024-10-31 ucrt). Yearly and site-specific trends in hopper populations were analyzed by calculating the mean counts of each species per year and per monitoring site, respectively, to show temporal and spatial variations. To ensure the accuracy and reliability of the results, any data points from years with missing or incomplete records were excluded from the analysis.

Relative abundance by monitoring year and site was calculated by first summing the total counts of all hopper species for each year and site to obtain the total abundance. For each year and site, the abundance of each species was then summed individually. The relative abundance of each species was calculated by dividing its abundance by the total abundance for that year or site and multiplying by 100 to express it as a percentage. Relative abundance is important for the comparison of species populations across different years and sites, providing insights into their ecological roles and variations in distribution.

To analyze mean hopper counts by paddy stage, the data were categorized into Tillering (hopper catches in August), Booting (hopper catches in September), Grain Filling (hopper catches in October), and Maturity (hopper catches in November). For each paddy stage, the counts of green leafhopper (GLH), brown planthopper (BPH), white-backed planthopper (WBPH), and zigzag leafhopper (ZZLH) were summed across years and monitoring sites. The mean count for each hopper type was then calculated by dividing the total counts by the number of observations for each respective stage.

3 Results and Discussion

3.1 Population Trend by Year and Monitoring Sites

The four hopper species trapped were GLH, BPH, WBPH, and ZZLH (Figure 2). The mean number of different hopper species trapped per trap showed prominent year-to-year variation. In 2020, the GLH had the highest mean count of 245 individuals per trap, followed by the BPH at 134.5. WBPH and ZZLH were comparatively lower, averaging 87.2 and 18.6 respectively. The trend continued in subsequent years, with GLH consistently dominating, though its numbers slightly declined over time from 245.3 in 2020 to 173.6 in 2022 before increasing again to 214.8 in 2023. Meanwhile, BPH fluctuated, peaking again in 2023 at 112.1 per trap. WBPH and ZZLH followed similar fluctuations but remained the least abundant overall (Figure 3). A summary of total counts and means by year and site is provided in Table 1 and Table 2.

Figure 21. Four types of hoppers trapped in the light trap. From left to right: White-backed plant hopper, Zigzag leafhopper, Brown planthopper and Green leafhopper

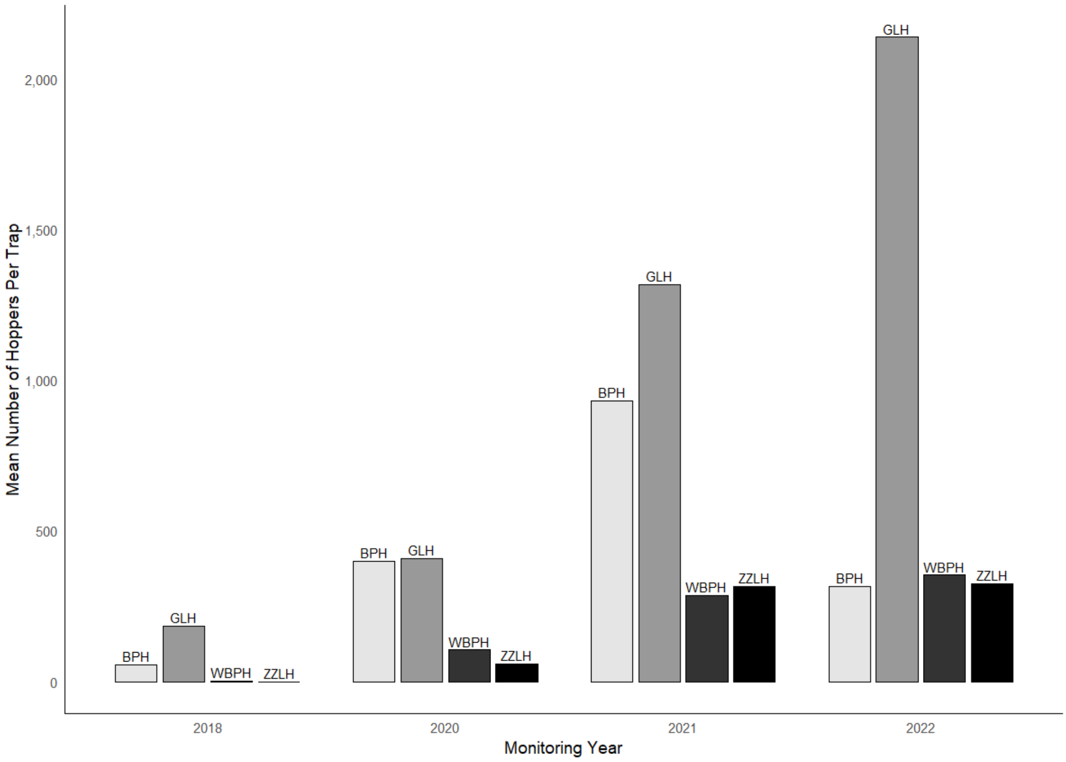

Figure 22. Mean number of hoppers per trap by year for BPH, WBPH, GLH, and ZZLH, showing yearly variation in species abundance.

Temperature strongly affects insect abundance, development rate, and number of generations (Haider et al., 2021). The surge in population may be attributed to favourable weather conditions, such as higher temperatures. Laszlo, Janos, & Marta (2012) found that light trap catches increased with rising temperatures. Conversely, the decline in hopper numbers could reflect adverse environmental conditions, such as excessive rainfall. Rainfall reduces the insect population by damaging their wings and dislodging from the plants (Karthik, Reddy, & Yashaswini, 2022). Madhuri, Dash, & Rout (2017) found that rainfall reduced the GLH population.

The mean number of different hopper species trapped per site showed prominent variation across locations. GLH had the highest mean counts, ranging from 182 individuals per trap at Karbithang to 1,736 at the farmer field in Samtenling. BPH counts varied between 76.9 and 608, while WBPH and ZZLH were comparatively lower, with WBPH averaging from 4.17 at Karbithang to 331 at ARDC Samtenling, and ZZLH ranging from 0 to 258 individuals per trap. This pattern indicates that GLH consistently dominates the hopper population across sites, whereas WBPH and ZZLH remain the least abundant overall (Figure 4).

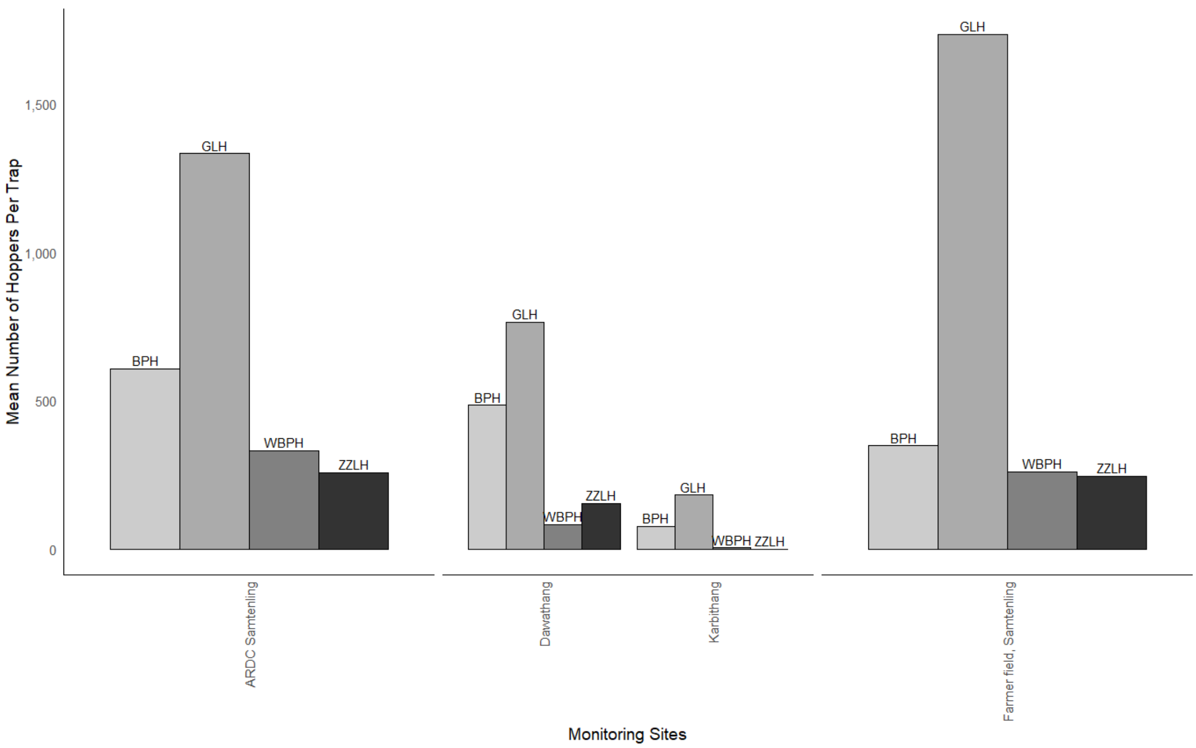

Figure 23. Mean number of hoppers per trap by year for BPH, WBPH, GLH, and ZZLH, showing yearly variation in species abundance. The data presented for ARDC Samtenling represent the total counts collected over three years (2020, 2021, and 2022), whereas the data for Farmer field, Samtenling correspond to only one year (2022).

Table 16. Hopper population counts by species and year from two monitoring sites in Samtenling Gewog.

Hopper species	ARDC Samtenling						Farmer field, Samtenlling					
	2018	2020	2021	2022	Total	Mean	2018	2020	2021	2022	Total	Mean
GLH	-	5851	18,070	25,407	49,328	16443	-	-	-	17357	17357	17357
BPH	-	5491	14,136	2867	22,494	7498	-	-	-	3479	3479	3479
WBPH	-	1699	6072	4472	12,243	4081	-	-	-	2606	2606	2606
ZZPH	-	949	4554	4051	9554	3185	-	-	-	2452	2452	2452
Total	-	13990	42,832	36,797	93,619	31206	-	-	-	25894	25894	25894
Mean	-	3498	10,708	9199	23,405	7802	-	-	-	6474	6474	6474

Table 17. Hopper population counts by species and year from two monitoring sites in Chuzergang Gewog.

Hopper species	Dawathang						Karbithang					
	2018	2020	2021	2022	Total	Mean	2018	2020	2021	2022	Total	Mean
GLH	2242	1506	21485	-	25233	8411	2173	-	-	-	2173	2173
BPH	443	1699	13829	-	15971	5324	923	-	-	-	923	923
WBPH	0	201	2511	-	2712	904	50	-	-	-	50	50
ZZPH	0	124	4949	-	5073	1691	0	-	-	-	0	0
Total	2685	3530	42774	-	48989	16330	3151	-	-	-	3153	3153
Mean	671	883	10694	-	12247	4083	788	-	-	-	788	788

* The dash (-) indicates that monitoring was not conducted during those periods.

3.2 Relative Abundance by Monitoring Sites

The relative abundance of hopper species showed significant variation across the monitored sites. At ARDC Samtenling, GLH constituted the majority of the hopper population, accounting for 52.7%, followed by BPH at 24.0%. The population of WBPH and ZZLH were comparatively lower, representing 13.1% and 10.2%, respectively. In Dawathang, GLH remained the dominant species with a relative abundance of 51.5%, while BPH comprised 32.6% of the population. The proportions of WBPH and ZZLH were 5.5% and 10.4%, respectively. At the Farmer Field site in Samtenling, GLH was prevalent, constituting 67.0% of the hopper population. BPH accounted for 13.4%, whereas WBPH and ZZLH comprised

10.1% and 9.5%, respectively. In Karbithang, GLH was dominant population at 69.1%, with BPH contributing 29.3%. The presence of WBPH was minimal (1.6%), and ZZLH was nearly absent. Overall, GLH consistently exhibited the highest relative abundance across all monitoring sites, followed by BPH (Figure 5).

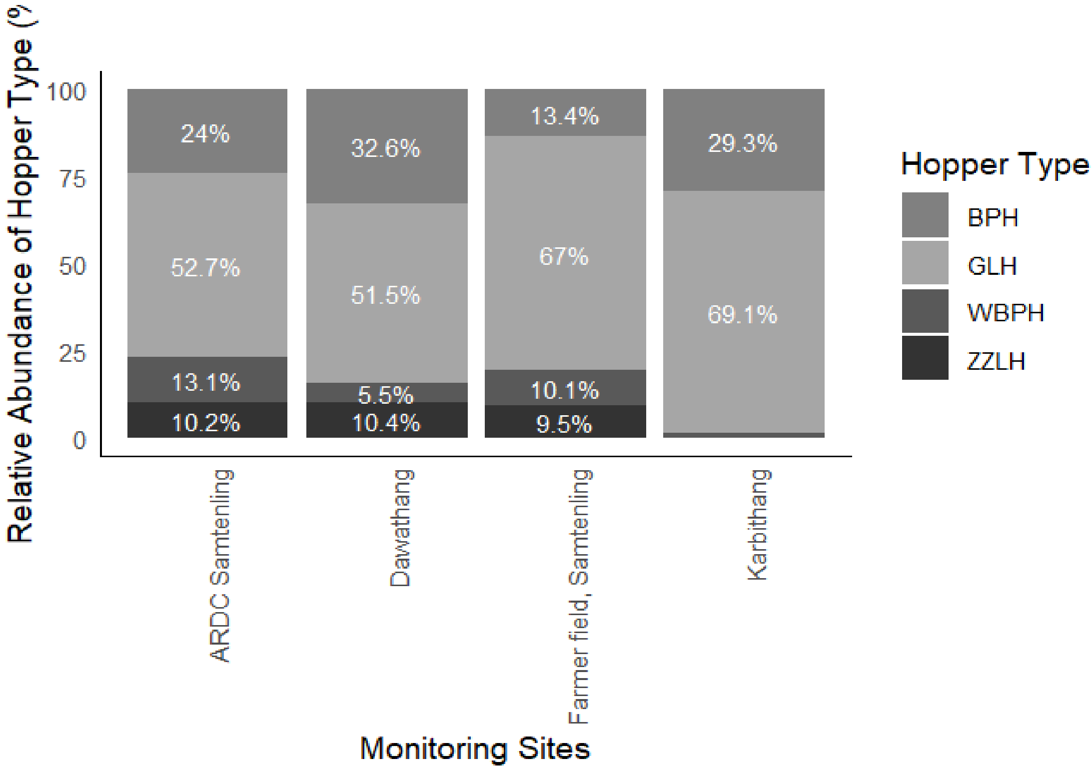

Figure 24. Relative abundance (%) of different hopper species across monitoring sites. The proportions of each species: GLH, BPH, WBPH, and ZZLH are stacked to illustrate inter-annual variations in species composition. *Note: WBPH relative abundance in Karbithang (1.6%) is not labelled due to its small value.*

Similar observations of GLH abundance have also been reported in Bangladesh (Rahman, Maleque, Uddin, & Ahmed, 2017). The GLH's dominance in rice fields is concerning due to its role in transmitting the tungro virus, a major threat to rice crop (Rosida, Kuswinanti, Nasruddin, & Amin, 2020). Rice Tungro Disease (RTD) is the most damaging viral disease of rice in South and Southeast Asia with numerous outbreaks in Bangladesh, Malaysia, the Philippines, China, Thailand, and India (Dey et al., 2024). Tungro virus infection causes stunted growth, yellow to orange-yellow leaves with brown spots, discoloration from the tip to the base, fewer tillers, and mostly hollow grains (Kim, Raymundo, & Aikins, 2019).

BPH was the second most abundant species. The presence of BPH is alarming as they cause hopper burn leading to significant crop damage. BPH is the most destructive rice insect pest in temperate and tropical regions of East and South Asia (Satturu et al., 2020). They transmit viral diseases such as grassy and ragged stunt viruses (Normile, 2008). In 2005, the brown plant hoppers caused an estimated 1.88 million tons of rice yield loss in China (Gurr et al., 2011). Extensive pesticide uses to manage brown plant hoppers has led to resistance to these chemicals (Tanaka, Endo, & Kazano, 2000).

3.3 Relative Abundance by Monitoring Year

The relative abundance of hopper species varied across the monitoring years. In 2018, GLH were the most dominant, comprising 75.7% of the total catch, followed by brown BPH at 23.4%, while WBPH and ZZLH were nearly absent. In 2020, GLH and BPH showed nearly equal abundance, accounting for 42.0% and 41.0% respectively, with WBPH and ZZLH contributing 10.8% and 6.1%. The trend shifted in 2021, where GLH maintained dominance at 46.2%, followed by BPH (32.7%), ZZLH (11.1%), and WBPH (10.0%). In 2022, GLH remained the most abundant species at 68.2%, with WBPH (11.3%), ZZLH (10.4%), and BPH (10.1%) showing comparable and lower proportions. These patterns highlight year-to-year fluctuations in species dominance, with GLH consistently being the most prevalent hopper across all years (Figure 6).

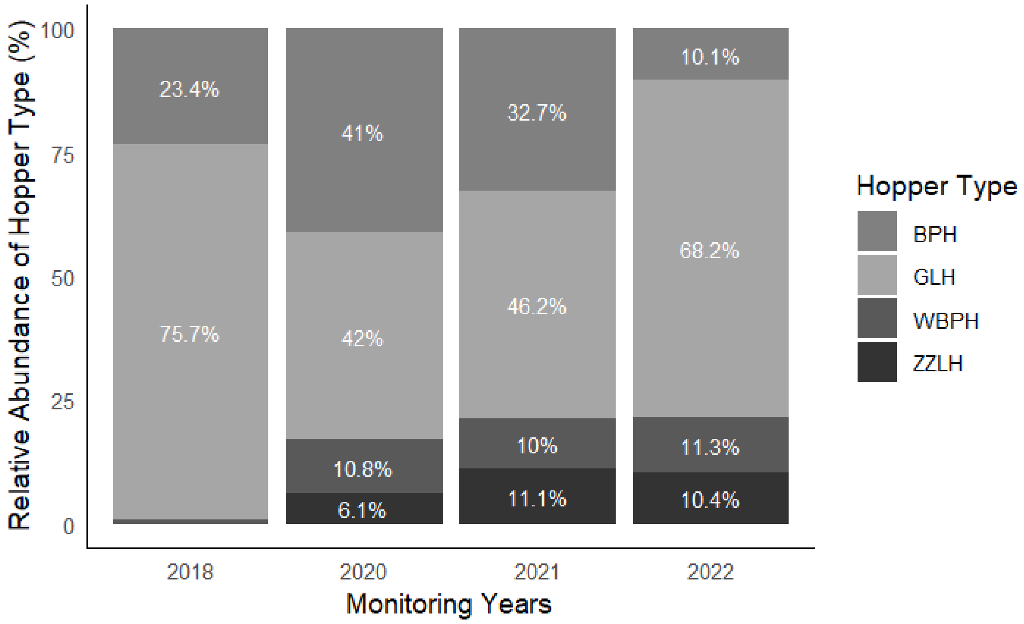

Figure 25. Relative abundance (%) of different hopper species across monitoring years. The proportions of each species: GLH, BPH, WBPH, and ZZLH are stacked to illustrate inter-annual variations in species composition. *Note: WBPH relative abundance in 2018 (0.86%) is not labelled due to its small value.*

The reasons for variations in abundance could not be conclusively determined. One possible explanation is that the light trap catches might have been influenced by the type of light used in the study. Variations in factors such as light intensity, wavelength, and trap design can affect the efficiency of trapping different species (Bowden, 1982). Future studies could explore the impact of different light trap types on hopper catch rates to optimize monitoring methods and ensure consistency in data collection.

Other possible reasons include changes in temperature, humidity, and rainfall, which can directly impact the life cycles and reproductive rates of hopper species (Laszlo et al., 2012; Sarkar, Baliarsingh, Mishra, Nanda, & Panigrahi, 2018; Haider et al., 2021). Variations in agricultural practices, such as the timing of planting, and crop stage could have contributed to changes in the population dynamics (Sharma, Raju, Singh, & Babu, 2023; Prabowo, Hidayat, Wiyono, & Dadang, 2023). Additionally, natural predation by predators and parasitoids might have affected hopper populations (Gurr et al., 2011).

3.4 Hopper Population Trends by Paddy Stage

Hopper pressure in the rice crop varied across different growth stages (Figure 7). During the tillering stage, hopper pressure was minimal, with mean counts of GLH at 52 per trap, BPH at 59 per trap, WBPH at 50 per trap, and ZZLH at 35 per trap. This observation aligned with the findings of Heong & Hardy (2009), who found that the early stages of rice growth were less conducive to hopper reproduction due to limited food availability.

As paddy progressed to the booting stage, hopper populations increased significantly, with mean counts of GLH at 1236 per trap, BPH at 171 per trap, WBPH at 117 per trap, and ZZLH at 110 per trap. Cheng, Zhu, & He (2013) highlighted that the booting stage offers a more favorable environment for hopper activity, with the denser crop canopy and higher nutrient levels promoting their reproduction. This stage represents a critical period for pest management interventions to prevent further increases in pest pressure.

The grain-filling stage experienced the highest pest pressure, with mean counts of GLH at 1484 per trap, BPH at 674 per trap, WBPH at 245 per trap, and ZZLH at 346 per trap. According to Han, Wu, Yang, Zhang, & Xiao (2018), the rice plants at this stage provide abundant nutrients for pest growth. Effective pest control during this phase is essential to safeguard yield potential.

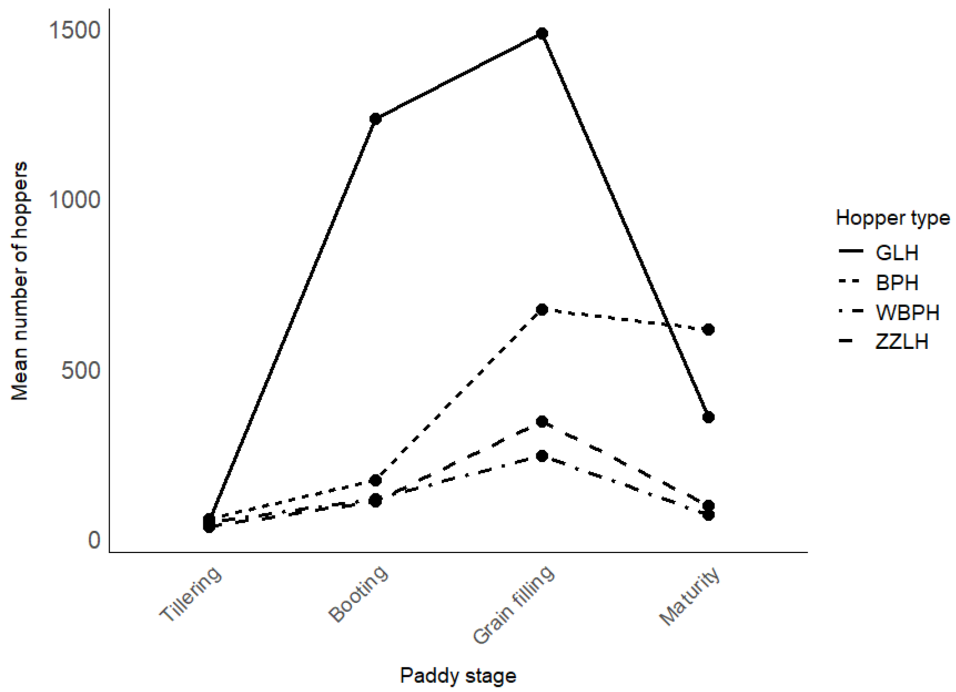

Figure 26. Mean number of hoppers trapped across different paddy growth stages.

At maturity, the mean counts showed variation, with GLH at 359 per trap, BPH at 616 per trap, WBPH at 71 per trap, and ZZLH at 96 per trap. Despite the decline in GLH and WBPH populations, BPH and ZZLH remained active, which supports Heong & Hardy (2009) findings that BPH remained persistent late into the rice cycle, potentially affecting final yields.

4 Conclusion

The study provides an understanding of the population dynamics, site variations, and seasonal patterns of major hopper species in rice fields, offering important information for sustainable pest management strategies. Among the four hopper species monitored, the green leafhopper was the most abundant across four different monitoring sites and years, highlighting its significant potential to impact rice crops. Its ability to spread viral diseases such as the tungro virus makes it a critical pest requiring focused management efforts. The brown planthopper was the second most abundant species, and it poses a major threat due to its role in causing hopper burn. The white-backed planthopper and zigzag leafhopper were less abundant but their population surged during the grain-filling and maturity stages, indicating that these stages are particularly vulnerable to pest pressure. Monitoring site-specific variations in hopper populations revealed that different environments could significantly influence pest abundance. Understanding these site-specific dynamics allows for targeted pest management interventions tailored to local conditions. Seasonal dynamics of hopper populations further highlighted the critical stages in the rice crop cycle that require intervention. The booting and grain-filling stages were identified as periods of peak hopper pressure, emphasizing the need for vigilant monitoring and timely pest control measures during these phases. Overall, the findings underscore the need for integrated pest management to minimize hopper populations and their impact on rice yields. Future research that focuses on exploring the factors driving site-specific variations and the role of climate change in influencing hopper dynamics will enhance pest management strategies, ensuring sustainable rice production.

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6 Authors' contribution statement

- Conceptualization and Design: Tshelthrim Zangpo.
- Data Collection: Ratu Kinley, Chinta Mani Dhimal, Tashi Dawa.
- Writing – Original Draft: Tshelthrim Zangpo.
- Review & Editing: Tshelthrim Zangpo, Ratu Kinley, Sonam Gyeltshen, Thirtha Maya Ghalley, Tshencho Dem, Ugyen Tshering, Jigme Wangchuk, Yeshey Dema.

7 References

Abbas, M., Ramzan, M., Hussain, N., Ghaffar, A., Hussain, K., Abbas, S., & Raza, A. (2019). Role of light traps in attracting, killing and biodiversity studies of insect pests in Thal. Pakistan Journal of Agricultural Research, 32(4), 684–690. https://doi.org/10.17582/journal.pjar/2019/32.4.684.690

Ali, M. P., Bari, M. N., Haque, S. S., Kabir, M. M. M., Nowrin, F., Choudhury, T. R., Ahmed, N. (2020). Response of a rice insect pest, Scirpophaga incertulas (Lepidoptera: Pyralidae) in warmer world. BMC Zoology, 5(1), 6. https://doi.org/10.1186/s40850-020-00055-5

Bandong, J. P., & Litsinger, J. A. (2005). Rice crop stage susceptibility to the rice yellow stemborer Scirpophaga incertulas (Walker) (Lepidoptera: Pyralidae). International Journal of Pest Management, 51(1), 37–43. https://doi.org/10.1080/09670870400028276

Bowden, J. (1982). An analysis of factors affecting catches of insects in light-traps. Bulletin of Entomological Research, 72(4), 535–556. https://doi.org/10.1017/S0007485300008579

Cheng, X., Zhu, L., & He, G. (2013). Towards understanding of molecular interactions between rice and the brown planthopper. Molecular Plant, 6(3), 621–634. https://doi.org/10.1093/mp/sst030

Dadmal, S. M., & Khadakkar, S. (2014). Insect faunal diversity collected through light trap at Akola vicinity of Maharashtra with reference to Scarabaeidae of Coleoptera. Journal of Entomology and Zoology Studies, 2(3), 44–48. Retrieved from https://www.entomoljournal.com/vol2Issue3/pdf/18.1.pdf

Deshwal, R., Sachan, S. K., Singh, G., Singh, D. V, Singh, G., & Chand, P. (2019). Seasonal abundance of insect pests associated with paddy crop in western plain zone of Uttar Pradesh. Journal of Entomology and Zoology Studies, 7(3), 1347–1350.

Dey, S. R., Das, R., & De, M. (2024). A Brief Review on Present Status of Rice Tungro Disease: Types of Viruses, Vectors, Occurrence, Symptoms, Control and Resistant Rice Varieties. International Journal of Advancement in Life Sciences Research, 07(03), 15–23. https://doi.org/10.31632/ijalsr.2024.v07i03.002

FAO. (2023). Crops and livestock products. Retrieved from Food and Agriculture Organisation of the United Nations website: https://www.fao.org/faostat/en/#data/QCL

Gurr, G. M., Liu, J., Read, D. M. Y., Catindig, J. L. A., Cheng, J. A., Lan, L. P., & Heong, K. L. (2011). Parasitoids of Asian rice planthopper (Hemiptera: Delphacidae) pests and prospects for enhancing biological control by ecological engineering. Annals of Applied Biology, 158(2), 149–176. https://doi.org/10.1111/j.1744-7348.2010.00455.x

Haider, I., Akhtar, M., Noman, A., & Qasim, M. (2021). Population Trends of Some Insect Pests of Rice Crop on Light Trap and its Relation to Abiotic Factors in Punjab Pakistan. Pakistan Journal of Zoology, 53(3), 1015–1023. https://doi.org/10.17582/journal.pjz/20190822060844

Haider, I., Akhter, M., & Sabir, M. A. (2014). Evaluation of Different Insecticides Against Rice Leaffolder Cnaphalocrocis medinalis (Guenee) Under Field Conditions. Pakistan Journal of Zoology, 46(5), 1458–1461. Retrieved from https://www.researchgate.net

Han, Y., Wu, C., Yang, L., Zhang, D., & Xiao, Y. (2018). Resistance to Nilaparvata lugens in rice lines introgressed with the resistance genes Bph14 and Bph15 and related resistance types. PLoS ONE, 13(6), 1–15. https://doi.org/10.1371/journal.pone.0198630

Heong, K. L., & Hardy, B. (2009). Planthoppers: new threats to the sustainability of intensive rice production systems in Asia. In AgEcon Search (Vol. 1). Los Baños, Philippines: International Rice Research Institute. Retrieved from https://ideas.repec.org/

Hereward, J. P., Cai, X., Matias, A. M. A., Walter, G. H., Xu, C., & Wang, Y. (2020). Migration dynamics of an important rice pest: The brown planthopper (Nilaparvata lugens) across Asia—Insights from population genomics. Evolutionary Applications, 13(9), 2449–2459. https://doi.org/10.1111/eva.13047

Horgan, F. G., Peñalver Cruz, A., Bernal, C. C., Ramal, A. F., Almazan, M. L. P., & Wilby, A. (2018). Resistance and tolerance to the brown planthopper, Nilaparvata lugens (Stål), in rice infested at different growth stages across a gradient of nitrogen applications. Field Crops Research, 217(1), 53–65. https://doi.org/10.1016/j.fcr.2017.12.008

Hu, G., Lu, F., Zhai, B.-P., Lu, M.-H., Liu, W.-C., Zhu, F., Zhang, X.-X. (2014). Outbreaks of the Brown Planthopper Nilaparvata lugens (Stål) in the Yangtze River Delta: Immigration or Local Reproduction? PLoS ONE, 9(2), e88973. https://doi.org/10.1371/journal.pone.0088973

Hu, G., Lu, F., Zhai, B.-P., Lu, M.-H., Liu, W.-C., Zhu, F., Zhang, X.-X. (2014b). Outbreaks of the Brown Planthopper Nilaparvata lugens (Stål) in the Yangtze River Delta: Immigration or Local Reproduction? PLoS ONE, 9(2), e88973. https://doi.org/10.1371/journal.pone.0088973

Huang, S. H., Lai, P. Y., Hwang, S. Y., Borhara, K., Huang, W. R., & Wang, S. Y. (2022). Climate Variability Shifting Immigrated Rice Planthoppers in Taiwan. Climate, 10(5), 1–12. https://doi.org/10.3390/cli10050071

Karthik, S., Sai Reddy, M. S., & Yashaswini, G. (2022). Climate Change and Its Potential Impacts on Insect-Plant Interactions. In S. Harris (Ed.), The Nature, Causes, Effects and Mitigation of Climate Change on the Environment (pp. 116–124). London, New York: IntechOpen

Kim, K. H., Raymundo, A. D., & Aikins, C. M. (2019). Development of a rice tungro epidemiological model for seasonal disease risk management in the Philippines. European Journal of Agronomy, 109(5), 125911. https://doi.org/10.1016/j.eja.2019.04.006

Kumar, A., Kumar, P., Chandra, U., Patel, P. K., Omar, V., Pathak, R., & Rajak, R. K. (2023). Abundance of Major Insect Pests in Rice and Their Relation to Weather Parameters. International Journal of Environment and Climate Change, 13(8), 1752–1760. https://doi.org/10.9734/ijecc/2023/v13i82129

Laszlo, N., Janos, P., & Marta, L. (2012). Efficiency of Light-Traps Influenced By Environmental Factors. International Journal of Science and Nature, 3(3), 521–525. Retrieved from https://www.researchgate.net/

Lu, G., Zhang, T., He, Y., & Zhou, G. (2016). Virus altered rice attractiveness to planthoppers is mediated by volatiles and related to virus titre and expression of defence and volatile-biosynthesis genes. Nature, 6(1), 38581. https://doi.org/10.1038/srep38581

Madhuri, G., Dash, P. C., & Rout, K. K. (2017). Effect of Weather Parameters on Population Dynamics of Paddy Pests. International Journal of Current Microbiology and Applied Sciences, 6(10), 2049–2053. https://doi.org/10.20546/ijcmas.2017.610.243

Maurya, R. K., Dwivedi, D., Khan, N., Giri, S., & Dixit, S. (2022). Genetic variability studies for qualitative and quantitative traits in rice (Oryza sativa L.). The Pharma Innovation Journal, 11(5), 1140–1143.

National Statistics Bureau. (2023). Integrated Agriculture and Livestock Census of Bhutan. Retrieved from www.nsb.gov.bt

Normile, D. (2008). Reinventing Rice to Feed the World. Science, 321(5887), 330–333. https://doi.org/10.1126/science.321.5887.330

Otuka, A., Matsumura, M., Watanabe, T., & Van Dinh, T. (2008). A migration analysis for rice planthoppers, Sogatella furcifera (Horváth) and Nilaparvata lugens (Stål) (Homoptera: Delphacidae), emigrating from northern Vietnam from April to May. Applied Entomology and Zoology, 43(4), 527–534. https://doi.org/10.1303/aez.2008.527

Patidar, S., Sanjay, V., SS, B., & Sahu, B. (2019). Seasonal activities of major insect pest species of paddy collected in light traps. Journal of Pharmacognosy and Phytochemistry, 8(3), 4278–4282. Retrieved from www.phytojournal.com

Prabowo, D. P., Hidayat, P., Wiyono, S., & Dadang. (2023). Population dynamics of brown planthopper Nilaparvata lugens stall and arthropod diversity on rice ecosystem with returned straw and different spectrum of insecticides. IOP Conference Series: Earth and Environmental Science, 1133(1). https://doi.org/10.1088/1755-1315/1133/1/012044

Quayum, M., Hossain, M., & Sharmin, T. (2023). Impact of Brown Plant Hopper (BPH) Management Training on Boro Rice Cultivation In Serajganj District. Bangladesh Journal of Agricultural Research, 46(2), 211–226. https://doi.org/10.3329/bjar.v46i2.64124

Rahman, M., Maleque, M., Uddin, M., & Ahmed, J. (2017). Abundance and Diversity of Insect Pests on Boro and Aman Rice in Sylhet. Journal of Sylhet Agricultural University, 4(1), 53–60. Retrieved from www.researchgate.net

Rashid, M., Ridoy, M. K., Rahman, M. M., Rahman, M. M., & Mondal, M. F. (2022). Does solar light trap reduce the cost of pesticides used in rice field? SAARC Journal of Agriculture, 20(1), 171–183. https://doi.org/10.3329/sja.v20i1.60615

Rosida, N., Kuswinanti, T., Nasruddin, A., & Amin, N. (2020). Green leafhopper (Nephotettix virescens Distan) biotype and their ability to transfer tungro disease in South Sulawesi, Indonesia. IOP Conference Series: Earth and Environmental Science, 486(1). https://doi.org/10.1088/1755-1315/486/1/012147

Sarkar, D., Baliarsingh, A., Mishra, H. P., Nanda, A., & Panigrahi, G. (2018). Population Dynamics of Brown Plant Hopper of Paddy and Its Correlation with Weather

Parameters. International Journal of Chemical Studies, 6(6), 920–923. Retrieved from www.thepharmajournal.com/

Satturu, V., Vattikuti, J. L., Durga Sai, J., Kumar, A., Singh, R. K., Srinivas Prasad, M., … Thirunavukkarasu, N. (2020). Multiple genome-wide association mapping models identify quantitative trait nucleotides for brown planthopper (Nilaparvata lugens) resistance in MAGIC Indica population of rice. Vaccines, 8(4), 1–16. https://doi.org/10.3390/vaccines8040608

Sharma, K. R., Raju, S. V. S., Singh, K., & Babu, S. R. (2023). Effect of Crop Growth Stages on the Field Population of Rice Hoppers. Indian Journal of Entomology, 85(3), 701–703. https://doi.org/10.55446/IJE.2022.667

Tanaka, K., Endo, S., & Kazano, H. (2000). Toxicity of insecticides to predators of rice planthoppers: Spiders, the mirid bug and the dryinid wasp. Applied Entomology and Zoology, 35(1), 177–187. https://doi.org/10.1303/aez.2000.177

Wilson, M. R., & Claridge, M. F. (1991). Handbook for the Identification of Leafhoppers and Planthoppers of Rice. Wallingford, UK: CAB International.