Seasonal patterns of *Zonocerus variegatus* developmental stages in Kisangani, Democratic Republic of the Congo, Democratic Republic of the Congo

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ABSTRACT

Zonocerus variegatus is an important pest in tropical agroecosystems, but its seasonal population dynamics remain poorly documented in the Kisangani region of the Democratic Republic of the Congo. This study used a quantitative, longitudinal observational design based on repeated monthly field surveys. This study examined monthly changes in the developmental stages of the species in two localities within the humid forest zone. It also assessed how temperature, rainfall, and relative humidity were related to fluctuations in post-embryonic stages. Specimens were classified into developmental stages using morphological criteria, and monthly counts were summarized over two annual cycles. Relative abundances were calculated by developmental stage, month, and year. The relationships between developmental-stage structure and climatic variables were analysed using redundancy analysis, after standardizing temperature, rainfall, and relative humidity. Pairwise correlations were also used to examine direct associations between developmental stages and climatic variables, while graphs were produced to show monthly and annual patterns. The results showed clear seasonal variation. Juveniles were dominant at the beginning and end of each annual cycle, whereas adults were more abundant between June and September. Pseudo-nymphs remained rare throughout the year. Ordination and correlation analyses indicated that climatic conditions were associated with changes in developmental-stage structure, although their explanatory power was limited. These findings suggest that the phenology of *Z. variegatus* in Kisangani is seasonally structured and is probably influenced by both climatic and ecological factors. From a management perspective, the high abundance of juveniles indicates that control measures should preferably target early developmental stages during seasonal peaks. Future studies should also consider host-plant availability, natural enemies, and habitat characteristics to improve prediction and management strategies.

Keywords: Climatic Drivers, Democratic Republic of the Congo, Population Dynamics, Seasonal Phenology, Tropical Agroecosystems, *Zonocerus variegatus*

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I. INTRODUCTION

Zonocerus variegatus (Linnaeus, 1758), commonly known as the variegated grasshopper, is one of the best-known polyphagous grasshopper pests in West and Central Africa. It attacks a broad range of cultivated plants, including cassava, maize, vegetables, legumes, and several perennial crops, and is particularly associated with disturbed habitats and heterogeneous agricultural landscapes (Blanford *et al.*, 2000; Chapman *et al.*, 1986). Its agricultural importance stems not only from direct defoliation but also from its capacity to persist across seasons and exploit a wide host-plant spectrum.

Previous studies have described the ecology and biology of this species, demonstrating that its life cycle is strongly influenced by seasonal changes, local vegetation, and moisture availability (Chiffaud & Mestre, 1990; Chapman *et al.*, 1986; Kekeunou *et al.*, 2007) . In humid forest environments, *Z. variegatus* populations can be found year-round; however, the relative abundance of different developmental stages varies considerably over time, with early instars typically more prevalent during wetter periods and adults more abundant during drier seasons (Kekeunou *et al.*, 2007; Chapman & Joern, 1990). Golding's seminal study (1940a) on the variegated grasshopper, *Zonocerus variegatus*, in Nigeria documented its severe impact on local cropping systems. By examining the species' biology and ecological dynamics, the study provided a foundation for the development of contemporary pest management strategies. Golding's findings remain highly relevant to food security in Nigeria and in other regions affected by this pest.

Climatic variables are expected to play a central role in shaping these seasonal patterns. Temperature influences insect development rates, metabolism, activity, and survival, while rainfall and humidity affect egg viability, host-plant condition, pathogen prevalence, and the suitability of microhabitats (Blanford *et al.,* 2000; Bale *et al.*, 2002; Deutsch *et al.*, 2008). For tropical ectotherms organisms whose body temperature depends on external sources—even small environmental fluctuations can significantly alter developmental timing and the distribution of life stages (Deutsch *et al.*, 2008). Nevertheless, climate interacts with other ecological factors such as vegetation structure, host-plant quality, natural enemies, and land-use changes, all of which can influence the abundance and persistence of plant-feeding (phytophagous) insects (Chapman *et al.*, 1986; Kekeunou *et al.*, 2007; Modder, 1984).

Despite the practical importance of *Z. variegatus*, there is a paucity of region-specific studies from Kisangani. This represents a significant knowledge gap, as Kisangani is situated within a humid tropical forest landscape where unique rainfall patterns, agricultural mosaics, and perennial vegetation may influence pest phenology in ways that differ from the drier regions more commonly studied (White, 1983 ; Malaisse, 1997). Consequently, locally focused research is necessary to determine the periods of peak abundance for different post-embryonic stages and to identify the environmental variables most closely associated with their seasonal fluctuations.

1.1 Research Objective

This study aimed to describe the seasonal dynamics of *Zonocerus variegatus* in the Kisangani region by examining monthly changes in juvenile, pseudo-nymphal, and adult stages. It also assessed how temperature, rainfall, and relative humidity relate to these fluctuations. The study provides baseline information to improve seasonal monitoring and guide the timing of management interventions against this pest in humid tropical agroecosystems.

II. LITERATURE REVIEW

2.1 Theoretical Review

Zonocerus variegatus is a widespread polyphagous grasshopper pest in West and Central Africa. Its economic importance is linked to its ability to feed on a wide range of cultivated plants, including cassava, maize, vegetables, legumes, and other crops. This broad host range allows the species to persist in diverse agroecosystems and to exploit both cultivated plants and spontaneous vegetation when resource availability changes. It is particularly common in disturbed habitats, fallows, field margins, open vegetation, and agricultural mosaics, where host plants, shelter, and oviposition sites are often available (Chapman *et al,* 1986).

The abundance and developmental dynamics of *Z. variegatus* are influenced by seasonal variation. As an ectothermic insect, its development, survival, and activity are partly regulated by external environmental conditions. Temperature affects growth rate, metabolism and mobility, whereas rainfall and relative humidity may influence egg viability, hatching success, microhabitat suitability, and host-plant quality (Deutsch *et al.*, 2008; Bale *et al.*, 2002). In humid tropical environments, seasonal changes in moisture availability may also modify vegetation growth and, consequently, the availability of food resources for juvenile and adult stages.

Nevertheless, climatic variables alone are unlikely to fully explain the population dynamics of *Z. variegatus*. Their effects may interact with vegetation structure, crop phenology, host-plant availability, natural enemies and land-use disturbance. Disturbed habitats and fallows may favour population persistence by supporting preferred host plants and providing suitable conditions for different developmental stages. In addition, predators, parasitoids and pathogens may influence survival rates differently across juvenile, pseudo-nymphal and adult stages. Therefore, a comprehensive understanding of the seasonal dynamics of *Z. variegatus* requires consideration of both climatic drivers and local ecological conditions (Chapman *et al.*, 1986; Kekeunou *et al.*, 2007).

2.2 Empirical Review

Studies conducted in West and Central Africa have shown that *Z. variegatus* populations vary strongly across seasons. Juvenile stages are generally more abundant during wetter periods, whereas adults often become more common during drier periods (Chapman & Joern, 1990; Chapman *et al.*, 1986). Host plants also influence its distribution and feeding behaviour. For example, Chromolaena odorata has been reported as an important plant associated with the abundance and attraction of *Z. variegatus* in disturbed habitats (Kekeunou *et al.*, 2007; Modder, 1984). Environmental conditions may also affect biological control, as temperature and humidity can influence both grasshopper behaviour and the performance of fungal pathogens (Blanford *et al.*, 2000).

In the Kisangani region, information on the seasonal dynamics of *Z. variegatus* is still limited. The present study helps fill this gap by examining monthly changes in juvenile, pseudo-nymphal, and adult stages over two annual cycles. The results show that juveniles are dominant at the beginning and end of the year, while adults are more frequent between June and September. Pseudo-nymphs remain rare throughout the year. Although relative humidity appears to be associated with stage structure, the measured climatic variables explain only part of the observed variation. This suggests that the seasonal dynamics of *Z. variegatus* in Kisangani are shaped by climate, together with other ecological factors that were not directly measured in this study. Additionally, the low prevalence of nymphs could result from a natural biological regulation; Bakondongama et *al.* (2017) identified twenty families of Hymenopteran parasitoids within the Kisangani region.

III. METHODOLOGY

3.1 Research Design and Justification

The study used a quantitative, longitudinal observational design based on repeated monthly field surveys. *Zonocerus variegatus* populations were monitored in the same two localities from January 2021 to December 2022, thereby covering two complete annual cycles. This design was appropriate because the primary objective was to characterize seasonal changes in the relative abundance of post-embryonic developmental stages and to evaluate their relationships with contemporaneous climatic conditions without experimentally manipulating either the insect populations or their habitats.

3.2 Study Area

The study was conducted in Bawi (00°42′17.5″ N, 025°12′17.6″ E), located along the Buta road, and Malimba (00°42′55.5″ N, 025°15′26.7″ E), located along the Alibuku road, in the Kisangani region of Tshopo Province, Democratic Republic of the Congo. The area lies within the Guineo-Congolian humid forest domain and has a tropical rainforest climate characterized by high annual rainfall and limited thermal seasonality (White, 1983; Malaisse, 1997). The local landscape is a mosaic of smallholder cassava and maize fields, vegetable plots, fallows, open vegetation, and remnant woody vegetation. The two localities were selected because they contained suitable habitats with recurrent *Z. variegatus* populations and were accessible for standardized monthly monitoring.

3.3 Target Population and Sampling Procedures

The target population comprised all post-embryonic *Z. variegatus* individuals occurring in cultivated fields and adjacent open habitats in Bawi and Malimba during the study period. The operational sampling units were the locality-by-month surveys. Each locality was visited once per month for 24 months, giving 48 site-month sampling occasions. Within each locality, active sweep-net sampling was conducted in representative cultivated fields and adjoining open vegetation.

Sampling was carried out during the early morning, generally from 06:30 to 07:30, when lower temperatures reduce orthopteran locomotor activity and improve capture efficiency (Uvarov, 1977; Chapman, 1998; Gillott, 2005). Sampling effort was standardized at approximately 300 sweep-net strokes per locality per visit, equivalent to about one hour of active searching. All observed and captured individuals encountered during this standardized sequence were collected and placed in ventilated, labelled bags recording the locality, date, geographic coordinates, and collector. Comparable timing, duration, equipment, and sweep effort were maintained between localities and months to reduce effort-related bias.

3.4 Sample Size Determination

Because the study was designed as repeated ecological surveillance rather than a prevalence survey or randomized experiment, the sample size was not fixed through an a priori formula for human or household populations. It was determined by the standardized sampling effort applied at both localities across two complete annual cycles. The resulting sample comprised 11,989 *Z. variegatus* specimens: 8,482 juveniles, 377 pseudo-nymphs, and 3,130 adults, of which 1,743 were females and 1,387 were males. This effort-based census of all insects captured during each standardized survey provided sufficient temporal coverage to describe monthly stage structure and compare the two annual cycles.

3.5 Data Collection Methods and Instruments

Primary biological data were collected using a sweep net, ventilated specimen bags, field labels, a geographic positioning device, and laboratory counting and measuring equipment. After each survey, specimens were transported to the laboratory, sorted, counted, and examined. Body size was measured with a graduated ruler or an appropriate morphometric device. Developmental-stage identification was based on external morphology, particularly body size, wing development, and the number of antennal segments, following Vilardebo (1948) and Kekeunou et al. (2014). Seven developmental stages were initially recognized and then consolidated into three biologically interpretable groups for analysis: instars 1-5 as juveniles, instar 6 as the pseudo-nymphal stage, and instar 7 as adults or imagos. Adult sex was recorded when it could be reliably determined. A subset of specimens was preserved in 70% ethanol as reference material and for subsequent verification.

Monthly climatic data corresponding to January 2021-December 2022 were obtained from the NASA POWER database. Mean monthly air temperature and mean monthly relative humidity were used, whereas precipitation was expressed as the monthly total. The biological and climatic records were matched by month before statistical analysis.

3.6 Data Management and Statistical Analysis

Field and laboratory records were entered by locality, sampling date, developmental stage, and sex, and were checked for inconsistencies before analysis. Counts were summarized by developmental stage, month, locality, and year. Relative abundance was calculated as the number of individuals in a given stage divided by the total number collected during the corresponding sampling period, multiplied by 100. Monthly and annual patterns were visualized with ggplot2 (Wickham, 2016).

Differences in stage proportions among groups were assessed with the Kruskal-Wallis test when distributional assumptions for parametric analysis were not met. Where an omnibus comparison was significant, pairwise comparisons were interpreted using multiplicity-adjusted probability values. Relationships between developmental-stage composition and climate were evaluated with redundancy analysis (RDA), using the developmental-stage abundance matrix as the multivariate response and temperature, rainfall, and relative humidity as explanatory variables. Climatic predictors were standardized before ordination. The significance of the overall constrained model and canonical axes was evaluated by permutation tests, and the adjusted R^2 was used to quantify explained variation. Pairwise associations among stages and climatic variables were estimated with correlation coefficients and associated probability values using the Hmisc package, and the correlation matrix was displayed with corrplot (Harrell, 2026; Wei & Simko, 2024). Analyses were conducted in R version 4.5.1, with a two-sided significance threshold of $\alpha = 0.05$.

Monthly counts from Bawi and Malimba were pooled for the principal regional seasonal summaries only after confirming that the field protocol and sampling effort were equivalent. Locality and month remained the basic sampling descriptors in the database so that temporal replication was not confused with the number of insects captured.

3.7 Ethical and Environmental Considerations

The study involved field collection of an agricultural insect pest and did not include human participants, personal data, vertebrate animals, or experimental pesticide exposure. Access to cultivated plots was obtained with the knowledge and permission of the farmers or local land users. Sampling was restricted to the number of insects encountered during the standardized survey period, and unnecessary disturbance to crops and surrounding vegetation was avoided. Specimens were handled and preserved solely for scientific identification and verification. Accordingly, formal human-subject ethical approval was not applicable; nevertheless, the work followed principles of responsible field sampling, local cooperation, accurate record keeping, and minimal environmental disturbance.

IV. FINDINGS & DISCUSSION

4.1 Findings

4.1.1 Seasonal fluctuation of developmental stages

Monthly abundance data were summarized by developmental stage to describe temporal changes in the population structure of *Zonocerus variegatus*. Relative abundances were calculated by developmental stage, month, and year. Associations between developmental-stage structure and climatic variables were examined using redundancy analysis (RDA), with the stage-abundance matrix as the response matrix and temperature, rainfall, and relative humidity as explanatory variables. Climatic variables were standardized before analysis, and the significance of the global RDA model and canonical axes was tested using permutation tests. Pairwise correlations among developmental stages and climatic variables were computed using the Hmisc package to estimate correlation coefficients and significance values (Harrell, 2026). The correlation matrix was visualized using the corrplot package to show the strength and direction of bivariate associations (Wei & Šimko, 2024). Monthly and annual abundance patterns were plotted using ggplot2 to produce graphical summaries of developmental-stage dynamics (Wickham, 2016). All analyses were conducted in R 4.5.1 (R Core Team, 2024).

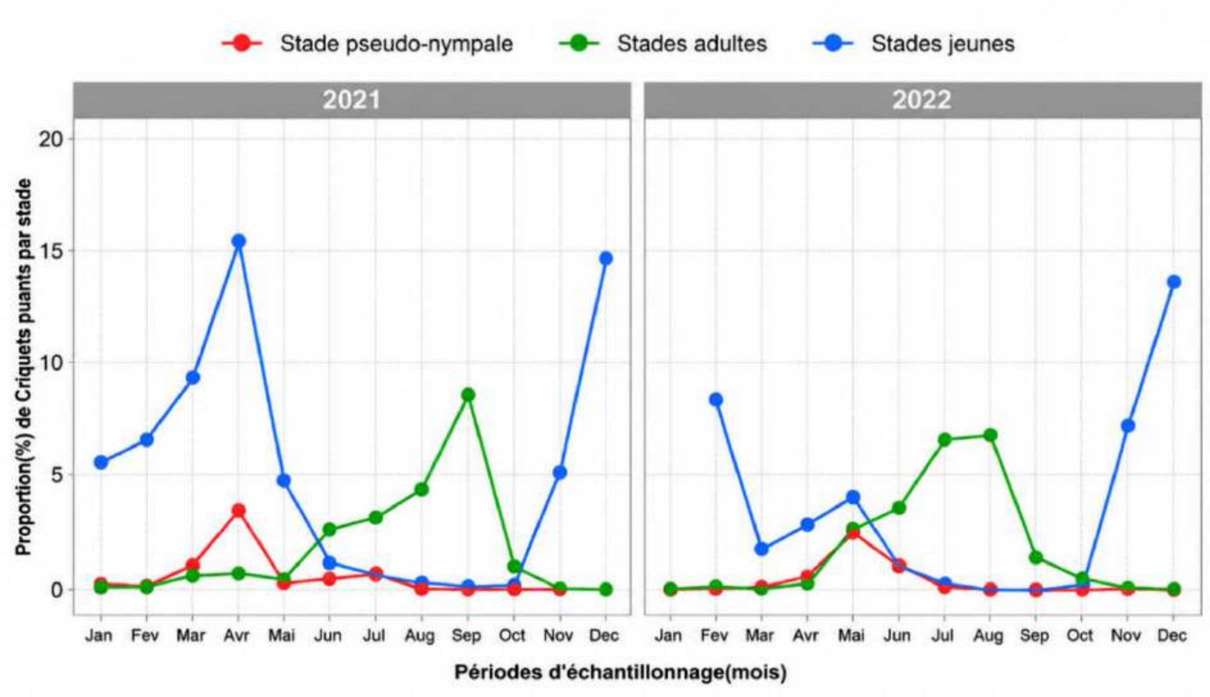

Figure 1
Monthly variation in the relative proportions of developmental stages of Zonocerus variegatus (juvenile, pseudo-nymphal, and adult stages) during 2021–2022 in the Kisangani region, Democratic Republic of the Congo.

4.1.2 Associations between Stage Structure and Climatic Variables

Redundancy Analysis (RDA) indicated a significant, though modest, association between climatic variables and developmental stage structure (Fig. 2; Table 1), with the overall model showing statistical significance (adjusted R^2 = 11.13%, p = 0.021) and most of the constrained variation explained by the first canonical axis. Notably, the ordination pattern showed that adult stages were aligned with the relative humidity vector, while juveniles were oriented in the opposite direction. Temperature contributed less to the ordination than relative humidity. The pseudo-nymphal stage was positioned away from the main humidity gradient, indicating that its variation was less influenced by the measured climatic variables.

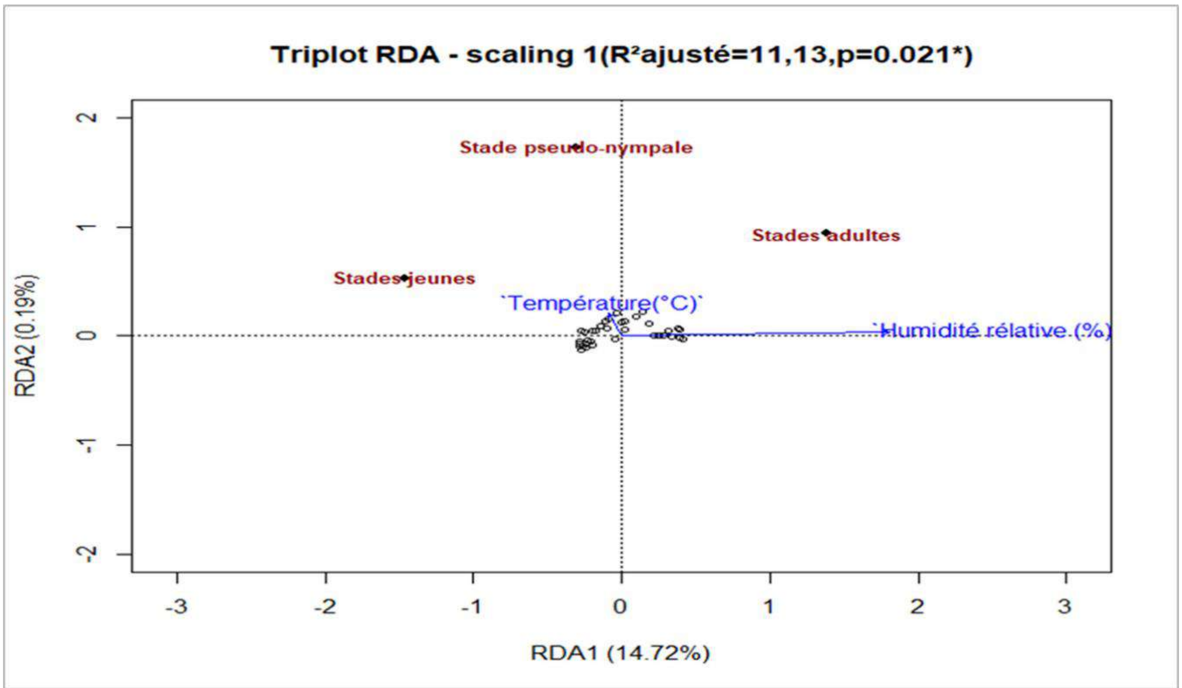

Figure 2
Effects of relative humidity and temperature on the post-embryonic development of Zonocerus variegatus

4.1.3 Relative Importance of Climatic Variables

Examination of the correlation matrix revealed weak to moderate relationships between developmental stages and climatic variables (Fig. 3). The strongest association was a positive correlation between relative humidity and rainfall, indicating that these two climatic variables covaried more strongly with each other than with any specific developmental stage. Juveniles showed weak negative associations with adults and temperature, while adults had only weak positive associations with humidity and precipitation. Overall, these patterns suggest that no single measured environmental variable fully explains the abundance of developmental stages. Rather, stage dynamics likely result from the combined influence of multiple climatic factors and additional ecological variables not assessed in this study.

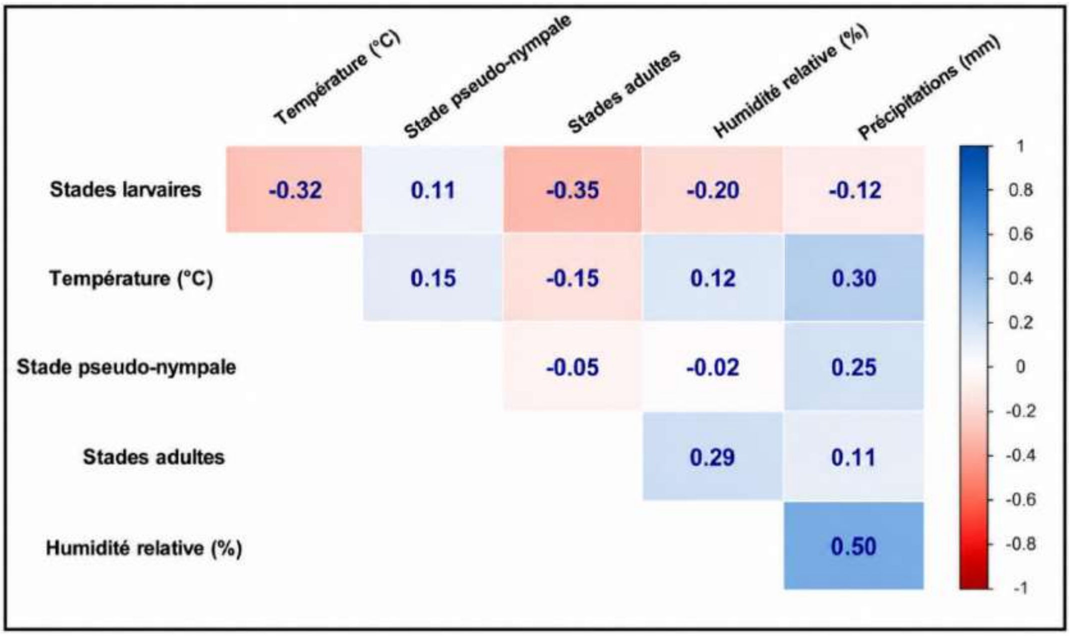

Figure 3

Combined effects of environmental factors on post-embryonic development in Zonocerus variegatus

4.1.4 Annual abundance by developmental stage

Across both annual cycles, juveniles overwhelmingly dominated the sampled population, accounting for approximately 72-74% of all individuals, while adults represented roughly 22% and pseudo-nymphs remained below 7% in both years. Although juveniles were numerically dominant, the pairwise comparison between juveniles and adults was not statistically significant, possibly due to variability among monthly observations and limited replication in the analysis.

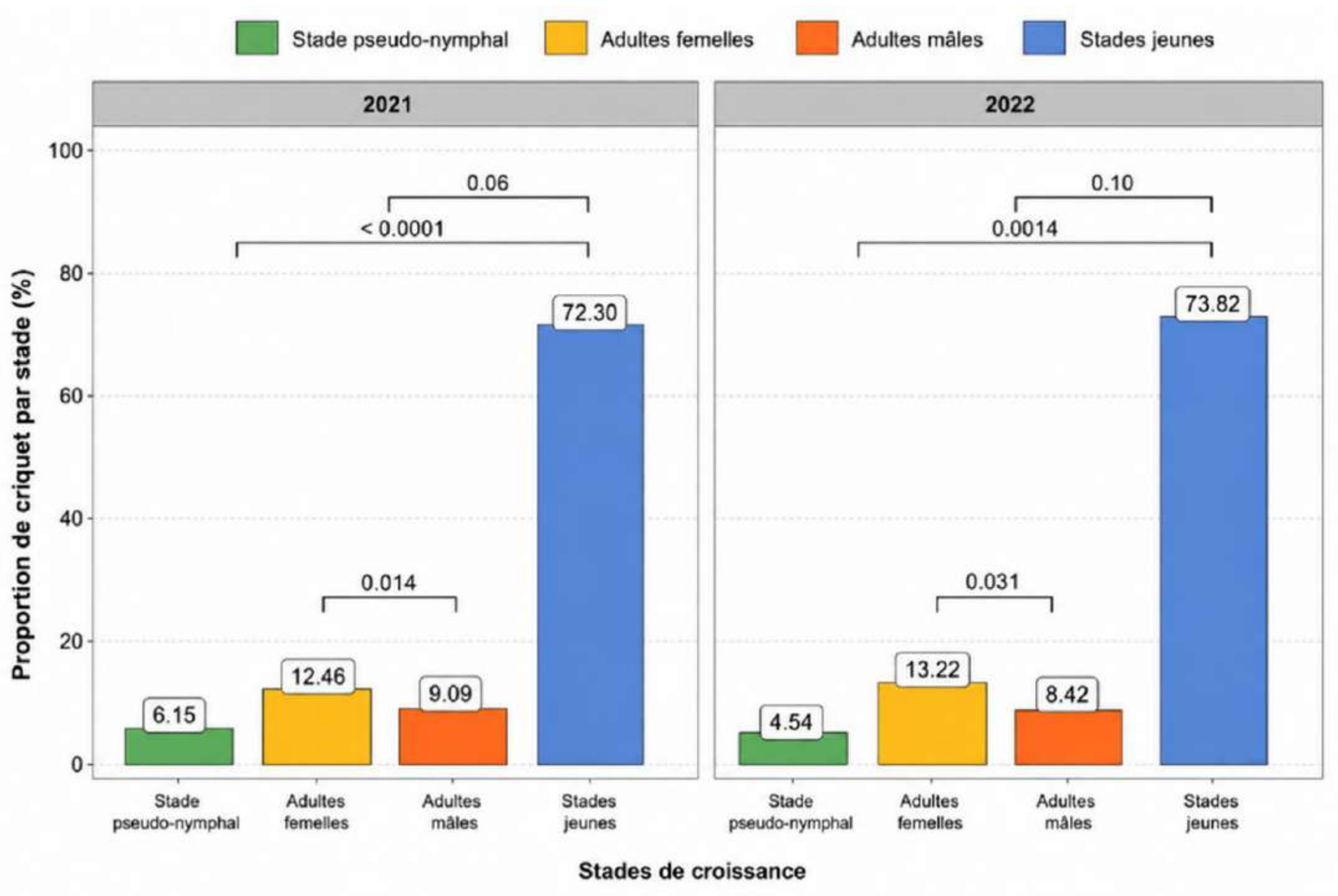

Figure 4
Abundance of Zonocerus variegatus *according to post-embryonic developmental stages per year*

4.2 Discussion

The present study demonstrates that the developmental-stage structure of *Zonocerus variegatus* in the Kisangani region is strongly seasonal rather than temporally uniform. Juveniles dominated the samples and reached their highest relative abundance near the beginning and end of the annual cycle, whereas adults were comparatively more abundant from June to September. This succession supports the general phenological pattern reported for Z. variegatus in West and Central Africa, where recruitment and adult occurrence vary with seasonal environmental conditions (Chapman et al., 1986; Chapman & Joern, 1990). The recurrence of the same broad pattern during both 2021 and 2022 strengthens the interpretation that the observed fluctuations represent a regular local seasonal signal rather than an isolated annual event.

The juvenile peaks are consistent with earlier empirical studies indicating that hatching and early post-embryonic development tend to increase when moisture conditions and young vegetation provide favourable feeding and microhabitat conditions (Kekeunou et al., 2006, 2007). However, the Kisangani results extend those studies by documenting this pattern in a humid Guineo-Congolian environment with relatively limited thermal seasonality. In contrast to drier or more strongly seasonal regions, juveniles occurred throughout much of the year but were concentrated in distinct peaks. This suggests that continuously humid conditions may permit year-round persistence, while shorter-term changes in rainfall, plant growth and habitat quality still synchronize recruitment.

The increase in adult abundance between June and September broadly agrees with previous accounts in which adults become more conspicuous after the main juvenile recruitment period (Chapman et al., 1986). The temporal displacement between juvenile and adult peaks is biologically coherent with the progressive development of immature stages into imagos. Nevertheless, the pattern should not be interpreted solely as a direct cohort transition because adult mobility and sweep-net detectability may also vary seasonally. The present findings therefore support earlier descriptions of seasonal stage replacement, while refining them by identifying the months during which adult occurrence is greatest under Kisangani conditions.

Pseudo-nymphs represented only a small fraction of the total sample in both years. This result does not contradict the seven-stage developmental scheme described by Vilardebo (1948) and Kekeunou *et al.* (2014); rather, it indicates that the sixth stage was rarely encountered during standardized field collections. Its low frequency may reflect the relatively short duration of this transitional stage, stage-specific mortality, or reduced detectability in the vegetation. The consistency of the pattern across two annual cycles suggests that it is not merely a random sampling anomaly, although stage-specific survival and duration were not measured directly. This observation adds locally relevant information to the literature because most previous studies have emphasized total abundance or broad juvenile-adult contrasts rather than the persistent scarcity of the pseudo-nymphal stage.

The redundancy analysis showed that temperature, rainfall and relative humidity were significantly associated with developmental-stage structure, but jointly explained only a modest proportion of the variation. This finding supports the theoretical and empirical literature showing that climatic conditions influence grasshopper development, survival and activity (Bale et al., 2002; Altieri, 1999; Deutsch *et al.*, 2008), while also demonstrating that climate alone is insufficient to account for local population dynamics. Relative humidity was more closely aligned with adult abundance than temperature, which is plausible in a humid tropical system where thermal variation is comparatively restricted. The result partly differs from studies conducted in environments where temperature is a stronger seasonal constraint, and it indicates that moisture-related processes may be relatively more important in Kisangani.

The weak to moderate bivariate correlations further show that no single climatic variable acted as a dominant predictor. This is consistent with Chapman *et al.* (1986), Modder (1984) and Kekeunou *et al.* (2007), who emphasized the combined roles of host plants, vegetation structure, disturbance and seasonal resource availability in shaping *Z. variegatus* populations. In particular, the association of the species with *Chromolaena odorata* and other vegetation in disturbed habitats suggests that rainfall and humidity may influence grasshopper abundance indirectly by modifying food availability and habitat structure. Natural enemies may also contribute to the unexplained variation; parasitoid diversity documented in the Kisangani region by Bakondongama *et al.* (2017) provides a plausible biological mechanism, although parasitism rates were not quantified in the present study. Thus, the modest adjusted R^2 should be interpreted as evidence of multiple interacting controls rather than as evidence that climate is unimportant.

The principal contribution of this study is the provision of a two-year, standardized, stage-specific phenological baseline for *Z. variegatus* in the central Congo Basin, a region for which empirical information remains scarce. The findings confirm the broad seasonal patterns described elsewhere, extend them to the humid forest zone of Kisangani, and identify locally relevant windows of juvenile and adult abundance. From an applied perspective, the predominance of juveniles, which accounted for approximately 72-74% of individuals in both years, indicates that surveillance and control should be intensified around the recurrent juvenile peaks, before populations develop into more mobile adults. At the same time, the limited climatic explanatory power shows that future predictive models should integrate host-plant phenology, vegetation structure, land use, natural enemies and stage-specific survival. By distinguishing what is supported by previous research from what is specific to Kisangani, the study advances both ecological understanding and the timing of locally adapted pest-management interventions.

V. CONCLUSION & RECOMMENDATIONS

5.1 Conclusion

This study shows that *Zonocerus variegatus* populations in the Kisangani region vary clearly with the seasons. Juveniles were most abundant at the beginning and end of the year, while adults were more frequent during the drier middle part of the year. Pseudo-nymphs remained rare throughout the study period. Although temperature, rainfall and relative humidity were linked to changes in developmental stages, they explained only part of the observed variation. This suggests that other factors, such as host plants, vegetation structure, pathogens, predators and habitat conditions, may also influence population dynamics. These findings highlight the importance of monitoring juvenile peaks to improve the timing of local control measures.

5.2 Recommendation

Future research should include longer-term monitoring of *Z. variegatus* to better understand seasonal and year-to-year changes in its population. This monitoring should also record host-plant availability, crop phenology and vegetation structure, as these factors may help explain why populations increase at certain periods. Studies should further consider the role of natural enemies, including predators, parasitoids and pathogens, because they may affect survival at different developmental stages. For pest management, control efforts should focus mainly on juvenile stages, especially during periods of high abundance, when individuals are less mobile and easier to control. Similar studies should also be conducted in other ecological zones of the Democratic Republic of the Congo to determine whether the seasonal pattern observed in Kisangani is local or more general.

Acknowledgments

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