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*Original Research*

# Impact of Building Height on Necrophagous Insect Succession and Carcass Decomposition

**Nourhan W. Shoghy[1]*, Ahmed S. El-Khodary[1], Fouad M. El-Agamy[1], Reda Ibrahim[1], Hany M. Hassan[1, 2]**

[1]Department of Economic Entomology, Kafrelsheikh University, Kafrelsheikh 33516, Egypt
[2]Biology Department, College of Science at Yanbu, Taibah University, King Khalid Rd., Al Amoedi, 46423, Yanbu El-Bahr, Saudi Arabia

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## Abstract

Rapid urbanization has profoundly altered environmental conditions, presenting new challenges to forensic entomology by influencing key insect evidence used to estimate the postmortem interval (PMI). This study examined the impact of building height on necrophagous insect activity, diversity, and succession in Kafrelsheikh, Egypt. Guinea pig carcasses were placed at three height levels – ground level (L1, 0 m), intermediate (L2, 20 m), and high-rise (L3, 50 m) – and monitored for decomposition and insect colonization. Decomposition rates remained consistent across all heights, whereas insect density and diversity significantly declined with increasing elevation (e.g., mean insect abundance dropped from 84.59±6.12 at L1 to 15.85±3.14 at L3, and the Shannon diversity index from 2.7±0.08 to 2.2±0.12), likely due to stronger air currents, greater temperature variability, and limited accessibility at higher levels. Early colonizers, including Musca domestica and *Sarcophaga argyrostoma*, showed delayed arrival of one to several days or were completely absent at elevated sites, accompanied by notable shifts in species composition and succession timing. Statistical analyses (one-way ANOVA: $F(2,15) = 68.21$, $p<0.001$, $\eta^2 = 0.76$; Kaplan–Meier log-rank test) confirmed significant elevation-dependent differences in insect activity. These findings highlight the need for height-adjusted PMI estimation models in urban forensic investigations, particularly in high-rise environments.

**Keywords**: building height, insect succession, postmortem interval, species diversity, urban ecology

## Introduction

Forensic entomology is a critical tool in medicolegal investigations, offering valuable data for estimating the postmortem interval (PMI), reconstructing crime scenes, and accounting for geographical variations in decomposition processes [1, 2]. Necrophagous insects, particularly blow flies (Calliphoridae) and flesh flies (Sarcophagidae), are typically the first colonizers of decomposing remains and exhibit predictable succession patterns that enable accurate PMI estimation [3, 4]. However, the influence of urban environmental variables, especially elevation in high-rise buildings, on insect colonization remains underexplored [5].

Urbanization has significantly altered the environmental landscape, affecting insect diversity,

*e-mail: norhan_shoghy@agr.kfs.edu.eg
Tel: +00201020293440
0000-0001-9480-4154

behavior, and access to decomposing remains [6]. As a defining characteristic of modern cities, height creates a unique environment with varying air currents, temperature fluctuations, and physical barriers that can influence insect activity [7, 8]. Studies have shown that height affects the abundance and diversity of forensic insects, with species composition differing between ground-level and upper-floor environments [5, 9, 10]. While previous research has investigated insect succession in enclosed spaces, research on the impact of height on outdoor insect colonization, particularly in urban environments with varying vertical layers (such as rooftops of multi-story buildings), remains limited.

The United Nations (2025) reported that rapid urbanization has significantly altered global environmental landscapes, with cities now home to 45% of the world's 8.2 billion people in 2025, more than double the 20% share in 1950, and projections indicating that cities will account for two-thirds of global population growth by 2050 [11].

Egypt, specifically the Kafrelsheikh Governorate, has experienced rapid urbanization resulting in a mix of agricultural land and buildings of varying heights [12]. This situation presents a unique forensic challenge, as insect access to decomposing bodies may vary with height. Despite the forensic significance of such variations, no comprehensive studies have been conducted in Egypt to assess how different building heights affect insect density, succession patterns, and decomposition rates. This knowledge gap poses a critical challenge for forensic investigators, as traditional postmortem estimation models may not be directly applicable in urban environments with significant vertical segregation [13]. This study, therefore, represents one of the first attempts in Egypt to address this important issue, offering new insights into forensic entomology in urban contexts.

Building on Oliveira and Vasconcelos (2021) [5], who investigated the vertical distribution of adult Sarcosaprophagous Diptera using baited traps in uninhabited buildings to assess access to ephemeral resources at different heights, the present study extends this approach by employing mammalian carcasses (guinea pigs) to examine full decomposition processes, insect succession patterns, and quantitative changes in density and diversity across three building heights in an urban Egyptian setting.

Understanding the impact of height on forensic insect activity is crucial for accurate postmortem estimation in urban environments. The findings of this study are expected to contribute to the advancement of forensic entomology methodologies and the development of more accurate postmortem estimation models applicable to crime scenes in high-rise buildings.

Therefore, this study aims to bridge this gap by systematically examining how forensic insect diversity and colonization patterns change across different height levels. The study hypothesizes that increasing building height will lead to a significant decrease in insect diversity indices (such as the Shannon Diversity Index), delays in the initial arrival times for resident insects, and changes in succession patterns due to the environmental and physical barriers associated with tall structures.

## Materials and Methods

### Study Area and Environmental Conditions

This study was conducted in Kafrelsheikh Governorate, located in the northern Nile Delta. The region features a variety of habitats, including urban landscapes, agricultural fields, and natural environments. It experiences a Mediterranean climate, characterized by hot summers and mild winters, with most rainfall occurring in the winter months. The study took place from mid-September to October 2023, with three replications within this period.

#### *Environmental Monitoring*

Environmental parameters were recorded at each height level using digital thermohygrometers (Model HT-350; temperature accuracy, ±0.5°C; humidity accuracy, ±3%) for temperature and relative humidity, and a handheld anemometer for wind speed, with readings taken during each visit.

### Experimental Design and Building Heights

Three experimental locations were chosen to reflect the architectural diversity of the region, focusing on differences in building heights (Fig. 1):

- Ground Level (L1): Kafrelsheikh University's farm (31°05'48.0"N, 30°57'16"E), an agricultural area with diverse vegetation, including fruit trees, field crops, and ornamental plants. The site is also surrounded by an apiary and an animal production farm.
- Mid-Level (L2): A 20-meter-high building (Building B) at the College of Agriculture (31°05'46.0"N, 30°56'48"E). The experimental boxes containing the carcasses were placed on the rooftop. The building is surrounded by several university structures and a motorway.
- High-Level (L3): A 50-meter-high residential building with 16 floors (31°06'16"N, 30°56'41"E), surrounded by residential complexes in all directions. The experimental cages containing the carcasses were placed on the rooftop.

### Test Animals and Carcass Preparation

Eighteen adult guinea pigs (*Cavia porcellus*) weighing between 400 and 600 g were obtained from a local farm. Animals were sacrificed using carbon dioxide. Although this method does not perfectly mimic natural death conditions, it was used in accordance with the ethical standards adopted in laboratory experiments.


Fig. 1. Map showing the three experimental sites and their geographic coordinates in Kafrelsheikh, Egypt. Sites include: (1) ground level (L1) at Kafrelsheikh University's farm (31°05'48.0"N, 30°57'16"E); (2) mid-level (L2) on a 20-m-high building at the College of Agriculture (31°05'46.0"N, 30°56'48"E); and (3) high-level (L3) on a 50-m-high (16-story) residential building (31°06'16"N, 30°56'41"E).

### *Caging and Placement*

To prevent scavenging by vertebrates while allowing insect access, 18 wooden cages (80 × 70 × 60 cm) covered with wire mesh with openings 1.5 cm in diameter were used. These cages were specifically designed to prevent vertebrate access while allowing the entry of insects essential for decomposition, including flesh flies (such as the bluebottle fly family Calliphoridae) and large beetles (such as the Staphylinidae family). The cages were spaced 10 meters apart to minimize cross-contamination between carcasses and ensure independent insect colonization events. This spacing was chosen based on previous studies examining insect attraction to decomposing remains in outdoor settings [14].

## Carcass Monitoring and Data Collection

Carcasses were monitored twice daily (11:00 a.m.-12:00 p.m. and 4:00 p.m.-5:00 p.m.) to capture peak necrophagous insect activity. Decomposition stages were documented photographically and descriptively following Goff and Lord (1994).

### *Insect Diversity*

The Shannon Diversity Index (H') was used to quantify species diversity across different building heights. This index measures species richness and evenness, with higher values indicating greater diversity and lower values suggesting dominance by fewer species. An H' value of 0 denotes the presence of only a single species. Diversity calculations were performed using the formula:

- Shannon Diversity Index (H′):

$$H' = -\sum_{i=1}^{s} p_i ln(p_i)$$

where $p_i$ represents the proportion of individuals belonging to the species and s represents the total number of species (species richness).

## Insect Collection and Identification

### *Collection Methods*

Forensic insects were collected following the methodology described in [14], with slight modifications. Specimens were obtained using sweep nets, traps, aspirators, and manual collection (for Coleoptera). It is noteworthy that the effectiveness of the aerial sweeps, conducted at a low height directly above the bodies, was largely consistent across the three elevation levels (L1, L2, and L3). The one-meter-high perimeter fences at both elevated sites (L2 and L3) helped protect the direct collection area from the strong winds and turbulence prevalent at ground level. This wind mitigation at body level allowed for a uniform and efficient collection methodology for resident flying insects at all sites, reducing the potential bias caused by varying environmental conditions on the effectiveness of the primary collection device. Collections began on the first day of the experiment and continued daily until insect activity ceased. Specimens were gathered twice daily, between 11:00 a.m. and 12:00 p.m. and again from 4:00 p.m. to 5:00 p.m. These periods were chosen to represent the peak daily activity of necrophagous insects in the study area, when warm temperatures and optimal lighting conditions facilitate flight and foraging. This twice-daily sampling was sufficient to document the main resident species and record significant shifts in insect populations without the need for continuous sampling, which might not substantially improve the accuracy of postmortem estimation in this context. Representative samples were preserved in 70% ethanol for laboratory identification. Yellow sticky traps were placed near the carcasses from day 2 to day 18 and replaced daily to monitor insect attraction.

### *Taxonomic Identification*

Fly and beetle specimens were identified using standard taxonomic keys, with additional support from the Entomology Department, Faculty of Science, Ain Shams University.

### Ethical Considerations

The study was conducted in full compliance with ethical standards for animal research. Ethical approval was obtained from the Kafrelsheikh University Institutional Animal Care and Use Committee (approval number: KFS-IACUC/148/2023).

### Statistical Analysis

Data analysis was conducted using Minitab 18 software. A one-way analysis of variance (ANOVA) was performed to compare the Shannon Diversity Index across different height levels, with statistical significance set at $p<0.05$. Data normality was assessed using the Shapiro–Wilk test, and homogeneity of variances was evaluated using Levene's test. When significant differences were detected, Tukey's post-hoc test was applied to identify pairwise differences between height levels. Mean values and standard deviations were calculated to summarize treatment effects, and effect sizes were reported where applicable using eta-squared ($\eta^2$) for ANOVA results. Kaplan–Meier survival analysis was applied to time-to-odor development, and differences among elevation groups were evaluated using the log-rank test.

## Results

### Temperature and Decomposition Stages

The average maximum temperature recorded during the experiment was 34°C in September and 29°C in October, while the average minimum temperature was 20°C in September and 17°C in October, based on meteorological data from the Kafrelsheikh University station (Fig. 2(a-c)).

The decomposition period lasted an average of 18 days, during which carcasses progressed through five distinct stages: fresh, bloated, active decay, advanced decay, and remains. No significant differences in overall

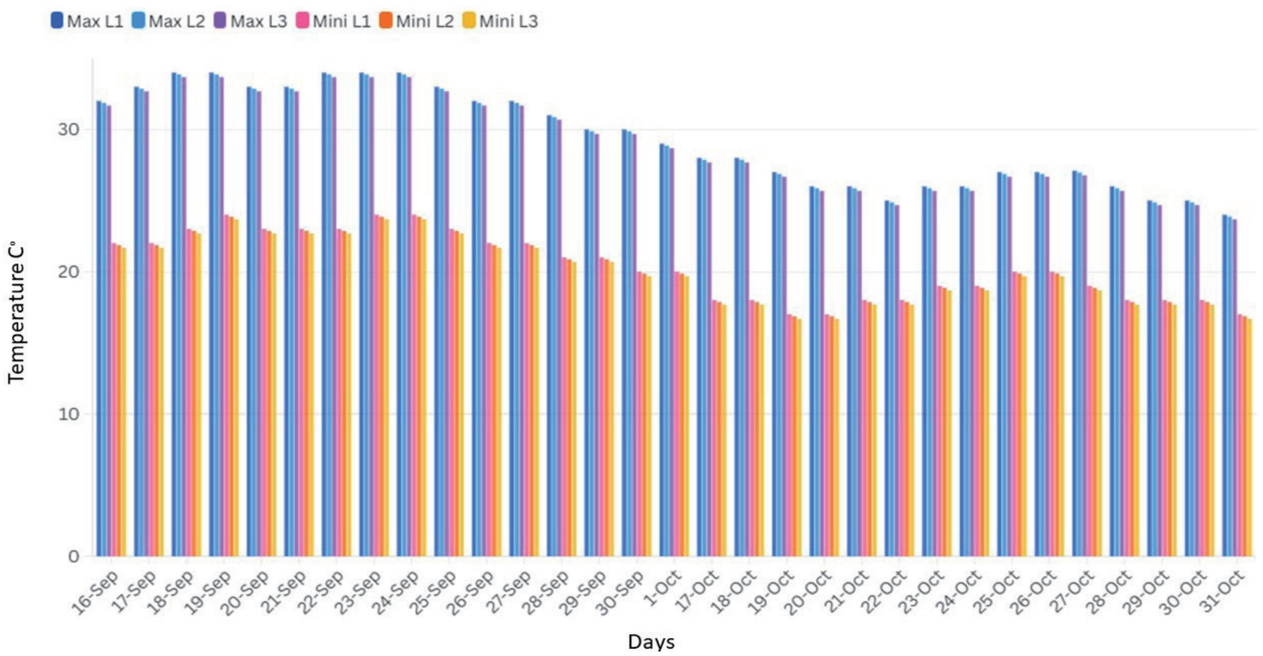


Fig. 2. a) Daily maximum and minimum temperatures recorded at the three experimental height levels (L1: ground level, L2: 20 m, L3: 50 m) during the study period (mid-September to October 2023).

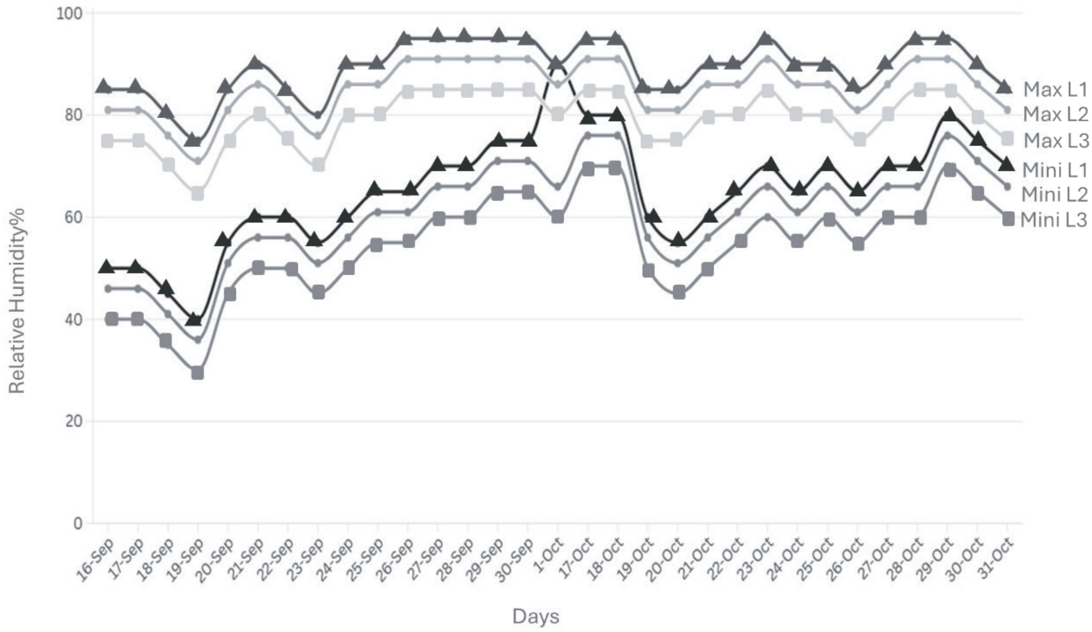


Fig. 2. b) Daily maximum and minimum relative humidity (%) recorded at the three experimental height levels (L1: ground level, L2: 20 m, L3: 50 m) during the study period (mid-September to October 2023).

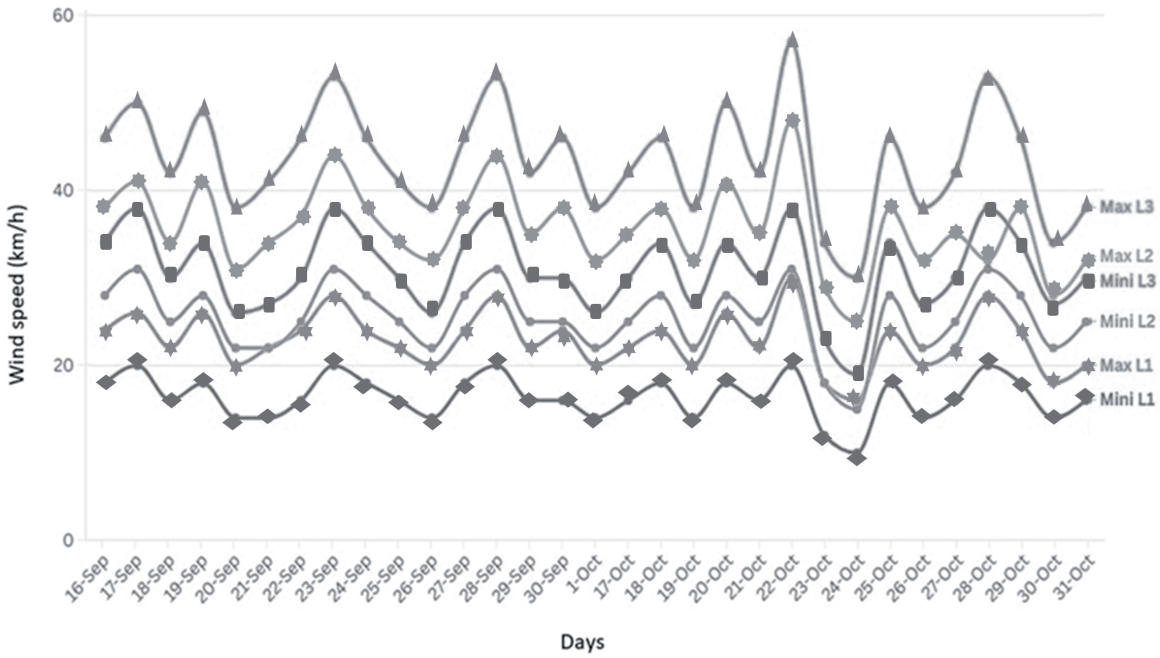


Fig. 2. c) Daily maximum and minimum wind speeds recorded at the three experimental height levels (L1: ground level, L2: 20 m, L3: 50 m) during the study period (mid-September to October 2023).

decomposition rate were observed across the three elevation levels. Carcasses exhibited comparable physical changes and patterns of weight loss regardless of height, indicating that elevation had minimal influence under the conditions of this study (Table 1).

Although the initial stages (fresh and bloated) occurred almost simultaneously across all levels, a slight delay (~1 day) was noted in the active and advanced decay stages at the highest elevation (L3). However, log-rank tests showed no statistically significant differences among the survival curves of the elevation groups (p>0.05). All carcasses reached the remains stage within a consistent timeframe (days 11-18), further supporting the conclusion that elevation did not meaningfully affect the total duration of decomposition.

Table 1. Duration of carcass decomposition stages at varying heights.

| Decomposition stage | | Ground level (L1) | Mid-level (L2) | High-level (L3) |
|---|---|---|---|---|
| Fresh | | 0-1 day | 0-1 day | 0-1 day |
| Bloated | | 2-3 days | 2-3 days | 2-4 days |
| Decay | Active | 4-6 days | 4-6 days | 5-7 days |
| | Advanced | 7-10 days | 7-10 days | 8-10 days |
| Remains | | 11-18 days | 11-18 days | 11-18 days |

Kaplan–Meier survival analysis was applied to time-to-odor development as an early indicator of decomposition progression. Survival curves showed a faster decline (earlier odor onset) at 0 m and 20 m compared to 50 m, where odor development was delayed. Although the log-rank test indicated no statistically significant differences among groups ($p = 0.10$), descriptive statistics revealed a clear trend: the median and mean times to odor onset were 2.5 days at 0 m and 20 m, increasing to 3.0 and 3.17 days, respectively, at 50 m. Pairwise comparisons consistently suggested a delayed onset at the highest elevation. Moreover, 33.3% of carcasses at 50 m remained odorless until day 3, while odor was detected earlier at lower levels. Although these differences did not reach statistical significance, the large effect size (Cohen's $d \approx 1.2$) indicates a biologically relevant trend, likely driven by elevation-related environmental conditions. The lack of significance is likely due to limited sample size and reduced statistical power. Overall, these results support the hypothesis that increased elevation delays early decomposition-related changes.

## Insect Density and Diversity

Insect density and diversity varied significantly across elevation levels. Ground-level carcasses (L1) showed the highest mean density (84.59±6.12 individuals) and Shannon diversity (H' = 2.7±0.08). Mid-level (L2) recorded 69.54±5.87 individuals and H' = 2.3±0.10, while high-level (L3) had the lowest values: 15.85±3.14 individuals and H' = 2.2±0.12.

Total insect abundance per carcass over the entire decomposition period also decreased markedly with height: 1124.33±14.90 at L1, 883.67±328.41 at L2, and 209.33±102.77 at L3. One-way ANOVA confirmed a significant effect of height on species diversity ($F(2,15) = 68.21$, $p<0.001$, $\eta^2 = 0.76$). Tukey's HSD post-hoc tests revealed significant pairwise differences between all levels: L1 vs. L2 ($p = 0.003$), L1 vs. L3 ($p<0.001$), and L2 vs. L3 ($p = 0.015$). These findings demonstrate a strong negative relationship between building height and both insect abundance and species richness (Fig. 3).

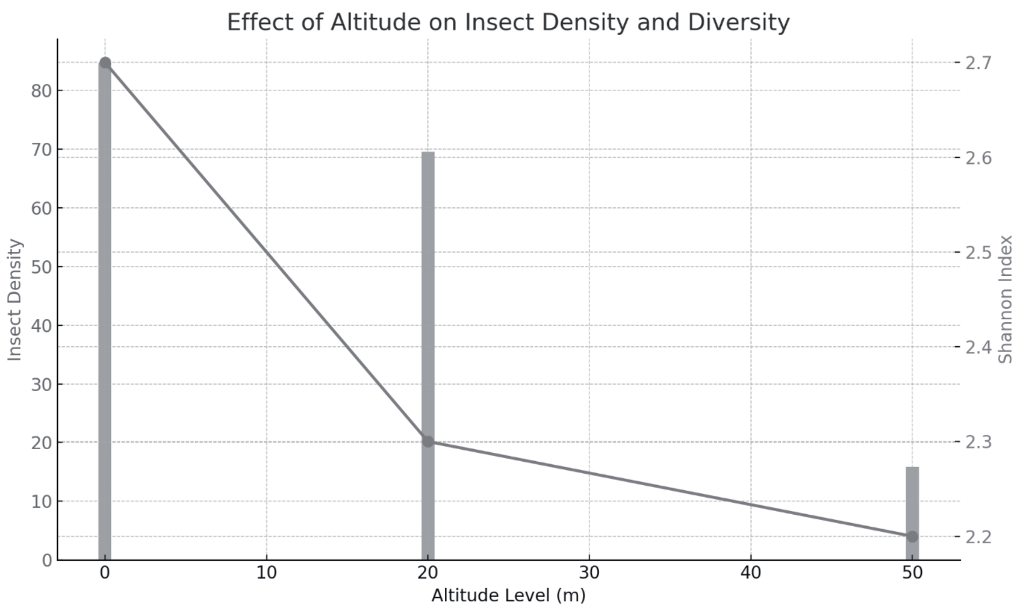


Fig. 3. Effect of height on mean insect density (bars) and Shannon diversity index (line) across the three experimental levels: L1 (0 m), L2 (20 m), and L3 (50 m).

## Species Composition and Succession Patterns

At ground level (L1), Muscidae dominated (30.14% of total insects), with *Musca domestica* (12.22%) and *Musca sorbens* (10.47%) as the most abundant species. Sarcophagidae contributed 6.55% (including *Sarcophaga argyrostoma* and *Wohlfahrtia magnifica*), and Calliphoridae contributed 5.45% (*Lucilia sericata* at 1.82%). Dermestidae beetles accounted for 21.27%, while Histeridae were absent (0%) (Fig. 4).

At the mid-level site (L2), Muscidae remained dominant (56.55%), followed by Dermestidae (32.47%) and Histeridae (21.01%). Insect arrival was delayed by 1-2 days compared to L1, and *Calliphora vicina* was absent in early stages (Fig. 5).

At the high-level site (L3), density and diversity were markedly reduced. Muscidae (26.54%) and Phoridae (14.68%) were most frequent, with Dermestidae (25.71%) and Histeridae (10.13%) also present. Species composition varied markedly across elevations, highlighting the role of height in structuring insect communities (Fig. 6; Table S3).

## Insect Succession Across Decomposition Stages

Insect succession patterns differed substantially across elevations (Fig. 7). At ground level (L1), colonization began in the fresh stage (Day 1) with *Musca domestica*, *Calliphora vicina*, and *Sarcophaga argyrostoma*. The bloated stage (Days 2-3) included additional species such as *Chlorichaeta tuberculosa*

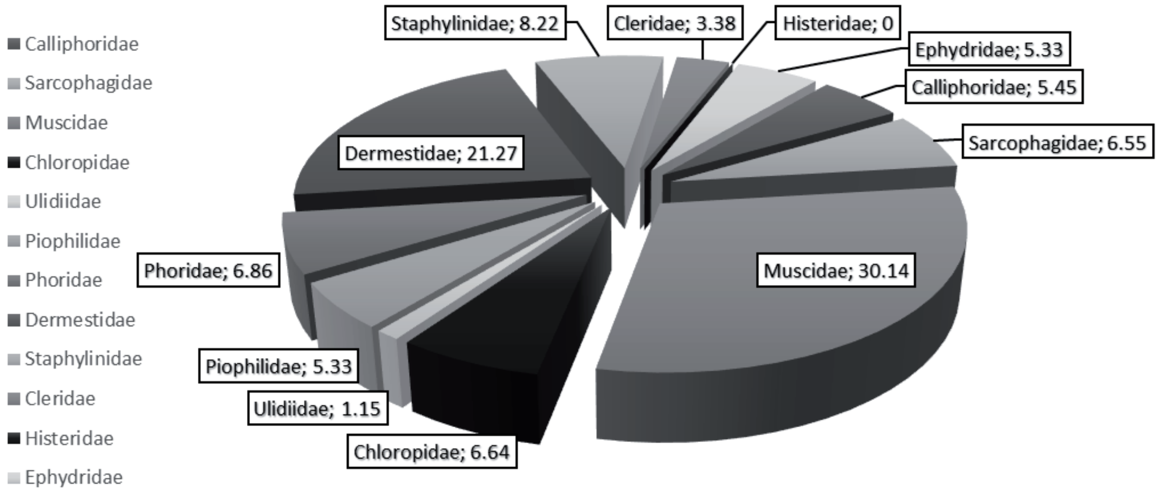


Fig. 4. Relative abundance (%) of major forensically relevant insect families collected from guinea pig carcasses at the three height levels: (A) ground level (L1, 0 m), (B) mid-level (L2, 20 m), and (C) high-level (L3, 50 m).

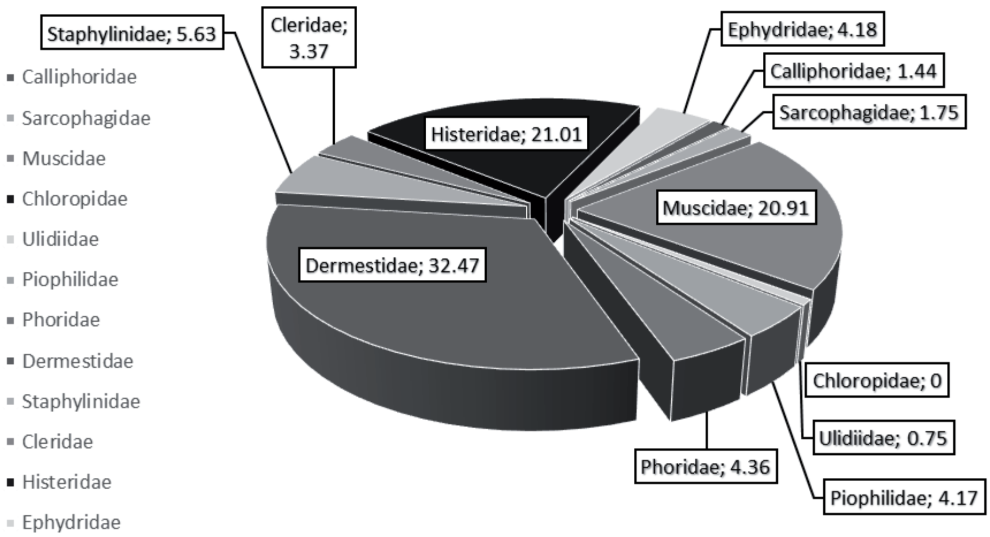


Fig. 5. Relative abundance (%) of major forensically relevant insect families collected from guinea pig carcasses at the mid-level site (L2, 20 m).

(Ephydridae) and *Liohippelates sp.* (Chloropidae), the latter likely associated with the nearby animal production farm (Figs 8-9).

During active decay (Days 4-6), diversity peaked with the appearance of *Piophila casei* (Piophilidae) and *Megaselia scalaris* (Phoridae). Advanced decay (Days 7-10) was dominated by Coleoptera (e.g., *Dermestes maculatus* and *Creophilus maxillosus*), with larvae persisting into the remains stage (Days 11-18).

At mid-level (L2), colonization was delayed by 1-2 days. Initial colonizers were mainly *Sarcophaga argyrostoma* and *Musca domestica*, with *Lucilia*

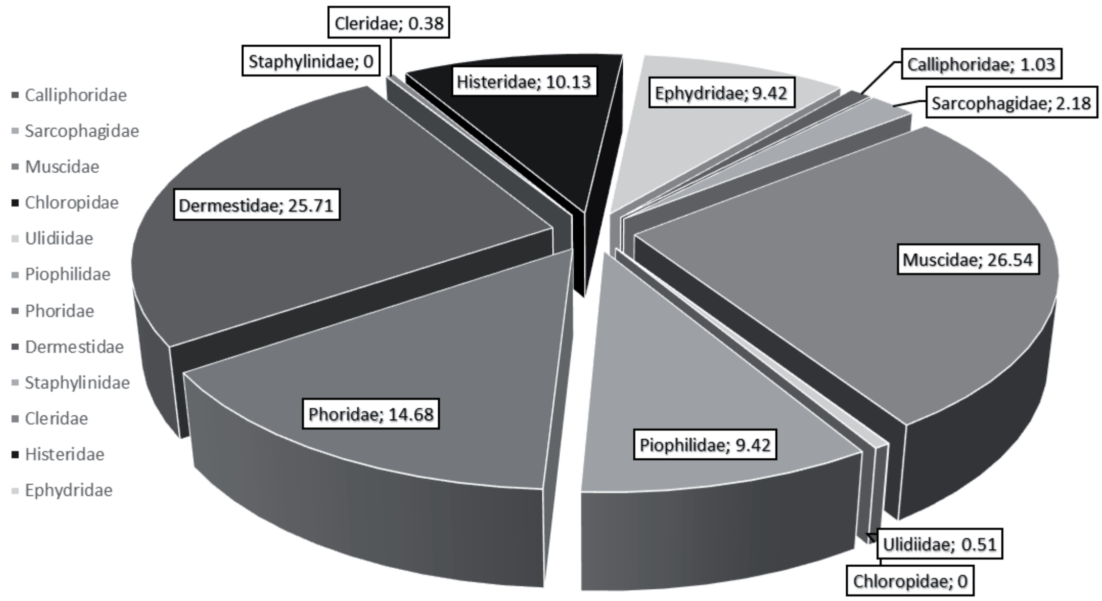


Fig. 6. Relative abundance (%) of major forensically relevant insect families collected from guinea pig carcasses at the high-level site (L3, 50 m).

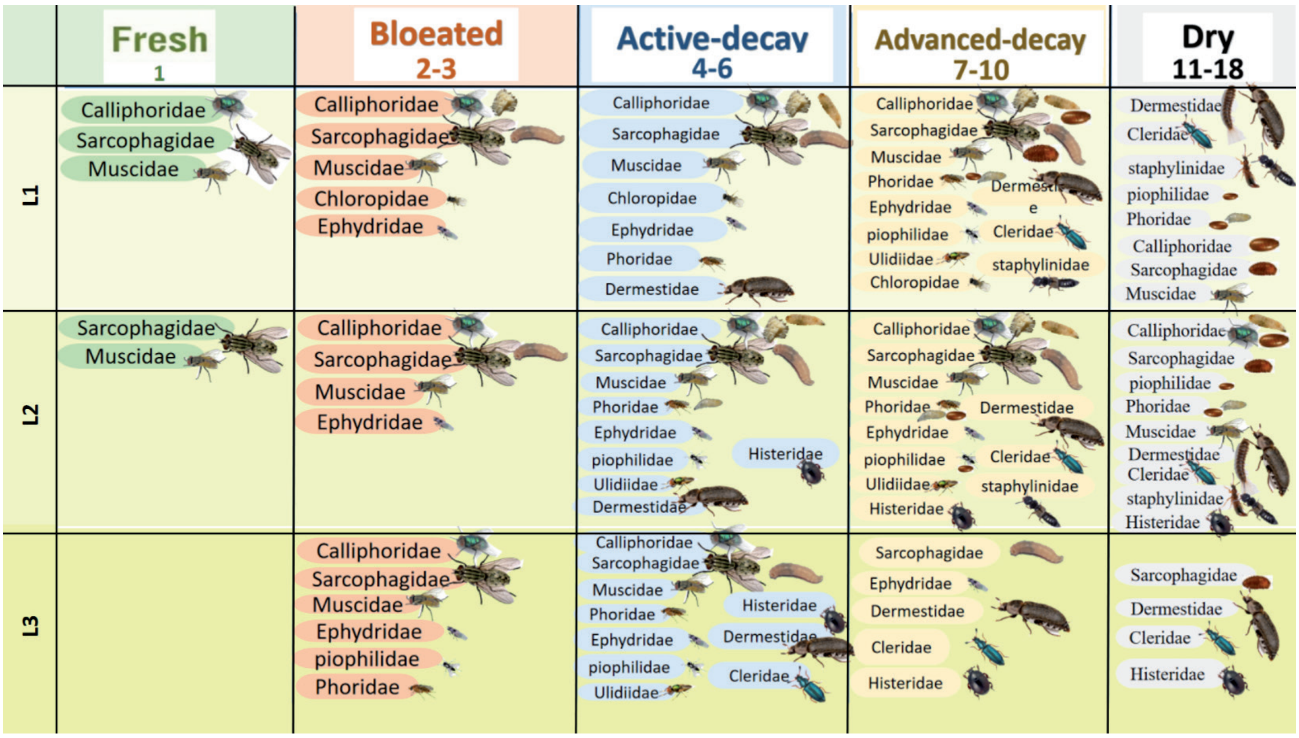


Fig.7. Temporal occurrence and succession patterns of forensically important insect families on guinea pig carcasses at different elevation levels: L1 (ground level, 0 m), L2 (mid-level, 20 m), and L3 (high-level, 50 m). Presence is shown across decomposition stages: Fresh (Day 1), Bloated (Days 2-3), Active Decay (Days 4-6), Advanced Decay (Days 7-10), and Dry Remains (Days 11-18).

*sericata* not appearing until Day 3. Coleopteran colonization (e.g., *Dermestes haemorrhoidalis*, *Saprinus semistriatus*) began on Days 4-5.

At the high-level site (L3), dipteran colonization was markedly delayed and limited to *Musca domestica*, *Sarcophaga argyrostoma*, and Phoridae (especially *Dohrniphora cornuta*). Adult Diptera were absent after Day 7, with only larvae persisting. Coleopteran presence was sporadic (mainly *Dermestes maculatus* in advanced decay). Overall, succession timing and completeness decreased significantly with increasing height (Figs 10-12).

## Discussion

The findings demonstrate a clear inverse relationship between building height and forensic insect activity, succession, and diversity, with height acting as a significant environmental barrier to colonization.

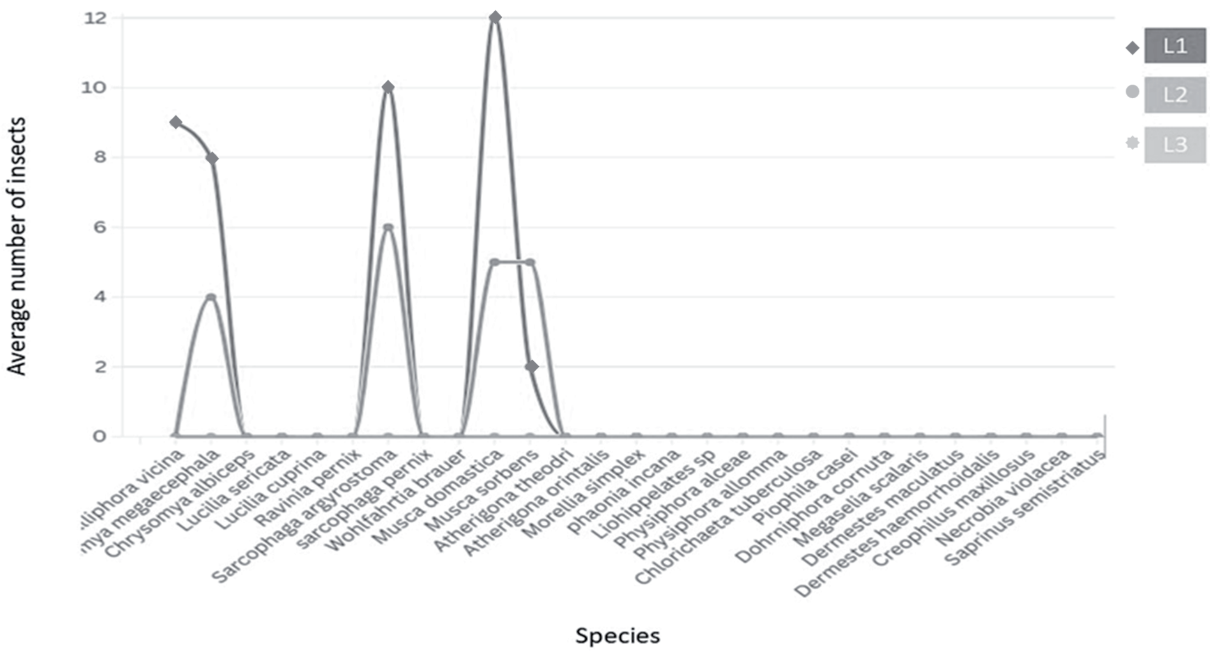


Fig. 8. Insect species composition attracted to guinea pig carcasses during the fresh decomposition stage at the three height levels: L1 (0 m), L2 (20 m), and L3 (50 m).

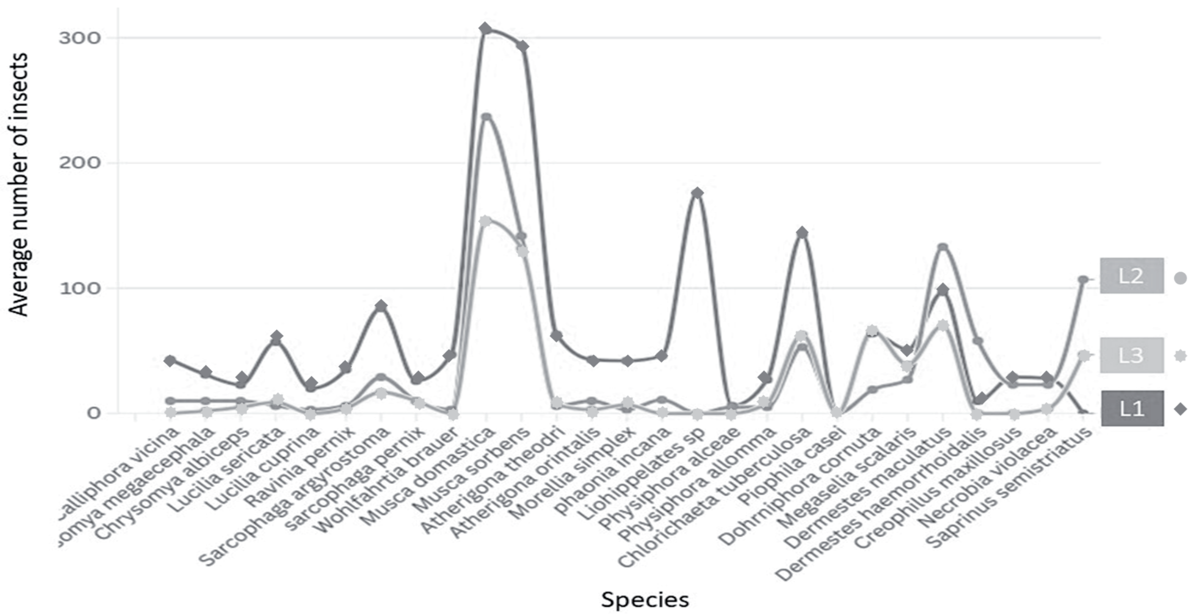


Fig. 9. Insect species composition attracted to guinea pig carcasses during the bloated decomposition stage at the three height levels: L1 (0 m), L2 (20 m), and L3 (50 m).

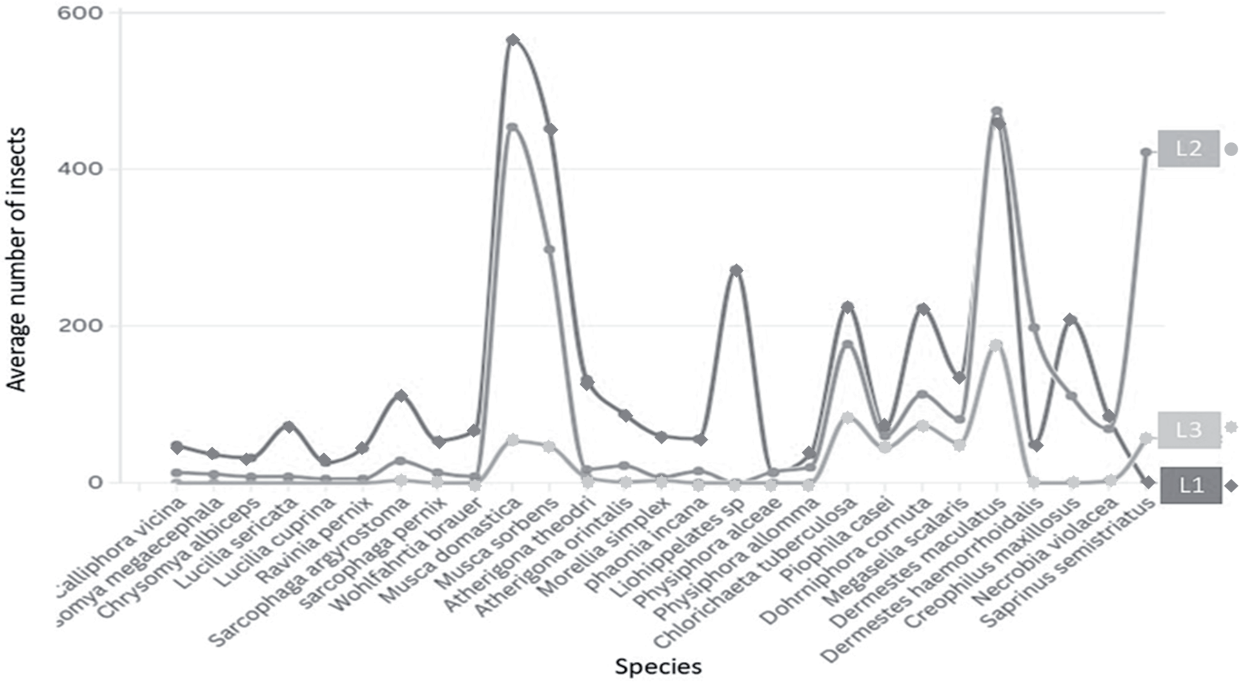


Fig. 10. Insect species composition attracted to guinea pig carcasses during the active decay decomposition stage at the three height levels: L1 (0 m), L2 (20 m), and L3 (50 m).

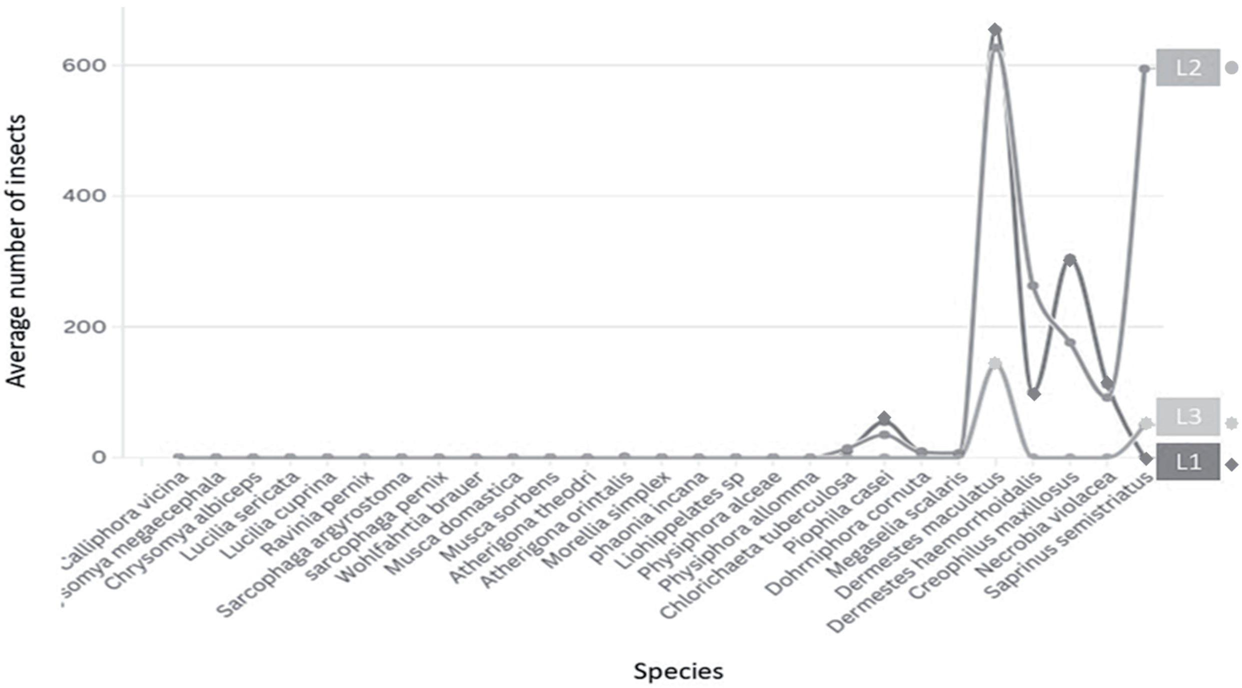


Fig. 11. Insect species composition attracted to guinea pig carcasses during the advanced decay decomposition stage at the three height levels: L1 (0 m), L2 (20 m), and L3 (50 m).

Delayed arrival and reduced species richness at higher elevations (L2 and L3) are likely driven by stronger wind currents and increased air turbulence, which rapidly disperse carrion odor plumes and impair long-distance olfactory detection by necrophagous flies, as supported by wind tunnel studies on volatile dispersal [15-19]. This olfactory constraint provides a mechanistic explanation for the absence or delayed arrival of early colonizers such as Calliphoridae at upper levels. Furthermore, physical barriers presented by tall structures may

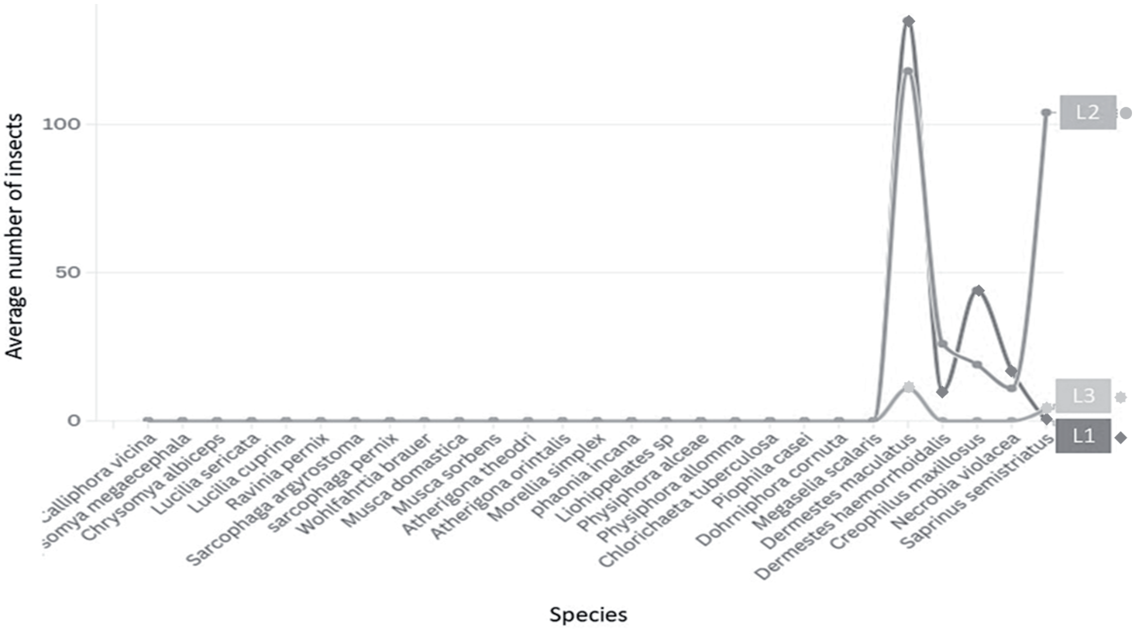


Fig. 12. Insect species composition attracted to guinea pig carcasses during the dry remains decomposition stage at the three height levels: L1 (0 m), L2 (20 m), and L3 (50 m).

restrict insect movement, while temperature fluctuations on rooftops, often cooler at higher elevations, could delay colonization and affect insect behavior [6, 20]. The lower abundance of species like *Calliphora vicina* and *Lucilia sericata* at higher levels aligns with prior research indicating these species prefer open, ground-level environments [18, 21-24].

A striking and counterintuitive result is the consistent decomposition timeline across all elevations despite markedly lower insect density and diversity at L2 and L3. This suggests that microbial autolysis and abiotic factors (enhanced UV exposure, temperature fluctuations, and lower humidity on rooftops) were the primary drivers of tissue breakdown [19-21]. Given the small carcass size (~400-600 g), microbially driven decomposition proceeded efficiently with minimal reliance on necrophagous insects, unlike in larger mammalian models or human cadavers where maggot-mediated removal dominates [16, 19, 22, 25]. These compensatory mechanisms explain why elevation had little overall impact on decomposition rate under the study conditions. Additionally, the limited volume of wet tissue in small carcasses may reduce the critical dependence on biomass removal by insects, further mitigating the impact of variations in their populations [5, 9]. Microclimatic variations, especially temperature and humidity, likely influenced the rate of tissue breakdown and insect activity at specific stages, as even small gradients can substantially affect microbial and insect-driven processes [16, 17].

Variations in insect succession patterns further reflect differences in resource detectability and environmental tolerance [26-29]. At ground level (L1), initial colonizers included common necrophagous species like *Musca domestica* and *Sarcophaga argyrostoma* during the fresh stage [1, 3, 23, 27], while mid- and high-level sites showed delayed colonization and the absence of some species in early stages. Synanthropic species (e.g., certain Muscidae and Sarcophagidae) showed greater resilience at higher levels, suggesting behavioral adaptation to urban microhabitats [23, 30]. The presence of these species, albeit limited, highlights the potential for adaptation in insects exploiting urban high-rise environments [21, 22].

These elevation-dependent differences have direct implications for postmortem interval (PMI) estimation. Current ground-based models may overestimate colonization speed and diversity in high-rise settings [31-34]. Forensic protocols should therefore incorporate elevation as a key variable, using height-specific succession data, site-specific microclimatic measurements (wind speed, temperature gradients, humidity), and adjusted confidence intervals to account for delayed arrival and reduced diversity [12, 18, 19].

Future research should explore interactions between building height, microclimatic gradients, and insect behavior through multi-season trials, continuous monitoring, and advanced tools (remote sensing for microclimatic data collection, DNA barcoding for species identification) across diverse urban architectures to refine PMI methodologies.

Limitations must be considered when interpreting and applying these results. The single-season design (September-October 2023) may limit generalizability across seasons, as temperature, humidity, and photoperiod strongly influence insect activity and decomposition. Additionally, although guinea pigs (~400-600 g) were used for ethical and practical reasons, their size and tissue composition differ markedly from those of larger animal models (e.g., pigs weighing 50-100 kg) and human cadavers. This likely reduced dependence on necrophagous insects, especially at higher elevations, and favored microbial autolysis, potentially masking stronger elevation effects in real forensic cases. Caution is therefore advised when extrapolating findings to adult human remains in high-rise environments.

## Conclusions

Building height significantly affects necrophagous insect density, diversity, and succession patterns in urban settings, while decomposition rates remain consistent across elevations. These findings indicate that elevation acts as an important environmental barrier, leading to delayed colonization and reduced species richness at higher levels.

Current postmortem interval (PMI) estimation models, primarily derived from ground-level studies, may lead to inaccuracies in high-rise environments. Forensic protocols should therefore incorporate elevation as a key variable in PMI calculations, using height-specific succession timelines, local microclimatic data (e.g., wind speed, temperature gradients), and adjusted confidence intervals to account for delayed arrival and limited diversity.

Adopting elevation-adjusted entomological approaches would enhance the accuracy of time-of-death estimates in multi-story urban crime scenes and improve the reliability of insect evidence in legal contexts. Future research should prioritize multi-season trials and standardized guidelines that routinely include building height in urban forensic entomology.

## Conflict of Interest

The authors declare no conflict of interest.

## AI Usage Disclosure Statement

While preparing this manuscript, the authors employed Gemini: used for summarizing sum paragraphs and rephrasing a few sentences, QuillBot: used for grammar and spell checking.

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# Supplementary Materials

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