

Comparison of Swiftlet (*Aerodramus fuciphagus*) Waste Accumulation Between Floors in Two Swiftlet Houses Based on Microhabitat Characteristics

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ABSTRAK

Burung walet (*Aerodramus fuciphagus*) merupakan salah satu satwa bernilai ekonomis tinggi di Indonesia. Meskipun demikian, usaha budidaya burung walet juga menimbulkan permasalahan lingkungan, salah satunya berupa limbah kotoran. Kotoran burung walet (*Aerodramus fuciphagus*) merupakan salah satu bentuk limbah organik yang dihasilkan dari proses metabolisme burung dan mengandung berbagai unsur hara, sehingga memerlukan pengelolaan yang tepat. Pengukuran berat basah kotoran burung walet dapat mencerminkan mengenai aktivitas serta jumlah individu dalam satu koloni. Penelitian ini bertujuan menganalisis variasi akumulasi berat basah kotoran burung walet berdasarkan lantai, bangunan, tipe koloni, dan periode pengamatan, serta mengevaluasi hubungannya dengan karakteristik mikrohabitat pada dua rumah burung walet di Kabupaten Gresik, Jawa Timur. Pengumpulan kotoran dilakukan selama empat periode dengan interval dua minggu, yaitu pada minggu ke-2, ke-4, ke-6, dan ke-8, disertai pengukuran suhu, kelembapan, dan intensitas cahaya. Data berat kotoran dianalisis menggunakan Linear Mixed Model dengan wadah pengamatan sebagai subjek dan periode sebagai pengukuran berulang, sedangkan hubungan mikrohabitat dianalisis menggunakan regresi linear berganda. Hasil menunjukkan bahwa pada Bangunan 1, posisi lantai tidak memberikan pengaruh yang signifikan terhadap akumulasi kotoran ($p=0,926$), tipe koloni ($p=0,024$) dan periode pengamatan ($p=0,008$) berpengaruh signifikan, sedangkan lokasi-lantai tidak signifikan ($p=0,418$). Koloni indukan dan anakan menunjukkan akumulasi kotoran lebih tinggi dibandingkan koloni indukan saja. Model mikrohabitat secara simultan signifikan ($p=0,031$) dan menjelaskan 51,0% variasi rata-rata berat kotoran ($R^2=0,510$), meskipun tidak signifikan secara parsial. Penelitian ini dapat menjadi informasi awal dalam mendukung pengelolaan limbah organik pada rumah burung walet. Meskipun demikian, penelitian ini terbatas pada dua rumah walet dengan struktur lantai yang tidak seimbang, menggunakan berat basah, serta belum mencakup beberapa faktor ekologis dan karakteristik bangunan lainnya.

Kata kunci: Akumulasi kotoran, Burung walet, Koloni, Lantai bangunan, Mikrohabitat

ABSTRACT

The swiftlet (*Aerodramus fuciphagus*) is one of Indonesia's most economically valuable species. However, swiftlet farming also poses environmental problems, one of which is droppings. Swiftlet droppings (*Aerodramus fuciphagus*) are a form of organic waste produced by the birds' metabolic processes and contain various nutrients, thus requiring proper management. Measuring the wet weight of swiftlet droppings can provide insight into the activity and number of individuals within a colony. This study aims to analyze variations in the accumulation of wet weight of swiftlet droppings based on floor, building, colony type, and observation period, as well as to evaluate their relationship with microhabitat characteristics at two swiftlet houses in Gresik Regency, East Java. Droppings were collected over four periods at two-week intervals, namely, in the 2nd, 4th, 6th, and 8th weeks, along with measurements of temperature, humidity, and light intensity. Fecal weight data were analyzed using a linear mixed model with observation containers as subjects and observation periods as repeated measures, while microhabitat relationships were analyzed using multiple linear regression. The results showed that in Building 1, floor level had no significant effect on feces accumulation ($p=0.926$); colony type ($p=0.024$) and observation period ($p=0.008$) had significant effects, whereas the interaction between location and floor level was not significant ($p=0.418$). Colonies consisting of both adult and juvenile birds showed higher droppings accumulation compared to colonies consisting of adult birds only. The microhabitat model was simultaneously significant ($p=0.031$) and explained 51.0% of the variation in average droppings weight ($R^2=0.510$), although none of the microhabitat parameters were significant when analyzed individually. This study can serve as preliminary information to support the management of organic waste in swiftlet houses. However, this study was limited to two swiftlet houses with unbalanced floor structures, used wet weight measurements, and did not account for several ecological factors and other building characteristics.

Keywords: Accumulation of droppings, Swiftlet, Colonies, Building floors, Microhabitats

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1. INTRODUCTION

The swiftlet (*Aerodramus fuciphagus*) is one of Indonesia's most economically valuable species, as its nests are used both as food and as an export commodity with a very high market value (Kuntjoro *et al.*, 2014; Nurwati & Purwati, 2024). Data from the Central Statistics Agency (BPS) show that in 2020, Indonesia exported 1,312.5 metric tons of swiftlet nests worth 540.4 million U.S. dollars, making it a major contributor to foreign exchange earnings in the wildlife farming sector (BPS, 2021). Nevertheless, swiftlet farming also poses environmental challenges, one of which is the large volume of droppings produced, which are often not utilized optimally. Swiftlet droppings are organic material resulting from the birds' metabolic processes and contain various nutrients essential for plants. According to a study by Alfionita *et al.* (2018), swiftlet droppings contain key nutrients, including 50.46% organic carbon, 11.24% total nitrogen, 1.59% phosphorus, and 2.17% potassium, giving them great potential to enhance soil fertility.

Several previous studies have also demonstrated the potential of swiftlet droppings as fertilizer. For example, a study by Yulianingsih (2021) found that applying swiftlet droppings can increase sweet corn yields when applied at the appropriate dosage. This aligns with the findings of Iqbal and Ulpah (2022), who noted that swiftlet droppings can increase soil nutrient content and support the growth of horticultural crops. Thus, swiftlet droppings are not merely waste but a resource with both ecological and economic value.

In addition to swiftlets, insectivorous birds such as the sriti (*Collocalia esculenta*) also produce droppings with similar characteristics. Sriti droppings have a relatively high nitrogen and phosphorus content, making them a potential natural fertilizer and an indicator of habitat quality in the surrounding environment (Pamungkas *et al.*, 2023). Both swiftlets and sriti are insectivorous birds, so the composition of their droppings can reflect the types of food available in their habitat (Noor *et al.*, 2017).

Swallow droppings serve a socio-ecological function within the colony. Its distinctive odor acts as a natural attractant, drawing other swifts to roost and nest in the same location (Yaacob *et al.*, 2021). The accumulation of droppings in a given space can also serve as an indicator of activity and habitat suitability; the more optimal the conditions in a space, the higher the birds' activity and droppings production (Wahyuni *et al.*, 2022). However, if not properly managed, the accumulation of swiftlet droppings can become an environmental problem. Organic waste that accumulates in swiftlet houses can undergo decomposition by microorganisms, producing compounds that cause unpleasant odors. Furthermore, large accumulations can affect microhabitat conditions by increasing humidity and have the potential to cause soil and water source contamination as waste is carried away by surface

runoff. The high nitrogen and phosphorus content in swiftlet droppings also has the potential to increase the environmental nutrient load if the waste is disposed of without prior treatment (Kılıç & Sönmez, 2024).

The success of swiftlet farming depends heavily on environmental factors such as temperature, humidity, lighting, and food availability (Wahyuni *et al.*, 2022). Swiftlet houses located in forested areas with stable temperature and humidity have been shown to produce more nests than those in residential areas (Yaacob *et al.*, 2021). However, according to Abd Rahman *et al.* (2019), swiftlet farming practices in the field are still dominated by traditional methods without adequate scientific research support. Although numerous studies have been conducted on ecological conditions and the utilization of swiftlet droppings, no previous research has specifically compared the accumulation of swiftlet (*Aerodramus fuciphagus*) droppings by floor across two buildings based on microhabitat characteristics. In fact, the distribution of the swiftlet population within multi-story buildings is uneven; swiftlets tend to prefer floors with more stable temperature and humidity, which can affect the number of droppings produced (Abd Rahman *et al.*, 2019).

Measuring the weight and distribution of swiftlet droppings can provide insights into the activity and number of individuals in a colony, food availability, and the potential for organic waste production. For example, a single nest containing a parent and its chicks (one colony) can produce a certain number of droppings over a given period; when calculated over the course of a year, this can indicate the potential accumulation of droppings from both ecological and economic perspectives. This data can be used to estimate spatial capacity, food availability, and the potential for organic waste production (Nasruddin, 2021). Swallow droppings that are not cleaned up and are allowed to accumulate can pollute the environment, but if properly managed, they can be utilized as organic fertilizer rich in nutrients (Kesumawati *et al.*, 2024). Therefore, comparing the accumulation of wet weight of swiftlet (*Aerodramus fuciphagus*) droppings across floors in two buildings and its relationship to microhabitat characteristics can serve as an ecological indicator to understand swiftlet population behavior as well as the potential for utilizing droppings as a valuable byproduct.

The urgency of this study lies in the effort to bridge the knowledge gap regarding the relationship between the microhabitat characteristics of swiftlet houses and the accumulation of swiftlet droppings, both across floors and between buildings. The results of this study are expected to provide a scientific basis for more efficient swiftlet house management strategies, support the sustainable utilization of waste, and open up new economic opportunities based on swiftlet byproducts. Furthermore, this study is relevant to the Sustainable Development Goals (SDGs), particularly Goal 12 on Responsible

Consumption and Production which emphasizes sustainable production patterns through the utilization of organic waste and Goal 15 on Life on Land, which focuses on the conservation of terrestrial ecosystems through the sustainable management of economically important wildlife. Thus, the objective of this study is to compare the accumulation of swiftlet (*Aerodramus fuciphagus*) droppings across different floors in two swiftlet houses in terms of microhabitat characteristics, thereby providing a deeper understanding of the interaction between constructed ecosystems and swiftlet droppings production.

2. RESEARCH METHOD

This study was conducted over a period of four months, from September 2025 to January 2026. The research process included research preparation, collection of primary and secondary data, data analysis, and report writing. The data collected in this study consisted of primary data obtained through fieldwork on the research subjects and secondary data obtained from available documents or reports.

The sampling technique used in this study was purposive sampling, which involves selecting samples considered most relevant to the criteria that must be met by the samples used in this study (Sugiyono, 2019). This technique allows the researcher to focus on samples deemed most representative for measuring the weight of swiftlet droppings based on colony type, ensuring that the data obtained are more relevant to the research objectives. The equipment used in this study included writing utensils, a camera, a GPS device, a flashlight, gloves, a digital scale with 1-gram resolution, a thermometer, a hygrometer, a lux

meter, droppings collection containers, a scoop, and plastic bags.

2.1. Location Description and Research Period

This study was conducted in the Sedayu area, Gresik Regency, East Java, at two swiftlet (*Aerodramus fuciphagus*) houses with different characteristics. Swiftlet house 1 consists of three observation floors, while swiftlet house 2 consists of one observation floor. **Figures 1 and 2** show the sampling locations.

The observation period consisted of four observation periods, each two weeks apart: the 2nd, 4th, 6th, and 8th weeks after the droppings collection containers were installed. During each observation period, swiftlet droppings were collected, the weight of the collected droppings was measured, and microhabitat parameters were measured at each observation site.

Both swiftlet houses observed are located in lowland areas, situated within residential zones and along swiftlet flight paths (Wahyuni *et al.*, 2022). The locations of the two swiftlet houses studied are also relatively close to bodies of water, plantations, and rice fields, and are not near any significant sources of air pollution. Swallow House 1 is approximately ± 26 years old and contains 207 active nests. The building consists of three stories and measures approximately 12 m $\times$ 6 m. The interior is divided into four resting areas and one roving area and features a central corridor approximately 50 cm wide. There are three rectangular entry and exit openings facing north and south, measuring 15 cm $\times$ 40 cm, 12 cm $\times$ 80 cm, and 12 cm $\times$ 80 cm, respectively. The dimensions and orientation of these openings are designed to limit the amount of light entering the room.

Table 1. Characteristics of the Two Swiftlet (*Aerodramus fuciphagus*) Houses That Served as Research Sites

Characteristics	Swiftlet House (1)	Swiftlet House (2)
Neighborhood Location	Lowlands; residential areas/swallow flight paths; near bodies of water, plantations, and rice fields.	Lowlands; residential areas/swallow flight paths; near bodies of water, plantations, and rice fields.
Age of the Building	± 26 Years	± 6 Years
Active Nest	207 Nests	8 Nests
Number of Observation Decks	3 Floors	1 Floor
Building Length	12 m	± 8 -10 m
Building Width	6 m	-
Inlet and Outlet Holes	3 holes	3 holes
Hole Orientation	North and South	North and South
Hole Size	15 cm $\times$ 40 cm; 12 cm $\times$ 80 cm; 12 cm $\times$ 80 cm	15 cm $\times$ 40 cm; 60 cm $\times$ 80 cm; 60 cm $\times$ 80 cm
Flooring Materials	Brick, cement/plaster, coated with soil	Brick, cement/plaster, coated with soil
Wall	Double-sided brick, with the exterior plastered with cement and the interior with rough plaster	Double-sided brick, with the exterior plastered with cement and the interior with rough plaster
Ceiling	Wood	Wood
Nesting Site (lagur)	Seaside sengon/albasia wood	Wood and aluminum sheets.

Source: Primary data from field observations and information from swiftlet house operators, 2025.

Note: A hyphen (-) indicates that data is not available

Swallow House 2 is approximately $\pm$ 6 years old and has 8 active nests. The building has a single observation floor that is about 8–10 m long. As with Swallow House 1, there are three rectangular entry and exit holes oriented toward the north and south. The dimensions of the openings in this building are approximately 15 cm $\times$ 40 cm, 60 cm $\times$ 80 cm, and 60 cm $\times$ 80 cm. The entrance and exit holes in Swallow House 2 are relatively larger than those in Swallow House 1. In new houses, these holes are typically made somewhat wider, but once the swallow population inside the house increases, the holes are reduced to 15 cm $\times$ 40 cm or 12 cm $\times$ 80 cm.

In general, both types of swiftlet houses share nearly identical interior construction characteristics. The floors are made of bricks coated with cement or plaster and covered with a layer of soil to help maintain humidity in the room. The walls are built quite thick using double-layered brickwork to help dampen sound. The exterior walls are coated with cement plaster, while the interior uses rough-textured plaster; this is intended to ensure that young swallows just learning to fly do not have difficulty perching on the walls of the house. The ceiling is made of wood, while the framework (racks) where the swallows attach their nests is made of sengon laut or albasia wood combined with aluminum plates. The roofs of both buildings resemble those of residential homes and are constructed relatively high to ensure the swallows' flight is not obstructed and to maintain more stable humidity and temperature levels inside the rooms.



Figure 1. Building 1 for Swiftlet Houses (*Aerodramus fuciphagus*)



Figure 2. Building 2 for Swiftlet Houses (*Aerodramus fuciphagus*)

2.2. Sample Collection and Weighing

Sampling of swiftlet (*Aerodramus fuciphagus*) droppings was conducted by placing three droppings collection containers on each floor of the swiftlet house. Each container was assigned an identification code based on the building's location, floor, and colony type. Colony type was determined based on nest conditions and the presence of individuals within the colony, specifically: one droppings collection container for colonies consisting of adult birds (breeders) and two containers for colonies consisting of both chicks and breeders. The droppings collection containers were emptied once every two weeks over the course of four observation periods.

The collected feces were then analyzed based on wet weight without drying, using a digital scale with a resolution of 1 g. The weighing data were recorded by location, floor, and subplot (parent/offspring and parent). The weight values obtained represent the accumulation of feces under actual conditions at the time of sampling during each observation period.

2.3. Measurement of Microhabitat Parameters

The microhabitat characteristics observed in this study included temperature ($^{\circ}\text{C}$), humidity (%), and light intensity (lux). Temperature ($^{\circ}\text{C}$) was measured using a digital thermometer, relative humidity (%) using a digital hygrometer, and light intensity (lux) using a digital lux meter. Microhabitat parameter measurements were conducted on each observation floor concurrently with the collection of swiftlet droppings. Each microhabitat parameter was measured once on each observation floor during four observation periods at two-week intervals, namely, in the 2nd, 4th, 6th, and 8th weeks, between 8:00 a.m. and 12:00 p.m. WIB, when swiftlets are generally outside their nests foraging, allowing for the measurement of microhabitat conditions and sample collection. Relative humidity and room temperature were recorded to control for variations in moisture

content in the samples and because these factors can influence the metabolism and behavior of swiftlets (Wahyuni *et al.*, 2022).

2.4. Data Analysis

The research design used was a quantitative research design with a descriptive-comparative observational design and repeated measures. The observed variables included building location, floor level, colony type, observation period, and microhabitat characteristics, such as temperature, humidity, and light intensity. The response variable was the wet weight of swiftlet (*Aerodramus fuciphagus*) droppings accumulated during the observation period.

The data obtained from the study were analyzed quantitatively using descriptive and inferential analysis. Descriptive analysis was conducted to describe variations in the weight of swiftlet droppings based on building, floor, colony type, and observation period, as well as the microhabitat characteristics at each observation site.

The fecal weight data were then analyzed using a Linear Mixed Model (LMM) because measurements were taken repeatedly from the same observation container over four periods. The identity of the observation container was used as the subject, while the observation period was used as the repeated factor with an autoregressive covariance structure of order 1 (AR1).

The Linear Mixed Model (LMM) analysis was conducted using several models. The first model was used to evaluate differences in the accumulated weight of droppings across floors in Swallow House 1, which consists of three observation floors, taking into account the observation period and colony type. The second model was used to compare the accumulated weight of droppings between Swallow House 1 and Swallow House 2 on the same floor namely, the first floor taking into account the observation period and colony type. The third model was used to evaluate variations in the accumulation of droppings by weight based on colony type, taking into account floor location and observation period. Differences were considered significant if the p-value was less than 0.05.

The relationship between microhabitat characteristics and the accumulated weight of swiftlet droppings was analyzed using multiple linear regression, with the average weight of droppings as the response variable and microhabitat characteristics (temperature, humidity, and light intensity) as predictor variables (independent variables). The suitability of the regression model was evaluated using the coefficient of determination (R^2), a simultaneous model test, the regression coefficients for each predictor, and a check of regression

assumptions, including normality of residuals, multicollinearity, and homoscedasticity. All statistical analyses were performed using IBM SPSS Statistics software with a significance level of 5% ($\alpha = 0.05$).

3. RESULTS AND DISCUSSION

3.1. The Effect of Floors and Buildings on the Accumulation of Wet Weight of Swiftlet (*Aerodramus fuciphagus*) Droppings

Observations of the accumulation of wet weight of swiftlet (*Aerodramus fuciphagus*) droppings were conducted at two swiftlet houses with different characteristics. The observation period spanned four observation periods (2 months) at 2-week intervals, specifically in the 2nd, 4th, 6th, and 8th weeks after the droppings collection containers were installed. At each observation location on each floor, three droppings collection containers were placed and observed repeatedly, yielding the data presented in Table 2.

Table 2. Descriptive Statistics for the Cumulative Wet Weight of Swiftlet (*Aerodramus fuciphagus*) Droppings by Floor Location

Swallow House Building	Observation Deck	N	Mean $\pm$ Standard Deviation
Swallow House Building 1	1st Floor	12	11,00 $\pm$ 7,08
	2nd Floor	12	10,75 $\pm$ 7,16
	3rd Floor	12	12,25 $\pm$ 9,30
Swallow House Building 2	1st Floor	12	5,58 $\pm$ 1,83

Source: Data processed from descriptive statistics using IBM SPSS

Note: Data are presented as mean $\pm$ standard deviation; n = number of observations.

The descriptive statistics show that the average weight of droppings in Swallow House 1 is higher than that in Swallow House 2. In Swallow House 1, the average weight of droppings on each floor is 11.00 g on the first floor, 10.75 g on the second floor, and 12.25 g on the third floor. Meanwhile, the first floor of Building 2 had an average droppings weight of 5.58 g. The standard deviation in Building 1 was greater than that in Building 2, particularly on the third floor, which had a standard deviation of 9.30 g. This indicates that the droppings weight data for Building 1 exhibited a higher degree of variability during the observation period. In contrast, Building 2 showed lower variation in waste weight, as indicated by a smaller standard deviation.

In general, these descriptive statistics indicate variations in the accumulation of waste weight across observation sites, with the highest average value found on the 3rd floor of Building 1 and the lowest on the 1st floor of Building 2. However, the differences observed in the descriptive analysis do not yet indicate statistically significant differences and were further evaluated using Linear Mixed Model (LMM) analysis.

Table 3. Results of the Linear Mixed Model Test on the Accumulated Weight of Swiftlet Droppings (*Aerodramus fuciphagus*)

Model	Factors	F (df1, df2)	p-value
Model A- Swiftlet House 1	Floor	F (2, 4,119) = 0,078	0,926
	Observation period	F (3, 19,822) = 7,465	0,002
	Colony type	F (2, 4,119) = 20,505	0,007
Model B- First Floor of Both Swiftlet Houses	Building	F (1, 1,973) = 1,382	0,362
	Observation period	F (3, 14,509) = 1,216	0,339
	Colony type	F (2, 6,360) = 7,114	0,024
Model C- All Locations-Floor	Floor-location	F (3, 6,360) = 1,094	0,418
	Observation period	F (3, 31,148) = 4,731	0,008

Source: Data processed from the results of a Linear Mixed Model test using IBM SPSS

Note: df1 = numerator degrees of freedom; df2 = denominator degrees of freedom; $p < 0.05$ indicates a significant effect.

Although there were descriptive differences in the means across floor locations, the results of the Linear Mixed Model analysis indicated that the floor level in Swallow House 1 did not have a significant effect on the accumulation of wet weight of swallow droppings ($F = 0.078$; $p = 0.926$). In contrast, the observation period ($F = 7.465$; $p = 0.002$) and colony type ($F = 20.505$; $p = 0.007$) showed significant effects. A comparison between the two swiftlet houses, conducted specifically on the first floor, also showed that the building factor did not have a significant effect on droppings weight ($F = 1.382$; $p = 0.362$).

In Model A, the estimated marginal means for fecal weight on floors 1, 2, and 3 were 11.220 g, 10.937 g, and 11.843 g, respectively. The results of the paired comparison test with Bonferroni correction showed no significant differences between floors. This phenomenon is often observed in ecological data with considerable internal variation, particularly when the number of samples in each group is relatively limited (Field, 2018). This suggests that there is general variation across floors, rather than striking differences between specific floors. Thus, the vertical position of the floor cannot yet be identified as a determining factor in the variation in swiftlet droppings accumulation. Although there are descriptive differences in values across floors, these differences cannot be directly interpreted as the influence of the floor itself.

A greater accumulation of droppings on a particular floor reflects higher swiftlet activity. This is because swiftlets tend to be more active in spaces with relatively stable microhabitats and minimal disturbances (Ding *et al.*, 2023). Microhabitat conditions within a swiftlet house can indeed vary vertically, particularly in terms of temperature, humidity, air circulation, and light intensity (Ibrahim *et al.*, 2009). Differences in the weight of droppings accumulated across floors are also related to swiftlets' nesting site preferences. According to Ding *et al.* (2023), studies on various bird species indicate that nest site selection is influenced by environmental parameters such as elevation, vegetation, and human disturbance, which affect the distribution of bird activity. Higher fecal accumulation on upper floors may reflect a preference for perching and nesting at higher elevations, which provide protection and comfort for swiftlets. This pattern is similar to the

behavior of other birds that choose relatively high nesting sites to minimize disturbance and predation.

The comparison between Swallow House 1 and Swallow House 2 was limited to the first floor, as the two buildings have a different number of observation floors. This approach was used to ensure that the comparison was made at equivalent floor levels. Descriptively, the average droppings weight on the first floor of Swallow House 1 was 11.00 g, while on the first floor of Swallow House 2 it was 5.58 g. However, the results of the Linear Mixed Model indicate that the building factor did not have a significant effect on droppings weight ($F = 1.382$; $p = 0.362$), nor did the observation period ($F = 1.216$; $p = 0.339$).

These differences in values must be understood by considering the characteristics of each swiftlet house. Swiftlet House 1 is an older structure that has been in operation for approximately ± 26 years and has 207 active nests, whereas Swiftlet House 2 is approximately ± 6 years old and has 8 active nests. In addition, the two structures differ in building size and the dimensions of their entry and exit holes. These variations in characteristics indicate heterogeneity among the buildings, which may be related to the spatial utilization patterns of the swiftlet colonies. However, since this study only included two swiftlet houses and the building characteristics were not tested across multiple replicated locations, the effects of individual factors such as building age, the number of active nests, and the design of the entry and exit holes cannot be analyzed separately. Therefore, these characteristics are used only as supporting information in interpreting the differences between swiftlet houses. The difference in mean values between the two buildings cannot yet be considered evidence of the influence of the building design. Although the design and construction of swiftlet houses can create different microclimatic conditions (Hakim, 2011; Ibrahim *et al.*, 2009).

The absence of a significant effect from building factors indicates that differences in the location of swiftlet houses are not strong enough to influence droppings production, as long as the building design and available space functions are relatively similar. These results are consistent with the findings of a study conducted by Sakinah (2025), which states that internal building design characteristics, spatial

arrangements, and microhabitat conditions play a greater role in determining swiftlet activity than geographical location differences at the local scale. However, this does not mean that geographical location has no effect on swiftlet farming. Choosing the right location plays a crucial role in determining how quickly swifts will occupy a newly constructed building. Furthermore, location also significantly influences the population size of swifts that ultimately nest within the building (Budiman, 2012).

3.2. The Effect of Colony Type on the Accumulation of Swiftlet (*Aerodramus fuciphagus*) Droppings

Based on the results of the Linear Mixed Model analysis, Model C showed that colony type had a significant effect on fecal weight accumulation ($F = 7.114$; $p = 0.024$).

Table 4. Estimated Marginal Means and Comparison of Colony Types

Colony Type	EMM (g)	SE	95% CI
Parent + offspring (1)	13,891	2,191	8,611-19,172
Parent + offspring (2)	12,567	2,191	7,287-17,848
Breeding Stock	3,229	2,191	-2,052-8,509
Bonferroni Comparison:			
Comparison	Mean difference (g)		P
Parent + offspring (1)	1,324		1,000
Parent + offspring (2)	10,662		0,037
Breeding Stock	9,339		0,064

Source: Data processed from the results of a Linear Mixed Model test using IBM SPSS

Notes: EMM = estimated marginal mean; SE = standard error; CI = confidence interval. The p -values for comparisons between colony types were obtained from pairwise comparisons adjusted using the Bonferroni method. A p -value < 0.05 indicates a significant difference.

The estimated marginal means indicate that the colony consisting of the parent and offspring (1) had an estimated average feces weight of 13.891 g, followed by the colony consisting of the parent and offspring (2) at 12.567 g, while the colony consisting of the parent alone had a weight of 3.229 g. Paired comparisons showed that the parent and offspring colonies (1) had significantly higher fecal accumulation than the parent-only colonies ($p = 0.037$). Meanwhile, the group consisting of parent and offspring (2) also showed a higher value than the parent-only group, but the difference did not reach the 5% significance level ($p = 0.064$). The two groups of parents and offspring did not differ significantly from one another ($p = 1.000$).

These results indicate that colony composition is more closely related to variations in droppings accumulation than to the specific location or floor level. Biologically, the presence of both parents and chicks in a single nest area involves more individuals than nests occupied solely by the parent. According to Langham (1980), in the house swiftlet (*Aerodramus fuciphagus*), a pair typically lays two eggs, and the

chicks require about five to six weeks before they are able to fly. Biologically, colonies with both parents and chicks exhibit higher activity levels compared to colonies with only parents; this is due to the intensity of nest entry and exit, feeding activities for the chicks, and the chicks' movements around the nest area. This high colony activity is consistent with feeding and defecation activities. Colonies with chicks tend to exhibit higher feeding and defecation activity due to increased nutritional needs during the growth phase, resulting in more droppings. According to Lutviandary & Kuntjoro (2020), the growth phase of chicks correlates with more frequent feeding and defecation behavior.

Swiftlets have a habit of excreting waste outside their nests, which keeps the nests clean of droppings. According to Damayanti (2023), a swiftlet nest also known as an "edible bird's nest" is a nest made purely from the solidified saliva of the swiftlet, without any contamination or mixture of external materials. These nests are known to have numerous health benefits. Consequently, many people consume them. The swiftlet population plays a crucial role in determining nest production levels (Azizah, 2025), which in turn affects the amount of droppings produced (Alfionita *et al.*, 2018). Ecologically, the accumulation of swiftlet droppings can serve as an indicator of population density and the intensity of colony activity.

The significant effect of the observation period indicates that the accumulation of swiftlet droppings changed over the course of the study. Ecologically, these temporal changes may be related to various biological and environmental factors, particularly changes in the stages of reproduction and chick development. The swiftlet (*Aerodramus fuciphagus*) has a reproductive cycle that includes nest building, incubation, chick rearing, and the chicks' ability to fly. Langham (1980) reported that the incubation period for swiftlet (*Aerodramus fuciphagus*) eggs lasts approximately 23 ± 3 days, while the period of chick development until fledging lasts approximately 43 ± 6 days. A single pair typically lays two eggs and can complete more than one reproductive cycle using the same nest. These differences in reproductive stages may be accompanied by changes in individual activity around the nest. According to Mane & Manchi (2017), the activity patterns of swiftlets returning to their nesting sites differ significantly depending on the reproductive stage, including the nest-building phase, incubation, chick rearing, and the phase when the chicks leave the nest. This indicates that colony activity is not constant throughout the reproductive cycle. Changes in the accumulation of droppings between periods may reflect the dynamics of colony activity during the reproductive cycle (Viruhpintu, 2002).

In addition to colony dynamics, environmental conditions and food availability can also contribute to changes in swiftlet activity over time. Java was once the region with the highest level of swiftlet production; in recent years, however, production has

reportedly declined due to ecosystem degradation (Widyastuti *et al.*, 2024). External environmental factors such as food availability and insect populations also play a role in the distribution of fecal weight, as feeding and defecation rates increase in locations with more readily accessible food sources (External environmental and insect factors) (Ibitoye, 2025). Swifts are insectivorous birds that utilize various groups of flying insects as food sources. According to Langham (1980), the diet of swiftlets includes Hymenoptera, Ephemeroptera, Homoptera, and Diptera. However, since insect abundance and foraging activity were not measured in this study, this relationship can only be used as an ecological context and cannot yet be stated as a mechanism explaining the observed changes in fecal accumulation.

3.3. Accumulation of Swiftlet Droppings in Relation to Microhabitat Conditions

The highest accumulation of swiftlet droppings occurred in the single-story, three-unit swiftlet house, while the two-story, one-unit swiftlet house showed a lower accumulation. This difference is thought to be influenced by microenvironmental conditions such as temperature, humidity, light intensity, and other external disturbances. Therefore, a multiple linear regression test was conducted to determine whether microhabitat factors influence the accumulation of swiftlet droppings, and the results are presented in Table 5.

Table 5. Results of the Multiple Linear Regression Analysis of Microhabitat Factors on Swiftlet Droppings Production.

Parameters	Coefficient (B)	SE	β	p
Temperature	-0,064	1,445	-0,014	0,966
Humidity	0,410	0,223	0,581	0,091
Light Intensity	5,331	3,714	0,297	0,177
Model Statistics				
$R^2 = 0,510$				
Adjusted $R^2 = 0,388$				
$F = (3,12) = 4,163$				
$P = 0,031$				

Source: Data processed from the results of multiple linear regression analysis using IBM SPSS

Note: $p < 0.05$ indicates a significant effect.

The results of the multiple linear regression analysis indicate that temperature, humidity, and light intensity are simultaneously and significantly associated with variations in the weight of swiftlet droppings ($F(3,12) = 4.163$; $p = 0.031$). The model explains 51.0% of the variation in weight ($R^2 = 0.510$; adjusted $R^2 = 0.388$). Humidity has the largest standardized beta value ($\beta = 0.581$), indicating a tendency toward a positive relationship with droppings weight, but this relationship is not yet statistically significant. When analyzed individually, none of the microhabitat parameters had a significant effect at the 5% level, with p-values of 0.966 for temperature, 0.091 for humidity, and 0.177 for light intensity. This is consistent with Ibrahim *et al.* (2009), who noted that temperature, relative humidity,

airflow, and light intensity are important components in shaping the habitat conditions of swiftlet nests. However, conditions that support swiftlet habitats do not necessarily imply that they are factors that directly determine the accumulation of fecal weight. The regression model also did not reveal any significant violations of assumptions. The VIF values for all predictors were below 3, indicating no serious multicollinearity. Furthermore, the residual pattern approximated a normal distribution and showed no clear signs of heteroscedasticity.

According to swiftlet consultants, the optimal temperature for a swiftlet house ranges from 27–29°C with a humidity of 70–95%. Meanwhile, the light intensity preferred by swiftlets for nesting is 0 lux (total darkness) (Ayuti, 2016). Previous research has also indicated that swiftlets prefer locations with stable and relatively dark environmental conditions, similar to natural caves, as these provide optimal conditions for resting and nesting (habitat selection) and reduce thermal stress and visual disturbances for individual colony members (Idris *et al.*, 2014).

Swifts have a fairly high environmental tolerance, so variations in microhabitat conditions within certain limits do not directly affect their activity patterns. Other variables, such as population density, colony age, nest structure characteristics, and the level of environmental disturbance, are thought to contribute more significantly to the accumulation of droppings.

3.4. Environmental Implications and Management of Swiftlet (*Aerodramus fuciphagus*) Droppings

From an environmental perspective, managing accumulated swiftlet droppings is important because guano is an organic material that can introduce nutrients into the environment. According to Kılıç & Sönmez (2024), the high nitrogen and phosphorus content in swiftlet droppings also has the potential to increase the environmental nutrient load if the waste is disposed of without prior treatment. This is also consistent with the findings of Grant *et al.* (2022), who demonstrated that bird guano deposition can increase soil nutrient content; however, in excessive amounts under certain conditions, it also has the potential to cause nutrient enrichment or guanotrophication. Additionally, bird feces can serve as a medium for the transfer of various compounds and elements into the environment.

Swiftlet droppings have the potential to be reused as organic fertilizer. Bancin *et al.* (2021) reported the effects of liquid organic fertilizer made from swiftlet droppings on the growth of pak choi. This indicates that swiftlet droppings should not be viewed merely as waste but also have the potential to be reused as an organic resource. This study is also relevant to swiftlet house management in the context of cultivation, as excessive droppings accumulation can affect nest quality, nest environment cleanliness, and the health of the birds themselves. Previous research has also

found that an increase in droppings is associated with a decline in nest quality and other physical parameters of swiftlet nests (Azizah, 2025). The greater the weight of accumulated droppings, the higher the birds' activity in that space.

Thus, the results of this study not only illustrate variations in droppings accumulation across floors and buildings but also show that the dynamics of droppings accumulation are related to various interacting factors, particularly colony type and observation period. Characteristics of the two swiftlet houses such as building age, number of active nests, building dimensions, and entrance/exit hole sizes also need to be considered when interpreting differences between locations. However, since the study was conducted on only two swiftlet houses, the contribution of each of these building characteristics could not yet be tested separately. Therefore, future research should involve a larger number of swiftlet houses so that building and colony characteristics can be analyzed in conjunction with microhabitat conditions as factors related to variations in droppings accumulation. Continuous monitoring of microhabitat parameters is also necessary to obtain a more representative picture of the internal environmental conditions within the swiftlet houses.

3.5. Limitations of the Study

This study has several limitations that should be considered when interpreting the results. First, observations were conducted only at two swiftlet houses with different structural characteristics and numbers of floors; therefore, the findings are more representative of conditions at the study sites and cannot yet be generalized to all swiftlet houses. Second, the droppings were weighed while wet, so differences in moisture content among samples could potentially affect the weight measurements. Therefore, future studies should consider measuring dry weight or moisture content to obtain more standardized estimates of dry matter accumulation.

Third, measurements of temperature, humidity, and light intensity were taken only once at each location during each observation period. These conditions do not adequately represent continuous changes in the microhabitat throughout the day. Fourth, a number of biological, ecological, and building characteristics that may be related to swiftlet activity, such as the number of individuals and active nests, food availability, bird entry and exit activity, building age and size, and the dimensions of entry and exit holes, have not yet been quantitatively analyzed. Consequently, the contribution of each factor to variations in fecal accumulation cannot yet be determined separately. Future research is recommended to involve more swiftlet houses, conduct continuous microhabitat monitoring, use more standardized measures of droppings weight, and incorporate more detailed colony and building characteristics into the analysis.

4. CONCLUSION

The accumulation of wet weights of swiftlet (*Aerodramus fuciphagus*) droppings in two swiftlet houses showed variations that were more closely related to colony type and observation period than to floor level or building differences. In Building 1, floor level had no significant effect on droppings accumulation ($p=0.926$), whereas the observation period ($p=0.002$) and colony type ($p=0.007$) showed significant effects. A comparison of the two buildings on the same floor also showed no significant difference ($p=0.362$). The overall analysis indicated that colony type ($p=0.024$) and observation period ($p=0.008$) had a significant effect on droppings accumulation, whereas floor location had no significant effect ($p=0.418$). Parent-offspring colonies tended to have higher feces accumulation compared to parent-only colonies, with a significant difference found between the parent-offspring group (1) and the parent-only group ($p = 0.037$). Microhabitat conditions, including temperature, humidity, and light intensity, collectively showed a significant association with variations in average droppings weight ($p=0.031$) and explained 51.0% of the variation in the model, although no single microhabitat parameter showed a significant partial association. These findings suggest that information regarding colony type and changes in accumulation over time can be considered as a starting point for managing organic waste in swiftlet houses. However, this study was limited to two swiftlet houses with unbalanced floor structures, used wet weight measurements, and did not account for several ecological factors and other building characteristics. Future research should involve a larger number of swiftlet houses with a more balanced observational design, use dry weight or standardized moisture content, conduct more intensive microhabitat monitoring, and integrate biological characteristics of the colonies, building features, and the chemical quality of the droppings to strengthen our understanding of the factors influencing the accumulation and management of swiftlet droppings.

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