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Sound management strategies in swiftlet ranching from Southern Thailand

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Abstract. *Pongpattananurak N, Phumsathan S, Somleewong T, Rasri P. 2023. Sound management strategies in swiftlet ranching: An experiment from Southern Thailand. Biodiversitas 24: 6218-6228.* Edible-nest swiftlets are well-known for the medicinal properties of their nests. With the global demand, swiftlet ranching has emerged as a vital industry. Swiftlet houses employ acoustic stimuli to entice wild swiftlets. However, the use of loud acoustic stimuli in swiftlet houses has inadvertently led to sound pollution in urban areas. This study investigates the interplay of acoustic stimuli, loudness, and environmental factors in attracting swiftlets while reducing noise. Our findings highlight the critical role of sound management in swiftlet ranching. Higher loudness, especially around 80-90 dB, significantly increases swiftlet activity and maximizes daily counts. Furthermore, optimizing loudness levels, particularly at around 80 dB, extends the swiftlet presence duration, offering valuable ranching benefits. Strategic loudness management is recommended to balance attraction and noise control. Timing acoustic stimulation during mornings and late afternoons aligns with swiftlets' natural behavior. Lowering loudness to under 70 dB during midday minimizes disturbances, especially in populated areas. Weather conditions, including outdoor absolute humidity and temperature, also influence swiftlet attraction. The study finally provides guidance for complying with environmental noise regulations, demonstrating that sound levels of 70-80 dB effectively control noise. These insights support swiftlet ranching while respecting urban communities and coexisting harmoniously.

Keywords: Southern Thailand, sound management, swiftlet ranching

INTRODUCTION

Edible-nest swiftlets (*Aerodramus fuciphagus* Thunberg 1812) create nests from their saliva, which are highly regarded for their nutritional and pharmaceutical benefits, particularly in traditional Chinese cuisine. Classified as functional food, they are rich in bioactive compounds, including proteins, essential amino acids, and simple sugars like sialic acid, which are crucial for various human biological processes (Hao and Rahman 2016; Yew et al. 2018; Mursidah et al. 2021; Yan et al. 2021). Due to the remarkable belief in the pharmaceutical attributes of Edible-nest swiftlets and limited natural supply, bird's nests have gained recognition as luxury agricultural products, commanding significant global demand, particularly among Chinese communities worldwide.

Edible-nest swiftlets are native to Southeast Asia, inhabiting regions such as the Nicobar and Andaman Islands, Hainan Islands in China, Palawan Islands in the Philippines, and the coasts of Vietnam, Cambodia, Thailand, the Burmese Peninsula, Peninsular Malaysia, and Indonesian islands (Koon and Cranbrook 2002; Robson 2008; Pongpattananurak et al. 2018; BirdLife International 2023). Traditionally, bird's nests were harvested from natural caves in the Southeast Asian archipelago. However, over the last three decades, swiftlet ranching has gained prominence in ASEAN countries, including Indonesia, Malaysia, Vietnam, and Thailand. As reported in Malaysia, swiftlet farming contributes to nearly 95% of the national output's value, with the remaining 5% derived from traditional cave collections (Ito et al. 2021). China, with a growing population of health-conscious consumers, is the largest global importer of bird's nests as reported by Utusan Malaysia in 2012 (Aziz and Rahim 2022). In 2017, Alibaba’s e-commerce platform alone recorded bird’s nest sales exceeding 1.48 billion yuan (approximately $200 million), with nearly half of the purchases made by working-age individuals with medium to high incomes seeking to boost their health (Department of International Economic Affairs 2021). In Thailand, the combined trade value of natural and farmed bird’s nests is estimated at around THB 10 billion (USD 307 million) annually (Ito et al. 2021; Nation Thailand 2021). On a global scale, the industry's value is estimated to be around USD 5 billion (Ito et al. 2021). This trend presents an opportunity for bird's nest entrepreneurs worldwide to enhance product quality and access the lucrative Chinese market, the world's largest consumer of bird's nest products.

The increasing market value of bird's nests has led to a proliferation of swiftlet houses along the coastal regions of

Southeast Asia (Aziz and Rahim 2022). Swiftlet houses have become a key economic asset in the region, notably in the southern and eastern coasts of Thailand, similar to Indonesia and Malaysia, where they are prevalent in urban and suburban areas. Swiftlet ranching is distinct from conventional intensive farm management practices, such as those employed in most poultry farms. Swiftlet house owners primarily involve creating refuges and nesting areas for these avian inhabitants. Due to the biological characteristics of swiftlets, confining them to captive areas has proven unfeasible. Thus, swiftlet house owners employ strategies to attract wild swiftlets, especially when establishing new swiftlet houses. A common technique involves playing edible-nest swiftlet acoustics through audio devices to entice the birds to explore and potentially establish populations in these man-made habitats (Yassin et al. 2020; Aziz and Rahim 2022). However, the competition among owners to attract swiftlets by increasing audio loudness levels has unintentionally caused sound pollution, resulting in a surge in noise complaints in urban areas (Yassin et al. 2020; Trung 2023). Notably, in Thailand, sound pollution caused by swiftlet ranching has emerged as a prominent concern (Phumsathan et al. 2021; Ammartsena and Ditthapan 2023).

This study focuses on providing scientific evidence regarding the effectiveness of swiftlet acoustics in attracting wild edible-nest swiftlets to new swiftlet houses. The research goal is to offer guidance on achieving a balance between successful swiftlet attraction and the regulation of sound pollution in surrounding areas. The study comprises several key objectives, including assessing the impact of different sound levels of swiftlet acoustics in collaboration with varying weather conditions on attracting edible-nest swiftlets concerning their abundance and duration of appearances. Furthermore, the research evaluates how noise levels of swiftlet acoustics change at different distances from a swiftlet house. The study's findings hold practical utility for swiftlet house owners and relevant authorities responsible for managing swiftlet sounds in compliance with the law and in harmony with neighboring communities. Additionally, the study provides sound management strategies in swiftlet ranching in Thailand.

MATERIALS AND METHODS

Study area

The research took place at a new swiftlet house without an established swiftlet population in the Forestry Research and Student Training Station, Had Wanakorn, Huai Yang, Prachuap Khiri Khan, Thailand (Figure 1), located at 99°41’25” E and 11°37’24” N. This area falls within the typical range for edible-nest swiftlets in Thailand (Ito et al. 2021; Ammartsena and Dittapan 2023) in the upper southern region near the eastern coast. The local climate has three seasons: summer (February to May), rainy season (May to October) with southwest monsoon winds, and winter (October to February) with northeastern monsoon influence. Meteorological data (Amatyakul and Joamtha 2017; Meteorological Department 2017) show an annual rainfall average of 1113 mm, peaking at 231 mm in October and hitting a low of 22 mm in December. The average annual temperature is 27°C, with January as the coldest month at 20°C and May as the warmest at 33°C. The choice of this new swiftlet house was based on its ability to attract edible-nest swiftlets and provide a controlled setting for experimenting with swiftlet sound at varying loudness levels.

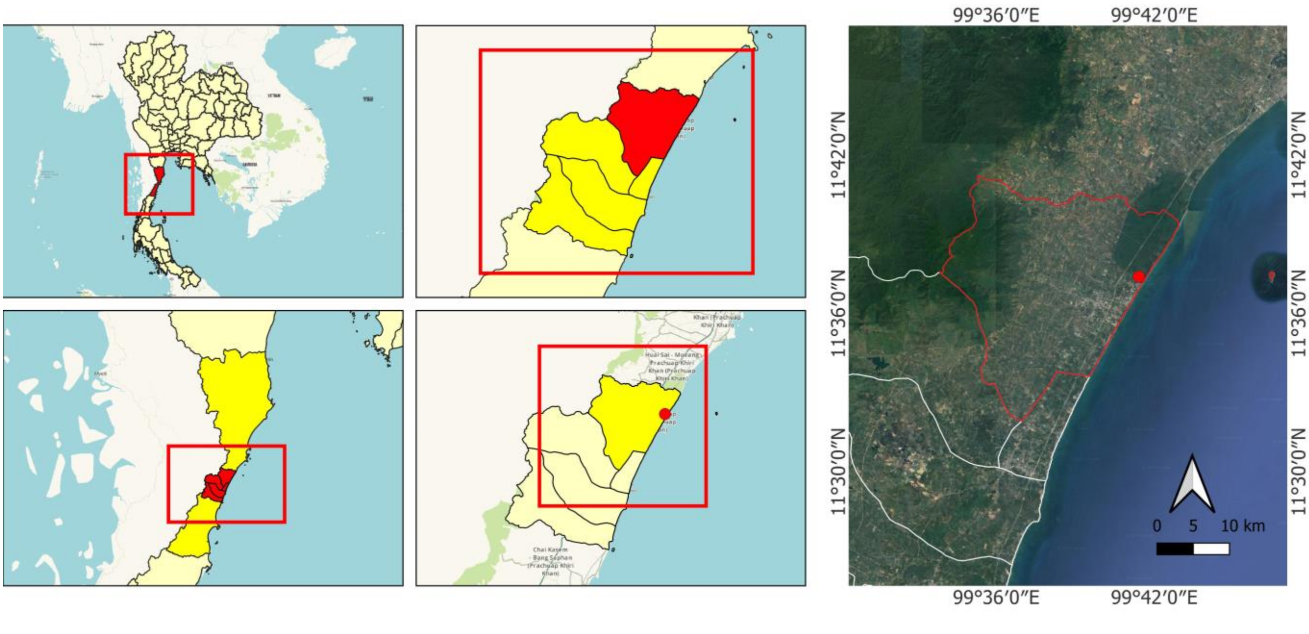

Figure 1. Location of the swiftlet house (99°41’25” E, 11°37’24” N) located in the Forestry Research and Student Training Station at Had Wanakorn, Huai Yang, Prachuap Khiri Khan, Thailand

Procedures

The study was conducted during the local peak behavioral responsiveness of edible-nest swiftlets to swiftlet sound from June 2017 through September 2017. The data collection procedures are outlined as follows:

Influence of swiftlet sound

The experiment was conducted in the swiftlet house located in suburban. The chosen swiftlet house is a four-story structure, with each floor having a height of 3 m. We employed a standard trumpet speaker commonly used in swiftlet ranching, typically rated at 25 W with an audio frequency range between 1.5 kHz to 20 kHz. A speaker was installed on the top floor of the swiftlet house, approximately 12 m above the ground, and directly above an entrance hole (Figure 2A). We set up three swiftlet entrance holes, each with one speaker, on the front and sides of the swiftlet house, and the speakers were installed parallel to the ground. All loudspeakers were connected via audio cables to an amplifier located in the control room of the swiftlet house. The recorded swiftlet sounds used in the experiment represented those commonly used in the local area. To minimize external influences, the chosen swiftlet house for the experiment had no other swiftlet ranching within a 1 km radius.

This experiment was designed using a Completely Randomized Block Design (RCBD), with each day serving as the experimental unit. The treatments consisted of five different sound levels, which included no swiftlet sound (a control at 0 dB), as well as 70, 80, 85, and 90 dB. Each week represented a block, and days within a week were randomly assigned to the various sound levels. The sound file was edited by selecting the most consistent loudness range and creating a new sound file. The loudness of the swiftlet sound was adjusted by setting the amplifier to the average loudness determined using a sound level meter, which measured and set up the loudness value at 50 cm from the loudspeakers installed at the entrance holes on the fourth floor of the swiftlet house. Different volume levels on the audio player's volume knob were marked according to the specified loudness levels: 70, 80, 85, and 90 dB, to control the varying loudness of swiftlet sounds each day of the experiment.

To assess the influence of the swiftlet sounds, we installed 3.6 mm lens CCTV cameras both inside and outside the swiftlet house, maintaining fixed camera positions throughout the study period (Figure 2B and 2C). Swiftlet behavior was observed by reviewing video recordings made between 6:00 and 19:00 on each day the swiftlet sound experiments were conducted. The study analyzed paused video recordings at 10 minutes intervals during this period to count the number of swiftlets and to evaluate the appearance duration both outside and inside the swiftlet house. The independent variables used to assess the influence of bird calls included daily maximum swiftlet count outside (count.max.out) and inside (count.max.in) the swiftlet house and daily appearance duration of swiftlets outside (duration.out) and inside (duration.in) the swiftlet house. Additionally, the study recorded daily outdoor weather conditions during the experiment. A weather data logger was installed outside the swiftlet house at the main entrance holes. This logger recorded outdoor weather conditions every 10 minutes from 6:00 to 19:00 during the study. The data included temperature (temp.out), relative humidity (hum.out), and absolute humidity (abs.hum). These variables served as independent covariates to explain variations in swiftlet responses along with different loudness levels of swiftlet sounds.

Variation in loudness across distances

The study investigated the variation in human perception of noise caused by playing recorded swiftlet sounds at different distances from the swiftlet house. The audio player played swiftlet sounds at five different loudness levels (0, 70, 80, 85, and 90 dB) at the sound sources (the speakers) outside the swiftlet house. For each loudness level, we measured a noise level at a point 1.20 m above the ground using a sound level meter mounted on a tripod. These measurements were taken at distances ranging from 0 to 200 m, with sound levels recorded every 10 m in the south direction (Figure 2D). The sound level meter was set to record the noise level every second for a 10 minute period, which matched the length of the swiftlet audio file. The mean of the 10-minute noise level at each distance point represented one replication of the sound level. The study conducted four replicates for each treatment across the distances, with each treatment randomly scheduled at different times during the experiment.

Data analysis

Testing the influence of swiftlet sound

We conducted the statistical analysis in the R program version 4.2.2 (R Development Core Team 2022). The analysis involved utilizing mixed-effects models, employing swiftlet counts and the duration of swiftlet appearances as dependent variables. Loudness treatments and outdoor weather conditions were considered fixed effects. Additionally, random effects were introduced to account for weekly and monthly variations, ensuring the results' robustness and accuracy. To address temporal variations of the dependent variable, a nested mixed-effect model with a random intercept of week nested in month (1|month/week) was employed (Bates et al. 2015). For count.max.out and count.max.in, a generalized linear mixed-effects model with the negative binomial family (glmer.nb) was used, which is available in the lme4 package by Bates et al. (2015). In the case of duration.out and duration.in, a generalized linear mixed-effects model with the Gaussian family (glmer) was applied. We constructed a null model, which consisted solely of an intercept term, for the purpose of model comparison. To identify the optimal model that includes significant covariates, we applied a backward stepwise selection procedure guided by Akaike's Information Criterion (AIC) (Bozdogan 1987). To evaluate the impact of different loudness levels on swiftlet counts and appearance duration, a post hoc analysis using Tukey's contrasts was performed with the multcomp package (Hothorn et al. 2008).

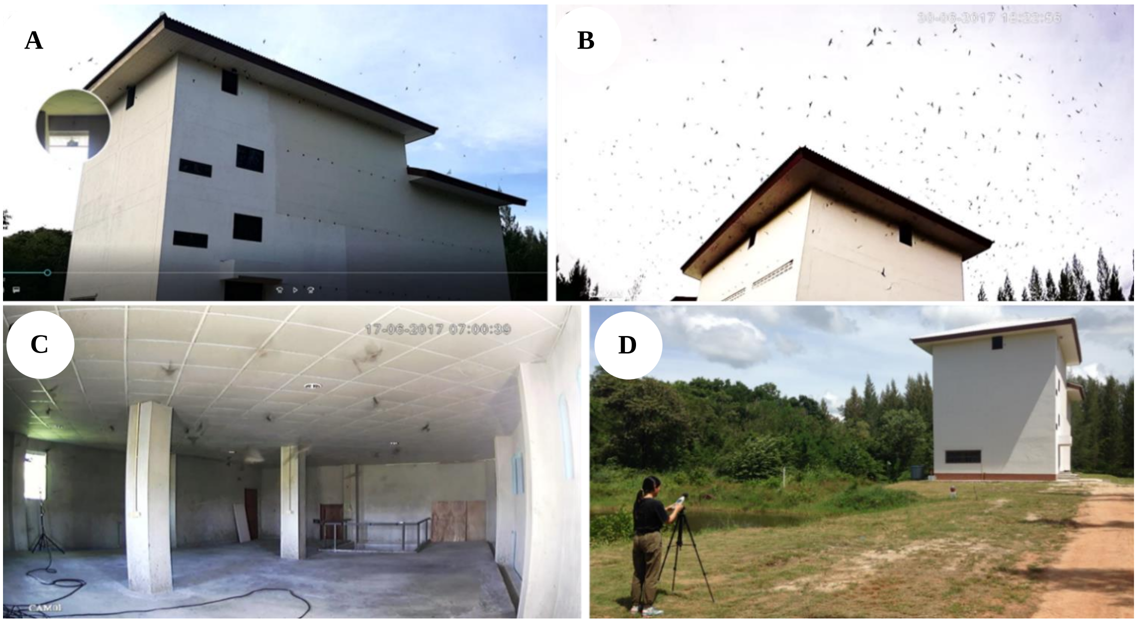

Figure 2. The experimental configuration employed to investigate swiftlet sounds in this study includes: A. Installation of a speaker on the top floor of the swiftlet house above an entrance hole; B. Fixed placement of a frame for the CCTV camera outside the swiftlet house; C. Fixed positioning of a frame for the CCTV camera within the roving area of the swiftlet house; D. Noise measurements taken at 10 m intervals across distances from 0 to 200 m

Evaluating daily swiftlet appearance

From the daily swiftlet count observations, both outside and inside the swiftlet house, the study calculated the average swiftlet counts over 10 minutes intervals for the different levels of the swiftlet sound. The averages were used to create graphs showing the variation in swiftlet counts over time (06:00-19:00).

Assessing variation of noise across distances

We utilized a sound level meter to estimate noise values generated by swiftlet sounds at varying distances. An analysis of variance was carried out to assess differences in measured noise values at a given 10 m interval. Post-hoc tests were conducted to evaluate these differences. The Tukey Honestly Significant Difference Test from the agricolae package (Mendiburu and Yaseen 2020) was employed to determine pairwise averages of loudness levels at each distance point. Additionally, we generated a plot to illustrate the relationship between average noise levels and distances from the swiftlet house. This plot was then used for comparison with established sound standards, including those defined by the National Environmental Quality Promotion and Preservation Act of 1992, which sets the 24-hour average noise level at a maximum of 70 dB(A) (Royal Thai Government Gazette 2022). This comparison allowed us to propose guidelines for managing swiftlet sound noise in urban areas of Thailand.

RESULTS AND DISCUSSION

Effect of swiftlet sound on swiftlets attraction

The swiftlet sound experiment extended over a period of 67 days, as outlined in Table 1. The variations in the number of replications were primarily a result of intermittent power outages that occurred during the study. The findings of the study are illustrated as follows.

Effect of swiftlet sound on maximum counts

At 0 dB, the average count outside the house was 24.92 individuals, while at 90 dB, it increased to 79.50 individuals. The trend was consistent across the loudness levels, indicating that higher loudness levels attracted more swiftlets. Inside the swiftlet house, the average count inside the house remained at 0.00 individuals for the 0 dB loudness level and increased to 22.42 individuals at 90 dB.

Effect of swiftlet sound on appearance duration

The mean appearance duration of swiftlets, both outside and inside the swiftlet house, from 06.00 to 19.00 increased with higher loudness treatments. Outside the swiftlet house, the mean duration rose from 3.01 hrs/day at 0 dB to 8.34 hrs/day at 90 dB. A similar pattern was observed in the roving area inside the house, with durations increasing from 0.00 hrs/day at 0 dB to 4.33 hrs/day at 90 dB. It is important to note that without swiftlet sound playing outside the swiftlet house, no swiftlets were observed entering the roving area inside the house, indicating a clear dependence on the presence of sound cues for swiftlet activity within the artificial habitat.

Acoustic stimuli on the daily behavior

Between 6:00 and 8:30

The trend outside the swiftlet house between 06:00 and 09:00 showed that swiftlet activity undergoes significant fluctuations. The mean swiftlet count (Figure 3A, the red line) started at 13.03 at 06:00, signifying some early morning activity. However, the activity gradually increased as the morning progressed. The peak in swiftlet counts occurred between 07:00 and 07:10, with average counts ranging from 22.04 to 22.97. This period marked the morning peak for swiftlet activity outside the house. During these moments, swiftlets were actively flying around the swiftlet house and likely foraging and surveying the house. Inside the swiftlet house during the same time frame, there was a different trend in mean swiftlet counts (Figure 3B, the red line). The average was 0.23 at 06:00, and there was a steady increase in swiftlet counts as the morning advanced. The peak swiftlet count inside the house was observed at 07:30, with a mean count of 9.22. Swiftlet counts for both outside and inside the swiftlet house exhibited a significant increase in response to acoustic sounds, particularly at higher loudness levels (80-90 dB). Notably, with a loudness of 80 dB, there was a peak swiftlet count of 28.08 at 07:00 outside and 13.85 at 07:30 inside the swiftlet house. This is the morning peak of swiftlet activity outside and within the building. Swiftlets seem to gradually enter the house during these hours, possibly to survey for shelter or roosting spots. Comparing the two locations, it is evident that swiftlets exhibited different activity patterns during the morning hours. Outside the house, swiftlets were most active between 06:00 and 07:30, while inside the house, the peak activity occurred slightly later between 07:00-08:00. The data suggests that swiftlets first engage in outside activities, possibly foraging or socializing, and then move inside the house, reaching their peak activity a bit later.

Table 1. The means with standard errors of the daily maximum counts and appearance duration of swiftlets outside and inside the swiftlet house from 06:00-19:00

Response variables	**Mean ± 1 standard error**				
Loudness of swiftlet sound	**0 dB**	**70 dB**	**80 dB**	**85 dB**	**90 dB**
Repetition (n)	13	14	14	14	12
Daily maximum swiftlet counts (individuals) outside the swiftlet house (count.max.out)	24.92 ± 8.89	51.14 ± 10.41	93.21 ± 15.83	99.71 ± 19.44	79.50 ± 26.59
Daily maximum swiftlet counts (individuals) inside the swiftlet house (count.max.in)	0.00 ± 0.00	14.57 ± 3.53	26.93 ± 5.20	25.71 ± 4.33	22.42 ± 3.54
Daily appearance durations of swiftlets (hrs/day) outside the swiftlet house (duration.out)	3.01 ± 0.38	5.61 ± 0.69	8.20 ± 0.86	8.21 ± 0.71	8.34 ± 0.68
Daily appearance durations of swiftlets (hrs/day) inside the swiftlet house (duration.in)	0.00 ± 0.00	2.41 ± 0.59	3.97 ± 0.85	4.56 ± 0.71	4.33 ± 0.57

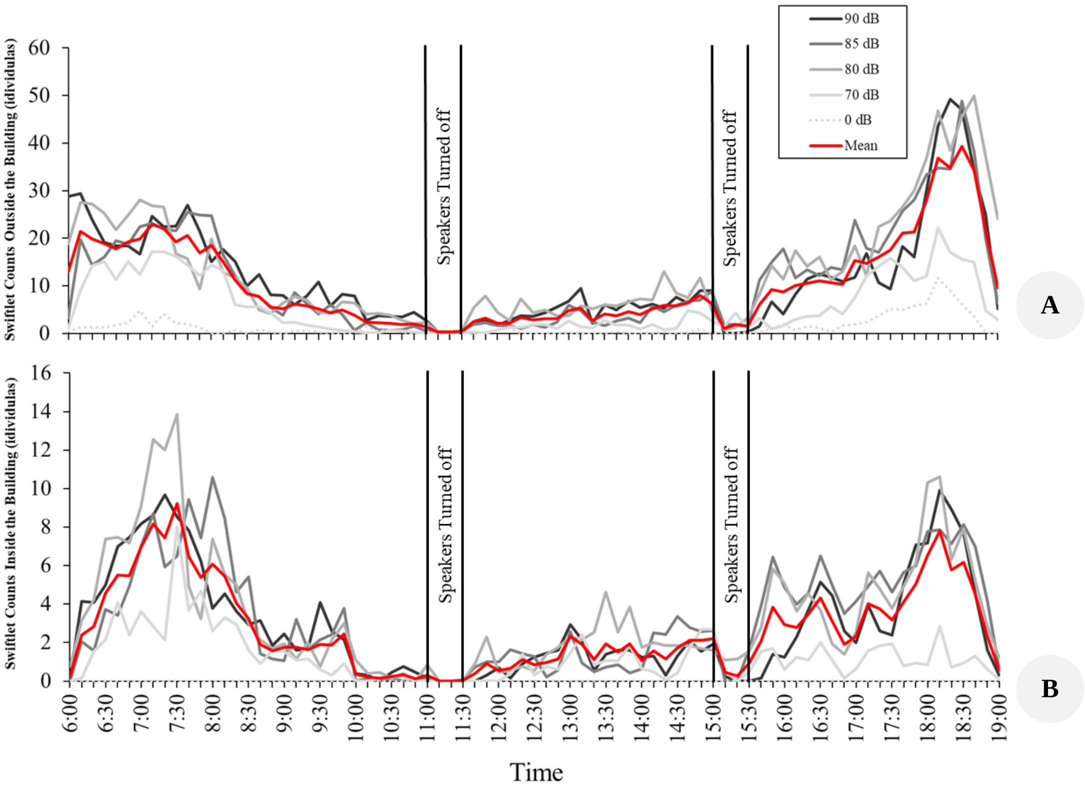

Figure 3. Average daily swiftlet counts every ten minutes. A. Outside and B. Inside the swiftlet house, across different levels of swiftlet sound loudness

Between 08:30 and 15:30

Between 08:30 and 15:30, a distinct pattern emerged in swiftlet activity outside the house (Figure 3B, the red line). The day started with a slow morning activity, with a mean swiftlet count of 8.41 at 08:30. As time progressed, counts gradually declined across all loudness levels of swiftlet sound. Until approximately 11:00, there was a consistently low level of activity, followed by a sudden drop in counts when the swiftlet acoustic was turned off at 11:00, disrupting their normal behavior. The lowest point occurred at 11:20, when the mean count was 0.26. Counts began to recover after 11:30 when the speaker resumed activity, indicating a partial return to normal behavior. Another sharp decline in counts occurred between 15:00 and 15:30, again coinciding with the acoustic being turned off. Inside the swiftlet house during the same period, mean swiftlet counts exhibited a slightly different trend. Counts started at 1.61 at 08:40, signifying decreased activity within the house. Similar to the outside, counts gradually decreased as the day progressed. The lowest point inside the house was between 11:10 and 11:20, with a count of 0.00, mirroring the outside pattern. Notably, swiftlet counts inside the house also decreased when the swiftlet acoustic was turned off from 11:00 to 11:30 and from 15:00 to 15:30 for audio player maintenance. This indicates the significant role of acoustic stimuli in shaping swiftlet behavior both inside and outside the house during the daytime. Overall, swiftlet activity was reduced between 08:30 and 15:30, with less prominent peaks compared to morning and evening hours.

Between 15:30 and 19:00

In the late afternoon and early evening, swiftlet counts outside the house exhibited distinctive patterns. Activity increased at 15:40, with a mean swiftlet count of 9.19, suggesting moderate activity. As the evening progressed, counts steadily rose, reaching their peak at 18:30, with a mean count of 39.28. Notably, at loudness levels of 80, 85, and 90 dB, the average swiftlet counts at 18:30 were 45.54, 48.87, and 47.08, respectively. This substantial increase implies heightened activity and a larger presence of swiftlets outside the house during this period. The late afternoon and early evening appear to be particularly favorable for swiftlets. During the afternoon, there is a noticeable trend in mean swiftlet counts inside the swiftlet house. Counts started to increase at 15:40, with a count of 2.10, indicating relatively low activity within the house. As the evening progressed, counts continued to rise, peaking at 18:10 with a count of 7.81. Notably, this peak did not align precisely with the peak observed outside the house. The substantial increase in swiftlet counts outside the house, peaking at 18:10-18:30, suggested that swiftlets preferred gathering outside during the evening, possibly for foraging, surveying, and social interactions. Direct observation revealed that swiftlet counts inside the house were generally lower, indicating that most swiftlets may leave the swiftlet house during the evening to return to their preferred roosting sites.

Modeling the effects of swiftlet sounds

We conducted an extensive analysis using mixed-effect models to assess the influence of swiftlet sounds in conjunction with weather covariates on daily maximum counts and appearance duration of swiftlets outside and inside the house. Weather predictors encompassed temp.out, hum.out and abs.hum directly measured outside the swiftlet house. Notably, a strong negative correlation between temp.out and hum.out (r: -0.86) raised concerns about multicollinearity. To address this issue, we selected temp.out and abs.hum (r: 0.33) as the weather covariates to explain variations in swiftlet counts and appearance duration alongside swiftlet sounds.

Swiftlet counts

Daily maximum swiftlet counts outside the house (count.max.out). In the investigation of count.max.out, the optimal model, determined through a backward selection procedure, exhibited improved goodness of fit compared to the null model (ΔAIC: -21.82) (Table 2). A significant positive correlation between abs.hum and count.max.out was observed based on the Incidence-Rate Ratio (IR) of 1.27 derived from the optimal model. This IR indicates a 27% increase in swiftlet activity for each unit increase in outdoor absolute humidity. Moreover, our study highlighted the role of noise levels, where higher loudness levels of 70, 80, 85, and 90 dB (all p-value<0.01) were associated with increased swiftlet counts. Notably, the presence of loudness 85 dB exhibited the most pronounced effect, resulting in swiftlet counts approximately 4.20 times higher than when this sound level was absent (IR: 4.20). These findings pointed out the intricate interplay between environmental factors and swiftlet behavior, indicating that both absolute humidity and swiftlet sound contribute significantly to swiftlet activity outside the swiftlet house.

Daily maximum swiftlet counts inside the house (count.max.in). The optimal model (ΔAIC: -46.40) identified only abs.hum as a significant predictor, with an IR of 1.31 in Table 2. This implies that an increase in outdoor absolute humidity is associated with a 31% increase in swiftlet counts inside the house during the daytime. However, loudness exhibited no significant effect on swiftlet counts occurring in the swiftlet house.

Swiftlet appearance

Daily appearance duration outside the house (duration.out). The optimal model (ΔAIC: -41.93) for predicting swiftlet appearance duration included temp.out (p-value=0.02), abs.hum (p-value=0.07), and loudness at different levels (loudness of 70, 80, 85, and 90 dB, all p-values<0.001) as significant predictors (Table 3). The outdoor temperature had a negative effect on the appearance duration of swiftlets, with a coefficient of -0.40, indicating that as the temperature outside increased, swiftlet appearances tended to be shorter. Conversely, absolute humidity showed a positive relationship, with a coefficient of 0.54, suggesting that higher humidity levels were associated with longer swiftlet appearances. Additionally, the loudness of 70, 80, 85, and 90 dB positively affected the swiftlet appearance duration, with coefficients of 2.57, 5.04, 5.18, and 5.50, respectively. These findings imply that higher loudness levels in the environment are linked to longer durations of swiftlet appearances.

Daily appearance duration inside the house (duration.in). The optimal model (ΔAIC: -26.2) identified significant effects on swiftlet behavior as indicated by the following coefficients: loudness of 70 dB (p-value=0.01), loudness of 80 dB (p-value<0.001), loudness of 85 dB (p-value< 0.001) and loudness of 90 dB (p-value<0.001), and abs.hum (p-value=0.06) (Table 3). These results infer that the duration of swiftlet appearance was significantly influenced by the swiftlet sound within the roving area of the swiftlet house, with louder conditions and higher outdoor absolute humidity being associated with longer swiftlet appearances. Notably, with the p-value a little exceeding the conventional alpha of 0.05, the absolute humidity exhibited somewhat significant effects on swiftlet behavior in this context.

Table 2. Parameter estimates of the null and optimal mixed-effect models for the daily maximum counts of edible-nest swiftlets outside and inside the swiftlet house obtained through a backward selection with mixed-effect Models using a negative binomial function

Formula	Predictors	Estimated Coefficient[1]	p-value	Incidence-rate Ratio[1] (IR)	AIC	ΔAIC
Swiftlet count outside (count.max.out)						
A null model:	Null model				702.95	
~ 1 + (1|month/week)						
An optimal model:	abs.hum	0.2428	0.015	1.27	681.13	-21.82
~ abs.hum + loudness + (1|month/week)	loudness at 0 db	-2.2597	0.299	0.10		
	loudness at 70 db	0.7670	0.005	2.15		
	loudness at 80 db	1.4359	< 0.001	4.20		
	loudness at 85 db	1.4788	< 0.001	4.39		
	loudness at 90 db	1.3873	< 0.001	4.00		
Swiftlet count inside (count.max.in)						
A null model:	Null model				1303.50	
~ 1 + (1|month/week)						
An optimal model:	abs.hum	0.2660	< 0.001	1.31	1257.10	-46.40
~ abs.hum + (1|month/week)						

Table 3. Parameter estimates of the null and optimal mixed-effect models for the daily appearance durations of edible-nest swiftlets outside and inside the swiftlet house obtained through a backward selection with mixed-effect Models using a Guassian function

Formula	Predictors	Estimated Coefficient[1]	p-value	AIC	ΔAIC
Swiftlet duration outside (duration.out)					
A null model:	Null model			350.51	
~ 1 + (1|month/week)					
An optimal model:	abs.hum	0.5437	0.07	308.58	-41.93
~ abs.hum + temp.out + loudness +	temp.out	-0.4002	0.02		
(1|month/week)	loudness of 0 db	3.7533	< 0.001		
	loudness of 70 db	2.5731	< 0.001		
	loudness of 80 db	5.0362	< 0.001		
	loudness of 85 db	5.1832	< 0.001		
	loudness of 90 db	5.5019	< 0.001		
Swiftlet duration inside (duration.in)					
A null model:	Null model			335.24	
~ 1 + (1|month/week)					
An optimal model:	abs.hum	0.5571	0.06	309.04	-26.2
~ abs.hum + temp.out + loudness +	loudness of 0 db	-12.0157	0.06		
(1|month/week)	loudness of 70 db	2.3403	0. 01		
	loudness of 80 db	3.9820	< 0.001		
	loudness of 85 db	4.5096	< 0.001		
	loudness of 90 db	4.3621	< 0.001		

The post-hoc tests for swiftlet sound

Daily maximum swiftlet counts outside the house

Based on the post-hoc test (Figure 4A), compared to the control group (0 dB), loudness levels at 80, 85, and 90 dB were statistically significant differences in swiftlet counts outside the swiftlet house (all p-values<0.001). Additionally, the loudness at 70 dB exhibited a significant increase in swiftlet counts compared to the control group (p-value=0.04), indicating a weaker yet still significant difference. Further, exploration through pairwise comparisons among the higher loudness levels (70, 80, 85, and 90 dB) using Tukey contrasts revealed that loudness70 and 85 dB displayed a significant difference in swiftlet activity (p-value=0.04), suggesting a relationship within this subset of loudness categories. However, no other significant differences were observed among these loudness levels.

Daily swiftlet appearance duration outside the house

The results of the multiple comparisons of means using Tukey Contrasts indicated that loudness levels significantly affected the duration of swiftlet appearance outside the swiftlet building (Figure 4B). Specifically, the loudness levels of 70, 80, 85, and 90 dB were significantly different than those of 0 dB (all p-values<0.05). The results also revealed that no significant difference in the pairwise comparison among 80, 85, and 90 dB (all p-values>0.1). However, the loudness of 70 dB indicated significantly different than that of 80, 85, and 90 dB (all p-values≤0.01).

Daily swiftlet appearance duration inside the house

The results of the multiple comparisons of means had a statistically significant influence on the duration of swiftlet presence in the roving area. Compared to the baseline loudness level at 0 dB, loudness levels of 70, 80, 85, and 90 dB showed significantly longer durations of swiftlet appearance (Figure 4C). This suggests that increasing the loudness of swiftlet acoustics can attract swiftlets to the roving area of the building and promote longer periods of their presence. The significance of this effect was similar as loudness levels rose, with the highest loudness level at 90 dB still yielding longer durations but with a smaller effect size. Nevertheless, no significant differences were observed among these four elevated loudness levels (70, 80, 85, and 90 dB).

Assessing acoustic loudness at various distances

Five loudness treatments, including 0, 70, 80, 85, and 90 dB were measured at ground level, with measurements taken every ten meters up to 200 m. A key observation was the consistent decrease in loudness levels as the distance from the swiftlet house increased (Figure 5).

Post-hoc testing using a Tukey honestly significant difference test was applied to compare each treatment at a significance level of 0.05. At 0 m, loudness levels were significantly higher across all treatment levels, with the maximum loudness observed at 90 dB (78.15 dB) and the minimum at 0 dB (44.17 dB). There were no significant differences in the mean loudness values between the 85 dB and 90 dB treatments across all distances. However, the loudness of 80 dB exhibited significant differences from the 0-, 70-, 85-, and 90-dB treatments across all distances. In comparison to the baseline loudness at 0 dB, only the 70-dB treatment showed no significant differences in detected noise beyond 70 m. Higher loudness levels beyond 80 dB consistently yielded significantly different mean loudness values compared to the baseline loudness at all distances.

Notably, for treatments with loudness levels of 80 dB or less, the detected noise levels consistently remained below 70 dB at all distances, in accordance with the Thailand Environmental Noise Regulation's requirement that the 24-hour average sound level must not exceed 70 dB. However, for the 85 dB and 90 dB treatments, noise levels fell below 70 dB only when distances exceeded 30 meters from the swiftlet house. It is important to emphasize that even in these cases, the detected noise levels significantly exceeded the background noise level in the absence of swiftlet sound (38 to 45 dB).

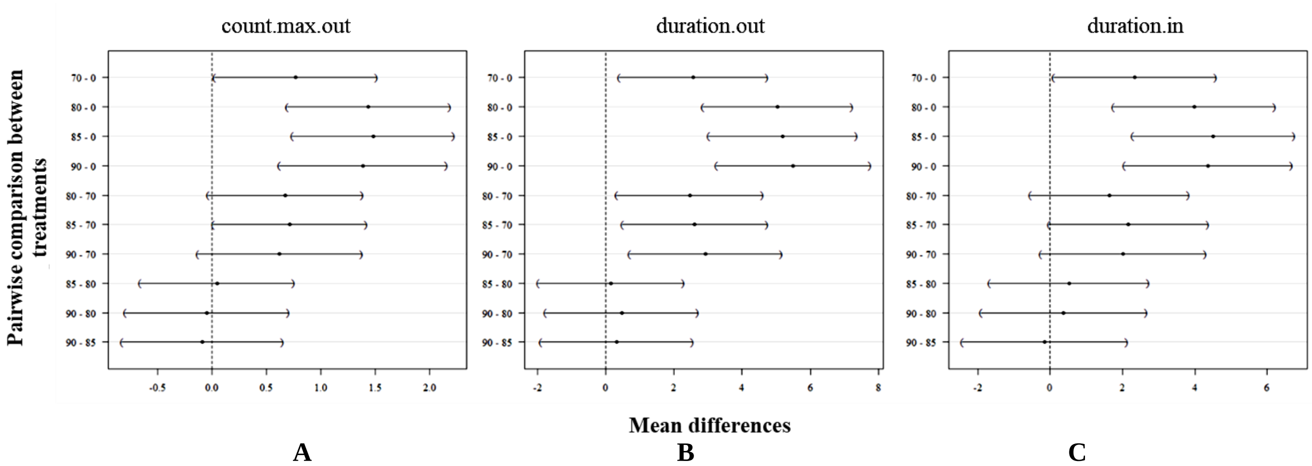

Figure 4. Post-hoc Tukey tests with a 95% confidence interval comparing swiftlet acoustic loudness levels

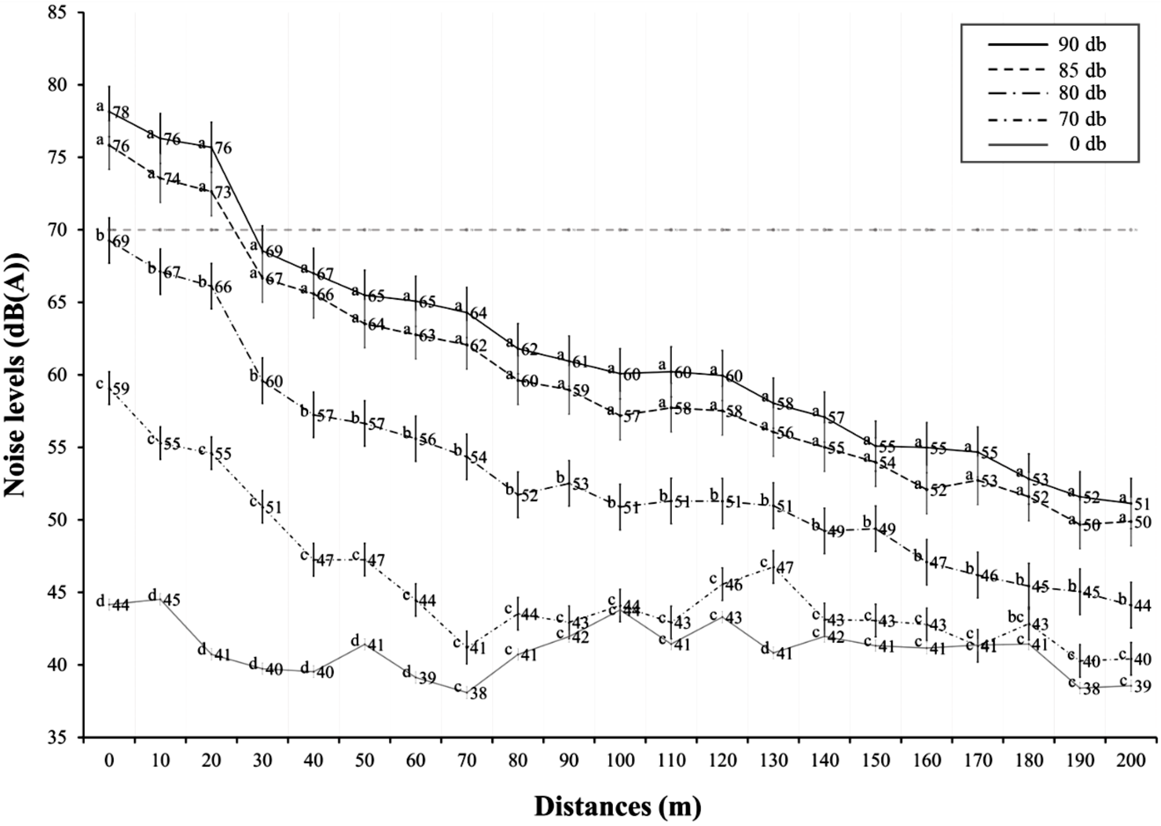

Figure 5. Means and standard errors of different noise levels measured by a sound level meter at different distances from the swiftlet house. Notes: At the same distances, significant differences in means of measured loudness (α: 0.05), denoted by different letters (a, b, c, and d), were reported in relation to specific loudness levels of 0, 70, 80, 85, and 90 dB played by an audio device

Discussion

Swiftlet Sound enhancing swiftlet attraction

Our analysis emphasizes the pivotal role of swiftlet sound loudness in attracting swiftlets. The results reveal that higher loudness levels, especially within the 80-90 dB range, are significantly associated with increased swiftlet activity outside the swiftlet houses. This finding highlights the effectiveness of sound management as a potent tool for attracting swiftlets, thereby enhancing daily swiftlet counts and appearances. It implies that swiftlet ranching can benefit from the strategic control of loudness levels, particularly within this effective range, thereby encouraging swiftlet habitation. In comparison with the studies conducted by Ibrahim et al. (2009) and Rahman et al. (2018), which investigated suitable artificial sound levels in two areas in Malaysia: Terengganu and Sarawak, we find relevant insights. Rahman et al. (2018) reported that in the rural area of Terengganu, Malaysia, the loudest mean external sound level recorded was approximately 70.0 dB. Additionally, in Sarawak, the suitable sound level within swiftlet houses fell in the range of 60-80 dB for external sound, as noted by Ibrahim et al. (2009). This indicates a similar preference for higher loudness levels when attracting swiftlet populations in three distinct areas: the southern part of Thailand, Terengganu, and Sarawak. However, when we assess the effectiveness of these results in relation to the increased swiftlet population in the southern part of Thailand, a noteworthy distinction emerges. Our findings indicate that at 80 dB, there is a significant increase in the swiftlet population compared to lower sound levels. This emphasizes the specificity of the optimal loudness level and its impact on swiftlet habitation, highlighting the important factor influencing swiftlet attraction.

Daily behavior and sound management

The study highlights the intricate daily behavioral patterns of edible-nest swiftlets in response to acoustic stimuli. While the morning hours (06:00-08:30) exhibit a significant peak in swiftlet activity, with the birds actively foraging and surveying the house, there is a notable difference in the timing of peak activity inside and outside the swiftlet house. Swiftlets show a preference for outdoor activities during the early morning hours, transitioning to indoor behavior slightly later. This suggests that employing swiftlet acoustic stimulation, particularly in the morning, can effectively attract swiftlets and encourage their presence within the house. However, during midday (08:30-15:30), a substantial decrease in swiftlet activity is observed, both inside and outside the house. To mitigate the potential disturbance caused by playing swiftlet sounds in urban areas, it is recommended to lower the loudness of the acoustic stimulus to less than 70 dB during this period, particularly in highly populated areas. In contrast, the late afternoon and early evening (15:30-19:00) witness a resurgence in swiftlet activity, making this time frame highly favorable for acoustic stimulation.

The best time to use sound for luring swiftlets is during the morning hours, particularly from 06:00 to 08:30 and the late afternoon and early evening from 15:30-19:00. However, based on the studies of Ibrahim et al. (2009) and Rahman et al. (2018), they have emphasized the importance of considering local community activities to prevent conflicts. This concerns the need for a holistic approach to sound management in swiftlet ranching that considers both the behavior of the swiftlets and the impact on the surrounding environment. This corresponds with the regulatory measures in place in Binh Phuoc, Vietnam. The Binh Phuoc Department of Agriculture and Rural Development has taken steps to implement a plan for swiftlet ranching areas in accordance with the Law on Livestock Production. They aim to reduce noise pollution from the swiftlet lure sound systems. To achieve this, they have established specific guidelines. For instance, active swiftlet houses must be situated at a minimum distance of 300 m from residential areas, and the use of lure sound is strictly regulated according to a set schedule (Trung 2023). A similar approach has been adopted in Rach Gia City, situated within the Vietnam Mekong Delta region. In this area, local government authorities permit the use of sound for swiftlet attraction solely between 07:00 am and 09:00 pm (Tuoi Tre News 2018). This demonstrates an effort by government agencies to strike a balance between promoting swiftlet ranching and safeguarding the acoustic environment of local communities, thus ensuring harmony between these coexisting interests.

Therefore, the strategic timing and management of loudness in swiftlet acoustic stimulation can play a pivotal role in enhancing the effectiveness of attracting and maintaining swiftlet populations while simultaneously minimizing potential sound pollution and its impact on local communities. This approach reflects a conscientious balance between the interests of swiftlet ranching and the well-being of the surrounding areas, contributing to the sustainable coexistence of these practices.

Weather conditions and swiftlet attraction

Outdoor absolute humidity and temperature appear as significant predictors, with an increase in humidity and a decrease in temperature correlating with a substantial rise in swiftlet activity. This observation supports the findings of previous researchers, including Hendri (2007), Ibrahim et al. (2009), and Rahman et al. (2018). Their research has consistently explained that, naturally, swiftlets tend to assess the design of the swiftlet house as they enter. If the relative humidity within the swiftlet house falls within a suitable range, they are more inclined to nest on the designated nesting planks. However, this study demonstrates the critical role of outdoor weather conditions in influencing swiftlet behavior and nesting decisions. Second, we observed a substantial impact of loudness levels on swiftlet counts, with the presence of loudness levels of 70, 80, 85, and 90 dB associated with significantly increased swiftlet counts. Among these, the loudness of 80 dB exerts a pronounced effect, leading to swiftlet counts approximately 4 times higher than in its absence. These findings illuminate the intricate balance between environmental conditions and sound, establishing that both absolute humidity and loudness are crucial factors influencing swiftlet activity outside their nesting sites. These findings are in line with the study of Rahman et al. (2018) study, which investigated the role of environmental parameters in successful edible bird nest swiftlet houses in Terengganu, Malaysia. The research highlighted the significance of favorable environmental conditions, particularly relative humidity, as an important factor in attracting swiftlets to nest within swiftlet houses. In addition to environmental factors, sound management also plays a crucial role in facilitating swiftlet nesting. Properly timed and controlled sounds create an environment that signals to swiftlets that the location is conducive to nesting (Nasir 2009; Rahman et al. 2018). This comprehensive perspective mentions the need for a multifaceted approach to effective swiftlet house management, where both environmental and sound-related factors are considered in concert.

Limitations

The study's limitations are rooted in its exclusive focus on a particular geographic location and the specific design of the swiftlet house. However, the conditions of this swiftlet house align with the typical setup in Thailand. The study did not pay attention to the complexities of social and economic factors that can significantly impact swiftlet ranching success.

Recommendation

Swiftlet ranching success hinges on maximizing swiftlet populations within designated areas. As loudness levels increase, especially within the 80-90 dB range, swiftlet activity outside the swiftlet houses significantly intensifies. However, recognizing the significance of mitigating potential sound pollution to local communities in urban areas, we propose the management strategies of loudness levels and timing for swiftlet acoustic stimulation. The morning (06.00-08.30) and afternoon (15.30-19.00) hours present an ideal timeframe for acoustic stimulation with 80 dB. During midday (08.30-15.30), when swiftlet activity subsides, it is advisable to lower the loudness of acoustic stimuli (70-80 dB) to minimize disturbances. The sound management strategy creates a win-win situation for both swiftlet attraction and community noise mitigation. Ultimately, it offers harmonious coexistence and aligns with the stipulation of the Thailand Environmental Noise Regulation that the 24-hour average sound level must not exceed 70 dB (Royal Thai Government Gazette 2022).

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