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The Identification of the Frequency Variations in Swiftlet (*Aerodramus fuciphagus*) Calls on Breeding, Nestling, and Flocking Behavior

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Abstract: This study aims to analyze the acoustic characteristics of swiftlet (*Aerodramus fuciphagus*) calls on their three main behavioral phases: breeding, nestling, and flocking. The data in this study were collected by using the observation technique. The tools used were a sound recorder in the form of a Zoom Handy Recorder H1n and a laptop equipped with Audacity software and Swiftlets as the research subjects. The acoustic data analysis was carried out descriptively by describing the results of the four selected calls in each behavior displayed on the Audacity spectrogram for each observed parameter. In addition, the frequency parameters were analyzed descriptively by calculating the average (mean), minimum value, and maximum value from the results of the Fast Fourier Transform (FFT) display in Audacity. The data were then analyzed statistically and inferentially to test the differences in the sound characteristics between the behavioral phases by using SPSS software. The parameters with homogeneous variance were analyzed by using one-way analysis of variance (ANOVA), while the parameters with inhomogeneous variance were analyzed by using the Welch test. Based on the research results, the vocalization of swiftlets (*Aerodramus fuciphagus*) has clear variations in the temporal and frequency characteristics in the breeding, nestling, and flocking behavioral phases.

Keywords: Aerodramus Fuciphagus; Breeding; Flocking; Nestling; Swiftlet

Introduction

Swiftlets (*Aerodramus fuciphagus*) are a highly economically valuable bird, producing nests that are an export commodity with increasing global demand. (Amalia et al., 2021). Swiftlet nests from Indonesia are of higher quality and priced than those from other countries, thus encouraging swiftlet farming practices (Wahyuni et al., 2021). Communities build swiftlet houses that mimic cave ecosystems, regulating temperature and humidity, and playing recordings of swiftlet calls to attract nesting colonies (Fujita & Leh, 2020). In swiftlet farming, these sounds are played through speakers to produce clearer and stronger audio frequencies to attract swiftlets (Ikhsan, 2017).

In fact, the use of call in swiftlet farming is related to bioacoustics, a branch of science that studies sound production, transmission, and its effects on living organisms. The principles of bioacoustics and ecology form ecoacoustics, a cross-disciplinary field that studies the interrelationships between natural and anthropogenic sounds in ecosystems (Fajri et al., 2022). The parameters analyzed include duration, intensity, and frequency of sound (Mulyana et al., 2025). Bird sounds can also be used as the parameters to detect the presence of species because each type has a distinctive vocalization pattern that serves as the basis for identification (Budiman et al., 2016).

Obviously, the various bioacoustic studies have shown that the acoustic characteristics of sounds are related to the behavioral functions of birds. The differences in the acoustic parameters have been found to influence the behavioral responses in the various bird species in the different ecological contexts (Dong et al., 2025; Elvianti et al., 2024). In general, each bird species has a characteristic peak frequency characteristic of its vocal communication system (Wibowo & Kadarisman, 2018).

Audacity is software used to edit, visualize, and measure sound frequencies based on recorded sound signals via waveforms and spectrograms, allowing detailed observation of sound characteristics (Putri et al.,

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2023; Risondang et al., 2019). The previous research has shown that Audacity is capable of identifying frequencies and distinguishing vocalization characteristics between bird species (Hujatulatif et al., 2022).

Based on this background, the present study aims to identify the variations in the call frequency of swiftlets (*Aerodramus fuciphagus*) across the three distinct behavioral phases: breeding, nestling, and flocking, using a bioacoustic approach.

Method

This study used observational research to analyze the acoustic characteristics of swiftlet (*Aerodramus fuciphagus*) calls during the three main behavioral phases: breeding, nesting, and flocking. The study was conducted from September to December 2025 at a swiftlet house owned by CV. Dwi Anugrah Surabaya, located in Sidayu District, Gresik Regency, East Java. The tools and materials used included a Zoom Handy Recorder H1n sound recorder, a laptop equipped with *Audacity* software, and swiftlets as the research subjects. The research process is shown in Figure 1.

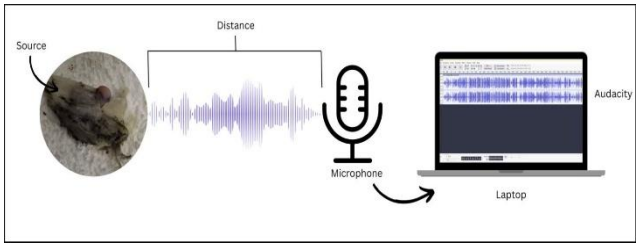

Figure 1. Implementation Process

The voice data were collected directly in the field by using a Zoom Handy Recorder H1n. The recordings were made for 10 minutes at each behavioral phase. The obtained voice data were then processed using the Audacity software. From the waveform and spectrogram displays, the four best calls for each behavioral phase were selected for the analysis. The temporal parameters included the call duration (s), call period (s), pulse number, and interpulse number (s), as shown in Figure 2.

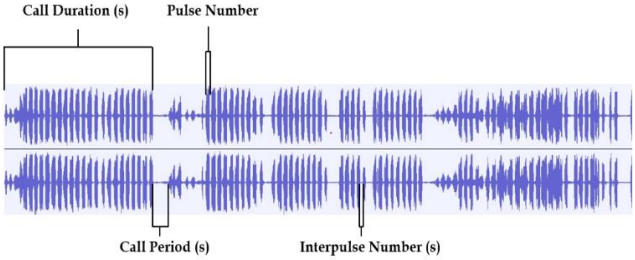

Figure 2. Voice Analysis Parameters

Meanwhile, the frequency parameters analyzed included the minimum frequency (Hz), maximum frequency (Hz), and dominant frequency (Hz) by using the Fast Fourier Transform (FFT) method. This method divides a signal into the different frequencies in a complex exponential function. It is an algorithm for calculating discrete Fourier transforms quickly and efficiently. Because signals in a communication system are continuous, the results can be used for the Fourier transform (Kusuma, 2021). The Fourier Transform can be defined by Formula 1:

$$S(f) = \int_{\{-\infty\}}^{\{\infty\}} s(t) e^{-j2\pi ft} dt \qquad (1)$$

S(f) : signals in the frequency domain (*frequency domain*)
s(t) : signals in the time domain (*time domain*)
$s(t)^{\,e-j2\pi ft}$: constant value of a signal
f : frequency
t : time

The acoustic data analysis was conducted descriptively by describing the results of four selected calls for each behavior displayed on an Audacity spectrogram for each observed parameter. This analysis aimed to describe the acoustic characteristics of swiftlet (*Aerodramus fuciphagus*) calls at each behavioral phase. Furthermore, the frequency parameters were analyzed descriptively by calculating the average (mean), minimum, and maximum values from the Fast Fourier Transform (FFT) displayed in Audacity.

Furthermore, the data were then analyzed statistically by using the inferential analysis to test for the differences in the vocal characteristics between the behavioral phases by using SPSS software. The parameters with homogeneous variance were analyzed by using one-way analysis of variance (ANOVA), while the parameters with heterogeneous variance were analyzed by using the Welch test. If the ANOVA results showed a significant difference, the analysis was continued with the Tukey HSD test, while significant Welch test results were followed by the Games-Howell test to identify differences between pairs of behavioral phases.

Results and Discussion

Based on the research results, the data on the temporal, frequency, and spectrum parameters were obtained in swiftlets (*Aerodramus fuciphagus*) across three distinct behavioral phases. The results of the data processing for the breeding behavior phase are presented in Tables 1 and 2.

Table 1. Temporal parameters in breeding behavior

Calling Number	Call Duration (s)	Call Period (s)	Pulse Number	Interpulse Number (s)
1.	5.212	5.807	28	0.073
2.	1.890	2.032	9	0.084
3.	5.352	7.910	29	0.080
4.	7.529	8.630	34	0.064
Mean	4.995	6.095	25	0.075

Based on the temporal parameter data generated during the breeding phase, call-duration ranged from 1,890 s to 7,529 s, with an average of 4,995 s. and the call-period ranged from 2,032 s to 8,630 s, with an average of 6,095 s. The number of pulses produced ranged from 9 to 34 pulses, with an average of 25 pulses. Meanwhile, the interpulse values ranged from 0.064 s to 0.084 s, with an average of 0.075 s.

Table 2. Sound frequency parameters in breeding behavior

Calling Number	Dominant Frequency (Hz)	Maximum Frequency (Hz)	Minimum Frequency(Hz)
1.	5456	15934	368
2.	4165	19834	355
3.	4433	15745	374
4.	5199	17156	378
Mean	4813	17167	369

The frequency analysis of the breeding behavior phase showed that the dominant frequency ranged from 4165 Hz to 5456 Hz, with an average value of 4813 Hz. The maximum frequency ranged from 15745 Hz to 19834 Hz, with an average value of 17167 Hz. Meanwhile, the minimum frequency ranged from 355 Hz to 378 Hz, with an average value of 369 Hz. A visualization of the Fast Fourier Transform (FFT) of breeding behavior can be seen in Figure 3 below.

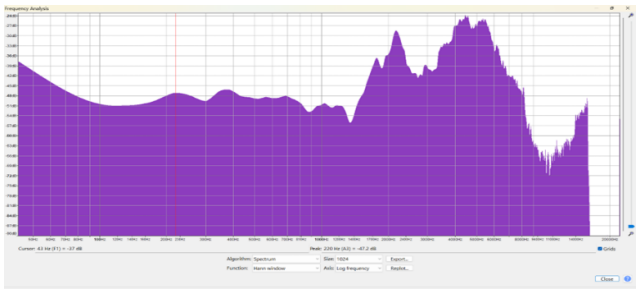

Figure 3. The Fast Fourier Transform (FFT) of breeding behavior

Based on the analysis, the breeding behavior exhibited fast and dense vocal characteristics. This was indicated by the shorter call-duration and the call-period values compared to other behavioral phases. The high number of pulses and the denser interpulse number values compared to other behavioral phases also indicated the vocal characteristics that tended to be intense, repetitive, and consistent. These vocal characteristics are part of the periodic structure of the sound used to describe the resulting sound patterns (Lapp et al., 2021).

In addition, the frequency analysis results indicated that the breeding behavioral phase had a relatively lower dominant frequency compared to other behavioral phases. The dominant frequency is defined as the frequency with the maximum amplitude in the amplitude spectrum (Haraguchi et al., 2023). Therefore, the dominant frequency value in the breeding behavior indicated the greatest sound energy at low frequencies.

Nevertheless, the breeding behavioral phase still produces a relatively broad sound spectrum because it produces the highest maximum value compared to other behavioral phases. The maximum frequency represents the highest frequency limit reached by the sound, while the minimum frequency represents the lowest frequency limit of the sound (Ningrum et al., 2024). This indicated that despite having a low dominant frequency, the swiftlets maintained a broad frequency range, albeit with smaller amplitudes. Meanwhile, the minimum frequency value in the breeding behavioral phase was lower than in flocking but higher than in nestling. However, the minimum frequencies in all three behavioral phases were in a relatively close range, indicating that the low frequency limits tend to be uniform.

Overall, the swiftlets had a vocal energy focused on the relatively low frequencies, yet maintained a wide frequency range to support effective communication during the reproductive phase.

However, the breeding period typically occurs during favorable environmental conditions, namely during the rainy season (wet season), which is associated with an abundance of insects that serve as swiftlet food (Petkliang et al., 2017; Wahyuni et al., 2021). This condition is accompanied by an increase in the intensity of swiftlet vocalizations, which breeders utilize to record sounds to attract birds to nest in breeding buildings (Ikhsan, 2017).

Table 3. Temporal parameters of nestling behavior

Calling Number	Call Duration (s)	Call Period (s)	Pulse Number	Interpulse Number (s)
1.	10.949	16.460	18	0.116
2.	9.934	15.300	15	0.238
3.	12.726	13.161	19	0.242
4.	11.239	16.786	17	0.161
Mean	11.212	15.427	17	0.189

Based on the temporal parameter data generated during the nestling behavior phase, call-duration ranged from 9.934 s to 12.726 s, with an average of 11.212 s. The call period ranged from 13.161 s to 16.786 s, with an average of 15.427 s. The number of pulses produced ranged from 15 to 19 pulses, with an average of 17 pulses. Meanwhile, the interpulse values ranged from 0.116 s to 0.242 s, with an average of 0.189 s.

Table 4. Sound frequency parameters in nestling behavior

Calling Number	Dominant Frequency (Hz)	Maximum Frequency (Hz)	Minimum Frequency(Hz)
1.	6180	10572	304
2.	6260	10243	300
3.	6139	11562	302
4.	6327	10103	310
Mean	6226	10620	304

The frequency results in the nestling behavior phase showed that the dominant frequency ranged from 6139 Hz to 6327 Hz with an average value of 6226 Hz. The maximum frequency ranged from 10103 Hz to 11562 Hz with an average value of 10620 Hz. Meanwhile, the minimum frequency produced was in the range of 300 Hz to 310 Hz with an average value of 304 Hz. The visualization of Fast Fourier Transform (FFT) in breeding behavior can be seen in Figure 4.

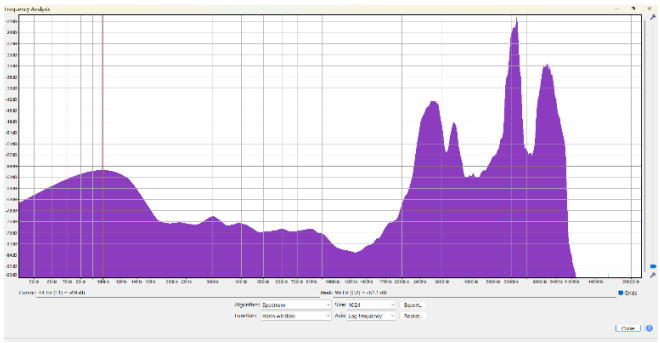

Figure 4. The Fast Fourier Transform (FFT) on Nestling Behavior

Based on the analysis, the nestling phase exhibited relatively longer and slower vocal characteristics compared to other behavioral phases. This was evident from the higher call-duration and call-period values. Furthermore, the pulse number produced was also relatively low, indicating that over a long duration, the sound density tends to be low. The interpulse number obtained was relatively higher compared to other behavioral phases, indicating a wider spacing between pulses.

Moreover, the frequency analysis results showed a higher dominant frequency value compared to the breeding phase but lower than the flocking phase. This indicated that the peak acoustic energy was at a higher frequency than in the breeding behavior. Although the maximum and minimum frequencies produced were relatively smaller than in the other two behavioral phases, this indicated that during the nestling phase, swiftlets produced a spectrum of sounds encompassing high frequencies. However, the amplitude was not dominant across the entire frequency range.

Furthermore, this vocalization pattern aligns with their biological function: begging calls/submissive chick-like vocalizations, which are common in young birds when they are hungry or need parental attention, especially after a period without food the previous day (Dermi et al., 2018).

Table 5. Temporal parameters of flocking behavior

Calling Number	Call Duration (s)	Call Period (s)	Pulse Number	Interpulse Number (s)
1.	6.266	7.005	25	0.093
2.	6.737	7.240	24	0.093
3.	3.524	4.102	15	0.084
4.	7.744	8.301	29	0.101
Mean	6.068	6.662	23	0.093

Based on the temporal parameter data generated in the flocking behavior phase, the call-duration value ranged from 3,524 s to 7,744 s, with an average value of 6,068 s. The call-period value was in the range of 4,102 s to 8,301 s with an average value of 6,662 s. The number of pulses generated ranged from 15 to 29 pulses with an average value of 23 pulses. Meanwhile, the interpulse value generated was in the range of 0,084 s to 0,101 s with an average value of 0,093 s.

Table 6. Sound frequency parameters in flocking behavior

Calling Number	Dominant Frequency (Hz)	Maximum Frequency (Hz)	Minimum Frequency (Hz)
1.	7192	15596	488
2.	7315	15791	325
3.	6493	15701	306
4.	6733	15899	388
Mean	6933	15747	377

The frequency results in the flocking behavior phase showed that the dominant frequency ranged from 6493 Hz to 7315 Hz with an average value of 6933 Hz. The maximum frequency ranged from 15596 Hz to 15899 Hz with an average value of 15747 Hz. Meanwhile, the minimum frequency produced ranged from 306 Hz to 488 Hz with an average value of 377 Hz. Fast Fourier Transform (FFT) visualization of breeding behavior can be seen in Figure 5.

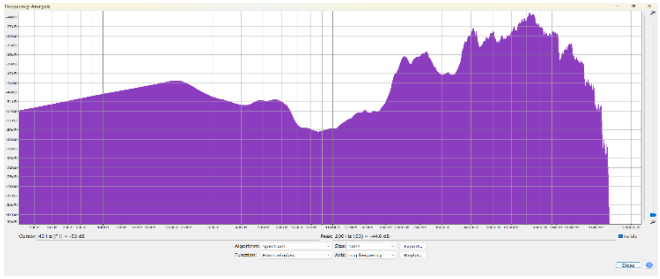

Figure 5. The Fast Fourier Transform (FFT) for Flocking Behavior

Based on the analysis, the flocking phase exhibited a more balanced vocal character compared to other behaviors. This was evident from the call-duration and call-period values, which were shorter than those in the nestling phase but higher than those in the breeding phase. Furthermore, the pulse number and interpulse number also fell between the two behavioral phases, indicating a more balanced density and spacing between pulses.

Therefore, the frequency analysis results indicated that the flocking phase had a higher dominant frequency compared to other behaviors. This indicated that during the flocking phase, the acoustic energy of swiftlet vocalizations was more focused on the higher frequencies. Furthermore, the maximum frequency produced was smaller than that in the breeding phase but higher than that in the nestling phase, and the minimum frequency was relatively higher than that in both behavioral phases. This indicated that the swiftlets in the flocking phase maintained a fairly broad frequency spectrum, although it was not as broad as the breeding phase or as low as the nestling phase.

This condition is closely related to the need for coordination and communication between individuals within a group, so acoustic energy tends to be focused on certain, higher frequencies to increase the effectiveness of signal transmission (Sinaga et al., 2024).

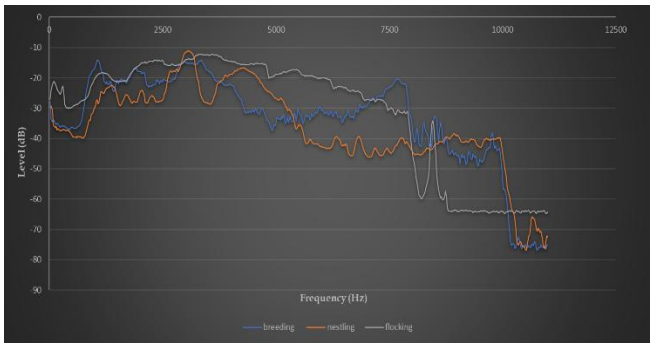

Figure 6. Fast Fourier Transform (FFT) spectrum of swiftlets (*Aerodramus fuciphagus*) in all behavioral phases.

Based on the Fast Fourier Transform (FFT) spectrum results of swiftlet (*Aerodramus fuciphagus*) calls across all behavioral phases, it had the differences in the spectral patterns, relative intensity, and frequency distribution, which were observed for each behavioral phase, allowing for comparative observation of frequency characteristics.

Based on the results of inferential statistical analysis using SPSS, the normality test showed that all parameters were normally distributed ($p > 0.05$). The homogeneity test showed that the call-duration, call-period, and pulse number parameters had homogeneous variance ($p > 0.05$), while the interpulse number, dominant frequency, maximum frequency, and minimum frequency parameters showed non-homogeneous variance ($p < 0.05$). Therefore, testing for the differences between the behavioral phases was conducted by using one-way ANOVA on parameters with homogeneous variance and Welch's test on parameters showing non-homogeneous variance.

The results of the one-way ANOVA and Welch's test showed significant differences between the behavioral phases in almost all tested parameters ($p < 0.05$), except for pulse number ($p > 0.05$). Therefore, the analysis continued with a Tukey HSD test on the parameters analyzed using ANOVA and a Games-Howell test on the parameters analyzed using Welch's test, to identify pairs of behavioral phases that differed significantly. Tukey's further test on the parameters of call-duration and call-period showed the significant differences in certain pairs of behavioral phases. For both parameters, the significant differences were found between breeding and nestling behavior, as well as between nestling and flocking ($p < 0.05$), while breeding and flocking showed no significant differences.

Furthermore, a Games-Howell test on the interpulse parameter and the swiftlet call frequency parameters showed the distinct patterns of the differences between the behaviors. For the interpulse parameter, a significant difference was found only between breeding and flocking behavior ($p < 0.05$), while the other behavioral pairs showed no significant differences. For the dominant frequency parameter, the significant differences occurred between breeding and nestling, as well as between breeding and flocking ($p < 0.05$), while nestling and flocking did not differ significantly. Meanwhile, the significant differences were found in the maximum frequency parameter across all pairs of behavioral phases ($p < 0.05$), indicating that the highest frequency range in swiftlets varies significantly according to their behavioral phase. Significant differences were found only between the breeding and nestling behavioral phases ($p < 0.05$), while no significant differences were found in the other pairs of behavioral phases.

Conclusion

Based on the research results, the vocalization of swiftlets (*Aerodramus fuciphagus*) had clear temporal and frequency characteristics variations in the breeding, nestling, and flocking behavioral phases. The breeding phase was characterized by a fast, dense, and consistent vocal pattern with a relatively low dominant frequency but a wide spectral range, reflecting the intensity of communication during reproductive activity. The nestling phase showed a longer and slower vocal character, with a low pulse density and a higher dominant frequency compared to breeding, which was related to the biological function of chick vocalization. Meanwhile, the flocking phase showed a more balanced vocal character, with the highest dominant frequency and a fairly wide spectral range, supporting the effectiveness of communication in group interactions.

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Author Contributions
Conceptualization, R.R. and S.K.; methodology, R.R.; software, R.R.; validation, R.R. and S.K.; formal analysis, R.R.; investigation, S.K.; resources, S.K.; data curation, R.R.; writing—original draft preparation, R.R.; writing—review and editing, R.R. and S.K.; visualization, R.R.; supervision, S.K.; project administration, S.K.; funding acquisition, R.R. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest
The authors declare no conflict of interest.

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