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Acoustic Characteristics of Alarm Calls in Sika Deer in Relation to Escape Behavior

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Abstract

Sika deer (*Cervus nippon*) invade farmlands and grazing areas, causing agricultural damage through feeding. We aimed to create an effective technology that utilizes the natural communication patterns of sika deer to regulate behavior and encourage escape responses. However, the vocalization characteristics of sika deer, particularly those related to alertness and escape, have not been fully clarified. This study examined how the acoustic characteristics of sika deer alarm calls differed according to the presence or absence of escape behaviors during alert states. Alarm calls were collected from mixed herds of male, female, and juvenile sika deer and analyzed. Vocalizations were converted into spectrograms using the acoustic analysis software Praat and analyzed based on 27 acoustic parameters, including call duration. Significant differences ($P < 0.05$) were revealed in the fundamental frequency (mean, minimum, and maximum), intensity (mean), formants 1 and 3, number of pulses, number of periods, fraction of locally unvoiced frames, number of voice breaks, and degree of voice breaks between groups with and without escape behavior. In particular, an increase of at least 280 Hz in the fundamental frequency (mean) of alarm calls increased by at least 280 Hz when escape behavior accompanied the alarm call.

Discipline: Animal Science
Additional key words: acoustic features, alarm call, vocalization

Introduction

Japan is facing a challenge with its sika deer (*Cervus nippon*) population, which is growing rapidly. These sika deer are spreading into cattle grazing areas, which is a concern because of their potential to cause conflict and disease. Public pastures are enclosed by electric fences and physical barriers to prevent cattle from escaping. However, these barriers do not stop the far more agile sika deer. In addition, because sika deer and cattle are both herbivores, they compete for food. This reduces grassland productivity and ultimately affects livestock production. The authors are developing a technology that uses sika deer vocalizations to keep sika deer out of grazing areas, and to encourage them to flee if they have already entered these areas.

Sika deer use different vocalizations depending on the situation. Minami & Kawamichi (1992) observed sika deer vocalizations directly and linked these to behavioral characteristics. They classified the vocalizations into five groups: successive grunts, moans, distress calls, howls, and alarm calls. Alarm calls are vocalizations produced when sika deer detect predators or other threats. Minami & Kawamichi (1992) reported that sika deer vocalize alarm calls in response to humans, foreign objects, and wild dogs. After emitting this call, the sika deer either gathered around the individual that vocalized or began to flee. These vocalizations were analyzed spectrographically to quantify call duration and fundamental frequency. On average, the alarm call was 0.12 s long, with fundamental frequencies ranging from 1,824 to 2,688 Hz. However, the authors did not specify the acoustic type or variation within alarm call. We previously collected alarm calls from sika deer (*C. n. centralis*) in an alert state (Nakamura & Tooyama 2025a). We then performed hierarchical cluster analysis and classified the calls into two populations. Furthermore, we demonstrated differences in the acoustic characteristics

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of call duration, fundamental frequency, and formants 2-5 between the groups. These results suggest that acoustic parameters can be grouped when quantified, even among vocalizations considered functionally equivalent, revealing significant differences. Similar to cattle (Nakamura & Tejima 2024, Nakamura & Tooyama 2025b), this suggests that individual and intraspecific variations exist in sika deer alarm calls. An alarm call of the Sichuan sika deer (*C. n. sichuanicus*), a subspecies of sika deer (*C. n.*), have also been reported by Yang et al. (2012). They reported that the fundamental frequency of alarm calls decreases with age and is significantly higher in females than in males. Additionally, they used physical proximity to observers to collect alarm calls from Sichuan sika deer. The fundamental frequency of Sichuan sika deer alarm calls differed depending on whether the approach was relatively slow and distance was maintained or rapid with abrupt movements. In particular, the duration of the alarm call was reported to become shorter, and the fundamental frequency to increase, when the animals were approached suddenly. However, the acoustic factors other than fundamental frequency were not investigated. Furthermore, the relationship between the presence or absence of escape behavior and acoustic factors was not clarified. To date, no studies have investigated the effects of escape behavior on changes in the acoustic factors of sika deer alarm calls.

In the present study, we clarified how the acoustic characteristics of alarm calls change depending on the presence or absence of escape behaviors.

Materials and methods

1. Animals

This study was conducted in accordance with the regulations of the National Agriculture and Food Research Organization for the Implementation of Animal Experiments; sika deer experiment approval nos. R5-W03-NILGS-2 and R7-W01-NILGS. Twenty-eight sika deer (*C. n. yakushimae*) (6 adult males, 14 adult females, and 8 juveniles) housed in the Ueda City Shimin-no Mori Park (Ueda City, Nagano Prefecture, Japan) were observed from March to June 2024. The same group of sika deer (4 adult males, 14 adult females, and 7 juveniles) was also observed from October to December 2025. Adult males, adult females, and juveniles were housed in groups at a fenced exhibition facility in the park. The facility was located on a slope in the park surrounded by woods (Fig. 1). The sika deer were fed roughage and compound feed daily and had free access to drinking water. The change in deer population between 2024 and 2025 was due to births within the group and deaths caused by indigestion following accidental excessive soybean intake.

2. Collection of vocalizations

Recordings of alarm calls of sika deer were collected from March to June 2024 and from October to December 2025. Sampling was conducted between 10:00 and 14:00. Recording was suspended during periods of strong wind or rain. Additionally, the experiment was paused and a break of at least 30 minutes was taken whenever visitors came to the deer facility. The recordings were carefully obtained to ensure the exclusion of environmental sounds in the vicinity. We addressed the issue of ambient noise in two ways. First, the experimenter took care to avoid generating any ambient noise. Second, we attached a windscreen to the recording device to eliminate ambient noise. The sika deer calls were collected using the method described by Nakamura & Tooyama (2025a). By combining canine calls with the presentation of animal models, we provoked the sika deer into an alert state and encouraged vocalization (Fig. 1). In addition to using balloon models of dogs and tigers, the experimenter wore a dog mask to mimic animal behavior. The experimenters varied the stimuli used in the animal models to prevent the sika deer's behavior from becoming dulled due to habituation.

Canine vocalizations were used as stimulus sounds for the sika deer. The canine sounds were obtained from a Karelian bear dog (ELF, born on April 1, 2018, female, 5 years old at the time of voice collection) owned by the Picchio Wildlife Research Center (Karuizawa, Japan). In this study, we used Karelian bear dogs, which can vocalize in response to human commands and typically vocalize toward bears and deer. Therefore, we defined the vocalizations produced by these dogs as having the same meaning when directed at wild animals. A Linear Pulse Code Modulation (LPCM) recorder (PCM A10, Sony, Tokyo, Japan) was used to record the canine calls. The recording mode was STEREO with a sampling frequency of 44.1 kHz and a quantization bit rate of 16 bits. The sound files were saved in the Waveform Audio File Format (WAV). Canine sounds were saved as audio files on a smartphone and played using a Bluetooth speaker (SRS XB01, Sony, Tokyo) set up in front of the sika deer exhibition facility.

Playback and volume were controlled remotely using a smartphone. Alarm calls of the sika deer were recorded using an LPCM recorder (PCM, Sony, Tokyo) with a windscreen that was installed on the fence of the exhibition facility (Fig. 1). The recording mode was STEREO with a sampling frequency of 96.0 kHz and a quantization bit rate of 24 bits. The sound files were

saved in WAV.

The procedure used to elicit sika deer vocalizations is described below. The alarm calls of sika deer were recorded using our method of combining dog barking with the manipulation of animal models (Nakamura & Tooyama 2025a). The onset and termination of vocalizations in sika deer under investigation were determined by sequentially performing methods (A) and (B). (A) One of the experimenters used a smartphone to play the sound of a dog barking three times from a wireless speaker to the target sika deer. The sika deer entered a tense state and looked in the direction of the dog barking sound. (B) Another experimenter presented an animal model to the tense sika deer. The sika deer could not see the experimenters standing at locations that were not visible to them. By repeating this procedure, the sika deer moved from a tense state to an alert state. Subsequently, the sika deer produced an alarm call while in an alert state. The alarm call of sika deer is a high-pitched, very short vocalization produced while the entire body is visibly tense. On the other hand, sika deer emitted alarm calls and displayed escape behavior when the level of alertness peaked. More specifically, the type of call was determined by whether escape behavior was present. For this experiment, we defined sika deer escape behavior as all deer issuing alarm calls and fleeing in response to an external stimulus. Additionally, the escape behavior consisted of the entire group running away from the stimulus.

The ambient sound level during recording was approximately 40 dB (SL-200U; Custom, Tokyo, Japan). However, individual identification of each sika deer vocalization was not possible. All vocalizations of the sika deer were recorded between 40 and 20,000 Hz in the

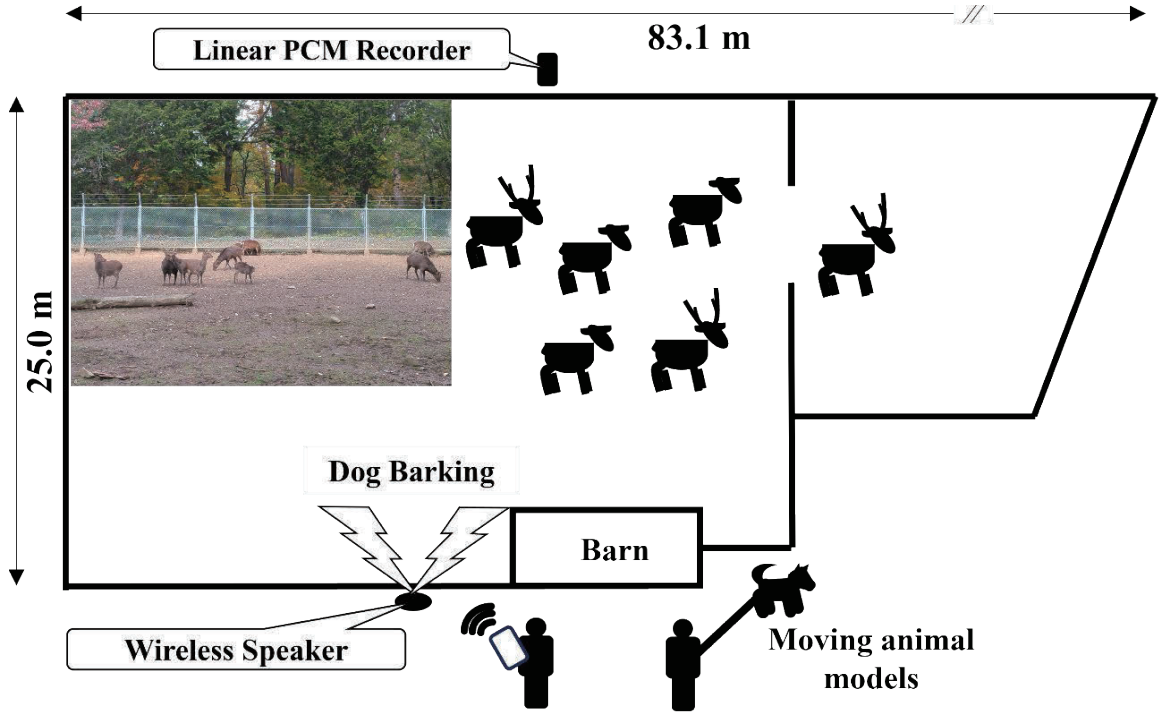


Fig. 1. Sika deer exhibition facility and method for collecting alarm calls
The following procedures were sequentially performed to elicit alarm calls in sika deer. (A) One of the experimenters used a smartphone to play the sound of a dog barking three times from a wireless speaker to the target sika deer. The sika deer entered a tense state and looked in the direction of the dog barking sound. (B) Another experimenter presented an animal model to tense sika deer. The sika deer could not see the experimenters standing at locations that were not visible to them. By repeating this procedure, the sika deer moved from a tense state to an alert state. Subsequently, the sika deer produced an alarm call while in an alert state. In contrast, sika deer emitted alarm calls and displayed escape behavior when the level of alertness peaked. More specifically, alarm calls were categorized according to the presence or absence of escape behavior. For this experiment, escape behavior was defined as a group response in which all deer emitted alarm calls and fled in response to an external stimulus. Specifically, the escape behavior consisted of the entire group running away from the stimulus. Alarm calls were recorded using a linear pulse code modulation recorder. Alarm calls were recorded at a distance of 10 m-20 m from the individual doing the vocalizing.

LPCM recording mode using an integrated circuit recorder (PCM; Sony, Tokyo). The distance from which the vocal sounds of the sika deer were recorded was approximately 10 m-20 m. We used a laser rangefinder (LKT-G03BK; Tajima, Tokyo, Japan) to measure the distance.

3. Data analysis

The recorded vocalizations from all sika deer were uploaded to a computer at a sampling rate of 44.1 kHz and saved as WAV files at a 16-bit amplitude resolution. Vocalizations that did not contain noise (e.g., metallic sounds produced by sika deer hitting fences or environmental sounds, such as bird and insect sounds) were extracted and used in the analysis. However, the sika deer were not individually identified.

We used Praat version 6.3.10 (Boersma & Weenink 2022) for the acoustic analyses. An example of the analysis of sika deer vocalizations is shown in Figure 2. First, the experimenter listened to a vocalization to confirm that it was an alarm call. The experimenter then observed the waveform and spectrogram to verify that no noise was present and to determine the vocalization to analyze. In this study, the range of intensity displays was defined as a single voice for the analysis. The conditions for analyzing the sika deer voice were as follows: vocalizations of sika deer were individually visualized on spectrograms in Praat (Fourier method, narrow-band spectrogram; window length, 0.01 s; dynamic range, 60 dB; view range, 0 ~ 22,000 Hz). Additionally, vocalizations of sika deer with high levels of background noise were not considered in the acoustic analysis. The remaining settings were as follows (with reference to Nakamura & Tooyama 2025a): pitch range, 600 ~ 3,000 Hz; intensity range, 50 ~ 100 dB; intensity averaging method, mean energy; formant ceiling, 10,000 Hz; number of formants, 5; formant window length, 0.025; and dynamic range, 30.

Definitions of the vocal parameters analyzed in the sika deer vocalizations are listed in Table 1 (see the Praat manual for more detailed information; Boersma & Weenink 2022). Vocalization duration (s) was measured using the waveform. The fundamental frequency (Hz), intensity (dB), formants 1 ~ 4 (Hz), bandwidths 1 ~ 4 (Hz), number of pulses, number of periods, fraction of locally unvoiced frames (%), number of voice breaks, degree of voice breaks (%), jitter (%), shimmer (%), mean autocorrelation, mean noise-to-harmonic ratio (%), and mean harmonics-to-noise ratio (dB) were analyzed. Particularly, formants are defined as the local maximum frequencies in the sound spectrum (Table 1) and typically represent multiple frequency peaks in vocalizations. This makes them factors that express the characteristics of vocalization.

In the present experiment, the number of vocalizations accompanied by escape behavior was low, with only 14 instances recorded. Therefore, the Mann-Whitney U-test, a non-parametric test, was

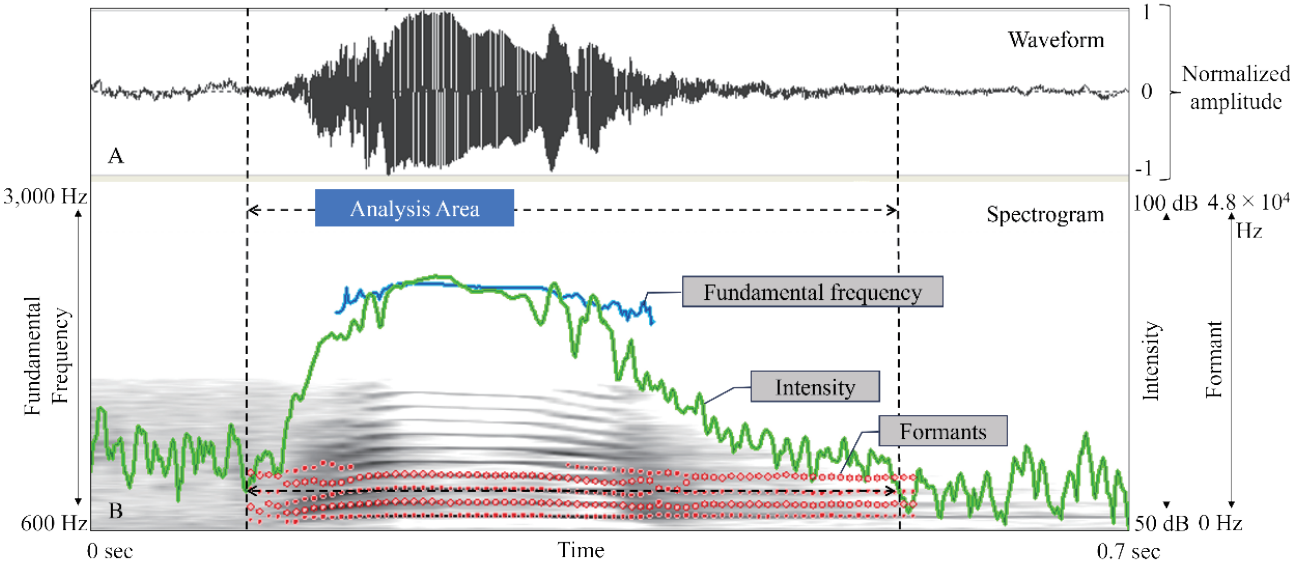


Fig. 2. Example of waveform (A) and spectrogram (B) of sika deer vocalization
The X- and Y-axes represent time and frequency, respectively. Blue lines indicate fundamental frequencies. Green lines indicate intensity, and red dotted lines indicate formant contours. The analysis range of the calls was defined as the interval during which the intensity increased and subsequently returned to its original level.

conducted using independent samples. Statistical analyses were conducted using IBM SPSS Statistics Version 21 (IBM, Armonk, NY, USA).

Results

In this study, a total of 268 sika deer alarm calls were recorded during the experimental period. Additionally, 35 calls were excluded due to noise. Ultimately, 233 calls were used for analysis, representing 87% of the total.

Sika deer alarm calls were categorized based on the presence or absence of escape behavior and the acoustic factors of the alarm calls were compared (Table 2). Significant differences were observed between the groups for fundamental frequency (mean, minimum, and maximum), intensity (mean), formants 1 and 3, number of pulses, number of periods, fraction of locally unvoiced frames, number of voice breaks, and degree of voice breaks. Specifically, the mean fundamental frequency of alarm calls accompanied by escape behavior was 2,190 Hz, which was 280 Hz higher than the 1,906 Hz observed for alarm calls not accompanied by escape behavior ($P < 0.01$). Furthermore, the fundamental frequencies (minimum and maximum) were higher by 400 Hz and 250 Hz, respectively, than those of alarm calls not accompanied by escape behavior ($P < 0.05$ and 0.001, respectively). The intensity (mean) of alarm calls without

Table 1. Definitions of vocal parameters analyzed in sika deer vocalization

Parameters/Unit of measure	Definition
Call duration (s)	Total duration of vocalization (from start to end)
Fundamental frequency (Hz)	Subjective auditory sensation and depends on the frequency
mean	Mean of the fundamental frequency
minimum	Minimum of the fundamental frequency
maximum	Maximum of the fundamental frequency
range	Difference between minimum and maximum fundamental frequency
Intensity (dB)	The degree of strength of the vocalization
mean	Mean of the intensity
minimum	Minimum of the intensity
maximum	Maximum of the intensity
range	Difference between minimum and maximum intensity
Formant (Hz)	Local maximum frequencies in the sound spectrum
Formant 1	The first harmonic of resonance
Formant 2	The second harmonic of resonance
Formant 3	The third harmonic of resonance
Formant 4	The fourth harmonic of resonance
Bandwidth (Hz)	Range of frequencies or transmission speeds used for communication
Bandwidth 1	The first range of bandwidth
Bandwidth 2	The second range of bandwidth
Bandwidth 3	The third range of bandwidth
Bandwidth 4	The fourth range of bandwidth
Number of pulses	Pulse is defined as a short transient signal
Number of periods	Period is defined as the time to complete a cycle or repetition
Fraction of locally unvoiced frames (%)	The percentage of pitch frames analyzed as unvoiced
Number of voice breaks	The number of distances between consecutive pulses greater than 1.25 divided by the pitch floor
Degree of voice breaks (%)	Total length of pauses between voices divided by total length of analyzed portion
Jitter (%)	Frequency variation from cycle to cycle
Shimmer (%)	Amplitude variation from cycle to cycle
Mean autocorrelation	Correlation between the values of a signal at different points in time
Mean noise-to-harmonics ratio (%)	Ratio of detectable noise amplitude peaks to harmonic threshold
Mean harmonics-to-noise ratio (dB)	Ratio of detectable harmonic amplitude peaks to noise threshold

escape behavior was 80 dB, whereas that of alarm calls with escape behavior was significantly lower at 79 dB ($P < 0.001$). However, alarm call formants 1 and 3 involving escape behavior were 2,157 Hz and 4,910 Hz, respectively, and lower than those in the non-escape behavior alarm calls. These reductions were of 220 and 150 Hz ($P < 0.001$ and 0.05, respectively). Furthermore, the number of pulses and periods, as well as the number of voice breaks, were significantly lower ($P < 0.001$, 0.001, and 0.01, respectively) in alarm calls accompanied by escape behavior than those without. However, the fraction of locally unvoiced frames and the degree of voice breaks in alarm calls were significantly higher ($P < 0.001$ and 0.05, respectively) in alarm calls accompanied by escape behavior.

Table 2. Comparison of acoustic parameters in sika deer alarm calls between two groups

Parameters	Unit of measure	Alarm calls without escape	Alarm calls accompanied by escape	*P*-value
Number of calls		219	14	
Call duration	s	0.46 ± 0.12	0.42 ± 0.10	0.205
Fundamental frequency				
mean	Hz	1,906 ± 254	2,190 ± 320	**0.006**
minimum	Hz	1,406 ± 421	1,807 ± 412	**0.011**
maximum	Hz	2,215 ± 252	2,474 ± 277	**0.001**
range	Hz	809 ± 430	667 ± 371	0.287
Intensity [a]				
mean	dB	80 ± 2	79 ± 1	**0.001**
minimum	dB	58 ± 3	57 ± 2	0.219
maximum	dB	88 ± 2	87 ± 2	0.066
range	dB	29 ± 4	30 ± 3	0.878
Formant				
F1	Hz	1,936 ± 154	2,157 ± 198	**0.001**
F2	Hz	3,140 ± 339	3,339 ± 344	0.054
F3	Hz	4,757 ± 365	4,910 ± 167	**0.031**
F4	Hz	6,767 ± 490	6,642 ± 579	0.422
Bandwidth				
B1	Hz	274 ± 623	242 ± 273	0.198
B2	Hz	729 ± 838	468 ± 370	0.413
B3	Hz	651 ± 1,005	869 ± 799	0.097
B4	Hz	1,158 ± 1,039	1,152 ± 935	0.906
Number of pulses		400 ± 137	227 ± 117	**0.001**
Number of periods		397 ± 137	224 ± 115	**0.001**
Fraction of locally unvoiced frames	%	31 ± 13	58 ± 18	**0.001**
Number of voice breaks		0.8 ± 0.9	0.1 ± 0.4	**0.008**
Degree of voice breaks	%	5 ± 8	2 ± 7	**0.021**
Jitter	%	2 ± 1	2 ± 2	0.930
Shimmer	%	11 ± 4	13 ± 5	0.109
Mean autocorrelation		0.9 ± 0.1	0.9 ± 0.0	0.849
Noise/Harmonics ratio	%	0.1 ± 0.1	0.1 ± 0.1	0.924
Harmonics/Noise ratio	dB	13 ± 4	12 ± 3	0.087

Mean ± SD

Details of the parameters are listed in Table 1.

[a] Because the distance between the vocalizing individual and the integrated circuit recorder was not constant, the intensity may have been affected.

Discussion

The sika deer alarm call is a short, high-pitched vocalization that sounds like the Japanese onomatopoeic expression '*kyaan*.' The call duration was unaffected by the presence or absence of escape behavior. It ranged from 0.42 s to 0.46 s (Table 2). However, Minami & Kawamichi (1992) reported an average call duration of 0.12 s for adult female sika deer (*C. n.*), whereas Long et al. (1998) reported an average call duration of 0.17 s. Yang et al. (2012) reported the average call duration for an adult female sika deer (*C. n. sichuanicus*) as approximately 0.5 s. The discrepancies between results of previous studies and those of this study may be attributable to the following analytical issues. Call duration refers to the length of time between the beginning and end of vocalization. However, the method used to determine this has not been defined yet. The experimenter typically listens to the recorded vocalization and observes the waveform or spectrogram (Fig. 2) to determine the call duration range. In the present study, intensity was adopted as a potential metric to define the call duration range. Owing to vocalizations from the target animals, the intensity increases sharply, even in outdoor environments with background noise. This makes the intensity easily distinguishable and facilitates the determination of the vocalization ranges. However, in our previous study (Nakamura & Tooyama 2025a), we defined the range of the voiced segment as that of the first formant displayed in the spectrogram. As a result, the range of call durations was similar to values reported in previous studies (Minami & Kawamichi 1992, Long et al. 1998), ranging from 0.17 s to 0.23 s. Thus, the difference in call duration between the present study and previous ones was likely influenced by variations in how the analysis range was determined.

When escape behavior was observed, the fundamental frequency was significantly higher ($P < 0.01$) at a mean of 2,190 Hz (Table 2). Previous reports on sika deer indicated frequencies ranging from 1,824 Hz to 2,688 Hz (Minami & Kawamichi 1992) and from 1,814 Hz to 2,597 Hz (Long et al. 1998). These results are similar to those of the present study. By contrast, Yang et al. (2012) reported that when threat-induced tension is high, the fundamental frequency of alarm calls increases. This finding is supported by the results of the present study, which showed that the fundamental frequency of alarm calls accompanied by escape behavior was significantly higher than that of alarm calls without escape behavior. However, the present study found that call duration remained comparable and did not decrease, in contrast to the findings of Yang et al. (2012). In the present study, the maximum distance at which alarm calls were emitted was approximately 45 m and the maximum distance at which escape behavior commenced was approximately 15 m. Few studies have investigated the escape initiation distance in deer. LaGory (1987) observed white-tailed deer in both pastures and forests. He reported that deer located more than 100 m away from pastures were less likely to flee than those located at the same distance in the forests. In contrast, Ikeda & Koizumi (2024) examined how the hunting season affects the distance at which sika deer begin to flee. They found that during the non-hunting season, sika deer began to flee at distances ranging from 47.9 to 60.8 m. During the hunting season, however, sika deer began to flee at distances ranging from 37.3 to 102.5 m. These results suggest that the escape threshold distance differs between captive and wild deer populations. The results of the present study suggest that sika deer use distinct alarm calls with different acoustic characteristics depending on whether they exhibit escape behavior. However, further research, such as playing vocalizations to wild deer, is needed to determine the actual distance at which escape behavior is induced.

The intensity differed significantly ($P < 0.001$), with an average difference of 1 dB (Table 2). However, the distance between the vocalizing individuals and the integrated circuit recorder was not constant, ranging from approximately 10 to 20 m. Furthermore, it is unlikely that vocalizing individuals consistently maintained a constant vocal intensity or kept their heads fixed in one direction. Consequently, the intensity results are presumed to have been influenced by these factors.

Formants 1 and 3 were significantly higher in alarm calls accompanied by escape behavior ($P < 0.001$ and 0.05, respectively; Table 2). Few studies have examined vocalization formants in sika deer. For instance, Nakamura & Tooyama (2025a) examined formants 1 ~ 5 in sika deer alarm calls. Their results were similar to those of the present study; F1 ranged from 1,714 Hz to 1,777 Hz, F2 from 2,974 Hz to 3,395 Hz, F3 from 4,631 Hz to 5,032 Hz, and F4 from 6,661 Hz to 6,918 Hz. The fundamental frequency and formant are both crucial elements that constitute a voiced sound. However, they play different roles; the fundamental frequency indicates the pitch, whereas the formant is related to the timbre. In other words, the results of this study suggest that when faced with a significant impending threat, sika deer may exhibit escape behavior by increasing the fundamental frequency of their alarm calls and altering formants 1 and 3.

The present study focused on the *C. n. yakushimae* subspecies of sika deer. Other subspecies include *C. n.*

centralis and *C. n. yesoensis*. There are comparative reports of sika deer vocalizations across species and subspecies. For example, Long et al. (1998) compared rutting and alarm calls in red deer (*C. elaphus*), sika deer (*C. n.*), and red × sika hybrids (*C. e. × n.*). Wyman et al. (2011, 2014, 2016) reported differences in vocalizations between species using the rutting calls of red and sika deer. Frey & Riede (2013) examined the differences in rutting calls between North American elk (*C. canadensis*) and red deer, and presented anatomical findings. The present study analyzed alarm calls, a type of vocalization, using the subspecies *C. n. yakushimae* of sika deer as the test animal. To our knowledge, this is the first report on alarm calls of this subspecies. The sika deer (*C. n. centralis*) examined in our previous study (Nakamura & Tooyama 2025a) did not exhibit escape behavior, which was evident from the lack of such actions during the analysis of alarm calls. This was likely owing to the stair-step configuration of the enclosure. In the present study, the mean fundamental frequency of alarm calls without escape behavior was 1,906 Hz (see Table 2), which was more than 100 Hz higher than the range of 1,760 ~ 1,777 Hz reported by Nakamura & Tooyama (2025a). Additionally, the mean fundamental frequency of alarm calls accompanied by escape behavior was 2,190 Hz, which was over 400 Hz higher than the range reported by Nakamura & Tooyama (2025a). These results also suggested that the fundamental frequency of *C. n. yakushimae* was higher than that of *C. n. centralis*. This indicates that there may be differences in the acoustic characteristics of sika deer alarm calls between the subspecies.

This study is the first to report that the number of pulses, periods, locally unvoiced frames, voice breaks, and the degree of voice breaks in alarm calls of sika deer vary based on the presence or absence of escape behavior. Reports on the differences in the acoustic factors of deer vocalizations based on a single action, such as an alarm call, defined by the presence or absence of a certain behavior are scarce. Garcia et al. (2014) investigated the behavioral effects of common and harsh roars on male red deer. We found that the roars of the two groups differed in their waveform and spectrogram shapes. Additionally, the deer behaved differently when the two roars were played back. These results indicate that altering the acoustic characteristics of deer vocalizations with identical behavioral meanings changes the informational significance conveyed to other individuals, mirroring the findings of the present study.

A total of 268 sika deer alarm calls were recorded during the experimental period. Of these, 87% were used in the analysis. Furthermore, of the calls incorporated into the analysis, there were 165 calls in 2024, in comparison to 68 calls in 2025. The experiment to collect sika deer alarm calls was conducted in the spring of 2024, while the one in 2025 was conducted in the winter. In other words, depending on the season, the physiological and reproductive states of the calling sika deer may have varied. Since individual sika deer could not be identified in this study, the sex and age of the calling sika deer remained unknown. Consequently, the results reflect the influence of sika deer sex, age, and seasonal physiological state. Future studies should investigate the acoustic characteristics of sika deer alarm calls and the presence or absence of escape behavior while controlling for these factors.

In this study, we exposed a sika deer population to stimuli over several days in order to collect alarm calls. The stimuli consisted of dog barking and animal models. By varying the types of animal models used, we avoided habituation to the stimuli. Although this study is based on observational findings, there was a tendency for habituation to reset when the experiment was repeated on a different day. However, future studies should investigate changes in the acoustic characteristics of alarm calls when sika deer become accustomed to the stimuli.

In conclusion, the acoustic characteristics of sika deer alarm calls were found to change depending on the presence or absence of escape behavior. Specifically, when escape behavior is present, the fundamental frequency of the alarm call increases, as do formants 1 and 3. These results are believed to stem from increased tension in anticipation of a threat that may prompt others to flee. Our research aims to develop an acoustic device that can deter sika deer from entering grazing areas. This study provides foundational information for creating the sound source that will be incorporated into the device.

Conflict of interest

The authors declare no potential conflicts of interest.

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