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SHORT COMMUNICATION

Audible and ultrasonic vocalisations of two captive stoats (*Mustela erminea*): structural categorisation and an open annotated dataset

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Abstract: Stoat (*Mustela erminea*) vocalisations remain sparsely characterised, despite the species' significance as a major invasive predator in Aotearoa | New Zealand. Here, we describe the audible and ultrasonic vocalisations recorded from an adult male-female pair held in laboratory enclosures over three days, with blank-room control recordings. Audible calls attributed to the stoats were categorised into chitter, grunt, and hiss; the hiss is a narrowband c. 10 kHz tone of several seconds' duration, consistent with early descriptive accounts. All ultrasonic calls were concentrated in the c. 22–28 kHz band. We provide a structural description of seven low-band ultrasonic call types and report their relative proportions. The annotated recordings are released as an open dataset to support downstream work on automated detection, acoustic lure development, and comparative bioacoustics. The behavioural context of the ultrasonic calls cannot be determined from the present design and warrants further investigation.

Keywords: acoustic lure, acoustic monitoring, animal communication, bioacoustics, invasive predator, mustelid, predator management, spectrogram, USV

Introduction

Vocal signals convey important ecological information (Terry et al. 2005; Teixeira et al. 2019), yet stoat (*Mustela erminea*) vocalisations remain poorly described (Bowling et al. 2017). In Aotearoa | New Zealand, the stoat is a key predator of native birds, and improving acoustic recognition of their calls could enhance monitoring and surveillance efforts. Furthermore, characterising stoat vocal behaviour has the potential to inform acoustic luring strategies and advance our understanding of their social interactions and hunting behaviour. Here we describe the audible and ultrasonic vocalisations recorded from two captive adult stoats, with the aim of supporting bioacoustics monitoring, conservation programmes, and predator-management initiatives. In Aotearoa | New Zealand, mustelids have been identified as challenging target species for passive acoustic monitoring (McEwen 2024).

The stoat is a small, wide-ranging mustelid native to the Holarctic, adapted for hunting small mammals and birds (King & Powell 2006). In Aotearoa | New Zealand, stoats are recognised as invasive pests of considerable ecological concern. Introduced in the late 19th century to control expanding rabbit populations, they have since become prolific predators, exerting severe impacts on native birds and other endemic fauna (Cowan & Tyndale-Biscoe 1997; Brown et al. 2015; Parkes et al. 2017).

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Despite their ecological importance, descriptive work on stoat vocalisations is sparse and largely qualitative. Early descriptive accounts noted that stoats are generally quiet but can hiss, screech, grunt, and produce soft "took-took-took" calls (Burt 1952), with Gossow (1970) further distinguishing screech, squeal, and trill calls associated with threatening, defensive, and appeasing contexts. Defensive, social, and play-related signalling has also been described, including scream-like submissive calls from females (Erlinge 1977) and low-frequency muckers or purrs produced during social play (Fagen 1981). Earlier work has also explored acoustic detection and luring: Willey (1970) reported sound-based prey detection by *Mustela erminea muricus*, and Spurr and O'Connor (1999) showed that playbacks of prey and conspecific calls briefly attracted stoats, though the eliciting acoustic features were not resolved. Despite broad-frequency hearing and precise auditory localisation in mustelids (Mumm & Knörnschild 2018), and call frequencies lower than expected for body size (Bowling et al. 2017), stoats' capacity to produce ultrasound remains largely unexplored.

Middleton et al. (2023) reported recordings made from a captive family group comprising an adult female stoat and her five kits, in which audible calls including chatters, snarls, rasping sounds, and squeaks were noted alongside what the authors describe as emissions that "appear to have [been] recorded… coming from stoat", including c. 22 kHz calls

of broadly similar form to brown rat (*Rattus norvegicus*) vocalisations, though slightly higher in frequency. The authors themselves noted that "it is uncertain what behaviours these relate to", suggesting only that some of the high-frequency calls "may serve as a predatory function, or in a different context, as communication with neonates". Their attribution rested on the captive setting and the species' presumed ability to perceive the recorded frequencies, but environmental controls excluding other ultrasonic sources in the recording room were not reported. Independent observations from other individuals, recorded under documented conditions including environmental controls, are therefore needed to corroborate that the recorded ultrasonic structures originate from stoats and to begin building a structural account of the calls that can support eventual behavioural interpretation.

In rats, ultrasonic vocalisations (USVs) are well known to carry affective information: long (> 300 ms), near-constant-frequency calls in the 18–32 kHz range are associated with negative-affect states such as alarm and distress, whereas short (10–150 ms), frequency-modulated calls in the 35–80 kHz range reflect positive-affect states (Brudzynski 2013; Wöhr & Schwarting 2013). Whether other small mammals, including mustelids, produce affect-linked USVs in a comparable way is largely unexplored.

Building on Middleton et al. (2023), this study contributes independent observations of stoat vocalisations spanning the audible and ultrasonic ranges, recorded from a captive adult male-female pair under documented conditions including blank-room control recordings; a structural description of seven low-band ultrasonic call types observed in the male, with acoustic parameters and proportional frequencies of occurrence; and an open annotated dataset, made available on Kaggle (see Data and code availability). By providing annotated ultrasonic recordings, the present study also supports the integration of ultrasonic features into machine-learning classifiers for automated stoat detection (Stowell 2022; MacIsaac et al. 2024; McEwen 2024).

Methods

The recordings were made at Manaaki Whenua – Landcare Research (Lincoln, New Zealand) within laboratory enclosures. Subjects comprised one adult male stoat (320 g) and one adult female (212 g). Two AudioMoth recorders (Hill et al. 2018) were wall-mounted in dedicated housings: one positioned adjacent to the female's cage configured at 250 kHz sampling (effective Nyquist 125 kHz), and the other adjacent to the male's cage configured at 96 kHz sampling (effective Nyquist 48 kHz). The mismatch in recorder bandwidth between channels is addressed in the Discussion in relation to the asymmetric distribution of detected ultrasonic calls. Both devices operated without additional input gain. The recorders were separated by 2 m, with cages placed immediately next to the microphones and a 0.6 m gap between the cages. Recordings were collected over 22–25 August 2025, yielding a total of 119 h of audio.

Audio data were processed using a custom Python-based annotation and analysis tool (Barzegar 2025). No signal conditioning, such as band-pass filtering, was applied. To characterise the ambient acoustic environment of the recording room independently of the stoats, blank-room control recordings were collected in the same enclosure room with the same two AudioMoth units (positions, mounting, and gain settings matched to the experimental recordings), with the cages absent and the room otherwise undisturbed. These control recordings were used to identify and exclude environmental sources from the call structures attributed to the stoats. Background noise sources included HVAC noise, ultrasonic emissions likely from the air-conditioner inverter circuitry, digital timer ticks, and brief human activity during morning husbandry. Periods of human presence were identified retrospectively from human activity sounds in the audio (footsteps, door, voice, handling sounds) rather than from independent activity logs. All vocalisations were segmented into 5-s clips within two frequency bands (audible and ultrasonic). The full recordings, along with the annotated 5-s segments, are available at https://www.kaggle.com/datasets/mabiran/stoat-vocalisations.

Both stoats were wild-caught and held in captivity at Manaaki Whenua – Landcare Research for several days prior to recording. They were housed in separate wire-mesh cages within the same room, allowing visual, olfactory, and auditory contact. No other animals were present, and the facility was secured against rodents. We acknowledge that captive conditions may influence vocal behaviour; possible functional and affective interpretations, including the question of whether captivity stress may have contributed to the observed vocalisations, are addressed in the Discussion.

Although some acoustic cross-talk between microphones was possible, amplitude differences between channels provided a reliable basis for attributing calls to the nearer animal. All detected ultrasonic calls were attributed to the male, on the basis of amplitude differences between channels consistent with the nearer source. The female's own recorder did not yield ultrasonic detections above the noise floor.

The stoats were held under existing Manaaki Whenua – Landcare Research animal-facility protocols. The recordings were non-invasive and did not involve any manipulation of the animals beyond routine husbandry.

Results

Ultrasonic calls

Ultrasonic calls are defined here as vocalisations containing only frequency components above 20 kHz, and should not be confused with audible calls that may extend into the ultrasonic range. We detected a diverse repertoire of complex ultrasonic calls, exhibiting a wide range of temporal and spectral patterns, with some calls lasting several minutes. Ultrasonic calls were noted predominantly during human-absent intervals, an incidental qualitative observation that is treated in the Discussion.

In total, approximately 1000 distinct 5-s ultrasonic calls, representing c. 1.5 h of recording time, were manually annotated. The occurrence frequency of ultrasonic calls was roughly three times higher than that of audible calls, and all were attributed to the male stoat. Ultrasonic calls were categorised according to their spectral features (Figs 1–2). Acoustic parameters, typical band, and bout structure for all seven call types are summarised in Table 1

Figure 3 presents an approximately 3-min spectrogram representative of other short frequency-modulated train (S-FM_TRAIN) recordings, illustrating repeated bouts of ultrasonic stoat calling organised into structured trains. Several minute-long patterns were consistently observed. Although the syllable shapes differ from those typically reported in rat calls (Middleton et al. 2023), these stoat calls are quite similar

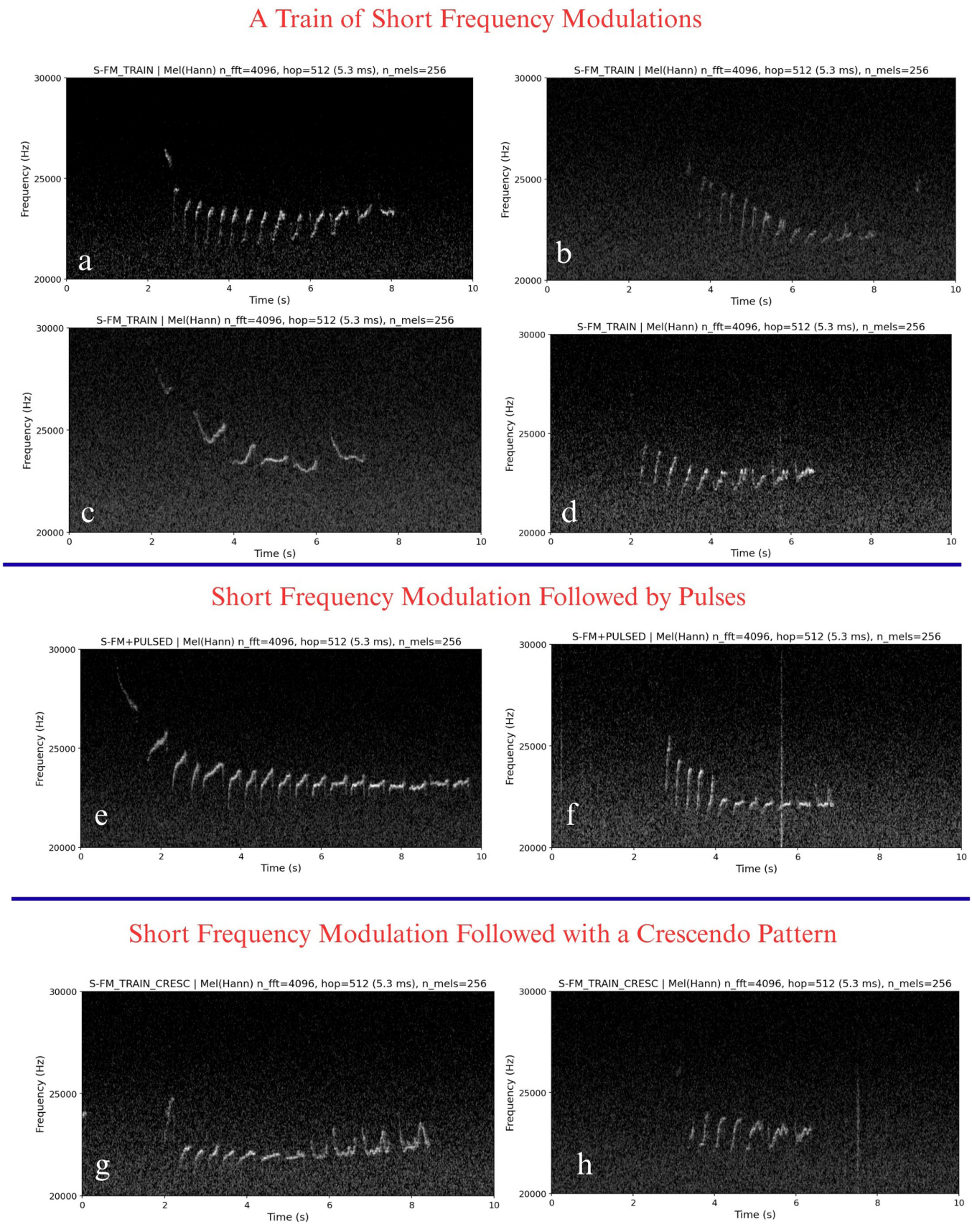

Figure 1. Examples of ultrasonic stoat call motifs, all attributed to the captive male stoat and recorded with a wall-mounted AudioMoth (96 kHz sampling). Each panel is a spectrogram (frequency, in kHz, on the vertical axis against time on the horizontal axis), and panels are grouped by the three short frequency-modulation (S-FM) call types defined in Table 1. (a–d) S-FM trains: series of brief tonal syllables repeating with near-constant inter-pulse intervals in the c. 22–30 kHz band. (e–f) S-FM trains that transition into pulse trains (the S-FM+PULSED type). (g–h) S-FM trains with a crescendo in amplitude (often with a slight upward drift in frequency; the S-FM_TRAIN_CRESC type), illustrating within-bout variation.

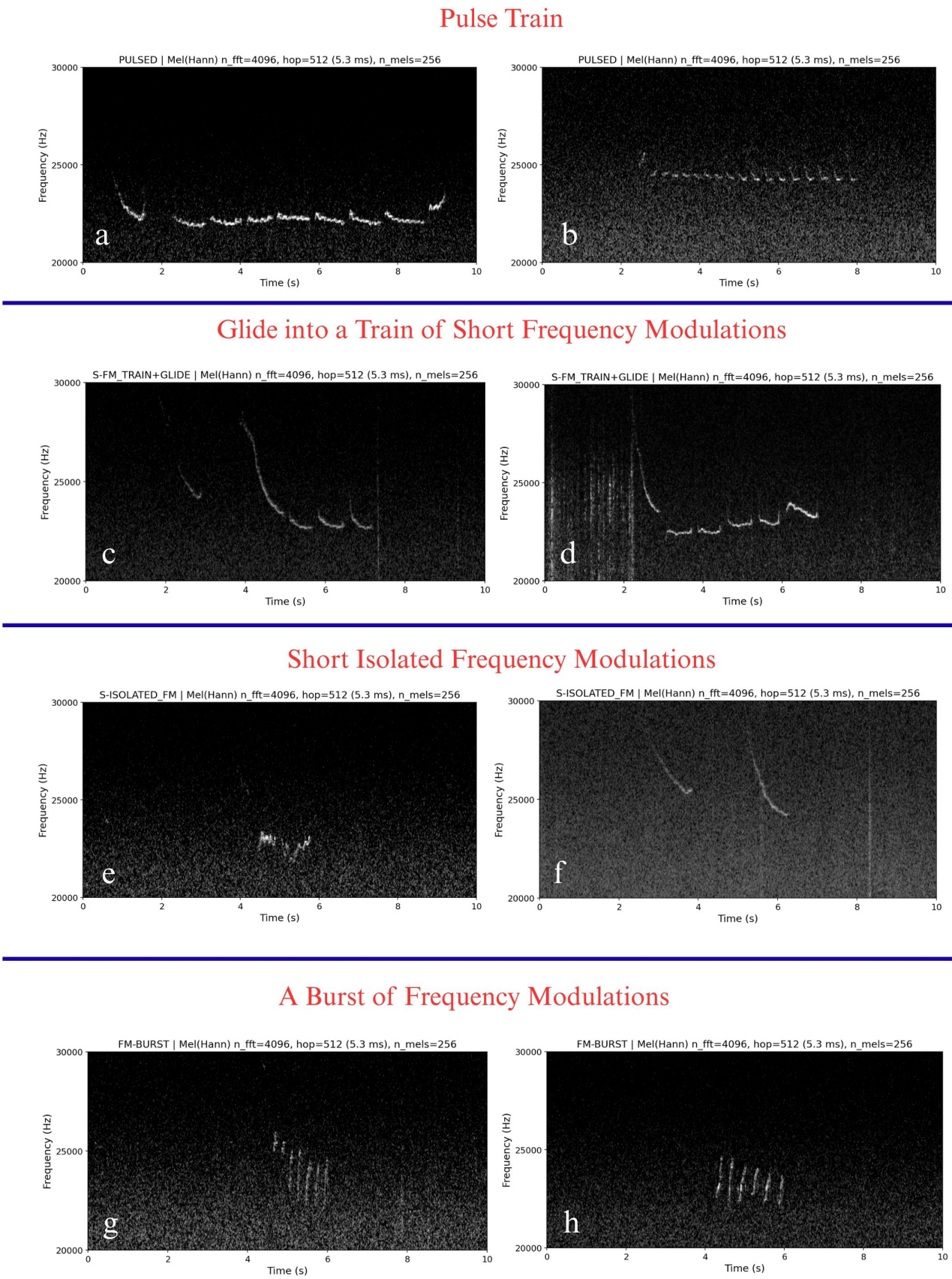

Figure 2. Additional ultrasonic call motifs used in our taxonomy, attributed to the captive male stoat and recorded with the same AudioMoth (96 kHz sampling) as in Fig. 1. Each panel is a spectrogram (frequency, in kHz, on the vertical axis against time on the horizontal axis), grouped by the four remaining call types defined in Table 1. (a–b) Pulse trains: repeating narrowband pips with minimal frequency modulation (FM) in the c. 22–30 kHz band (the PULSED type). (c–d) Glide-into-S-FM-train transitions (the S-FM_TRAIN+GLIDE type). (e–f) Short isolated FM elements not embedded in a train (the S-ISOLATED_FM type). (g–h) Compact FM bursts: rapid volleys of FM elements followed by silence (the FM-BURST type).

Table 1. Taxonomy table for the ultrasonic call types.

Call type	Label code	Brief acoustic description	Typical band	Bout/sequence pattern
Short frequency-modulation (FM) train	S-FM_TRAIN	Series of brief, tonal FM syllables (upsweeps/chevrons/stepped glides) with narrow instantaneous bandwidth.	c. 22–28 kHz	Regular trains with near-constant inter-pulse interval (IPI); occasional doublets/triplets.
Pulse train	PULSED	Repeating short, narrowband pips with minimal FM (click-like tonal blips).	c. 21–26 kHz	Long, evenly spaced pulse series; little frequency drift across the bout.
Glide into S-FM train	S-FM_TRAIN +GLIDE	A longer initial glide (down or up) that transitions into a standard S-FM train.	Glide spans c. 22–28 kHz, train c. 22–27 kHz	Single glide followed by a regular train; glide typically higher amplitude.
Short isolated FM	S-ISOLATED _FM	One to a few standalone FM elements (upsweep/chevron) not embedded in a train.	c. 22–27 kHz	Isolated events; no stable IPI context.
Burst of FM	FM-BURST	Compact cluster of several FM elements packed closely (brief rapid volley), then silence.	c. 22–28 kHz	0.5–1.5 s burst; higher within-burst rate than S-FM_TRAIN.
S-FM followed by pulses	S-FM+PULSED	S-FM train that resolves into a pulse train (FM elements give way to pips).	S-FM c. 22–28 kHz, pulses c. 22–26 kHz	Clear phase change: FM phase first, then pulsed phase with regular IPI.
S-FM train with crescendo	S-FM_TRAIN _CRESC	Standard S-FM train with a gradual amplitude increase (often slight upward drift in peak frequency).	c. 22–28 kHz	Amplitude ramps across the train; IPI remains regular.

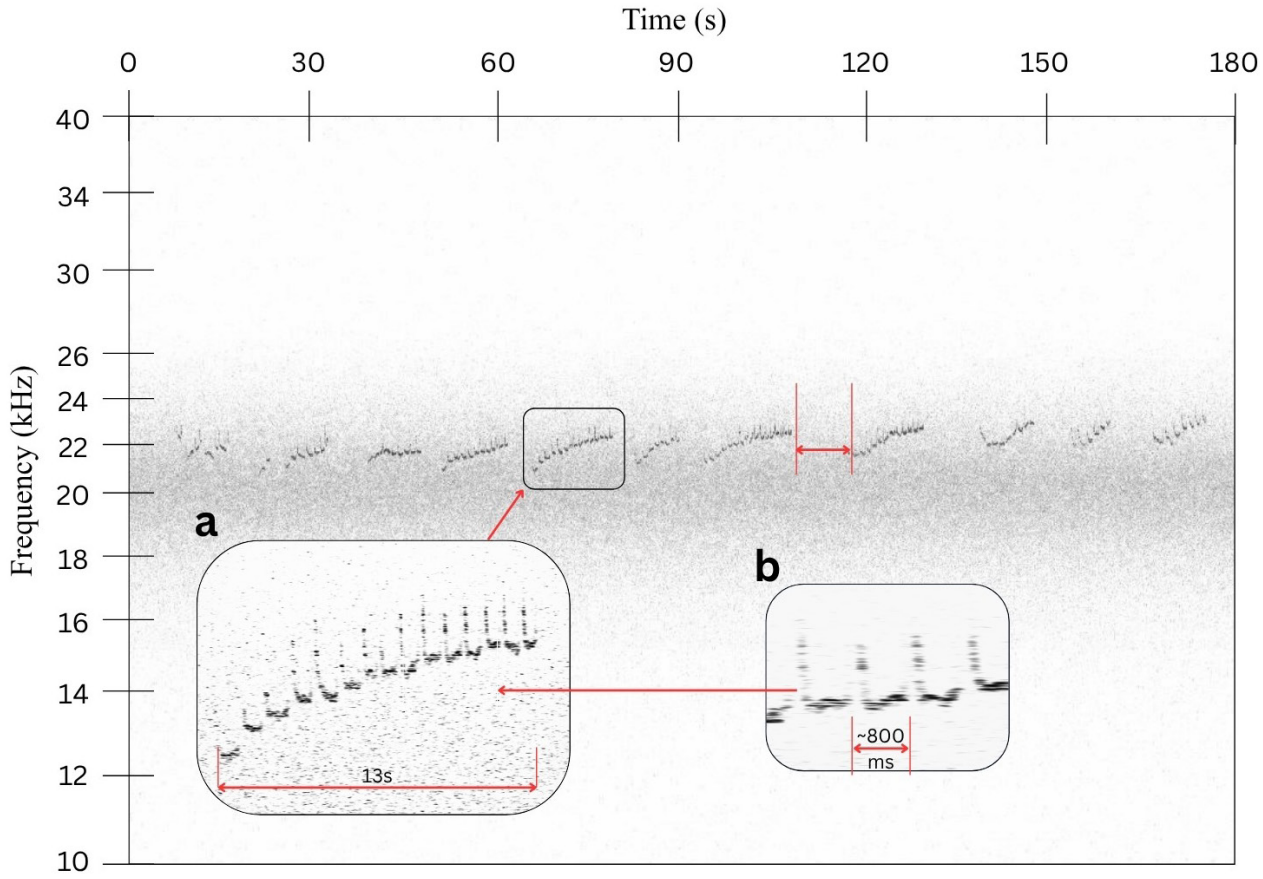

Figure 3. Representative c. 3-min spectrogram (frequency, in kHz, on the vertical axis against time on the horizontal axis) of ultrasonic calling by the captive male stoat, illustrating the S-FM_TRAIN call type organised into repeated, structured bouts. (a) Fine-scale view of a 13 s sequence, showing the rhythmic regularity of successive call elements. (b) Close-up in which individual calls recur at intervals of approximately 800 ms at a steady pulse rate, with successive bouts separated by gaps of c. 6–8 s. Individual elements exhibit slight rise-fall frequency modulation rather than the near-constant tones typical of rat 22 kHz calls.

to 22 kHz rat calls and exhibit a similar repeated pattern. As shown in Figure 3, the calls consist of repeated elements with a semi-consistent temporal spacing, typical for patterned vocal trains. At the fine-scale, a 13 s sequence demonstrates rhythmic regularity (Fig. 3a), while the close-up reveals call intervals of approximately 800 ms with steady pulse rate, separated by gaps of c. 6–8 s (Fig. 3b). In terms of frequency, the individual calls show slight rise-fall modulation, consistent with frequency-modulated (FM) elements rather than pure tones which are typical for rats. These features resemble chatter-type calls, in which repeating temporal organisation dominates a rich acoustic structure.

Audible calls

A total of c. 300 audible calls captured by the recording units were manually annotated and grouped into three audible call types: grunt, chitter, and hiss. The term 'screech' was used as an element-level descriptor for the explosive syllables comprising some chitter sequences and is not considered a separate call type. The hiss call was relatively rare, representing approximately 3% of all annotated calls.

As illustrated in Figure 4, grunts occur as short bursts with dominant energy in the low-kHz range. In the spectrogram they appear as compact, warm-coloured blobs below c. 3–4 kHz with relatively weak energy above c. 5 kHz (Fig. 4a). Individual tokens are spaced farther apart than those of other call types. The Welch Power Spectral Density (PSD) shows a broad peak at low frequencies with a steep roll-off toward higher bands, consistent with a low-frequency, broadband vocalisation (Fig. 4b).

Chitters consist of rapid trains of brief, explosive syllables, repeating at short, near-regular intervals. In the spectrogram, each syllable appears as a narrow vertical stripe, with energy concentrated across a broadband of 4.5–22 kHz and harmonics extending up to 125 kHz, the recorder's maximum Nyquist frequency (Fig. 4c). The Welch PSD shows highest energy in the c. 20–40 kHz range, declining gradually at higher frequencies, reflecting the crisp, impulsive nature of the syllables (Fig. 4d).

Hiss calls are continuous, monotone calls lasting up to several seconds. In the spectrogram they appear as sustained, narrowband calls with a faint, nearly horizontal tonal component around 9–10 kHz (Fig. 4e). The PSD combines a low-frequency noise floor with a distinct, narrow peak near 10 kHz, giving the hiss a tonal signature that distinguishes it from other call types (Fig. 4f).

Among the annotated ultrasonic calls, S-FM_TRAIN calls were the most frequent type, comprising approximately 40% of all ultrasonic vocalisations. Pulsed 22 kHz calls, resembling typical rat vocalisations, accounted for approximately 19% of ultrasonic calls. In the audible range, chitter and grunt calls together represented roughly 90% of annotated calls. Overall, combining both ultrasonic and audible vocalisations, stoat calls occupied approximately 3% of the total recording time.

Discussion

Attribution of ultrasonic calls to the stoats

Attribution of the recorded calls to the stoats rests on three independent lines of evidence. First, blank-room control recordings collected in the same enclosure room with matched equipment, mounting, sampling rates, and gain settings appear to exclude the dominant non-stoat ultrasonic sources present in the room such as HVAC inverter circuitry as the origin of the call structures reported here. Second, the spectro-temporal structure of the calls themselves, narrowband frequency-modulated elements organised into structured trains with rhythmic inter-pulse intervals, is characteristic of mammalian vocalisations rather than of the mechanical or electronic noise sources present in the recording environment. Third, the recordings were collected in a controlled enclosure with known occupants, and the temporal distribution of call detections is consistent with the calls being of stoat origin rather than environmental. Taken together, these three independent lines of evidence are consistent with the calls being attributed to the stoats.

A more vocally active species than assumed

Previous literature characterises stoats as generally silent (Burt 1952; Harris & Yalden 2008). However, ultrasonic calls attributed to the male in the present recordings were approximately three times more frequent than audible calls, raising the possibility that stoats may be considerably more vocally active than assumed, particularly in the ultrasonic range. These findings underscore the importance of broadband acoustic monitoring for understanding stoat acoustic behaviour, while the asymmetric detection between channels is itself instructive for design considerations.

All ultrasonic calls within the recorded bandwidth were attributed to the male; no ultrasonic calls were detected from the female within the male recorder's bandwidth, and the female's own recorder did not yield additional ultrasonic detections above the noise floor. The asymmetric distribution reflects a recorder-bandwidth mismatch as well as a possible biological pattern: the female's recorder sampled at 250 kHz (Nyquist 125 kHz) and the male's at 96 kHz (Nyquist 48 kHz), with the cages separated at a distance across which atmospheric attenuation of high-frequency calls is non-trivial. Two interpretations are possible: the female did not vocalise ultrasonically during the recording period, or she vocalised at amplitudes below the local detection threshold. We cannot distinguish these from the available data. The asymmetric distribution is therefore acknowledged as a design limitation rather than a behavioural finding, and matched broadband recordings of multiple individuals would be required to address whether the apparent sex asymmetry is biological.

Comparison with rat ultrasonic calls and functional interpretation

Some stoat calls were superficially similar to rodent vocalisations in frequency range, but exhibited more complex frequency modulation patterns. Rat alarm calls around 22 kHz are generally long and flat in frequency (Olszyński et al. 2024), whereas the present stoat ultrasonic calls frequently contained multiple modulations and varied spectral contours within a single call, potentially allowing reliable discrimination on spectrograms. Specifically, the low-band FM elements in our S-FM_TRAIN and glide into S-FM train (S-FM_TRAIN+GLIDE) types appear structurally consistent with elements visible in Middleton et al.'s (2023) Figure 6.59, a sequence of varied call structures that those authors did not formally classify. There is also a separate point about timing. Audible chitter and grunt calls occurred mainly when humans were present, whereas the ultrasonic calls were noted during the longer periods when no human was present. This is the opposite of what a rat-style alarm call would predict. We had only a few human-presence windows, so we cannot draw a firm

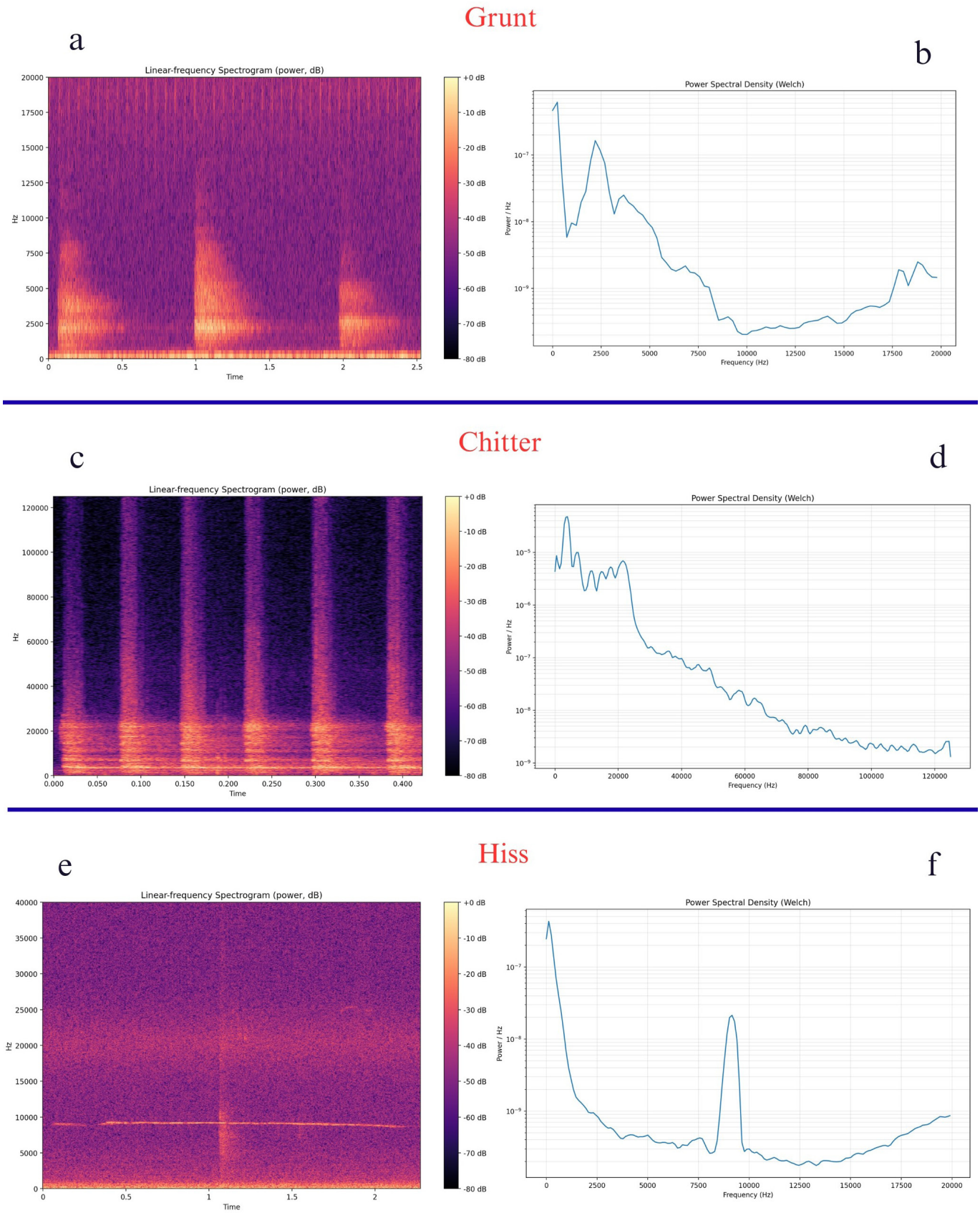

Figure 4. The three audible stoat call types, recorded from the captive pair. For each type the left panel is a spectrogram (frequency, in kHz, against time) and the right panel is the corresponding Welch power spectral density (PSD; power against frequency). (a–b) Grunt: short low-frequency bursts with dominant energy below c. 3–4 kHz and a steep roll-off above. (c–d) Chitter: rapid trains of brief, explosive syllables, each a narrow vertical broadband stripe (c. 4.5–22 kHz, with harmonics extending to the 125 kHz Nyquist limit). (e–f) Hiss: a sustained, narrowband tonal call with a distinct peak near 9–10 kHz. Spectrograms were computed with a 10 ms window and a 2048-point Fourier transform.

conclusion. The pattern does, however, raise the possibility that stoats suppress ultrasonic calling when a potential threat is nearby. Controlled disturbance trials would be needed to test this directly.

Mammalian ultrasonic communication is often associated with short-range, private signalling, as high-frequency sound attenuates rapidly and is less detectable by predators and competitors with lower hearing ranges. One hypothesis worth entertaining is that the recorded c. 22–28 kHz calls reflect a negative-affective state of the captive male, by analogy with the rat 22 kHz alarm system, given the frequency-band parallel and the wild-caught captive context in which routine handling commonly elicits 22 kHz USVs in rodents (Hwang et al. 2022). However, the short FM-modulated train structure of the present recordings differs from the long, near-constant-frequency rat alarm signature (Brudzynski 2013; Olszyński et al. 2024; see the comparison with rat calls above), and the qualitative pattern of ultrasonic calls occurring during human-absent rather than human-present intervals further argues against an acute rat-alarm interpretation.

Applications for detection and monitoring

The dataset of over 1000 annotated stoat calls generated in this study provides a valuable resource for automated acoustic monitoring. For example, when recordings are converted into mel spectrograms, convolutional neural networks can be trained to detect stoat vocalisations, as has been demonstrated for other animal sounds (Stowell 2022), including those of pest mammals (McEwen 2024). Such approaches could enhance conservation and pest management efforts in New Zealand by enabling non-invasive detection of stoats in the field, complementing existing trapping methods, and providing a scalable tool for monitoring their distribution and activity. Detection methodologies developed for related rare-acoustic-event problems in New Zealand pest contexts (McEwen 2024) are particularly relevant for downstream use of the present dataset. The recorded calls also raise the possibility of acoustic mimicry to deceive prey (Middleton et al. 2023)—that is, a predator imitating the calls of its prey or of another species in order to draw that prey closer. Acoustic mimicry has been observed in other predators, such as the margay imitating the calls of a tamarin monkey it hunts (de Oliveira Calleia et al. 2009). Separately, characterising stoat vocalisations could support the development of acoustic lures for predator control, building on Spurr and O'Connor (1999), who found that playback of conspecific and prey calls briefly attracts stoats. Because ultrasonic calls attenuate more rapidly than audible calls in air, lure deployment may require closer speaker placement, louder playback, or audible-band augmentation; these are design questions for future work. Future research should expand recordings to wild stoats, link call types to behavioural contexts, and develop automated classifiers to support more effective management of this invasive predator.

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Additional information and declarations

Author contributions: MAB: conceptualisation, methodology, software, formal analysis, data curation, writing – original draft, visualisation. AG: conceptualisation, supervision, writing – review and editing, funding acquisition. EL: supervision, writing – review and editing. SEN: methodology, validation, writing – review and editing.

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Data and code availability: The full audio recordings of both audible and ultrasonic calls, together with the annotated 5-s segments, are openly available on Kaggle at: https://www.kaggle.com/datasets/mabiran/stoat-vocalisations. The custom annotation tool is available at: https://github.com/mabiran/Audio-Annotator.

Ethics: The stoats were held under existing Manaaki Whenua – Landcare Research animal-facility protocols. No additional permits were required.

Conflicts of interest: The authors declare no conflicts of interest.

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