

## Article

# Visual classification of feral cat *Felis silvestris catus* vocalizations

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## Abstract

Cat vocal behavior, in particular, the vocal and social behavior of feral cats, is poorly understood, as are the differences between feral and fully domestic cats. The relationship between feral cat social and vocal behavior is important because of the markedly different ecology of feral and domestic cats, and enhanced comprehension of the repertoire and potential information content of feral cat calls can provide both better understanding of the domestication and socialization process, and improved welfare for feral cats undergoing adoption. Previous studies have used conflicting classification schemes for cat vocalizations, often relying on onomatopoeic or popular descriptions of call types (e.g., “miow”). We studied the vocalizations of 13 unaltered domestic cats that complied with our behavioral definition used to distinguish feral cats from domestic. A total of 71 acoustic units were extracted and visually analyzed for the construction of a hierarchical classification of vocal sounds, based on acoustic properties. We identified 3 major categories (tonal, pulse, and broadband) that further breakdown into 8 subcategories, and show a high degree of reliability when sounds are classified blindly by independent observers (Fleiss’ Kappa  $K=0.863$ ). Due to the limited behavioral contexts in this study, additional subcategories of cat vocalizations may be identified in the future, but our hierarchical classification system allows for the addition of new categories and new subcategories as they are described. This study shows that cat vocalizations are diverse and complex, and provides an objective and reliable classification system that can be used in future studies.

**Key words:** bioacoustics, communication, socialization, spectrograms.

The practical predicament of feral cat management is widespread and challenging. A substantial proportion of shelters and other welfare providers often use unreliable behavioral cues to identify feral cats (Slater et al. 2010, 2013), and errors in discrimination between frightened socialized cats and those that are feral often result in longer holding times in shelters, increased expenditures and delays in the possible re-uniting of lost and frightened domestic cats with their human families. This problem is based on two fundamental, and largely unresolved, questions: 1) what is “feral” and 2) how can

*Felis silvestris catus* vocalizations be reliably classified? If we have a standardized and dependable definition of “feral,” and if feral and domestic cats vocalize in clearly and recognizably different ways, some of these errors could be remedied. In this article we briefly treat the first question, but focus on the second.

In deciding what is a feral cat, Slater (2007) discusses the terminological differences that pervade the literature, exploring the lack of clear and consistent delineation between “feral cat,” “barn cat,” “stray cat,” and “free-roaming cat,” to name a few. Levy et al. (2003)

and Miller (1996) both note that distinguishing between feral and non-feral cat populations is difficult. Levy et al. (2003) offers a broad category, “free-roaming,” and then divides that cat population into a mix of socialized stray cats that are willing to interact with humans, and unsocialized, or feral, cats. A more refined definition comes from Gosling et al. (2013) a “feral cat” is one that is “unapproachable in its free-roaming environment and is capable of surviving with or without direct human intervention, and may additionally show fearful or defensive behaviour on human contact.” (Slater et al. 2013) and the ASPCA guidelines for identifying feral cats, were foundational to our Feral Classification System, detailed in the “Materials and Methods” section.

The social and environmental contexts of feral cats are rich and complex. Feral cats will often congregate into colonies around a food source; these colonies generally consist of sisters and their young (Crowell-Davis 2007). According to Crowell-Davis, cats generally exhibit several forms of social/cooperative behaviors (e.g., they will solicit allo-grooming with familiar and related conspecifics, cooperate in the care of kittens, teach kittens to hunt, and, anecdotally, may cooperate to hunt larger prey as well). Socialized and feral cats appear to form social bonds in colonies, and bonded pairs will often sleep in contact with one another and mutually rub against each other (Alger and Alger 2003). If future research continues to confirm sociality of wild-living *Felis s. catus*, we suggest that, as a social species, these cats would benefit evolutionarily from multiple modes of communication, including vocal communication.

There is substantive disagreement on how to identify, define, categorize, label, and analyze the vocalizations of cats in general. As an example, feline vocal sounds have been classified into categories as few as five (Schötz 2012) and as many as 16 (Moelk 1944). Other researchers (Crowell-Davis 2007) have taken a middle ground, parsing cat vocalizations into 9 categories. Notably, Schötz (2012) mentions “longer phrases” which are as yet unexplored. Potential obstacles to the development of an objective, standardized, and reliable classification system for cat vocalizations include human emotional response to different cat sounds (Nicastro and Owren 2003), which may bias our classification attempts, and a general human inability to consistently identify specific sounds made by cats or clearly identify contexts in which specific cat sounds are produced (Ellis et al. 2015). Further, as we will discuss below, discrepancies between human classifications of cat sounds and results of statistical clustering methods remain unresolved (McKinley 1982). Such human prejudices and methodological deficits raise questions as to whether research-based human categories for cat calls can, in any way, be found to represent the possible context-specific taxonomy of calls as used by the cats themselves. Such questions can be explored in future research after more basic questions, such as those that are the focus of this article, have been addressed. To promote a cohesive framework for future studies of animal communication, Kershenbaum et al. (2014) published a cross-discipline tutorial review clarifying terminology and outlining best practices. These terms and practices were applied here to develop a reliable, visual classification scheme for feline vocalizations.

In an early effort, Moelk (1944) provided a comprehensive study of one adult domestic cat’s vocal behavior, identifying a hierarchical classification system consisting of three classes of sounds organized into 16 categories of vocalizations. Vocalizations were recorded along with context and then described by ear (i.e., without the use of spectrograms) using phonetic patterns. Each of the three main classes of sounds was identified by mouth position and tension, and intensity of vocal effort during sound production. Phonetic patterns

present in vocalizations were used to identify each of the 16 categories, which were associated with different behavioral and psychological contexts. Of the 16 categories/contexts Moelk identified, 13 were observed in other cats. While fascinating, these data are difficult to use in comparative studies, with con- or hetero-specifics, because they were created before technological advances, like spectrographic analysis, became a predominant method used in studying animal communication.

Hubka et al. (2015) provide important evidence that kitten vocalization is modulated by auditory feedback (i.e., the sounds cats make are not automatic, nor are they independent of contextual forces; cats learn how to vocalize by hearing themselves and others). Hubka explores the vocalizations of deafened, hearing impaired, and hearing kittens during the maturation process. These results suggest that the contexts provided by socialization could impact vocalization repertoire, such that different call types could manifest in feral and socialized cat populations. While Hubka does not focus on call type classification, he points out a significant difference in the harmonic structures of calls in hearing and non-hearing cats; this could provide groundwork for further vocalization categorization.

Haskins (1979) presents a causal analysis of kitten vocalizations. The work focuses primarily on the relationship between stimuli (e.g., cold, isolation, and restraint), and increases and decreases in vocalizations. Interestingly, Haskins reports increase in kitten vocalization when mothers were in the litter box. Less surprisingly, Haskins’ kittens cried more when exposed to cold, as well as separation/isolation, corroborating the notion of *isolation calls* as suggested by Scheumann et al. (2012) and Hudson et al. (2015). Haskins reports a very general description of differences in vocalizations along axes of duration, fundamental frequency and peak frequency, and in doing so offers a beginning of vocalization typology in relation to context.

McKinley (1982) explored a quantitative method for classifying feline vocalizations testing the effectiveness of cluster analysis. McKinley inspected approximately 2,000 sonograms of 25, mixed-sex, domestic felines ranging in age from newborn to 16 years to create an initial classification scheme of 15 call types consisting of nine pure type calls and six complex type calls. These initial categories were compared to Moelk (1944) work and include 9/16 phonetic categories; the 7 missing Moelk categories were either not produced within the repertoires recorded or were lumped within other categories. Using five of the original subjects, and 80 of the vocalizations, McKinley used a discriminant function analysis to identify which variables best discriminate between these categories. These data were used to calculate a new, quantitative, classification scheme by running cluster analysis on the repertoires of two related, adult, female cats; 73 vocalizations and 93 vocalizations. Notably a different classification scheme was returned for each subject, indicating that individuals may have individually distinct repertoires. Another surprising finding was that “meow” was not a category substantiated by cluster analysis for either subject, suggesting that it is not a true, distinct call type. McKinley discusses the advantages and disadvantages of choosing different methods, criteria and variables to include in discriminant and cluster analyses, while addressing the mismatch between human and mathematical categorizations of vocalizations. The results, combined with the complexity of feline vocalizations, suggest that much more work needs to be done in order to deftly and reliably describe feline vocalizations.

Yeon et al. (2011) explored the difference in vocalizations between feral cats who socialize primarily with other cats and domestic cats that are at ease with inter-species interaction. Yeon’s group

has suggested that there are significant differences between feral and domestic cat vocalizations, both in duration and in production, as well as in several acoustic parameters such as fundamental frequency. The Yeon study observed a broader range of frequencies, and more fluctuation in frequency, as well as a higher number of call types in feral cats as compared to domestic cats. If feral cats have more calls than domestics, and more variation in their vocal repertoire, what would explain such a difference in size of the vocal catalogue?

The current study included four objectives, derived from the recommendations of Kershenbaum et al. (2014). The first was to identify the basic acoustic units of feline vocalizations. Second, to classify units into hierarchical categories based on the similarity, consistency, and continuum of their acoustic characteristics. Next, to label these categories using terms free of colloquial and emotional associations. For example, assigning a letter to each category rather than contemporary, often onomatopoeic or descriptive terms like “meow” or “hiss”, e.g., Crowell-Davis (2007); McKinley (1982); Schötz (2012, 2015), or situational dependent, like “isolation call”, e.g., Brown et al. (1978). Finally, to determine the reliability and robustness of these categories by conducting measures of Inter-Rater Reliability with untrained raters (Burghardt et al. 2012). As our goal was to characterize the vocalizations of feral, rather than domestic, animals, we made use of animals meeting the criteria for “feral” according to the ASPCA guidelines (<http://aspcapro.org/webinar/2010-09-15-000000/feral-vs-frightened-pet>), and previous work (Slater 2013), as well as recommendations for identifying feral cats from Stafford Animal Shelter in Livingston, Montana, USA. The vocal recordings used as data for this study were collected as part of a project testing new methods for socializing feral kittens alongside their littermates and nursemaids. Socialization methodology and detail are included where relevant.

## Materials and Methods

Thirteen unaltered domestic cats *Felis silvestris catus* were obtained from the Stafford Animal Shelter (Table 1). Kittens who entered the study were often too young to be sexed (and feral kittens are often undernourished, possibly delaying progression through physical stages of development), and recording of vocalizations began immediately. Our main research focus was to develop a basic categorization of vocal sounds, and while we recognize that sex of the kittens could provide important additional information, this is a topic for future research with older kittens. Subjects were transported from the shelter to the research location in a plastic carrier covered with a towel. All socialization procedures and vocal recordings were conducted in carpeted and sound-buffered rooms 2.5 m × 3.5 m located in the basement of a private home in Bozeman, Montana. These rooms include a window, bed, desk, computer, recorder, lamp, external hard-drive, litterbox, water bowls, small soft toys to provide enrichment, and a large cat tree to provide a safe retreat area. Where more than one group was undergoing socialization at the same time, the animals were kept in separate rooms and there was no contact between the groups. Water was available at all times for the subjects. Water and litterbox were both refreshed daily. Food was available on a limited basis, during socialization, per protocol. The temperature in the room was maintained between 20 and 21 degrees Celsius. Subjects remained in this room from their arrival to the property until their departure. An acclimation phase of 24 h preceded attempts at socialization, and the socialization phase continued until the animals' behavior made them suitable for adoption

(Table 1). The study was carried out between June 2014 to September 2014, and all aspects of this study were conducted in accordance with Montana State University IACUC protocol # 2014-13, granted to Sara Waller.

Cats were found by the shelter in 3 different “family groups,” including kittens with or without a nursemaid. To maintain this social context, we observed these family groups in the same social configuration. Family group 1 did not have a nursemaid, while groups 2 and 3 did; variation in group composition, social structure and weaning time spans the continuum of naturally occurring feral family groups (Bateson 2000). Nursemaids in this study were aged 1–4 years and kittens were aged 3.5 weeks–4.5 months at the date of entry into the study. In accordance with our agreement with the shelter, cats remained the property of the shelter for the duration of the study and were returned to the shelter for adoption following socialization.

Because there existed no validated methods for reliably distinguishing between socialized cats under stress and unsocialized feral cats, we developed a feral behavior scale based loosely on several successful predictors of cat socialization (Slater 2013; Slater et al. 2013). To determine each subject's level of socialization, we evaluated the presence or absence of eight behaviors by ad libitum observation: 1) approaches and solicits play, petting, and/or attention from a human; 2) eats in the daytime with a human present; 3) willing to eat food or treats from human hands; 4) purrs with a human present; 5) kneads with a human present; 6) licks lips and blinks at a human; 7) does not hiss or growl; and 8) uses litterbox in daytime hours with a human present. Presence of these behaviors is typical of socialized cats and absence or the inverse of each of these behaviors is typical of unsocialized, feral cats. To calculate a subject's degree of socialization, each cat was awarded one point on the scale for each behavior present; conversely, a point was subtracted from a cat's score for each absent behavior. Final scale scores ranged from 0 (More Socialized) 1–2 (Semi-Socialized), 3–4 (Neutral), 5–6 (Semi-Feral), 7–8 (Fully Feral). Cats' responses to humans are thought to be highly influenced by paternity (McCune 1995); however, the paternity of our subjects is unknown. Kittens tend to imitate the immediate behavior of the mother/nursemaid (Chesler 1969; Wyrwicka 1978, 1993; Wyrwicka and Long 1980). As such, each kitten received the same initial “socialization” score as its nursemaid. For a nursemaid and her kittens to be included in the study, a minimum score of 5 was required on the Feral Behavior Scale. All subjects were classified as “fully feral” at the start of the study (Table 1).

Our socialization protocol was adapted from methods used by Ramirez (1999) and includes basic operant conditioning techniques. The impetus was for subjects' behavior to be shaped from feral to socialized by providing food (a positive primary reinforcement) only when in the presence and proximity of a human (or humans). Food was provided ad libitum during the acclimation phase (24 h). During the socialization phase, food was made available only when a human was present. This socialization protocol encouraged subjects to engage in new behaviors such as approach or contact; however, all approach and contact between humans and cats was strictly initiated by the subjects. Research assistants did not intentionally approach, reach for, or force subjects to make contact at any time during the study. The goal of this socialization procedure was for subjects to establish a positive relationship with humans and to improve odds of adoption at the end of the study. To ensure this goal was achieved, the length of the socialization phase varied according to the responses of the subjects.

**Table 1.** Subject and family group information

Group	Subjects	Start date	End date	Final feral score
1	5 kittens: 8–10 weeks No nursemaid	6/28/14	7/10/14	All kittens: 0
2	2 kittens: 3.5 & 14 weeks 1 nursemaid: 2 years	7/10/14	Youngest kitten: 8/26/14 Nursemaid & older kitten: 9/13/14	Younger kitten: 1 Older kitten: 2 Nursemaid: 4
3	4 kittens: 3–4 weeks 1 nursemaid: 4 years	9/4/14	9/14/14	All Kittens: 0 Nursemaid: 8

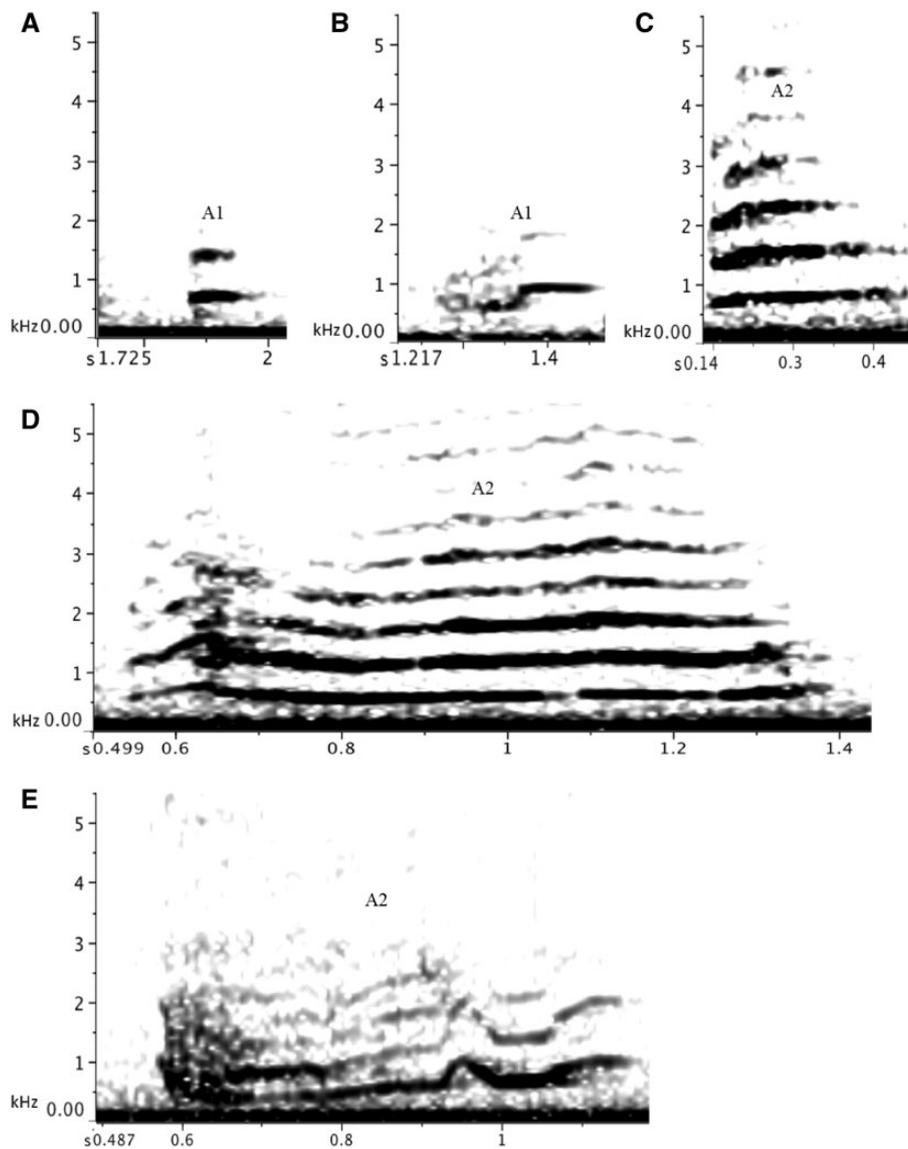
**Table 2.** Classification scheme

Category	Sub-category	Description	Duration (s)	Ranges (s)
Tonal	1. “A1”	Short tonal unit. Shorter than Category A2. If harmonics present: 3 or fewer.	0.148	0.041–0.215
	2. “A2”	Tonal units of longer duration than Category A1. Always harmonically structured.	0.719	0.187–1.435
Pulse	3. “B1”	Short-duration, frequency-focused, high-energy elements occurring in “bursts” or series of 2 or more.	0.114	0.033–0.281
	4. “B2”	A “burst” with a connected ending tone. Tone duration, modulation and presence of harmonics vary. Tone is present when frequency-focused energy mimics Categories A1 or A2.	0.802	0.401–1.13
Broadband	5. “C1”	Non-tonal, broadband unit. Duration varies. Frequency characteristics, e.g., presence of harmonics, visibility and clarity of fundamental frequency, etc., vary.	0.425	0.080–1.605
	6. “C2”	Category C1, with a connected starting tone. Tone duration, modulation and presence of harmonics vary. Tone is present when frequency-focused energy mimics Categories A1 or A2.	1.488	0.862–2.060
	7. “C3”	Category C1 with a connected ending tone. Tone duration, modulation and presence of harmonics vary. Tone is present when frequency-focused energy mimics Categories A1 or A2. Category C3 total duration is shorter than total duration of Category C4. Category C3 tone is less modulated than Category C4. Category C3 tone has fewer and less developed harmonics than Category C4.	0.823	0.427–1.24
	8. “C4”	Category C1 with a connected ending tone. Tone duration, modulation and presence of harmonics vary. A tone is present when frequency-focused energy mimics Categories A1 or A2. Category C4 total duration is longer than total duration of Category C3. Category C4 tone is more modulated than Category C3. Category C4 tones have more harmonics with higher acoustic energy than Category C3.	1.067	0.692–1.587

All of the animals were observed vocalizing on numerous occasions by the researchers and assistants. Recordings were made across social contexts (with and without humans present) and throughout the socialization process, to ensure that as much of the animals’ repertoire was captured. Subjects’ vocalizations were continuously recorded using a Sony PCM-D100 linear PCM recorder with built-in stereo microphones with a flat frequency response between 20 Hz–20 kHz, using 24-bit sound resolution and sampling rate 44.1 kHz. Acoustic files (.wav format) were uploaded daily to a 2009 MacBook Pro running OS 10.8 “Mountain Lion.” Sound files were viewed and processed in Raven Pro (Version 1.4; Cornell Laboratory of Ornithology). Files were opened using default spectrogram parameters and Hann window, but brightness, contrast and window size were adjusted to maximize spectrogram resolution according to the features of each file. These parameters were not standardized across spectrograms as subjects vocalized from different locations within the socialization room, producing recordings of varying quality. A semi-random selection process, in which files were first chosen at random, and then specifically selected for high quality content free of acoustic interferences (such as

overlapping signals or high levels of background noise), was used to identify sound files from each of the three study groups. Naive assistants visually scanned and listened to the original recordings for cat/kitten vocalizations. Each instance of a vocalization was selected in Raven and saved as a separate sound file. Assistants used silent space on spectrograms to identify individual vocalizations; differing discrimination between assistants resulted in sound files with varying numbers of vocalizations. This process resulted in 41 sound files, each containing one or two vocalizations. These sound files were then used to identify the basic acoustic units of feline vocalizations recorded, classify these acoustic units into hierarchical categories based on their structure, and test the validity and reliability of those categories.

Raven Pro was used to generate spectrograms of the 41 sound files. Each spectrogram was transferred into an image and organized into a document with one image per page. Beneath each image were notations including the settings for window size, brightness, contrast, y-axis and x-axis. Individually adjusting each spectrogram eliminated image distortion for units of varying duration. Spectrograms were then used by an experienced rater to visually

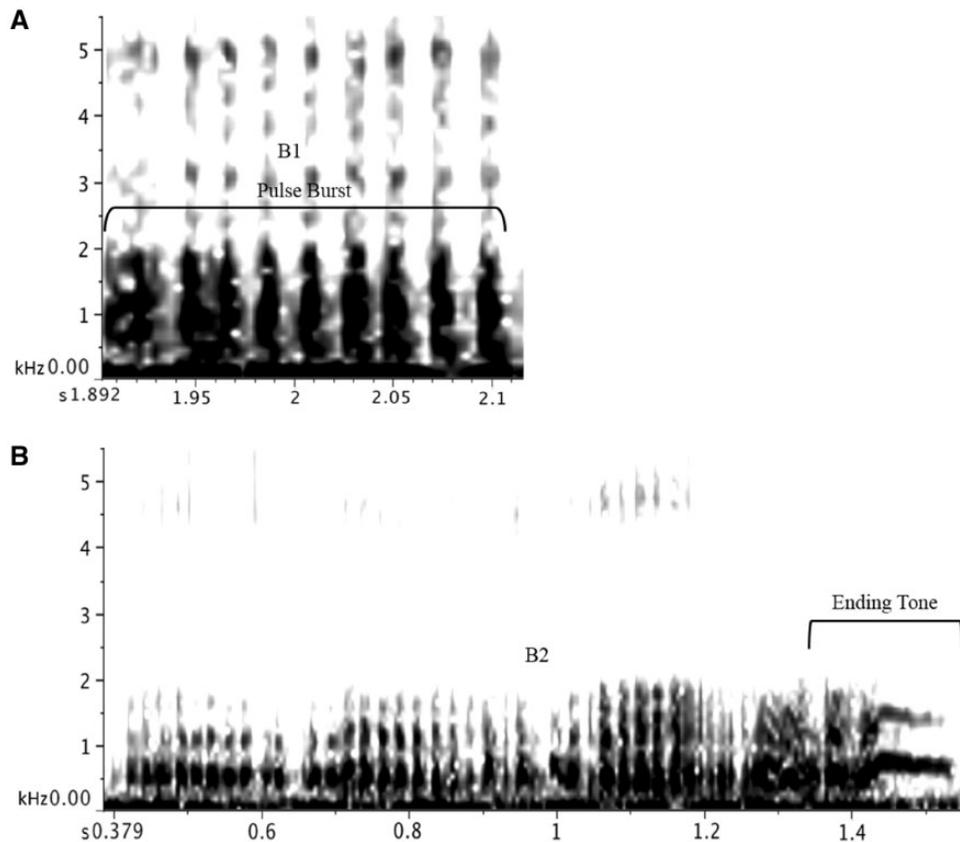


**Figure 1.** Tonal acoustic units. Spectrographic exemplars of category A, tonal units. Axis labels are included in each spectrogram and acoustic units are labeled with the appropriate classification directly above the frequency tracing. Spectrograms A and B represent variants of subcategory A1, a tonal unit. Spectrograms C, D, and E represent variants of subcategory A2, a tonal harmonic unit. Spectrograms were created with varying window sizes: A = 1656 samples; B, C = 656 samples; D = 756 samples; E = 556 samples.

identify acoustic units and create a classification scheme. For this reason, this rater and their scores were considered the standard for later comparisons.

An acoustic unit, or acoustic element, is defined here as the most basic identifiable acoustic aspect of a vocalization. Individual acoustic units were identified using two acoustic properties (Kershenbaum et al. 2014). The first was the presence of a silent gap. When visually classifying spectrograms, a sound was split into two units if there was a visible discontinuation of sound. The second combines the Gestalt Principles of similarity and proximity. Acoustic elements with similar acoustic properties, produced in rapid succession were grouped as a single unit regardless of silent gaps. The silent gap criterion was used to identify acoustic units for all acoustic elements except pulsed sounds. The second property is characteristic of pulse trains; individual pulses were grouped together into bursts. As pulses were typically separated by around 10 ms, no confusion could arise between separate pulses and separate vocalizations.

The experienced rater visually classified the acoustic units into hierarchical categories using consistent similarities in frequency, temporal, and energy patterns. All classification was done by inspection of the spectrograms, rather than by quantitative acoustic measurements, as there is currently insufficient understanding of the variation in acoustic parameters of feline vocalizations to make quantitative clustering practical (Kershenbaum et al. 2014). We define a call category as a group of acoustic units that share the same inclusive and exclusive features, i.e., fundamental acoustic and structural features. Likewise, subcategories are groups of acoustic units within categories that share the same inclusive and exclusive acoustic features. This structure of classification allows for continual addition of new subcategories. Each of the subcategories represents what the rater proposed to be distinct vocal units of the domestic cat. To determine the reliability and robustness of these categories two independent raters were invited to use the same category scheme to classify the pre-identified acoustic units. Neither



**Figure 2.** Pulse acoustic units. Spectrographic exemplars of category B, pulse units. Unlike the acoustic elements of tonal and broadband categories, where the individual units are identified by silent gaps in the spectrogram, individual pulses are grouped together into bursts. Each burst is considered one unit for the Pulse category and each of its two subcategories. Axis labels are included in each spectrogram and acoustic units are labeled with the appropriate classification directly above the frequency tracing. Brackets are used to indicate tonal portions of the unit. Spectrogram A illustrates the typical rapidity with which staccatoed pulses are produced within a burst. Spectrogram A represents subcategory B1, a pulse burst. Spectrogram B represents subcategory B2, pulse hybrids. A pulse hybrid is a pulse burst ending with a tonal element. Notice there is no interruption between the pulse burst and the tonal element in the pulse hybrid. Any silent gap or interruption of sound, and the classification would have changed to a sub-category 3 pulse burst and a sub-category 1 tone. Spectrogram A was created using a window size of 456 samples. Spectrogram B was created using a window size of 656 samples.

rater was naïve to the task of visual classification. Both raters had previous experience visually and aurally classifying cat vocalizations. However, neither had involvement in the creation of the category classification scheme presented here.

A description of each sub-category was created to permit the classification of an acoustic unit while visibly scanning spectrograms, without listening to the sound file. Both raters received descriptions of the categories (Table 2) with spectrographic exemplars for each (similar to images, without in-image annotations, in Figures 1–3). Raters were also provided a spreadsheet with the list of spectrogram, ID numbers, and a place for them to assign a classification next to each pre-identified unit. Raters were instructed to assign each acoustic unit to a category using only the provided category descriptions and exemplars.

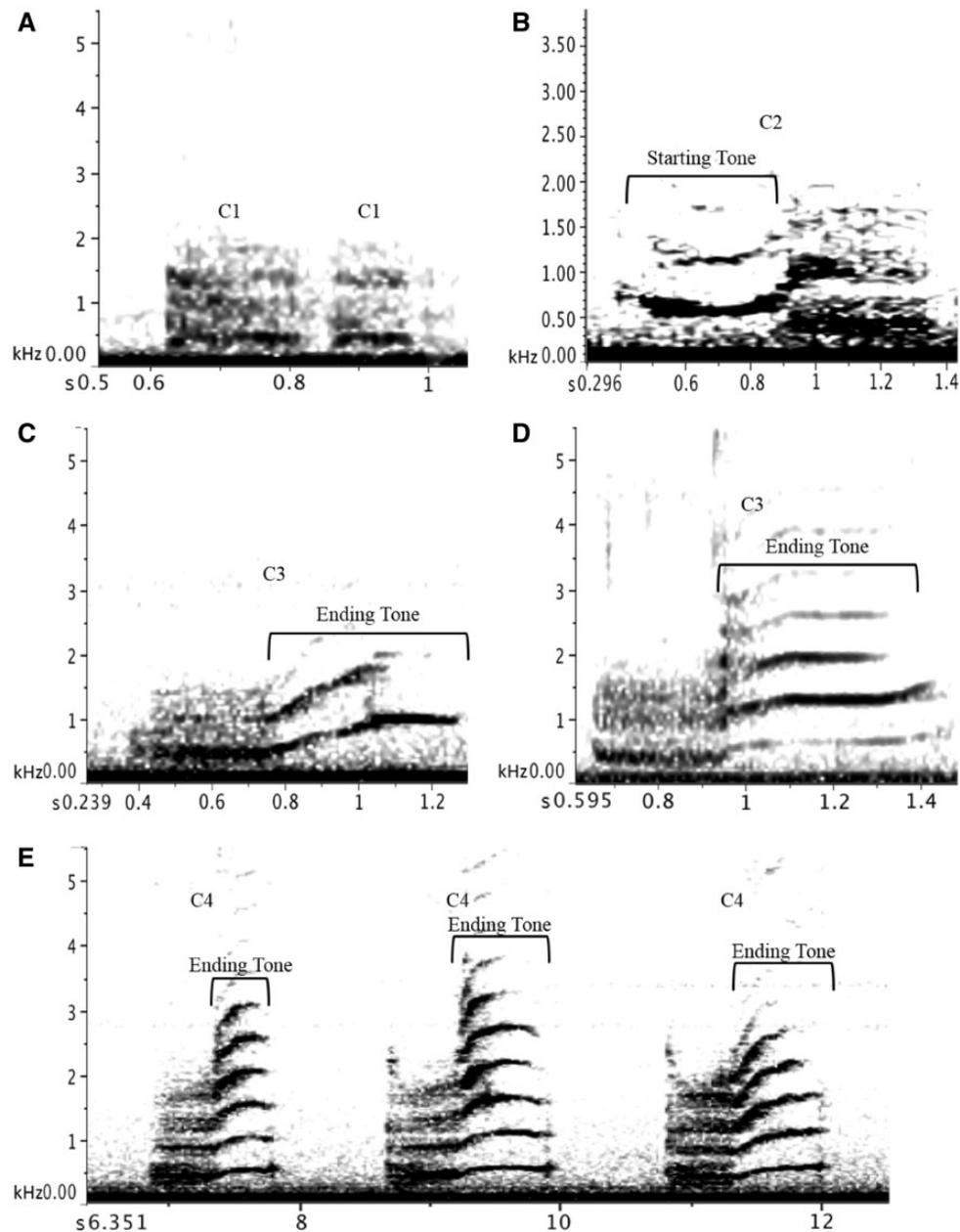
For best practices inter-rater reliability was tested using both percent agreement and Fleiss' Kappa (McHugh 2012).

## Results

A total of 71 acoustic units were identified. The resulting classification scheme, described in Table 2, consists of three major categories that further breakdown into eight subcategories: two tonal sounds (Figure 1), two pulse sounds (Figure 2), and four broadband sounds (Figure 3).

Each of the eight subcategories is represented by an arbitrary letter-number combination. Subcategory A1 consists of tonal units which can vary in duration and degree of modulation (Figure 1A and B). Subcategory A2 represents harmonically structured tonal units (Figure 1C–E). Pulse sounds, subcategories B1 and B2, consist of variants of pulsed sounds. B1 represents the pulse burst, which consists of a series of rapidly repeated, staccatoed, acoustic units of intense, time, and frequency focused acoustic energy (Figure 2A). Subcategory B2 represents the pulse hybrid, a pulse burst ending with a tonal element (Figure 2B). The broadband category contains four subcategories. Subcategory C1 contains non-tonal broadband units with diffuse energy (Figure 3A). C2 represents a broadband hybrid unit that begins with a tonal element (Figure 3B). C3 and C4 are both broadband hybrid units ending in tonal elements, but C4 units are longer in duration, and have tonal elements with more clearly defined harmonics that are more modulated than those ending C3 units (Figure 3C–E).

Agreement between the two independent, untrained raters was 76.1%. Agreement between the three raters, with standard included, was 78.9%. However, given our sample size of 71 units, Fleiss's Kappa is a more accurate measure of agreement between three raters with eight possible categorizations (Hallgren 2012, McHugh 2012). Using the interpretation of Landis and Koch (1977), agreement between all three raters was almost perfect  $K = 0.863$  (95% CI, 0.774–0.952)  $SE_K = 0.046$ .



**Figure 3.** Broadband acoustic units. Spectrographic exemplars of category C, broadband units. Axis labels are included in each spectrogram and acoustic units are labeled with the appropriate classification directly above the frequency tracing. Brackets are used to indicate tonal portions of the unit. Spectrogram A represents subcategory C1, a non-tonal broadband unit. Spectrogram B represents subcategory C2, a hybrid broadband unit beginning with a tonal sound. Spectrograms C and D represent variants of subcategory C3, a hybrid broadband unit ending with a tonal sound. Spectrogram E represents subcategory E, a second hybrid broadband unit ending with a tonal sound. When comparing subcategories C3 and C4 the ending tone is longer, more defined and more modulated in C4 units. Spectrograms A and D were created using a window size of 556 samples. Spectrogram B was created using a window size of 1656 samples. Spectrogram C was created using a window size of 956 samples and E was created using 1956 samples.

## Discussion

The goal of this study was to develop a reliable visual classification scheme for feline vocalizations. The spectrograms obtained from this sample of vocal recordings indicated 3 main categories of feline vocalization; further division of the categories resulted in 8 subcategories representing the acoustic units of the domestic cat. The resulting eight subcategory classification scheme proved to be a reliable method of visual classification when tested using two untrained raters and spectrograms of 71 acoustic units.

Previous efforts to categorize feline vocalizations have produced a variety of classification schemes, some more and less comparable to the one produced here. Early works cannot easily be compared to our scheme because they are either lacking in spectrographic images (Moelk 1944), or the images are of poor quality (McKinley 1982). Later studies show some overlap with our vocalization categories. Using the sonograms provided by Brown et al. (1978) it appears that their six categories would collapse into four of ours: Their categories A, B, and D would be visually classified as A2, tonal harmonic

sounds. Accordingly, their categories of C and E would be visually classified as C1, broadband sounds. Their category F includes two different acoustic units, according to our scheme, a C2, tonal broadband sounds and a B1, a pulsed sound. Feral kittens and cats spanning similar ages served as subjects in both the aforementioned and the current studies, which may contribute to some of the similarity between the vocalizations obtained even though the experimental contexts between the studies were so different. The repertoire described by Brown et al. (1978) does not include all of the sounds in our classification scheme or in the schemes provided by others, including Crowell-Davis (2007), who described cat vocalizations as belonging to nine onomatopoeic categories: purr, trill, miaow, growl yowl, snarl, hiss, spit, and shriek.

Small sample sizes in the current study, and indeed many studies (e.g., Moelk 1944; McKinley 1982; Schötz 2012), leave results in the field requiring repetition, validation, and expansion. This study included 13 subjects, of varying ages and stages of maturation, from three family groups. The vocal recordings used in this study were obtained while the subjects were exposed to a large number of novel contexts; however, the contexts presented by the experimenters were focused on socialization. More refinement in the description and analysis of context, especially an enumeration of specific behavioral and environmental contexts in relation to specific call types, per Haskins (1979), has the potential to shed more light on questions of the role and function of feline vocalizations. Likewise, a future comparison of the presence or absence of humans with the occurrence of particular cat vocalizations would elucidate factors relevant to the production and function of various feline vocal responses.

It is unlikely that this sample represents the entirety of either feral or domestic cat vocal repertoires. We expect more subcategories to be identified provided a larger sample of vocal recordings is obtained from more subjects spread across more family groups and a diversity of behavioral and situational contexts. Our basic strategy for the classification of vocal sound categories was to specify simple and unique acoustic units, as recognized by silent gaps and gestalt patterns described in the methods section. We intentionally avoided creating categories for complex or multi-part calls consisting of sound combinations, in order to provide a clear structure of classification of simple phoneme-like components that can incorporate the results of future research on cat vocalizations. For example, superficial examination of the range of pulsed vocalizations leads us to predict that further recording will reveal a new subcategory within the pulsed sounds, a pulse hybrid: pulse burst with a starting tonal sound. Additionally, because of the composition of our family groups and limited social contexts, agonistic sounds were likely not produced and may not be represented by the classification scheme as it stands now. However, the hierarchical classification system proposed here allows for the addition of new categories and new subcategories.

The link between social and vocal behavior is important both for the understanding of the adaptation of domestic cats to a feral existence, and also for a deeper understanding of the socialization and domestication process. The latter could provide important insight into the history of cat domestication, as well as assist in ensuring the welfare of feral animals offered for adoption. However, further study of the link between feral cat sociality and vocal behavior requires rigorous and well-defined descriptions of the extent of the vocal repertoire. Our study has shown the broad extent of this repertoire, and proposed an objective and reliable classification system that can be used in future studies.

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