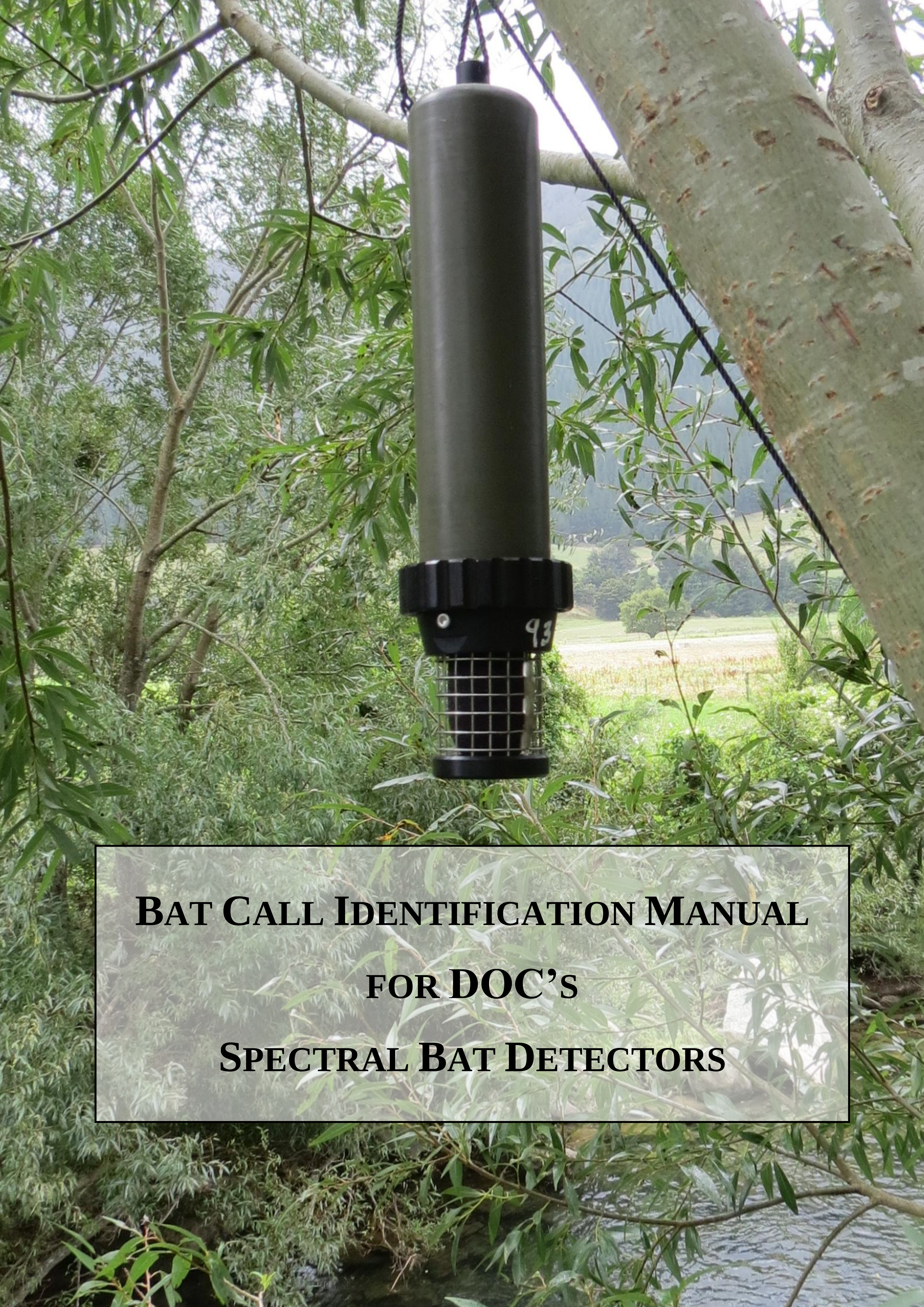

Bat Call Identification Manual for DOC's Spectral Bat Detectors

BAT CALL IDENTIFICATION MANUAL FOR DOC'S SPECTRAL BAT DETECTORS

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For: the Department of Conservation

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MICRO-BAT ECHOLOCATION

Micro-bats have evolved sophisticated echolocation abilities, which allow them to feed and fly freely in complete darkness. Echo-locating bats emit short, intense pulses of ultrasound and then interpret the patterns of the reflections or echoes from these pulses to "see" their surroundings (Figure 1). The same principle is used in radar and underwater sonar. Although the ultrasound pulses are very loud, humans cannot hear them because the pulses are at higher frequencies than people can hear. The frequency of sound is measured in kilohertz (kHz) or thousands of cycle per second. Bat's echolocation frequencies range between 20 and 140 kHz, while the highest frequency sound that most people can hear is 16 kHz. Occasionally, young people with good hearing can hear low frequency harmonics from echo-locating bats. Because ultrasound is attenuated by air, echolocation is only effective over short ranges (< 50 m). However, within this range echo-locating bats are able discriminate fine details, including surface texture, insect species, and target prey's speed.

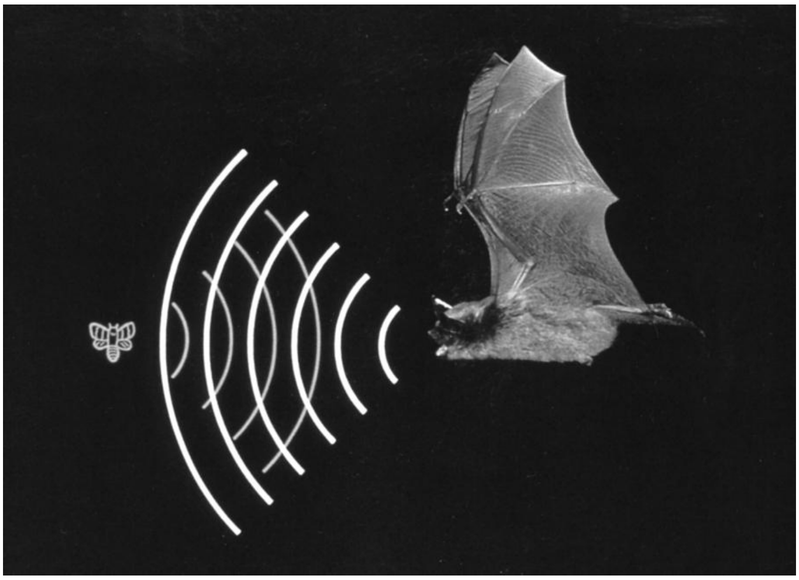

Figure 1. An echo-locating micro-bat using echoes from its calls to find a moth.

USING SPECTROGRAMS TO DESCRIBE BAT ECHOLOCATION CALLS

Spectrograms (e.g. Figures 2 & 3) are the best way to describe and compare bat echolocation calls. Basically, a spectrogram is a picture of sound showing how it varies with time. Typically the horizontal axis of a spectrogram represents time and the vertical axis represents sound frequency in kilohertz. Amplitudes at different frequencies and times are shown either by the intensity of shading or by colour. In spectrograms of bat calls, amplitude is usually measured in decibels (dB), which are on a logarithmic scale.

THE ECHOLOCATION CALLS OF NEW ZEALAND BATS

There are only two species of bats remaining in New Zealand: lesser short-tailed bat *Mystacina tuberculata* and long-tailed bat *Chalinolobus tuberculatus*. A third species, greater short-tailed bat *Mystacina robusta*, is either extinct or restricted to small offshore islands south-west of Stuart Island. It is relatively easy to distinguish the typical echolocation call sequences of New Zealand's two remaining bat species as they have very different characteristics (Figure 2 & 3, Table 1). Long-tailed bats' echolocation call structure is typical of bats that hunt on the wing for flying prey in open areas, whereas short-tailed bat call structure is typical of bats that forage in cluttered forest environments.

Table 1. Summary of the differences between call sequences from short-tailed and long-tailed bats.

Characteristic	**Short-tailed bat**	**Long tailed-bat:**	
		Search phase calls	**Feeding buzz**
Power Spectrum	Three or more harmonics centred at 26 kHz intervals: 26, 52 & 78 kHz	"J" shaped pulses with frequencies sweeping down from 80 to 38 kHz. Higher harmonic at >80 kHz	25–36 kHz
Peak frequency	24–28 kHz or 46–54 kHz	35–40 kHz	25–36 kHz
Pulse Repetition Rate	Fast, but variable 10–60 pulses/sec.	Slow 6–12 pulses/sec.	Fast to very fast 60–200 pulses/sec.
Pulse Length	Short 3–4 milliseconds	Long 20–40 milliseconds	Very short 1 millisecond

Lesser Short-tailed Bat *Mystacina tuberculata*

Individual pulses in short-tailed bat echolocation call sequences have three major harmonics centred at about 26, 52 and 78 kHz (Figure 2). Higher frequency harmonics are present at *c*. 26 kHz intervals, but are usually too faint to be detected. The maximum power in a pulse may be in either the first harmonic, centred at *c*. 26 kHz, or the second harmonic, centred at *c*. 50 kHz. The Pulse Repetition Rate is extremely variable (10–60 per sec.), but usually relatively high. Pulse Lengths are short, typically lasting between 3 and 4 milliseconds. Short-tailed bats occasionally use feeding buzzes, characterised by higher pulse repetition rates and shorter pulses, but they are relatively uncommon, because most short-tailed bat foraging is by gleaning rather than aerial hawking.

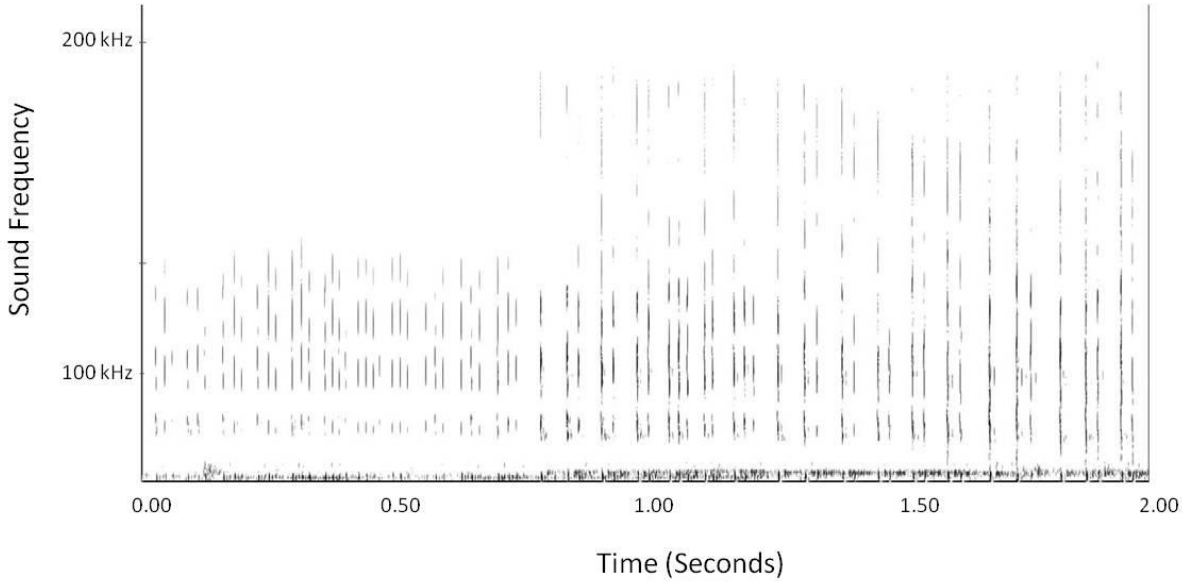

Figure 2. Spectrogram of short-tailed bat call sequence showing harmonics extending to 200 kHz.

Long-tailed Bat *Chalinolobus tuberculatus*

Most calls from long-tailed bats are search phase calls. In spectrograms of search phase calls, individual pulses are "J" shaped, with frequencies sweeping down from 80 to 35 kHz (Figure 3). The maximum power in pulses is between 35 and 40 kHz. Higher frequency harmonics are present, but are usually too faint to be detected. The Pulse Repetition Rate is much slower (4–10 per sec.) and the Pulse Lengths are longer (20–40 milliseconds) than in short-tailed bats.

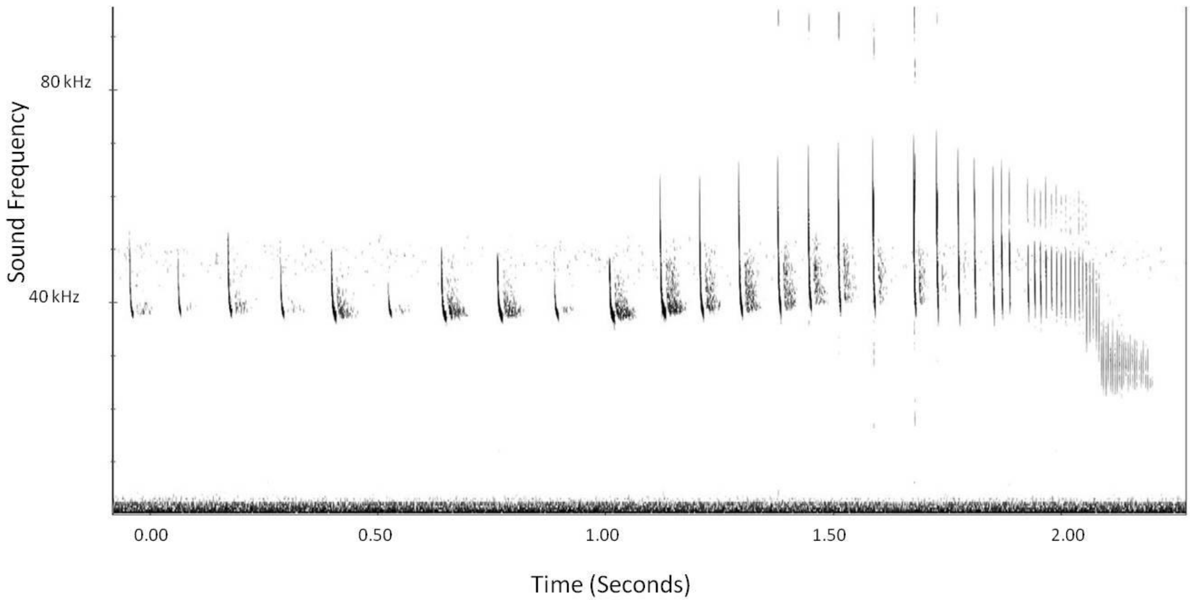

Figure 3. Spectrogram of long-tailed bat foraging call sequence.

When a foraging long-tailed bat detects a flying prey, its echolocation calls change from the usual search phase calls. Initially, as the bat approaches its target call, pulses get closer together and extend over a wider frequency range. Finally, just before prey capture, the Peak Frequencies in the bat's calls drop from 35–40 kHz to 25–36 kHz, the Pulse Lengths declines to very short pulses of about 1 millisecond, and the Pulse Repetition Rate increase to a very high value (>100 per second). The resulting call sounds like a buzz and appears as a blur on the spectrograms (Figure 3). The change in the call structure in a feeding buzz provides the bat with more information to assist prey capture. At early stages in the transition from search phase calls to a feeding buzz, the call can appear very similar to typical short-tailed bat calls.

Discriminating Between the Calls of NZ's Two Bat Species

The most reliable characteristic for discriminating between calls of New Zealand's two bat species is the differences in the peak frequencies of their calls. The peak frequencies for short-tailed bat calls are in either the 24–28 kHz or 46–54 kHz frequency bands, whereas the peak frequencies for long-tailed bat calls is almost always in the 35–40 kHz frequency band (Figure 4). Because the peak frequencies for individual pulses within a call sequence can vary over a fairly wide range, by as much as 5 kHz, it's best to consider the peak frequencies of the entire call sequence, not just of the individual pulses. In spectrograms, this difference is apparent as a distinct gap in the frequencies of short-tailed bat calls in the frequency range 31–43 kHz where long-tailed bat search phase calls are loudest (Figures 2 & 3).

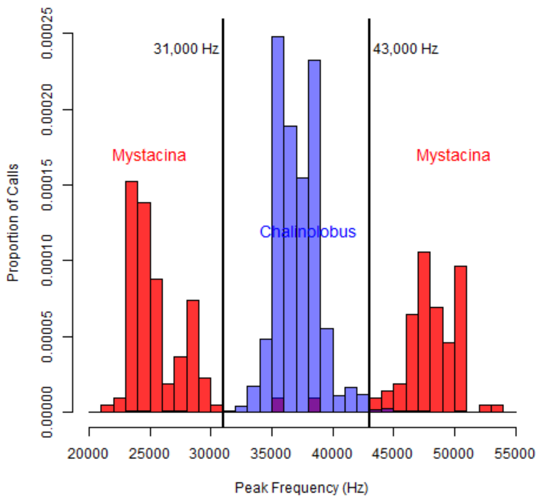

Figure 4. The Peak Frequencies of echolocation calls from short-tailed bats (*Mystacina*) and long-tailed bats (*Chalinolobus*).

DETECTING BATS

Bat Detection Systems

Most micro-bat species echo-locate almost constantly as they fly, consequently bat detectors, which detect bats' echo-location calls, have proved a very effective tool for studying micro-bats. Typically bat detectors work by transforming the inaudible ultrasound of bat's echolocation calls into lower frequency audible signals using either heterodyning or frequency-division. Automated bat detectors used for wide-scale surveys record the resulting audible sounds for later examination.

In heterodyne bat detectors, the bat calls are combined with an internally generated constant frequency tone to produce audible signals with frequencies equal to the difference between the call frequency and the constant tone. Heterodyne bat detectors are cheap, easy to use, and work in real time, but they only detect echolocation calls within a narrow frequency range (typically 5 kHz) around the frequency they have been set to and as a consequence don't detect bats with echolocation calls outside of this frequency range. In addition they don't provide much information about the frequencies present in the original sounds and aren't very good for identifying bats to species or rejecting non-bat ultrasound noises. In the past, all bat surveys in New Zealand were undertaken using heterodyne bat detectors (e.g. Stag Bat Box III and DOCs Automated Bat Monitoring system and Digital Bat Recorder). Frequency division or compression detectors typically reduce the frequency of signals by a factor of ten, i.e. changing ultrasound calls at 40 kHz to an audible 4 kHz signal. Although widely used overseas, frequency division detectors have not proved useful in New Zealand.

The most sophisticated method for studying bat calls entails recording ultrasound in the field and then post-processing the recordings using spectral analysis with a fast Fourier transform algorithm FFT to generate spectrograms. The extra information provided by the method makes it easy to discriminate among bat species and reject spurious non-bat ultrasound. However, the method is unsuitable for wide-scale bat distribution surveys because of the expense of the equipment and the high level of technical expertise required.

DOC's Spectral Bat Detection System

The bat detection system developed recently by the Department of Conservation's electronics team is a major innovation in bat detector technology, achieving the ease of use and low cost of heterodyne bat detectors at the same time as providing the detailed information on echolocation call structure previously only obtained by post-processing ultrasound recordings.

Instead of either converting ultrasound to audible sound or recording ultrasound for post-processing, DOC's new spectral bat detectors undertake on-the-fly spectral analyses of ultrasound input. When results of the spectral analyses indicate that the ultrasound might be a bat call, the results of the spectral analyses are saved in the form of a compressed bitmap of the spectrogram.. The saved spectrograms have time on the horizontal axis and sound frequency from 0 to 88 kHz on the vertical axis. The amplitude at each frequency is indicated by the intensity of shading, with light areas representing low amplitude and dark areas representing high amplitude (e.g. Figure 6 & 7). The spectrograms are saved to the detectors SD card as image files in a compressed bitmap format with a *.bmp* filename extension. The files are named automatically with the current date and time in the format *yyyymmdd_hh:mm:ss*. Thus, a spectrogram saved at 1:36:25 am on 30/08/2016 will be named "*20160830_013625.bmp*".

The spectrograms can be viewed using standard image software, but are best viewed using BatSearch, a proprietary software developed the Department of Conservation's electronics team specifically for reviewing the spectrograms and extracting data from them. There are several versions of the BatSearch program. Earlier versions of the program can only be used for examining heterodyne recordings. To view spectrograms from DOC's spectral bat detectors a recent version of the BatSearch (Version 3.11 or later) is required. This can be obtained from Department of Conservation's electronics team.

On-the-fly spectral analysis is used in DOC's Frequency Compression Recorder, released in 2013, and DOC's AR4 acoustic recorder, released in 2016. The Frequency Compression Recorder can only be used to detect bats, whereas the AR4 acoustic recorder can be used either to record wav files of audible bird calls, or to save spectrograms of ultrasound echolocation calls from bats.

REVIEWING SPECTROGRAMS IN BATSEARCH VERSION 3

Before reviewing spectrograms in BatSearch (Version 3.11 or later), switch on the Frequency Guide using the button at the bottom right of the BatSearch window and then adjust the spectrogram contrast using the slider on the right edge of the spectrogram to optimise image quality. (This contrast adjustment function was not included in early versions of BatSearch Version 3.) Having the slider in the middle of its range provides the best image quality for most spectrograms. The contrast can be re-adjusted to improve views of individual spectrograms as necessary. Increasing the contrast makes very faint calls more visible, while reducing contrast makes dark spectrograms more intelligible. The Frequency Guide (Figure 5) consists of three bands bracketing the frequency ranges: 20–36 kHz, 36–50 kHz and 50–60 kHz. Although the frequency ranges of these bands don't correspond exactly to the distinguishing frequency ranges for short-tailed bat calls and long-tailed bat echolocation calls in Figure 4 (23–31 kHz & >43 kHz c.f. 31–43 kHz), the bands do make it easier to distinguish the two bat species' calls.

50–60 kHz
36–50 kHz
20–36 kHz

Figure 5. Frequency bands in BatSearch's Frequency Guide.

Call Sequences

When an echo-locating bat flies past one of the DOC bat detectors, a train of echolocation pulses is detected and recorded as a spectrogram. This train of pulses is called a call sequence, or a bat pass. The duration of individual call sequences can vary from just one or two pulses to hundreds of pulses, with call sequence durations determined by a variety of factors such as the distance and direction of the bat flight path in relation to the recorder and how loudly the bat is echo-locating. The maximum duration of spectrograms saved by the AR4 is 12-seconds, which is longer than most individual call sequences. There can be more than one call sequence on a single spectrogram, with either a clear break between distinct call sequences or overlapping call sequences with more than one bat recorded at the same time. When detectors are placed close to roosts or swarming sites there can be multiple overlapping calls sequences from many bats. Although a single spectrogram can include more than one call sequence, it's too difficult to define and count individual call sequences, therefore for most purposes, each spectrogram with bat calls on it is counted as a single call sequence.

Short-tailed Bat

In spectrograms of short-tailed bat calls (Figure 6), the loudest (i.e. darkest) parts of calls can be either at the bottom of the bottom band or close to the top of the middle band of the Frequency Guide. In quiet calls there may be only one part of the call visible. Loud calls can extend from about 20 kHz right up to the top of the spectrogram with a gap visible in the call around the boundary between the bottom and middle bands between 32 and 43 kHz. This gap in visible calls is the distinguishing feature for short-tailed bat calls.

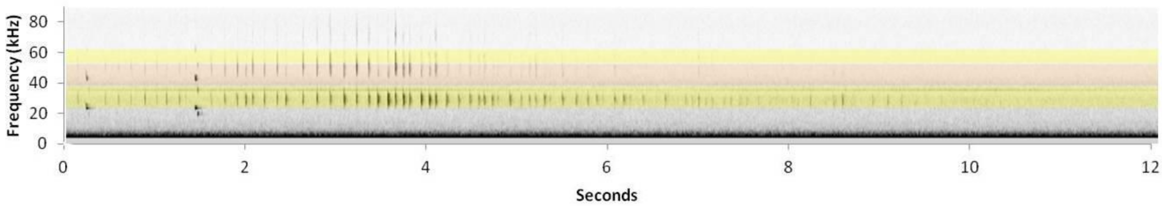

Figure 6. Short-tailed bat echolocation calls. Note the gap in calls around the boundary between the bottom and middle bands of the frequency guide.

Foraging call sequences (Figure 7) begin with typical search phase calls, then as the bat approaches its target the calls get closer together finishing with a very fast pulse rate feeding buzz with most energy in the lower frequency range.

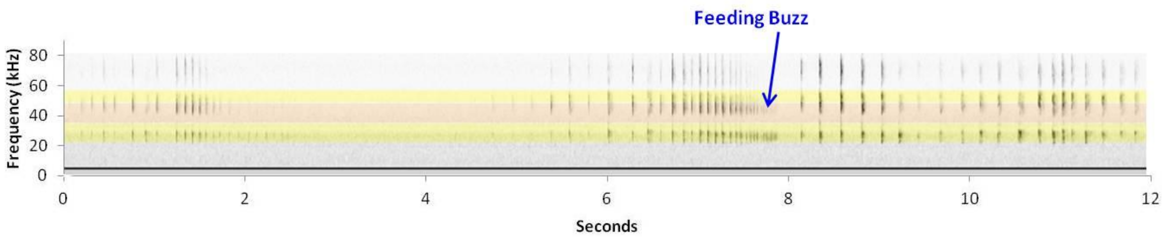

Figure 7. Short-tailed bat foraging call sequence with a feeding buzz.

Long-tailed Bat

In spectrograms of long-tailed bat search phase calls (Figure 8), the loudest part of calls is usually in the middle band of the Frequency Guide. Often this is the only part of the calls visible on the spectrogram. However, there can be calls visible in the upper part of the bottom band and loud calls can extend up to the top of the spectrogram. The most important distinguishing feature for long-tailed bat search phase calls is the absence of calls below 31 kHz, in the lowest part of the bottom band of the Frequency Guide.

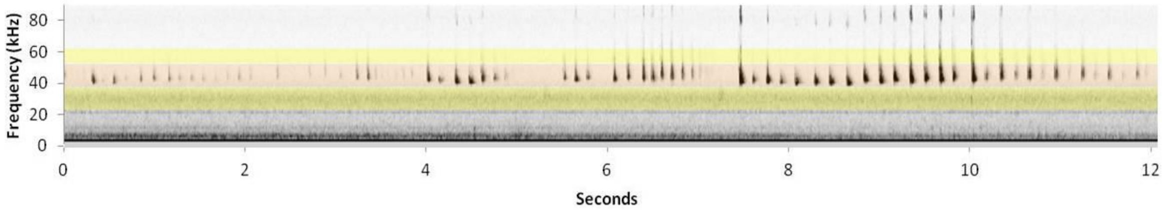

Figure 8. Long-tailed bat search phase echolocation calls.

Long-tailed bat foraging call sequences (Figure 9) begin with typical search phase calls, then as the bat approaches its target the calls get closer together and extend over a wider frequency range during the approach phase. Finally the foraging sequence finishes with the very fast pulse rate of a feeding buzz. Pulses of feeding buzzes are mostly in the bottom band of the Frequency Guide, outside of the typical frequency range of long-tailed bat search phase calls, but long-tailed bat feeding buzzes can be distinguished from short-tailed bat calls by the nature of the call sequences preceding them and the very fast pulse rate of the feeding buzz.

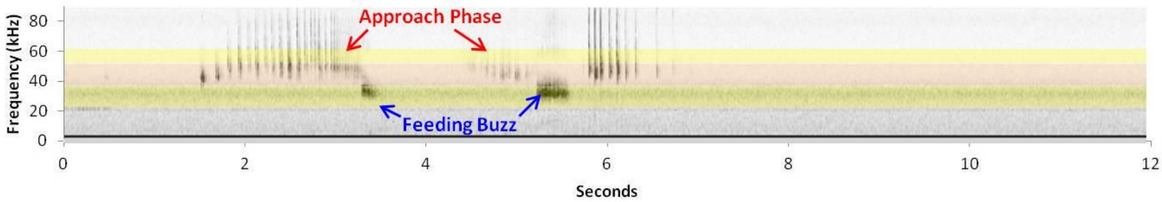

Figure 9. Long-tailed bat foraging call sequences showing the shift in call types from search phase, to approach phase which ends in a feeding buzz.

Faint Echolocation Calls

In most spectrograms only a small part of an echolocation call's frequency range is visible. Usually the lower frequencies in calls are most visible, because higher frequencies are more strongly attenuated by air than low frequencies. Echolocation calls are often only visible on the spectrograms as a series of faint short flat pulses, with short-tailed bat calls only visible in either the 24–28 kHz or 46–54 kHz regions (Figure 10), and long-tailed bat calls only visible in the 40–50 kHz region (Figure 11). Sometimes there may be only one or two faint pulses recorded. In these cases it can be difficult to decide whether the recording is from a bat.

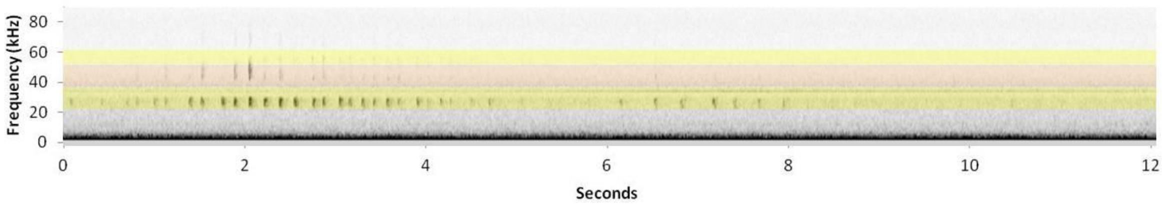

Figure 10. Faint short-tailed bat calls only visible as short flat pulses in either 24-28 kHz or 46 −54 kHz region.

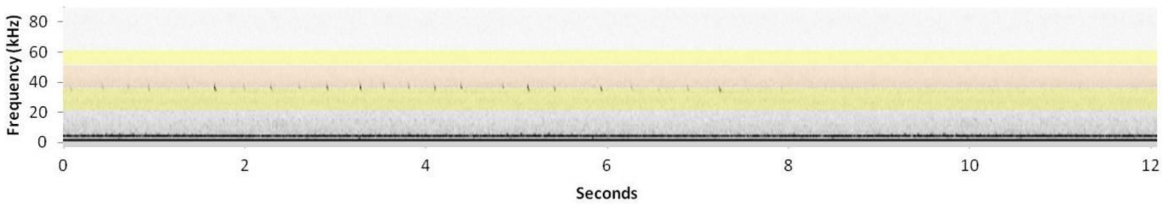

Figure 11. Faint long-tailed bat calls only visible as short flat pulses in the 40−50 kHz region.

Loud Echolocation Calls

In spectrograms of loud echolocation calls from either bat species, the images of very loud pulses are sometimes smeared across the frequency range of the spectrograms, confounding normal species diagnostics. This smearing may be either an artefact of the spectral analysis or a result of the recording system being overloaded by the loudness of the calls. Smearing is usually obvious, appearing as a thin dark line along the leading edge of individual pulses in the call (Figures 12 & 13).

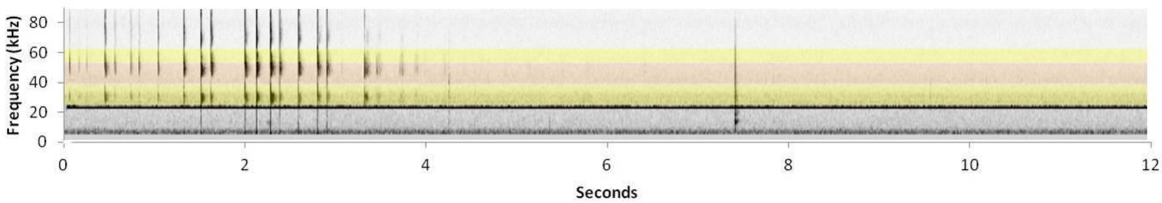

Figure 12. Loud short-tailed bat echolocation call sequence showing smearing outside the usual frequencies.

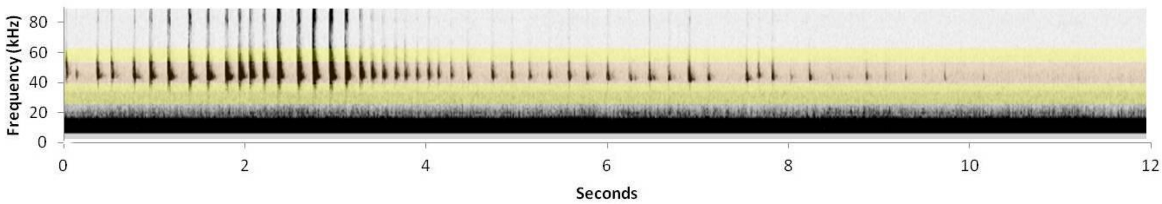

Figure 13. Loud long-tailed bat echolocation call sequence showing smearing outside the usual frequencies.

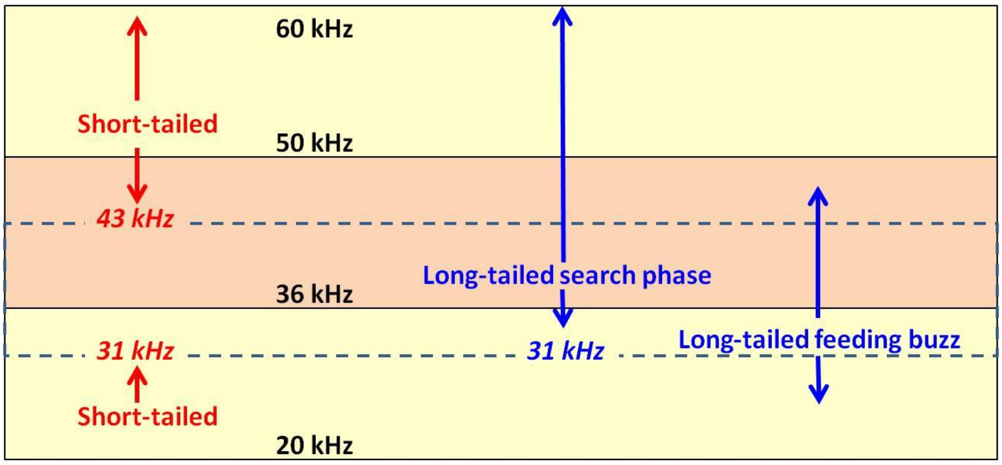

Figure 14. A summary of the typical distribution of the two bat species echolocation calls among the three frequency bands of BatSearch's Frequency Guide.

Geographic Variation in Echolocation Calls

Although there are indications of some geographical variation in the echolocation calls of NZ's two bat species, any geographical variation is minor compared to the variation in echolocation calls that can be recorded from bats at one site. Some of this local variation is a result of differences in the relative positions of bats and the recording equipment, but most of the variation is because individual bats are continually modifying their echolocation calls in response to the situation. Bats adjust pulse length and repetition rates, drop or include harmonics and adjust the power of their calls as necessary.

Bat Social Calls

Both bat species have social calls as well as the echolocation calls they use for navigating and hunting. Bats' social calls are commonly recorded in areas close to colonial roosts or swarming sites. The social calls are partly audible, with frequencies ranging from 10 kHz to 25 kHz, across the upper parts of the audible sound spectrum and the lower part of the ultrasound spectrum (Figure 15). The audible component of the social calls sounds like chattering or squeaking. There are no definitive diagnostics for identifying bat species from social calls on spectrograms other than that they usually accompany high levels of echolocation activity for one or other of the bat species.

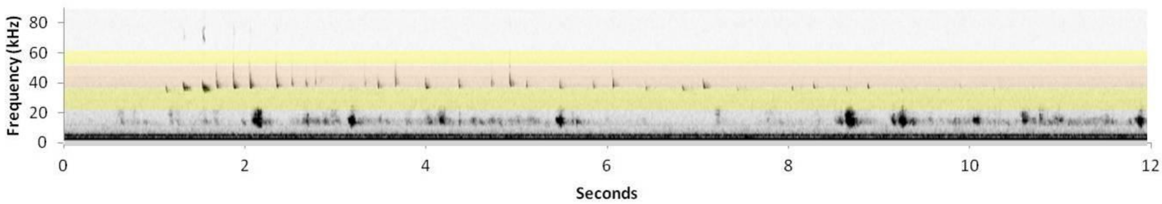

Figure 15. Social calls of long-tailed bat accompanying typical echolocation sequences. The social calls are the dark spots in the 10 kHz to 25 kHz frequency range.

Male short-tailed bats use courtship singing to attract females for breeding during early summer and autumn. The song extends across a wide range of frequencies from 8 kHz to 48 kHz in the ultrasound spectrum. The audible component of song sounds similar to a rifleman's song. Spectrograms of singing have complex patterns (Figure 16), with several harmonics between 8 kHz and 48 kHz. Short-tailed bat singing is reasonably common during early summer and autumn in areas with short-tailed bats, as males sing continuously throughout the night. However, the trigger mechanisms on the new detectors probably filter out most recordings of short-tailed bat singing because of the songs audible component.

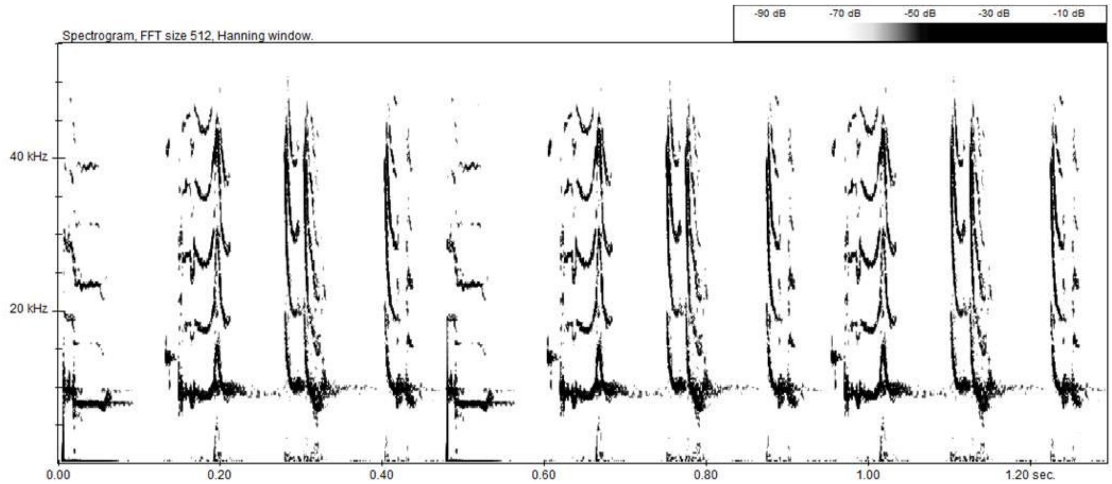

Figure 16. A spectrogram of male short-tailed bat courtship singing obtained by post-processing ultrasound recordings. The time scale on this spectrogram is expanded compared to spectrograms from DOC's detectors.

Other Ultrasound Noises

There is a wide range of ultrasound noise in the natural environment including rain and wind, river noise, rustling foliage or leaf litter from animals' movements and animal calls. This ambient ultrasound is more noticeable at lower frequencies, partly because they are less attenuated than higher frequencies. The detectors have a triggering mechanism designed to minimise recording spectrograms for these other ultrasound noises. The trigger mechanism only initiates spectrogram recording when there are rapid energy changes in ultrasonic frequencies not matched by energy changes in audible frequencies. The trigger mechanism suppresses recording spectrograms for many of the spurious ultrasound noises; successfully filtering out a range of sounds including: bird calls, many insect sounds, river noise, mechanical noises and noises from animals moving close to recorders. The main remaining sources of spurious spectrograms are wind and rain. In most cases spectrograms of wind and rain are easily distinguished by the hash of vertical lines and speckling in the spectrogram (Figure 17).

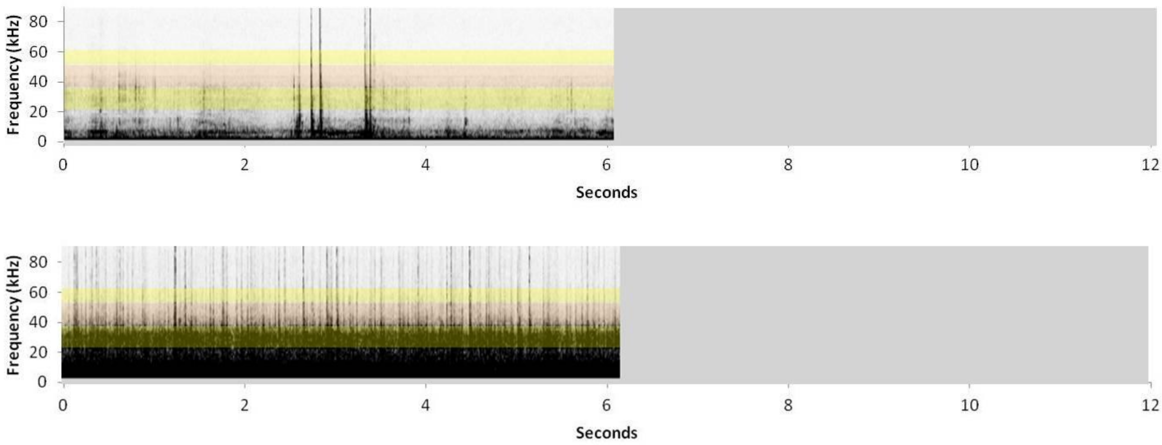

Figure 17. Spectrograms of wind and rain.

Other sources of non-bat ultrasound recordings are rodent vocalisations and insect noises. Rodent vocalisations are varied, but easily distinguished from bat calls. The loudest part of rodent vocalisations is in the 20–30 kHz range, with higher frequency harmonics sometimes visible (Figure 18). Individual pulses in the rodent vocalisations are flat and long and there only short breaks between successive pulses.

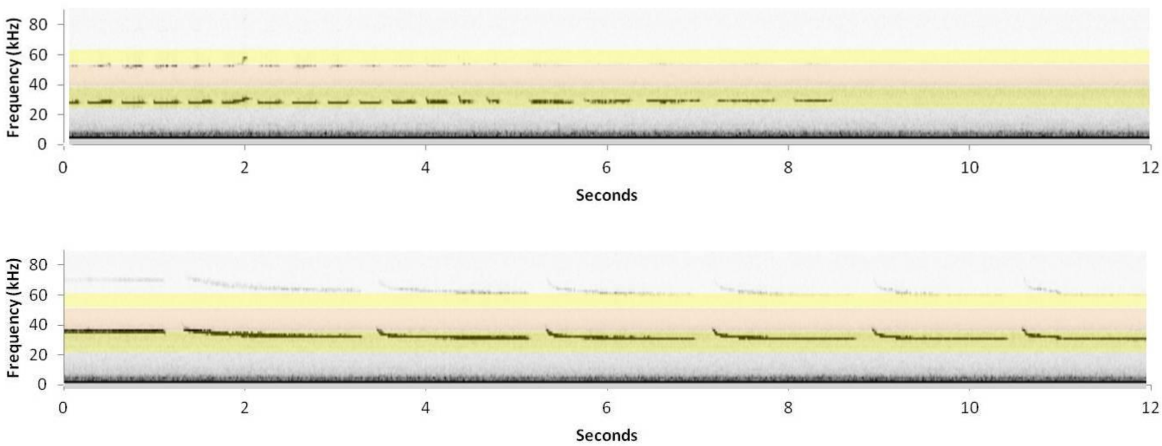

Figure 18. Spectrograms of rodent vocalisations.

Insect sounds are extremely diverse, but can usually be distinguished from bat calls by their very fast pulse repetition rates and lack of variation in either pulse amplitudes or frequency ranges within pulse sequences (Figure 19).

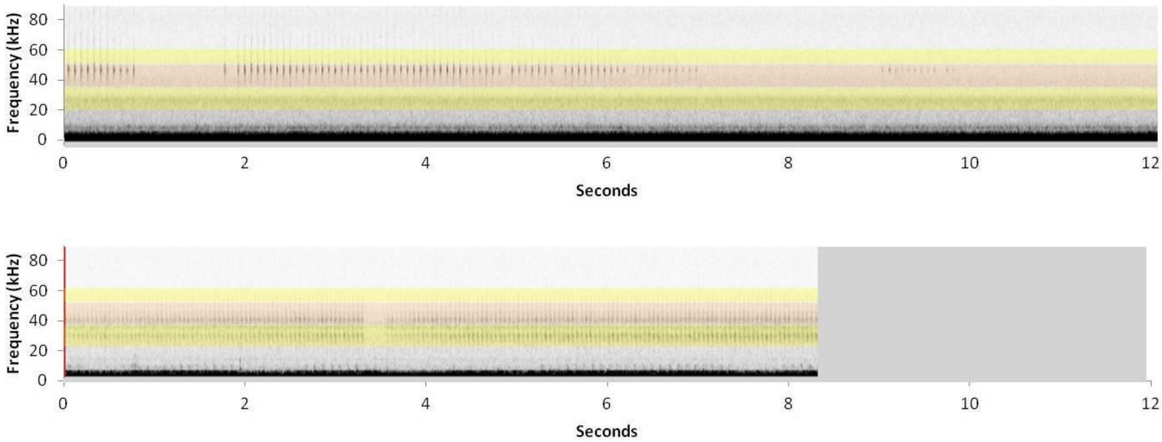

Figure 19. Spectrograms of typical insect noise showing the distinctive very fast pulse repetition rate and lack of variation in pulse amplitudes and frequency ranges.

LIST OF FIGURES