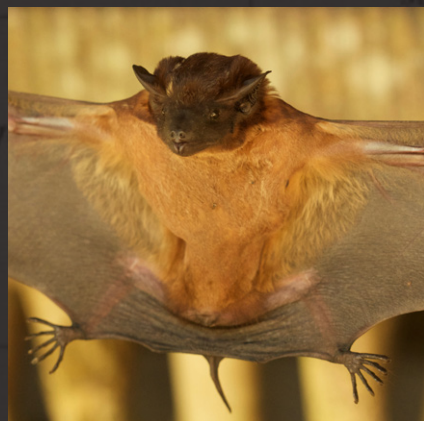


IDENTIFICATION GUIDE TO BAT ECHOLOCATION CALLS OF SOLOMON ISLANDS & BOUGAINVILLE

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In fond memory of Anna Kaveni

Kongulai, Guadalcanal

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Michael Pennay and Tyrone Lavery

ABOUT THIS GUIDE

Many bat species use high frequency calls known as 'echolocation' calls to navigate and find food. These calls are mostly ultrasonic. Ultrasonic noise is above the range of human hearing, which is about 20 kilohertz (kHz). To record these noises, bat detectors are used. Bat detectors are fitted with special microphones capable of recording ultrasonic noises.

Bat detectors have the potential to greatly improve our knowledge of bats. Bat detectors are easy to use and very efficient at collecting data because the bats being recorded do not need to be captured. A few nights of recording can capture hundreds or thousands of calls from almost all the species using a particular area. This is particularly valuable in tropical rainforest environments like the Solomon Islands where many species are adept at flying in and around thick vegetation and can easily detect and avoid nets and traps set by researchers. It may take many nights of trapping and netting to catch even a single individual of a species that could be recorded in mere minutes by a bat detector. Bat detectors can allow data to be collected about the distribution, abundance of bats to answer questions about habitats used and the conservation status.

Whilst recording bat species with a bat detector is easy, a large amount of work and data is required to know what it is that has been recorded. That is the purpose of this guide. We have captured and collected 'reference calls' from most species of bats in the Solomon Islands so that students and researchers may identify and study bats using recordings of the ultrasonic calls.

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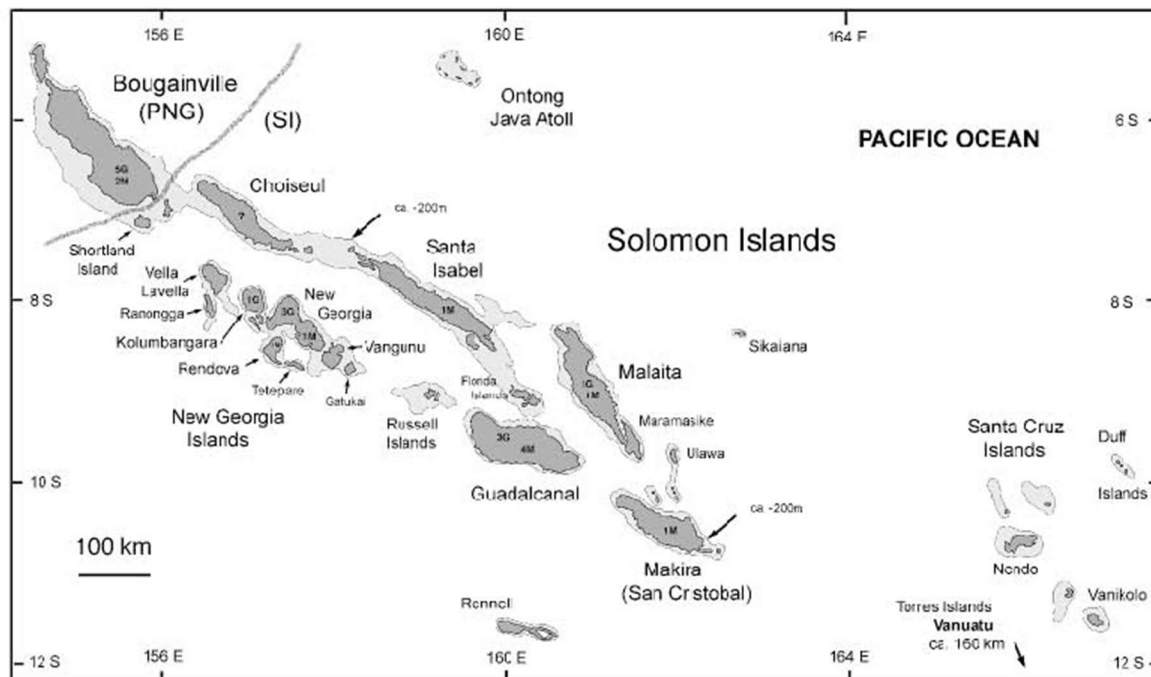
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LOCATION

This guide is for bat calls from the Solomon Islands biogeographic region, including the islands of Solomon Islands and Autonomous Region of Bougainville. We have recorded reference calls from locations in Bougainville, Choiseul, New Georgia, Isabel, Guadalcanal and Makira island groups. Representing the first time the echolocation calls of most species in the Solomon Islands have been recorded and documented.

Figure 1: Geographic coverage of this guide.



FURTHER WORK

This guide really represents the beginning of our understanding of Solomon Island bat calls. There are many gaps in our knowledge and areas where we don't understand well. We hope these gaps inspire future research questions for interested students and bat scientists, there is potential to make many new and interesting discoveries that improve our knowledge of Solomon Island bats and their unique role in the world. We are very happy to try answer questions, or receive feedback and make updates or amendments to this guide. Some specific areas for further work are:

GEOGRAPHIC COVERAGE

Although we have recorded bats at many locations, we have not yet been able to record species across their range in Solomon Islands. For example we have recorded calls of *Hipposideros dinops* in Guadalcanal, but not from Malaita, Isabel, New Georgia or Bougainville. There are some Island groups including; Malaita, Rennell and Bellona and Temotu (Santa Cruz) Island groups, where we have not recorded bat calls at all. This is an important knowledge gap, because our work so far has highlighted there is substantial call **variation** in different parts of species ranges.

REGIONAL VARIATION

The data we have collected shows that a number of species have substantially different calls in different locations. For example, *Hipposideros diadema* calls at 59kHz in Choiseul and New Georgia Island groups, which is similar to the frequency it has been recorded at in P.N.G. However, in Guadalcanal it consistently calls close to 66kHz. Other species that we've found vary their call depending on the location include *Hipposideros cervinus* and possibly *Saccolaimus saccolaimus*.

Because we don't yet have samples of species calls from across their range, we don't have a clear picture of the full extent of geographic variation. We also don't know the underlying reasons for the variation, it could be that species have significantly different habits and behaviour in different island groups, or it could even be that there are **cryptic species** that look similar to known species which we have not yet discovered are distinct.

At this stage all we can do is highlight to future researchers that geographic variation is a phenomena to be aware of.

UNIDENTIFIED CALLS

We have collected reference calls from all fourteen Solomon Island bat species that echolocate. Reviews of species records indicate an additional seven species may also occur in the region: *Anthops ornatus*; *Chaerephon solomonis*; *Emballonura beccarii*; *Emballonura raffrayana*; *Miniopterus macrocneme*; *Miniopterus medius*; and *Pipistrellus papuanus*. We therefore do not know with certainty what the calls of these species look like. Exactly how many species of echolocating bat may occur in the region is very uncertain.

While undertaking this work we recorded samples of free flying bats in Bougainville, Choiseul, New Georgia, Isabel, Guadalcanal and Makira Island groups. We analysed these calls to test if we could identify the species recorded based on our sample calls from and also any 'missing' species. We were able to identify most of the calls to species from the reference call library we assembled. Among free flying bats, the calls of *Mosia nigrescens* and *Pipistrellus angulatus*. *Hipposideros diadema* and *H. dinops* were recorded with regularity.

In the calls of free flying bats we were also able to identify several calls of bat species not included in our reference calls. These included; a constant frequency call at around 120kHz and a multi-harmonic flat FM type call between 38-43 kHz from multiple provinces, and, a long, low frequency, FM call with alternating pulses at around 21kHz from Guadalcanal. It is possible that these three unidentified call types represent calls from our missing species, cryptic species we do not know about, or geographic variations in calls from species we have recorded elsewhere.

TAXONOMIC QUESTIONS

Much about the bats of the Solomon Islands is poorly known. This includes their taxonomy (the naming of species). The taxonomy of the bentwing bats (genus *Miniopterus*) in particular is confusing. Multiple species have been reported from the Solomon Islands and current species descriptions make field identification difficult (or impossible) to determine which species is in the hand. It is also unknown if the species present in the Solomon Islands fit under current species or represent undescribed but similar looking species. There is ongoing genetic work by taxonomists to clarify these species boundaries.

We captured and recorded calls from three distinct *Miniopterus* bats, a small, moderate and large sized bat which we have tentatively named *Miniopterus cf. australis*, *M. cf. oceanensis*, and *M. cf. tristis* using current species descriptions they appeared to best fit, based on body measurements. We have also collected tissue samples which have been sent for genetic analysis to clarify the identity of the bats, but the results of this analysis are not yet known.

Aside from the confusion about *Miniopterus* taxonomy, this project has also highlighted some other tantalising taxonomic questions that warrant further investigation. For example: is the very different call used by *Hipposideros diadema* in Guadalcanal because it is a distinct cryptic species? or is it in the process of speciation? Is the unidentified bat that calls at 21kHz in Guadalcanal a new undescribed *Saccolaimus* species? Why do *Hipposideros calcaratus* and *H. cervinus* from Guadalcanal call at different frequencies than they reportedly do in Papua New Guinea and Indonesia? Is there something particular about Guadalcanal that has produced so many geographic variations in calls?

DIMORPHISM

In other countries, the calls of some types of bats have been found to be sexually dimorphic, meaning males and females make different calls, or age dimorphic meaning young bats and adults make different calls. We don't have enough data to confirm if any bats in Solomon Islands have dimorphic calls, however we did record *Aselliscus tricuspidatus* at two distinct frequency ranges (high 117-119 kHz, and low 114-116 kHz) in Guadalcanal. We don't know if this is due to sexual or age dimorphism, or other phenomena, or that we don't have enough reference calls and just missed calls from 116-117 kHz range.

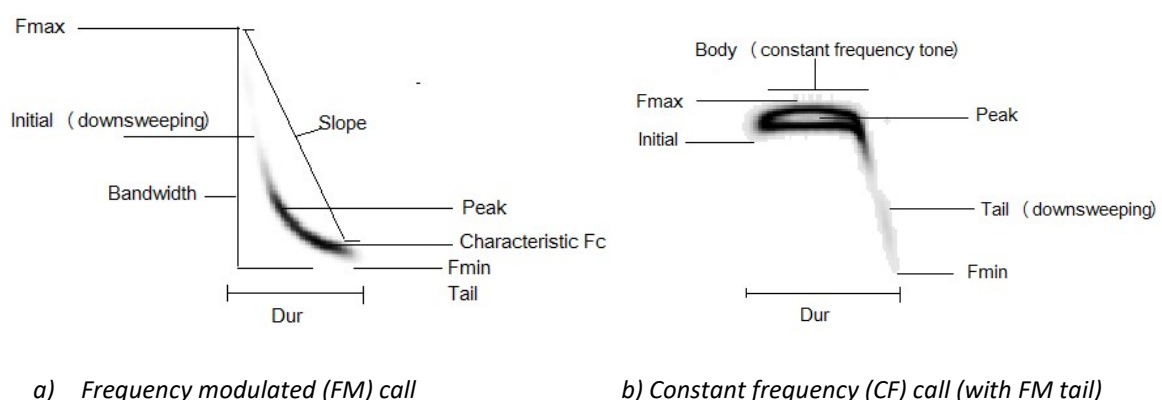
ULTRASONIC FLYING FOX CALLS

Traditionally ultrasonic calls have been associated with echolocation and are considered one of the defining characteristics differentiating microchiroptera from megachiroptera - the flying foxes. Interestingly some species of megachiroptera we encountered in the Solomon Islands have calls containing ultrasonic elements, *Rousettus amplexicaudatus* produces clicks and we recorded *Melonycteris woodfordi* producing 'trills' in ultrasonic frequencies.

BAT CALL TERMINOLOGY

We use a number of specific terms in this guide to describe different types and parts of bat calls that are useful in identifying species.

FIGURE 2: BAT CALL PARTS AND TERMS



Call, Sequence: In this guide we refer to a bat 'call' as a single pulse of sound made by a bat (as in Fig. 2 above). A sequence is a series of these calls recorded in succession by the detector (as in Fig. 4).

Call shape: Generally we describe calls as either being frequency modulated (FM) sweeps or constant frequency (CF) calls.

Frequency modulated: means that the call covers a range of frequencies; it may drop from a high frequency down to a lower frequency (Fig. 2a). Some genera make entirely frequency modulated calls (*Miniopterus*, *Pipistrellus*, *Saccolaimus*, *Mosia*, *Emballonura*), others may make calls that have constant frequency and have frequency modulated components such as a tail (Fig. 2b).

Frequency modulated calls are sometimes further described as **Steep** because they cover a large range of frequencies over a short duration which gives them a steep appearance when plotted on a frequency/time display, or **Flat** because they cover a low range of frequencies which gives them a flatish appearance on a frequency/ time display.

Constant frequency: means that the call has a flat constant frequency tone at a certain frequency. Bats in the genus *Hipposideros* and *Aselliscus* make constant frequency calls, sometimes with frequency modulated components (Fig. 2b).

Maximum frequency (Fmax): The highest apparent frequency of the call (when multiple harmonics - of the dominant harmonic).

Minimum frequency (Fmin): The lowest apparent frequency of the call (when multiple harmonics – of the dominant harmonic).

Peak frequency (Peak): The frequency of the maximum amplitude of the call (the loudest part).

Characteristic section: The point in the final 40% of the call with the lowest slope, (the flattest part of the call) or where the main trend of the body of the call ends.

Characteristic frequency (Fc): The frequency of the characteristic section (see above).

Compressed / real time: Some software allows calls to be viewed in ‘compressed’ mode where the quiet pauses between each call pulse are compressed in time. This allows more pulses to be viewed on the screen but removes information about the timing of pulses. Real time refers to displaying calls and the time between the calls are viewed at the same time scale.

Duration (Dur): The duration of the call in milliseconds.

Total slope (Slope): The slope of the call in kHz per ms, calculated from the difference in frequency and time between maximum frequency (Fmax) and the characteristic frequency (Fc).

Bandwidth: The total frequency spread of the call from maximum (Fmax) to minimum frequency (Fmin) (when multiple harmonics- of the dominant harmonic)

Kilohertz (kHz): The international measure of sound frequency, 1 kHz is equal to 1000 complete cycles per second.

Milliseconds (ms): International measure of time, one thousandth of a second. E.g. a 10 ms duration bat call lasts for one hundredth of a second, a 100 ms pause is one tenth of a second, and a 1000 ms sequence of calls is one second long.

Amplitude: Amplitude is used to describe the volume or loudness of a call. E.g. ‘maximum amplitude’ means ‘loudest’.

Body: The main, and often flattest, loudest part of the call, in constant frequency calling bats this is the constant frequency component.

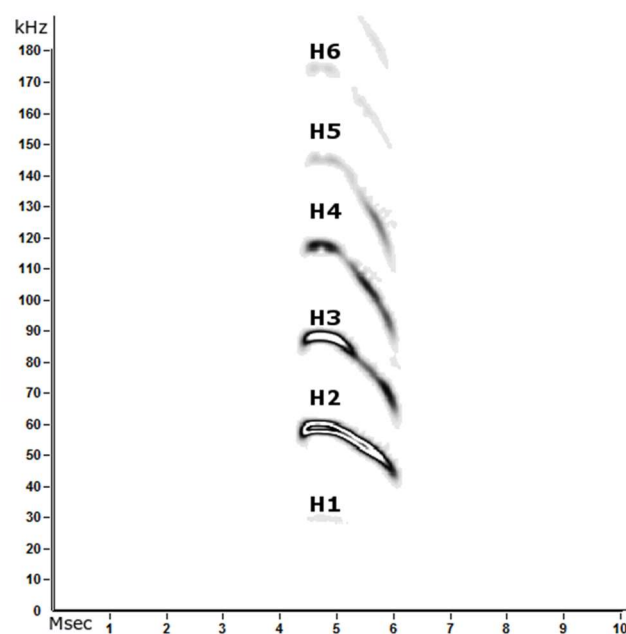
Tail: A frequency modulated sweep after the body at the end of a call, (can drop in frequency ‘downsweeping’, or increase in frequency ‘upsweeping’).

Initial: A frequency modulated sweep before the body at the start of a call, (can drop in frequency ‘downsweeping’, or increase in frequency ‘upsweeping’).

Knee: The point in a frequency modulated call at which the initial frequency sweep transitions into the flatter body section, called a knee because it visually represents a bend or corner in the call shape.

Harmonics: Multiple, parallel components of a call at repeated in consistent divisible patterns at higher or lower frequencies. Harmonics are labelled in order from H1 (being the lowest or ‘fundamental’ frequency) upwards. For example, *Mosia nigrescens* calls have fundamental harmonic of about 30 kHz, so H1 is 30 kHz, H2 is 60 kHz, H3 is 90 kHz and so on (Fig. 3). In *Mosia* the peak frequency occurs at H2 (60 kHz), which is typical of *emballonurid* and *hipposiderid* bats. *Vespertilionid* bats tend to have peak frequency in H1.

FIGURE 3: EXAMPLE OF BAT CALL HARMONICS



Mosia nigrescens call demonstrating a 30 kHz harmonic pattern.

Harmonics are not always visible, some calls only show the loudest harmonic, or loudest few harmonics depending on what the bat is doing and its proximity of the bat to the detector (see Fig. 4 b for another example of a *M. nigrescens* call where only H2 is visible until it begins feeding calls and H3, and H4 become visible).

In Figure 3, H1 is only barely visible, however H1 is often not visible in species that predominantly call at H2. H1 can be inferred by looking at the steps between other harmonics. For example H1 is not visible in *M. nigrescens* call in Figure 4 b, however by determining that there is a 30kHz gap between the harmonics displayed at H2, H3 and H4 we can infer there must be a 30kHz fundamental harmonic (H1).

BAT DETECTORS AND SOUND ANALYSIS

BAT DETECTORS

A bat detector is required to record the calls of most bats in this guide. The basic function of a bat detector is to record the ultrasonic noises of bats and save them as files for analysis and identification using **analysis software** later. There are a range of bat detectors available, new devices are continually being produced. In the past there has been debate about the benefits of different call recording techniques, in particular differences between **full spectrum** and **zero crossings** recorders. Most modern detectors are capable of recording in both full spectrum and zero crossings methods at the same time. Full spectrum recordings capture full harmonic and amplitude information about calls, which is particularly useful in analysing multi harmonic species. The zero crossings method uses much less data, but captures less information about each call. However, unless data storage is an issue we recommend recording all calls in full spectrum and converting them to zero crossings at a later time if required. Rather than recommend any particular detector to use, we highlight the important considerations that must be made before purchasing a bat detector.

PASSIVE OR HAND HELD

Perhaps the greatest difference between modern bat detectors is the difference between passive and handheld detectors.

Hand held detectors are designed for active monitoring or recording reference calls. They usually have a screen and sometimes speakers that display and play bat calls in real time so the observer can see and hear representations of the call live. Hand held detectors have easily accessible controls which make recording notes and reference calls easier. Some hand held detectors plug into mobile devices and use the screen of the device. They are sometimes programmable to switch on and off at set times, and can be used at a pinch for semi-remote detecting (for example you could set one to record from your balcony overnight). However, they are not well suited for true use as passive detectors because they are usually not waterproof, have less storage and battery capacity than remote detectors.

FIGURE 4: PASSIVE AND HAND HELD DETECTOR EXAMPLES



a) Passive (Echometer 4 by Wildlife Acoustics) b) Handheld (Anabat walkabout by Titley Scientific)

Passive detectors are designed to be left in the field to record bat calls remotely for extended periods. They are weather proof, have large battery and memory storage capacity. They are usually programmable to switch on and off at set intervals/dates/times. They have remote triggers so that they only record noises (bat calls) that are above set amplitude and frequency ranges to activate the trigger. Some have dual microphones, an ultrasonic microphone for bats and another capable of recording audible calls as well so they can be programmed to switch between microphones to record frogs or birds as well as bats. They can be used to record reference calls; however, they are not so well suited as handheld detectors for this purpose. This is because they usually don't have screens or speakers to play or display real time calls, so it is difficult to know what you have recorded. They can be also a little clumsy because they tend to be heavier, and anti-tamper and waterproof features may make programming buttons not easily accessible.

SAMPLE RATE

The minimum sampling frequency required to record a signal must be at least twice that of the bandwidth of the signal. Some parts of the world, like Europe and North America lack high frequency calling bats and can get away with detectors with lower sampling rates such as 256 kHz. Because some bat species in the Solomon Islands have very high frequency calls (up to 147 kHz), it is very important to get a bat detector capable of recording these calls (**minimum sampling rate of 300 kHz or higher**). We sampled most reference calls using a detector at 384 kHz.

To avoid missing calls of high frequency bats it is also important to check that you set your detector to sample at the higher rate as the defaults are sometimes set lower for European and American customers.

THINGS TO AVOID

Hetrodyne detectors: There are a range of cheapish bat detectors available on eBay such as bat seeker, build your own, baton, bat finder, magenta bat 4, Pettersson d240x. These are Hetrodyne detectors, they allow you to listen to certain frequencies for bats but lack recording capabilities so they have very limited usefulness other than listening to bats. A handheld full spectrum bat detector/ recorder is far more useful.

Defunct detectors: Because technology has changed, older detecting devices may be available for good prices (or free). This may sound good, but if the device no longer works, or the software is no longer supported it is not much use.

MANUFACTURERS

The following manufactures make the most commonly used bat detectors, although there are others. It is also worth checking online forums such as Bat Detector Reviews <http://batdetecting.blogspot.com/> for advice and recommendations the Australasian Bat Society (ABS) and South East Asian Bat Conservation and Research Unit (SEABCRU) are accessible on the web and Facebook for advice. If you contact a manufacturer and explain to them where and what you plan to use a bat detector for they will recommend a particular type.

Titley Scientific <http://www.titley-scientific.com/au/products/anabat-systems>

Wildlife Acoustics <https://www.wildlifeacoustics.com/>

Pettersson Elektronik <http://www.batsound.com/>

SOFTWARE

Software is required to view and interpret bat calls. Some software is free and others can be quite expensive. A list of bioacoustics software is available from Wikipedia at

https://en.wikipedia.org/wiki/List_of_Bioacoustics_Software

THINGS TO LOOK FOR IN SOFTWARE

There is no right or wrong software. Ideally the software you choose should allow you to do at least following things with relative ease: display bat calls and sequence; measure minimum, maximum, peak frequency, duration and other call characteristics; and navigate between call files.

Purchased software usually offer more advanced options such as batch processing and automated identification, however these may not be necessary or even available. It is not worth paying for software that automatically identifies bats in America or Europe if you are working only in the Solomon Islands.

Fortunately there are many free software options available, we mainly used Kaleidoscope (free) <https://www.wildlifeacoustics.com/products/kaleidoscope-software-acoustic> and Sonobat (purchased) <http://sonobat.com/> to produce this guide.

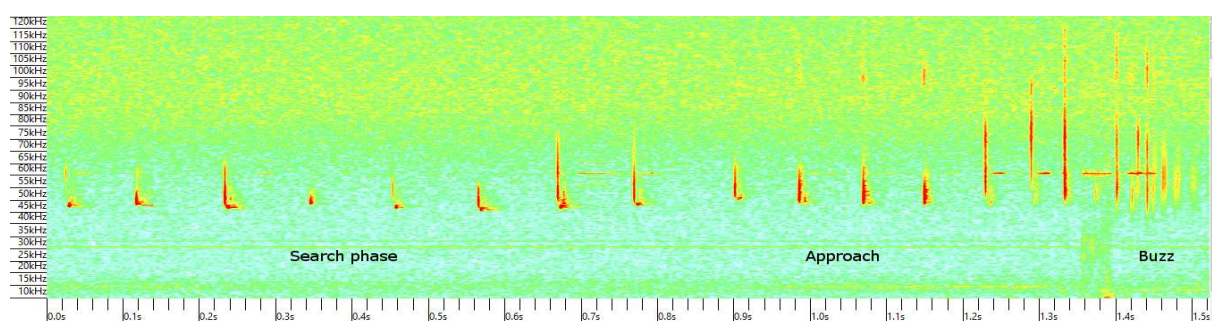
If you require automatic identification, a good free software option may be Songscope <https://www.wildlifeacoustics.com/products/song-scope-overview>. This software allows you to build your own 'recognizers' based on local reference calls and batch process large numbers of calls to aid identification.

UNDERSTANDING BAT CALLS

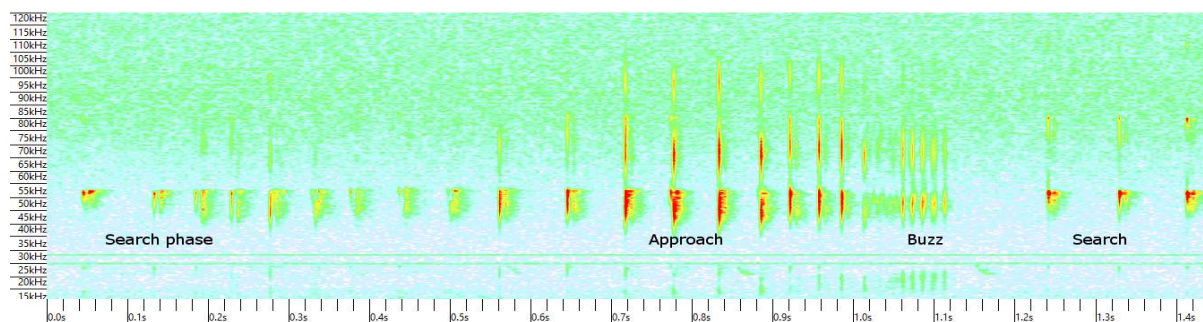
Bats produce many different types of calls. Each species has its own repertoire of calls it uses in different circumstances. The main type used for identification purposes are called **search phase** calls, these are usually the most commonly recorded calls and are produced by bats when they are navigating. Search phase calls are generally a consistent shape, duration and frequency (or sweep of frequencies). **Approach** and **feeding buzz** calls, are used by some species as they approach and 'zero in' to attack insect prey. These feeding calls are obvious in species that modulate the frequency of their calls. As the bat detects and approaches prey it increases the bandwidth of frequencies covered and reduces the duration between calls, giving a steeper appearance, sometimes upper harmonics become visible (Fig. 5 b), the attack ends with a series of very rapid calls called a terminal or feeding buzz (Fig. 5). Sometimes feeding calls can be used to differentiate between species, for example the buzz call of *Miniopterus* species drop rapidly in frequency whereas the buzz calls in *Pipistrellus* calls do not (Fig. 5).

It is important to recognise call phases, because sometimes approach and buzz calls of one species can appear similar to search phase calls of another species (for example *Myotis*). Some species vary their search phase calls depending on the type of habitat they are flying in, giving steeper, shorter duration calls in cluttered environments and flatter longer calls in open environments.

FIGURE 5: EXAMPLES OF SEARCH, APPROACH AND FEEDING BUZZ PHASES



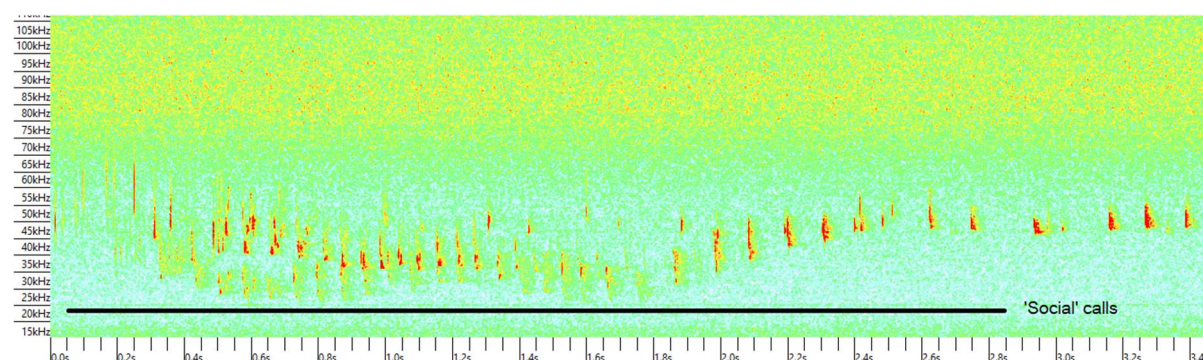
a) *Pipistrellus angulatus*



b) *Mosia nigrescens*

Other types of calls include: calls between mother bats and their pups; calls made at roosts; and calls used to attract mates, mark territory, or during other social interactions. These types of calls are generally clumped under the broad title of **'social' calls**. Social calls could be mistaken for the calls of other species, however they are often easy to identify because they contain erratic pulse shapes and broad fluctuations in frequency (Fig. 6). It's very likely social calls contain useful information to identify and separate species, but they are not commonly recorded under normal circumstances and we know so little about them that at present that they are generally not used to identify species.

FIGURE 6: EXAMPLE OF SOCIAL CALLS



Social calls of *Pipistrellus angulatus*, demonstrating pulses from multiple bats with erratic pulse shapes and changes in frequencies.

THINGS TO BE AWARE OF

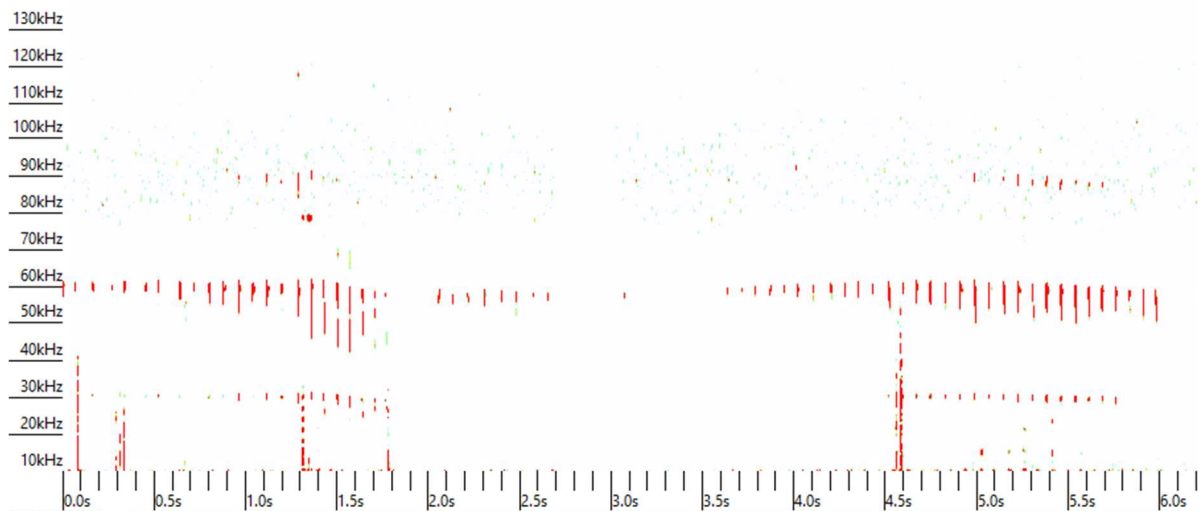
There are some natural and artificial phenomena that can affect recorded bat calls. It is important to be aware of these phenomena when trying to interpret bat calls to avoid potential confusion or misinterpretation.

DOPPLER EFFECT

The Doppler Effect is a phenomenon about the way sound waves are perceived when moving objects are involved. Although it sounds technical and complicated the Doppler Effect is actually very familiar, we can recognise when an outboard motor coming towards or away from us because the sound of the engine is Doppler shifted. Because most calling bats are flying and the bat detector is stationary the recorded bat calls can be affected by Doppler Effect – they appear higher in frequency as the bat approaches and lower in frequency when they fly away. The Doppler Effect may shift the recorded frequency of a call by several kHz depending on how fast the bat is flying, it may give the impression that the bat is calling over a wider range of

frequencies than it really is. Some species adjust their calls to match their flight speed to compensate for the Doppler Effect. The Doppler effect can help identify species by their behaviour, for example *Pipistrellus angulatus* and *Mosia nigrescens* hunt by flying in small tight circles, call sequences from these species often show up and down Doppler shifts as the bat circles towards and away from the detector (Fig. 7).

FIGURE 7: EXAMPLE OF THE DOPPLER EFFECT SHIFTING BAT CALL FREQUENCIES

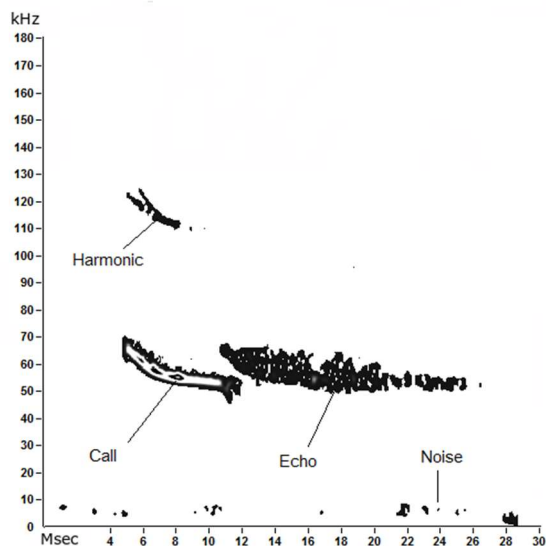


A 6 second *Mosia nigrescens* call sequence showing Doppler shifted frequencies (up and down) – above and below 60 kHz as the bat circles tightly towards and away from the detector.

ECHOES

Recorded bat calls are often followed by echoes. This usually occurs in circumstances where the bat is recorded close to the detector or there are structures nearby (e.g. trees, cave walls, buildings, people) that can reflect the echoes. Sometimes the echoes can be quite loud or close in time to the original call, which can be confusing or give the impression of multiple bats. Generally echoes are easy to identify, they follow shortly after the recorded call at similar frequencies, but usually have a less defined shape as the sound diffuses in the atmosphere (Fig. 8)

FIGURE 8: EXAMPLE OF AN ECHO



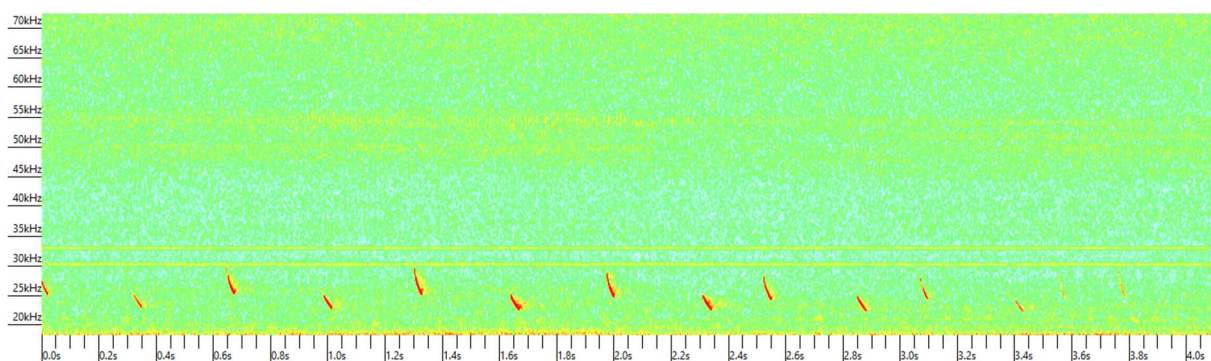
ATTENUATION

All sound waves attenuate (break down) in the atmosphere, if your friend whispers in your ear you can hear them, but if they whisper from 100 meters away you may not because the sound has attenuated. Attenuation varies with many factors including: original amplitude, humidity, wind, and temperature. Higher frequencies attenuate much more rapidly than lower frequencies. At the same amplitude and atmospheric conditions a low frequency sound will travel further than a high frequency sound. In practice this means that bats with lower frequency calls can be detected from further away and for longer sequences than bats with high frequency calls. Some bats from Solomon Islands have very high frequency calls, over 100 kHz. At these frequencies, atmospheric attenuation is extreme and the bat may only be detected within a couple of meters of the detector. It is less common to record calls from very high frequency bats because the area being sampled by the detector is so much smaller relative to lower frequency bats. This does not necessarily mean these bats are rarer- they are just harder to detect.

ALTERNATION

Some bats produce calls that alternate in characteristics such as frequency, amplitude or shape. In a sequence, alternation produces a pattern where each consecutive call appears different than the call before it. This can be confusing as it may look like 2 different bats are calling, one at a higher or lower frequency. Alternating calls can be identified by viewing them in **real time** (not compressed mode). In alternating sequences the time between each call is relatively evenly spaced with no calls very close to each other (Fig. 9).

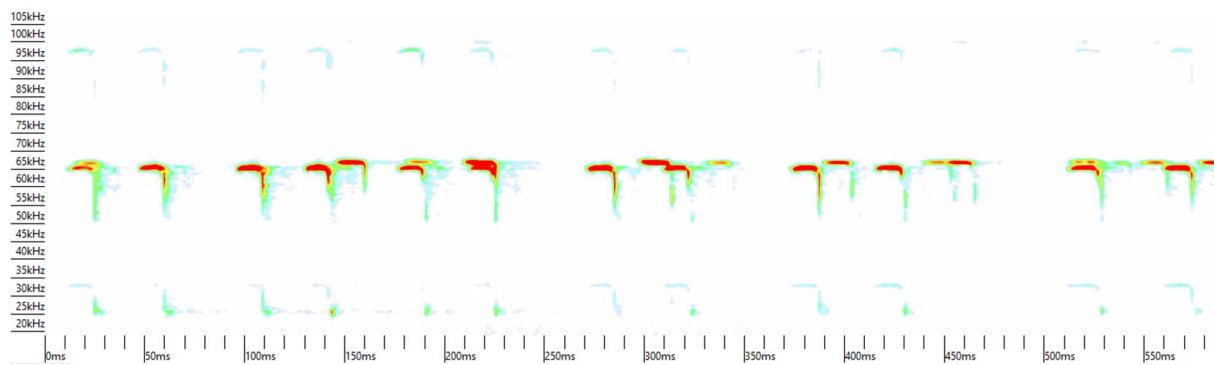
FIGURE 9: AN EXAMPLE OF ALTERNATION IN A CALL SEQUENCE



MULTIPLE BATS

The presence of multiple bats in a call sequence can often easily be identified if the bats are different species with different call types, however when there are multiple individuals from the same species or species with similar calls then it can be confused with alternating calls (see above). The best way to determine if multiple bats are present is to look at the time between calls in a sequence in **real time** (not compressed mode). A sequence with multiple bats will have irregular timing between call pulses and sometimes the calls will be close or even overlapping (Fig. 10)

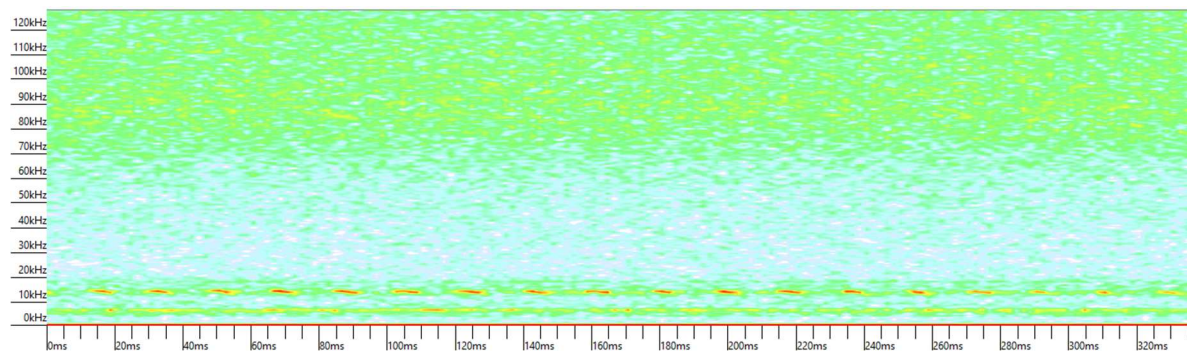
FIGURE 10: EXAMPLE OF MULTIPLE BATS IN A SEQUENCE



INSECT NOISE

Some insects, particularly katydids produce ultrasonic noises. Insect noises are quite common in the Solomon Islands and can cause problems with remote detectors filling memory cards with unwanted noise files. Luckily many software packages have noise filters to search for and separate files containing bat calls. These filters are not fool proof and some files have to be visually inspected. Insect calls can sometimes be confused with bat calls. Insect calls can usually be identified by the following characteristics, they are usually relatively low frequency, they have very short duration and time between pulses, they are very consistent and do not show Doppler effects or other variations in pulse shape or frequency (Fig. 11).

FIGURE 11: EXAMPLE OF INSECT NOISE



SPECTROGRAM ANOMALIES

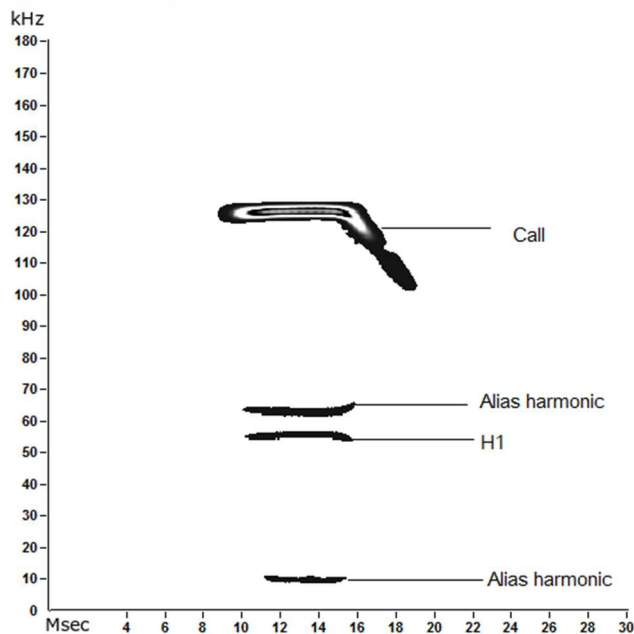
There are a number of relatively common anomalies inadvertently produced as a result of call recording and display processes that can cause confusion. They are not products of the actual bat calls but the computing processes. The most common ones are:

Alias harmonics where unusual 'upside down' calls are sometimes produced in odd places in very loud calls giving the impression of an unusual call from an un-recorded species (Fig. 12 a).

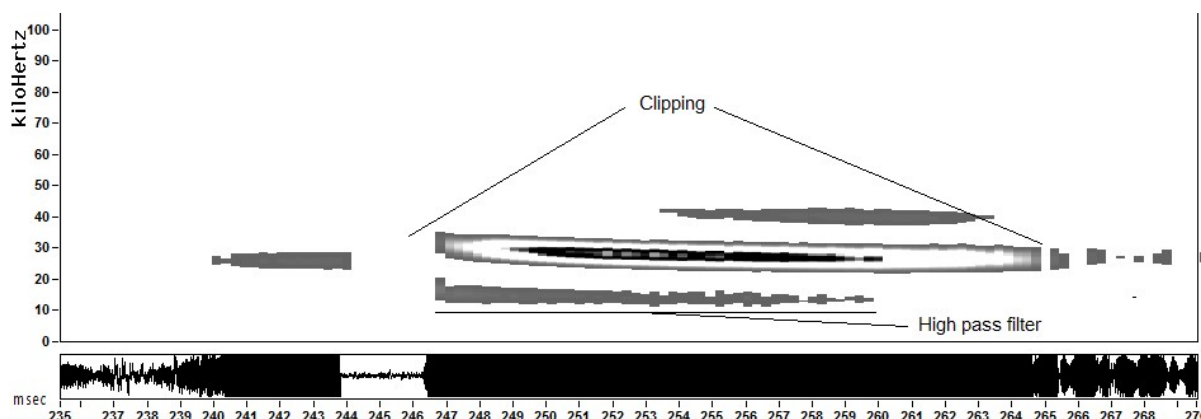
Clipping is where parts of calls are skipped due to recording software being unable to handle signal overload, it can make calls appear shorter, or of a different shape (Fig. 12 b).

High pass filters designed to reduce interference from low frequency audible noises (like people talking, bird and insect noises etc) sometimes remove all or substantial proportions of low frequency call components (Fig. 12 b).

Figure 12: Spectrogram anomaly examples



a) Alias harmonics



b) Clipping of main call of *Saccolaimus saccolaimus* (H2) due to overloaded signal, and clipping of H1 below 10 kHz due to high pass filter.

REFERENCE CALLS

TYPES

This guide was produced using reference calls, these are calls recorded from known bats that have been identified prior to recording their calls. There are a number of ways to record reference calls;

Release calls: A release call is a call from a bat that has been caught in a net/ trap or other method, measured and identified to species, and then let go. As it is released its call is recorded as it flies away. Most of the calls we used in this guide are release calls. Release calls are good because the identity of the bat making the call can be known with certainty; tissue samples for DNA testing can even be taken if there is doubt. The down side

of release calls is that bats often emit stressed (scared – freaked out!) calls for a time after they are released. Stressed calls are often higher in frequency, shorter duration and have greater frequency modulation than typical search phase calls for the species. If there are lots of bats flying around at the time you record release calls it is possible to confuse which bat belongs with which call.

Cave and Exit calls: Sometimes bats can be identified in a cave or other roost, they can then be recorded in the cave as they fly around in the cave or fly out of the cave. Some of our reference calls are cave calls where we identified bats roosting in the cave and recorded them. Cave and exit reference calls can be good because the bat is disturbed less and is less prone to stress calls, although it requires the bat to be identified often from a distance which is not always possible. Cave and exit calls also suffer from the same problem as release calls if other species are flying around at the same time.

Free flying calls: Some species can be identified based on how they look, their behaviour or other distinctive characteristics that allows them to be identified when they are freely flying. Free flying reference calls are excellent because the bat is behaving naturally. The downside is that positive identification can be difficult or impossible and there is a risk of mistakes and misidentification. We have used only a few free flying reference calls in this guide, some from *Saccolaimus saccolaimus* which produces an audible call and could be seen and identified flying over gardens in Bougainville. And some free flying calls from *Myotis moluccarum* recorded foraging over a river near Kira Kira in Makira. *Myotis* produce distinctive steep calls; we also recorded matching release calls from *Myotis* in western province.

IMPORTANCE

Because so little is known about the bat calls from Solomon Islands, and what little we do know suggests there is regional variation in calls, we recommend that anyone undertaking should try record as many reference calls as they can to confirm local call variations.

TIPS TO RECORDING GOOD REFERENCE CALLS

The best time to record release reference calls is at dusk. There is enough light in the sky to follow the silhouette of the released bat so it can be recorded for longer time and settle into a less stressed call pattern. It is also before other bats have emerged to create interference.

If you have a bat that you are worried you may miss recording its call (for example one with a very high frequency call) you can release it in a mosquito net, tent or room and record it flying in there as ‘insurance’ in case your release calls don’t work.

Recording release calls with multiple helpers and multiple detectors always is a good idea, make sure they are well spaced to reduce the risk of the bat flying away in a direction where no one is recording.

The greater the distance and time between the release and the recording, the better the call will be.

We generally use the call labelling in the bat detector to pre-label release calls. For example if we were releasing *Hipposideros calcaratus* in Guadalcanal our call would be labelled “hica- gu” and the time stamp that is permanently attached to the call files. This saves confusion later. We have ‘lost’ reference calls in the past because we’ve noted the call timestamp and species on a separate scrap of paper and never managed to locate the two again.

When looking at your reference calls, only select good examples for analysis, set aside obvious stress, uncertain or unusual calls and use only clear natural looking calls.

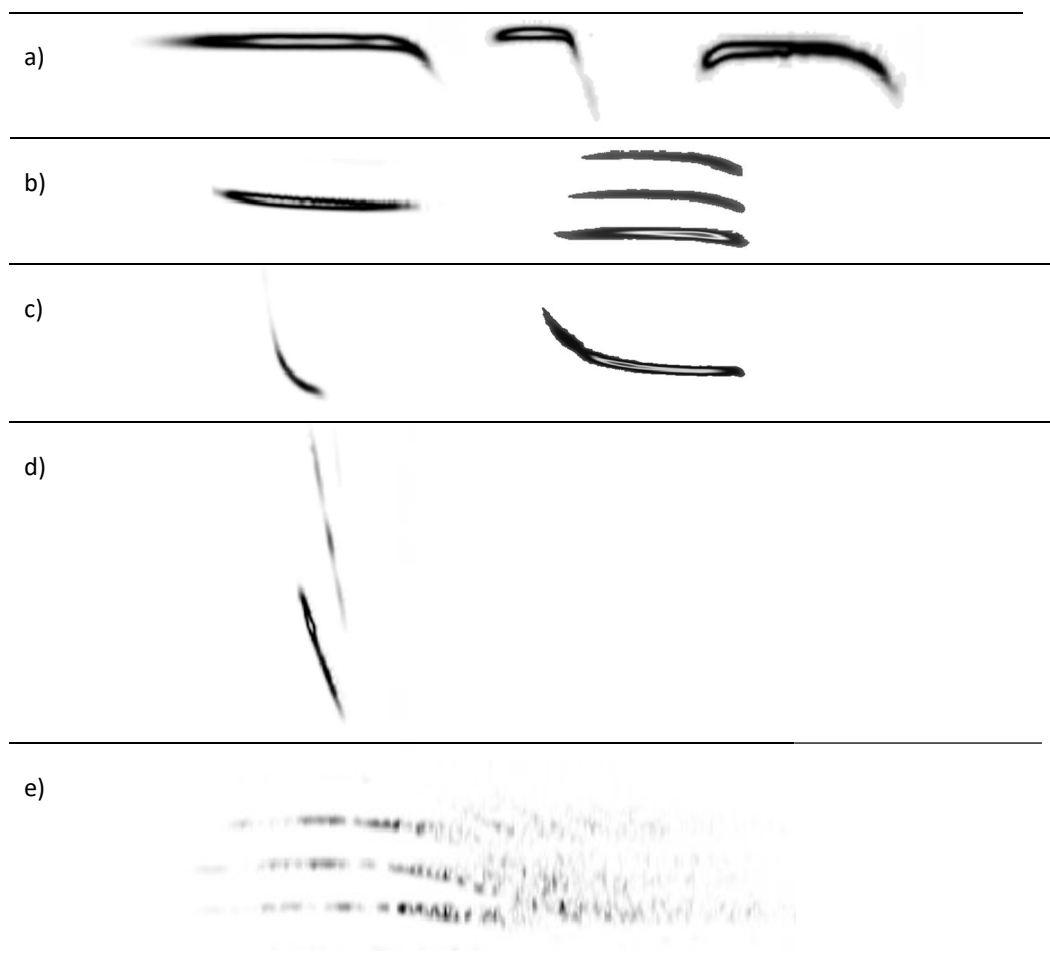
SPECIES IDENTIFICATION

In this section we provide tools to help researchers identify bat species from calls that they have recorded in Solomon Islands and Bougainville. The two main tools are: an **identification key** that can be worked through to identify a species if call parameters are known; and **individual descriptions** detailing the characteristics of each species call and ways to assist with identification. All calls in this section are displayed at the same frequency and time scale (0-180 kHz and 30 ms) to give the reader an idea of the relative duration and frequency of each pulse. It is important to remember that looking at calls in different time and frequency scales will make them appear differently.

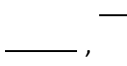
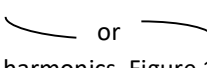
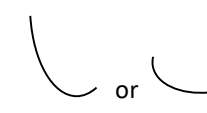

When analysing bat calls it is also important to remember that even in the best circumstances not all calls can be identified to species. It may be that there are not enough calls recorded to be sure you are looking at usual search phase calls, that the recording is too short, or noisy or have too many different bats calling at the same time. If you have doubts about the identification of a call it is good practice to skip that call and look through others until you find a better example that you can identify more conclusively.

IDENTIFICATION KEY

FIGURE 13: CALL SHAPES REFERRED TO IN THE IDENTIFICATION KEY



1) Call shape (Fig. 13)

- a)  shapes, resulting from flat constant frequency tones (CF) with or without a frequency modulated (FM) upsweeping initial at start, or, more commonly downsweeping at 'tail'. Figure 13 a.....3
- b)  shapes, resulting from a shallow frequency sweep, with or without multiple harmonics. Figure 13 b.....5
- c)  shapes, resulting from a steep commencing frequency sweep transforming into a flatter section. Figure 13 c.....6
- d)  shapes, resulting from steep frequency sweeps with no flatter sections. Figure 13 d.....2
- e) Fan like appearance, consisting of multiple curved, long duration (>30ms) frequency sweeps commencing over multiple harmonics and dropping towards a single terminal frequency Figure 13 e.....7

2) Call steep frequency sweep with no flatter sections (Fig. 13 d)

- a) Consistent sequences of 2 -3 simultaneous steep pulses dropping rapidly in frequency. Loudest pulse in each simultaneous group sweeping from \bar{x} 79 kHz to \bar{x} 33 kHz over a short duration \bar{x} 2.8 milliseconds, total slope > 12 kHz/ms \bar{x} 16.6 kHz/ms.....*Myotis moluccarum* (32)
- b) Pulses consecutive (or with mirror at higher harmonic), with curved shape calls (Fig. 13 c) immediately before or after the steep pulses (Fig. 14) Non-search phase calls of another FM species.....6

3) Predominantly constant frequency (CF) call (Fig. 13 a)

- a) average call duration less than 10 milliseconds.....4
- b) Average call duration greater than 10 milliseconds
- Constant frequency component 52-55 kHz peak \bar{x} 53 kHz*Hipposideros dinops* (29)
 - Guadalcanal, constant frequency component 65-66 kHz peak \bar{x} 65.9 kHz.....*H. diadema* (28)
 - Other provinces, constant frequency component 58-59 kHz peak \bar{x} 59 kHz...*H. diadema* (28)
 - Makira, constant frequency component peak \bar{x} 69 kHz.....*H. demissus* (29)

4) Predominantly CF call (Fig. 13 a) with call duration <10 ms.

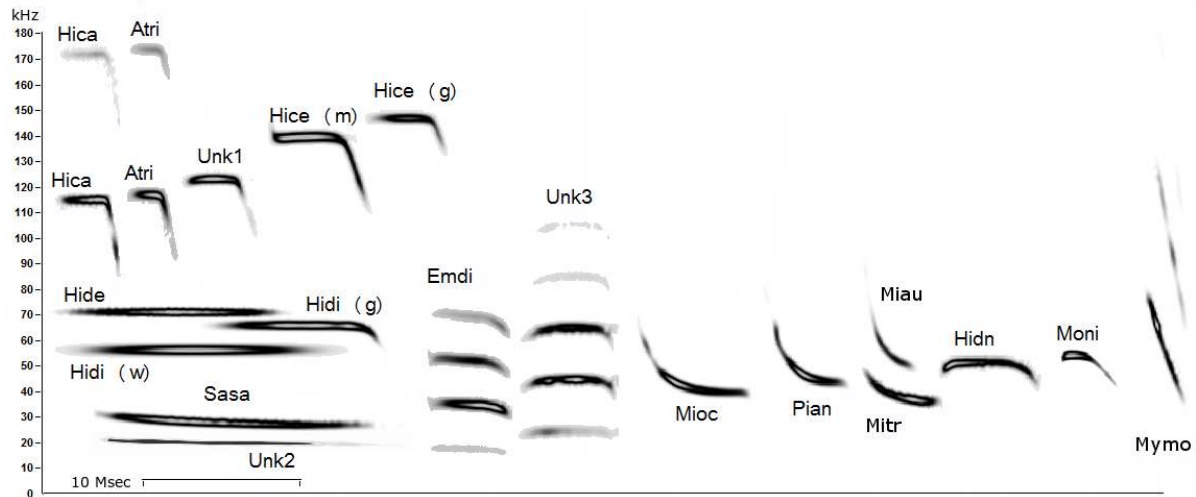
- a) Constant frequency component peak \bar{x} 138 kHz.....*H. cervinus* –Makira (26)
- b) Constant frequency component peak \bar{x} 147 kHz.....*H. cervinus* –Guadalcanal (26)
- c) Call duration \bar{x} 3.96 ms, constant frequency component peak \bar{x} 117.2 kHz, tail dropping to \bar{x} 100 kHz*H. calcaratus* (26)
- d) Guadalcanal, Call duration \bar{x} 2.9 ms, constant frequency component \bar{x} 114-116 kHz, peak \bar{x} 115 kHz*Aselliscus tricuspidatus* -Low form(25)
- e) Guadalcanal, Call duration \bar{x} 2.9 ms, constant frequency component \bar{x} 117-119 kHz, peak \bar{x} 118 kHz*Aselliscus tricuspidatus* -High form(25)

- f) Makira, Call duration \bar{x} 2.9 ms, constant frequency component \bar{x} 114-116 kHz, peak \bar{x} 116kHz.....***A. tricuspidatus*** (25)
- g) Call duration \bar{x} 6.1 ms, constant frequency component \bar{x} 121-123 kHz, peak \bar{x} 121.9 kHz.....**Unidentified species** (Unk1) -possibly *Anthops ornatus*(27)
- h) Call duration \bar{x} 3.7 ms constant frequency component \bar{x} 54-62 kHz, often long sequences (3-10 seconds) containing many pulses and Doppler variation in frequency (Fig. 7).....***Mosia nigrescens*** (33)
- 5) 'Flat' FM Call frequency modulated calls with low total slope (\bar{x} less than 1 kHz/ms) giving a flat, gentle curved appearance with no abrupt changes in frequency, multiple harmonics may be visible in louder pulses, harmonic with peak power H2, although H1 may not always be visible. (Fig. 13 b)
- a) Long call duration (>10 ms)
- i) Long duration frequency sweep (\bar{x} 17.9 ms), commencing at highest frequency \bar{x} 30 kHz and dropping to lowest frequency \bar{x} 25 kHz. Peak frequency \bar{x} 26-27 kHz.....***Saccolaimus saccolaimus*** (30)
- ii) Long duration frequency sweep (\bar{x} 17.9 ms), call sequences loosely alternating between 'high' (peak 22.3 kHz) and 'low' (peak 19.8 kHz) pulses. Peak frequency \bar{x} 21.9 kHz. H1 audible.....**Unidentified species** (Unk2)-Guadalcanal (31)
- b) Short duration call (<10 ms)
- i) Short duration frequency sweep start and end of each call pulse often lower than highest frequency, total slope average less than 1 kHz/ms. Multiple harmonics almost always visible, peak harmonic H2.
- (1) Duration \bar{x} 4 ms, Peak frequency 31-37 kHz (\bar{x} 35.3 kHz), harmonics in c.17.5 kHz steps***Emballonura diana*** (33)
- (2) Duration \bar{x} 4 ms, Peak frequency 38.5- 42 kHz (\bar{x} 40 kHz) harmonics in c.20 kHz steps**unidentified species** (Unk 3) – probably *E. raffrayana* (34)
- (3) Peak frequency 37-38.5 kHz either *E. diana* or *E. raffrayana*
- (4) Duration \bar{x} 3.7 ms, peak frequency between 54-62 kHz (\bar{x} 57 kHz) often long sequences (3-10 seconds) containing many pulses and Doppler variation in frequency (Fig. 7)***Mosia nigrescens*** (33)
- 6) Predominantly frequency modulated 'hook shape' type calls (Fig. 13 c), commencing in a steep frequency sweep transitioning to a flatter 'characteristic' section. Total slope usually averages between 5- 13 kHz/ms.
- a) Characteristic frequency (Fig. 2) >50 kHz. Frequency sweep starting at \bar{x} 81 kHz and dropping to \bar{x} 50.5 kHz, flatter characteristic section \bar{x} 51.6 kHz. Pulses vary widely in frequency however peak frequency usually > 52 kHz (\bar{x} 55.5 kHz).....***Miniopterus cf australis*** (35)
- b) Characteristic frequency (Fig. 2) <50 kHz.
- i) Characteristic frequency \bar{x} 47.5 kHz, sweep starting at \bar{x} 70.5 kHz and dropping to \bar{x} 46.8 kHz, peak frequency \bar{x} 50.7 kHz. Call sequences often long duration (5-15 seconds) consisting of many pulses and showing Doppler Effect (variations in frequency) sometimes approach and feeding buzzes.....***Pipistrellus angulatus*** (34)
- ii) Characteristic frequency \bar{x} 44.07.5 kHz, sweep starting at \bar{x} 77 kHz and dropping to \bar{x} 42 kHz, peak frequency \bar{x} 47.2 kHz***Miniopterus cf 'oceanensis'*** (36)
- iii) Characteristic frequency \bar{x} 36.16 kHz, knee \bar{x} 39 kHz, peak frequency less than 40 kHz (\bar{x} 36.5 kHz)***Miniopterus cf 'tristis'*** (36)
- 7) Series of multiple simultaneous very long duration (>30 ms) frequency sweeps in 11 kHz harmonic steps spaced \bar{x} 74 ms apart over a period of about 1 - 1.5 seconds. H1 (11 kHz) audible as a loud bird like trill. Peak usually in H2 (22 kHz) or H3 (33 kHz)***Melonycteris woodfordi*** (37)

IDENTIFICATION SUMMARY

Most species we have examined can be differentiated quite simply on the basis of three main characteristics, call shape/type, peak frequency and call duration (Fig. 14).

FIGURE 14: DIAGRAMATIC SUMMARY OF SOLOMON ISLAND BAT CALL SHAPES AND PEAK F



Key: Hica= *Hipposideros calcaratus*, Hice = *H. cervinus* (m- Makira, g-Guadalcanal), Atri=*Aselliscus tricuspidatus*, Hidi =*H. diadema* (g-Guadalcanal, w- Western/New Georgia), Hidn = *H. dinops*, Hide= *H. demissus*, Mymo= *Myotis moluccarum*, Mioc = *Miniopterus cf oceanensis*, Miao= *M. cf australis*, Mioc= *M. cf oceanensis*, Mitr= *M. cf tristis*, Moni = *Mosia nigrescens*, Emd= *Emballonura diana*, Sasa= *saccolaimus saccolaimus*, Unk1 = Unknown Hipposiderid c 121kHz, Unk2 = Unknown bat 21kHz, Unk3= unknown Emballonurid 40kHz.

When the calls we used for this guide are plotted on a frequency vs time plot, four general groupings of call types emerge (Figure 15). These groupings could loosely be described as follows:

Group 1: Very high frequency short duration constant frequency calls. This group is made up of smaller species from the family Hipposideridae (Old world leaf-nosed bats). The group contains calls from one unidentified bat (labelled unk1 in Figures 14 and 15), based on the shape and type of call it is likely this bat is also a small member of the Hipposideridae family. Members of this group are likely to use a forest interior foraging strategy with calls well suited for navigating in highly cluttered environments at low speeds.

Group 2: Mid-frequency long duration constant frequency calls. This group is made up of large/robust species from *Hipposideros* genus. The members of this group are likely to use both perch hunting and forest gap foraging strategies, either navigating forest openings at higher speeds or hunting larger prey from perches (observed in both *H. Dinops* and *H. Diadema*). Each species in this group can clearly be distinguished by two parameters peak frequency, and call duration.

Group 3: Very low frequency, long duration frequency modulated calls. This group is made up of *Saccolaimus saccolaimus* and an unknown bat from Guadalcanal (which may represent a regional a call variation of *S. saccolaimus* or something else). Although the calls of *Chaerephon solomonis* are unknown we expect that it would fit within group 3 based on calls of closely related species (*Chaerephon jobensis* –Australia and PNG and *Chaerephon bregullae* from Vanuatu and Fiji). We don't know if it overlaps with calls of *S. saccolaimus*. The bats in this group almost certainly use an open space insectivore foraging strategy, flying at high speeds in open areas such as above the canopy, over rivers, beaches, gardens and uncluttered environments.

Group 4: Mid-frequency, short duration, frequency modulated calls. This group contains is made up of a mix of Vespertilionid genera (*Myotis*, *Miniopterus*, *Pipistrellus*) and Emballonurids (*Mosia*, *Emballonura*). This group contains calls from one unidentified bat (labelled Unk3 in Figures 14, and 15), this bat is almost certainly a species of the genus *Emballonura*, it may be *E. raffrayana* that we did not record, it may be we *E. diana* and

we did not record its full repertoire or it may be another *Emballonura* species. It is likely that the group utilise Forest edge and gap foraging strategies, flying in semi cluttered environments. This group has the most overlapping calls, and species identification cannot be resolved based on frequency and time parameters alone, additional parameters such as call shape, harmonics and behavioural characteristics are required to separate out some calls.

FIGURE 15: PEAK FREQUENCY AND DURATION OF BAT CALLS USED IN THIS GUIDE

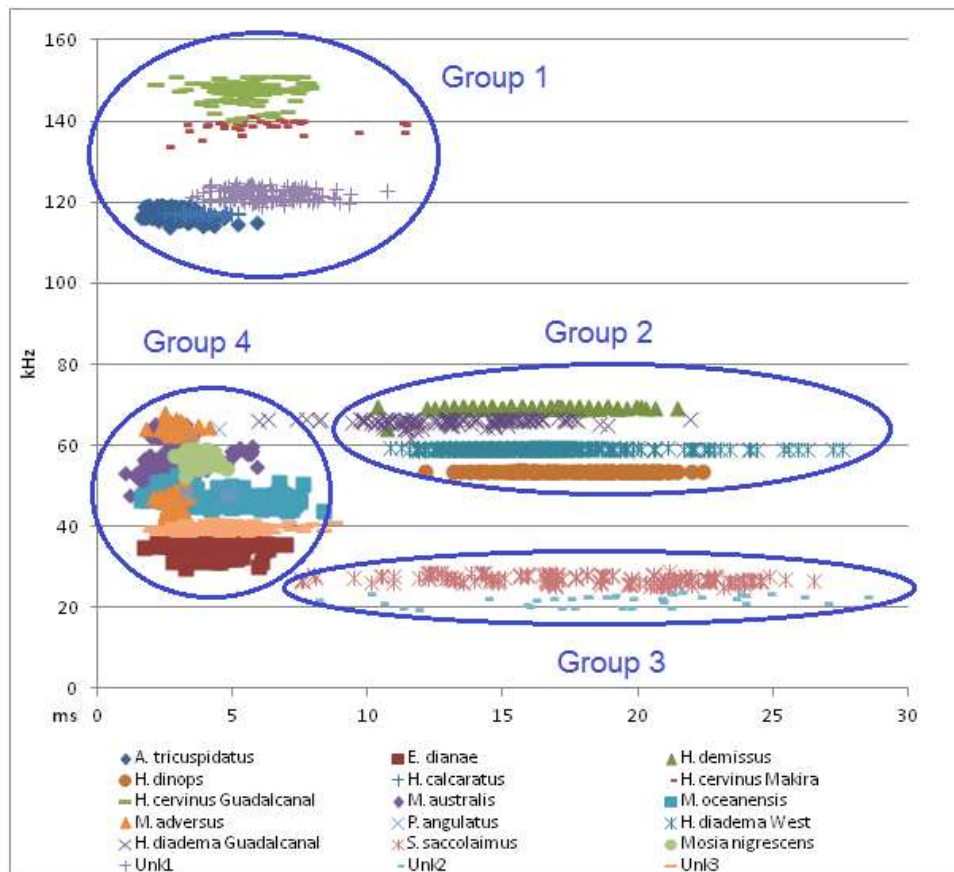


TABLE 16 AVERAGE CALL CHARACTERISTICS FOR SOLOMON ISLAND BAT CALLS

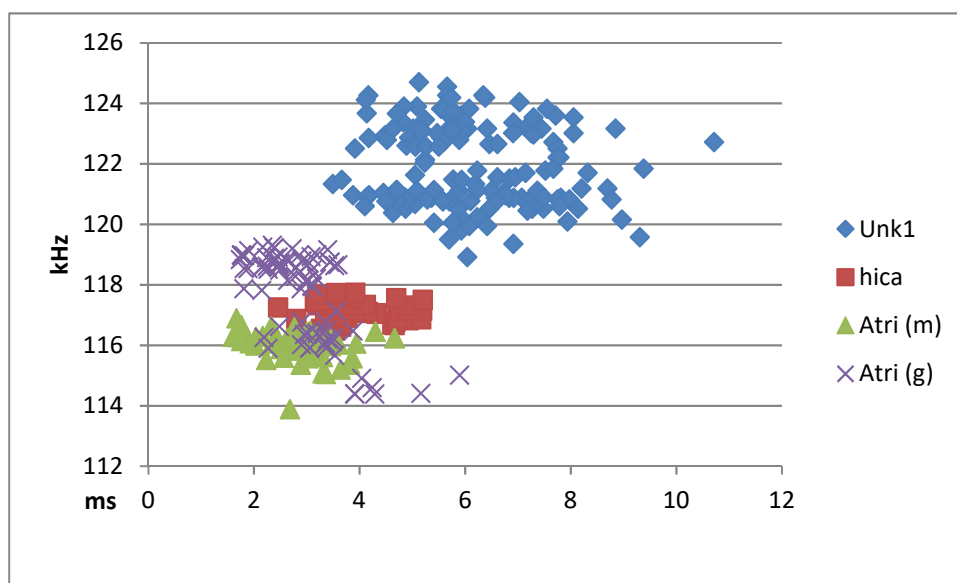
Species	Bandwidth (kHz)	Call Duration (ms)	Characteristic frequency (kHz)	Maximum frequency (kHz)	Minimum frequency (kHz)	Peak frequency (kHz)	Total Slope (kHz/ms)	Number sampled
Unidentified bat Ndoma, Guadalcanal	3.05	17.94	21.48	23.33	20.37	21.88	0.14	45
<i>Saccolaimus saccolaimus</i>	4.97	17.96	26.46	30.48	25.51	27.08	0.31	201
<i>Emballonura diana</i>	3.80	4.00	34.74	36.23	32.42	35.35	0.53	199
<i>Miniopterus cf tristis</i>	10.78	4.13	36.16	46.65	35.86	36.16	3.90	10
Unidentified Emballonuridae	3.74	4.49	38.91	39.96	36.49	39.48	0.47	273
<i>Miniopterus cf oceanensis</i>	34.48	4.72	44.07	76.92	42.44	47.23	9.68	125
<i>Pipistrellus angulatus</i>	13.33	4.12	45.15	79.65	43.56	50.99	9.46	9
<i>Hipposideros dinops</i>	3.32	17.99	53.57	55.32	51.99	53.57	0.09	144
<i>Miniopterus cf australis</i>	31.46	2.64	51.62	81.98	50.24	55.32	12.68	176
<i>Mosia nigrescens</i>	7.50	3.67	55.62	57.05	49.65	57.05	0.74	402
<i>Myotis moluccarum</i>	46.59	2.80	38.54	58.22	32.99	58.22	16.66	101
<i>Hipposideros diadema</i> (West)	0.59	16.20	59.16	59.30	58.71	59.18	0.00	286
<i>Hipposideros diadema</i> (Guadalcanal)	5.12	13.19	65.93	66.20	61.09	65.92	0.02	125
<i>Hipposideros demissus</i>	7.42	15.99	69.32	70.47	59.17	69.32	0.71	106
<i>Hipposideros calcaratus</i>	18.67	4.03	115.85	117.12	98.45	116.61	0.38	50
<i>Aselliscus tricuspidatus</i>	12.33	2.92	115.06	117.47	105.14	116.97	0.74	157
Unidentified Hipposideridae	10.36	6.14	121.94	123.20	112.84	121.94	0.21	148
<i>Hipposideros cervinus</i> (Makira)	26.39	6.04	138.97	140.34	113.95	138.97	2.93	43
<i>Hipposideros cervinus</i> (Guadalcanal)	26.24	5.38	147.23	150.24	123.99	147.23	1.58	143

SPECIES DESCRIPTIONS

GROUP 1 VERY HIGH FREQUENCY SHORT DURATION CF CALLS

The calls of all species in this group are similar. They are short duration (< 10 ms) CF calls at very high (>100 kHz) frequencies. Identification to species level can generally be resolved by peak frequency and call duration parameter (Fig. 17), although, the calls of *Hipposideros calcaratus* and *Aselliscus tricuspidatus* are very similar and sometimes overlap entirely in Guadalcanal. More information is required to determine if this overlap occurs more widely and also if the apparent dimorphism in *A. tricuspidatus* calls from Guadalcanal is genuine and not an artefact of inadequate sampling.

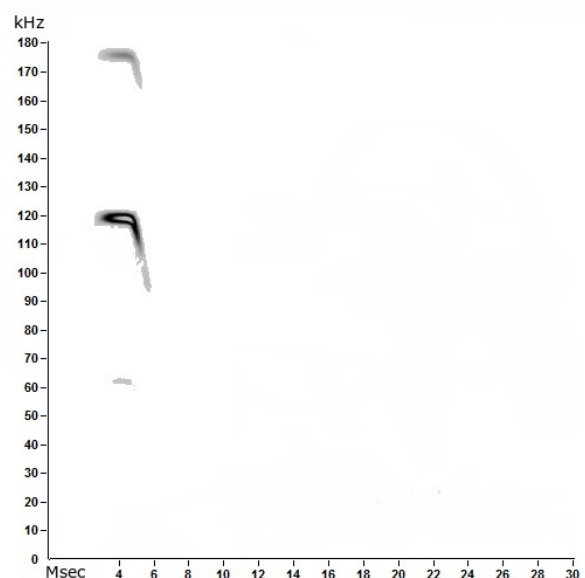
FIGURE 17 FREQUENCY VS TIME PLOT OF GROUP 1 BAT CALLS BETWEEN 110-125 KHZ



TRIDENT LEAF-NOSED BAT (*ASELLISCUS TRICUSPIDATUS*)

Description: A very short duration (\bar{x} 2.9 ms), constant frequency tone with peak frequency \bar{x} 116.97 kHz. Most calls have a frequency modulated tail dropping about 12 kHz to an Fmin \bar{x} 105.14 kHz. Fundamental harmonic 58.5 kHz.

Comments: Widespread in Bougainville and most Islands in Solomon Islands. Calls from Guadalcanal appear dimorphic (Fig. 17) with higher calls \bar{x} 118.65 kHz and lower type calls \bar{x} 115.84 kHz. Call sequences usually contain only one type (either high or low). Calls from Makira all appear to fit the low type call \bar{x} 116.06 kHz



Similar species: Very similar and partly overlapping with calls from *Hipposideros calcaratus* on average parameters. Calls with a peak frequency in the 117 kHz range and with a duration of >4 ms appear to be *H. calcaratus*. Calls with a peak frequency from 118 kHz to 119 kHz, or 116-115 kHz, or with a duration <2 ms appear likely to be *A. tricuspidatus*. If the call duration is between 2-4 ms and frequency of 117 kHz then it may be either species.

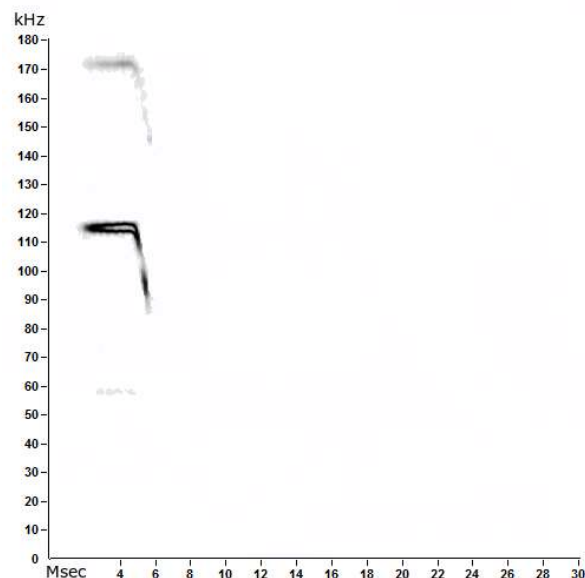
Calls strong in H1 (58.5 kHz) could be confused with calls from *Mosia nigrescens* just below 60 kHz however these should be able to be separated by H3 being visible around 90 kHz in *Mosia* calls.

SPURRED LEAF-NOSED BAT (*HIPPOSIDEROS CALCARATUS*)

Description: A short duration (\bar{x} 4.03 ms), constant frequency tone with peak frequency \bar{x} 116.61 kHz. Most calls have a long frequency modulated tail dropping about 18 kHz to a Fmin \bar{x} 98.45 kHz. Fundamental harmonic c. 58.5 kHz.

Comments: Widespread in Bougainville and most Islands in Solomon Islands.

Similar species: Very similar and partly overlapping with calls from *Aselliscus tricuspidatus* on average parameters. May also possibly be confused in H1 with *Mosia nigrescens*. To differentiate, refer to *A. tricuspidatus* description above

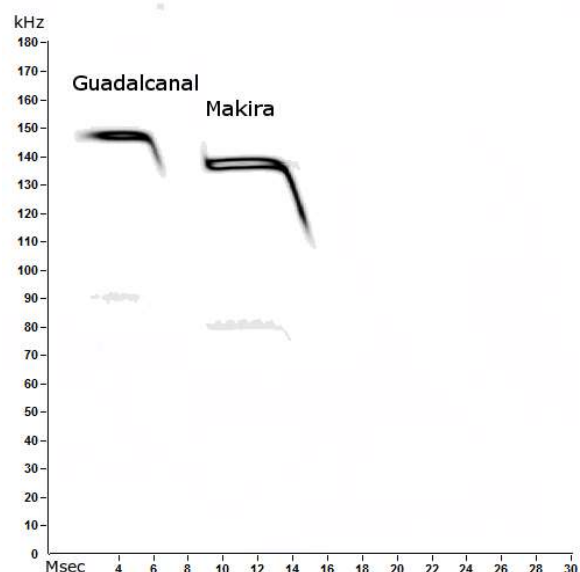


FAWN LEAF-NOSED BAT (*HIPPOSIDEROS CERVINUS*)

Description: Regionally variable call.

A short duration (\bar{x} 5.38- 6.04 ms), constant frequency tone with peak frequency \bar{x} 147.23 kHz in Guadalcanal and \bar{x} 138.97 kHz in Makira. Most calls have a long frequency modulated tails dropping about 24-25 kHz to a Fmin \bar{x} 123.99 kHz in Guadalcanal and \bar{x} 113.55 kHz in Makira.

Comments: Widespread Solomon Islands, New Guinea and throughout S.E Asia. Calls not readily mistaken with any other species given the very high frequency. It is unknown what frequency variation exists in other Island groups.

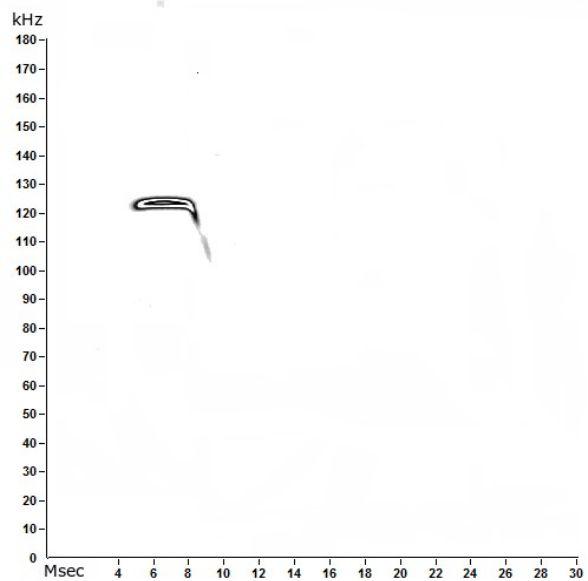


UNIDENTIFIED HIPPOSIDERID BAT (UNK1)

Description: A distinct call not matching any reference calls we have recorded (Figs 15 and 17). Recorded from free flying bats at multiple locations in Makira, Guadalcanal and Isabel.

Call is moderately short in duration (\bar{x} 6.14 ms), constant frequency tone with peak frequency \bar{x} 121.94 kHz. Most calls have a frequency modulated tail dropping about 9 kHz to a Fmin \bar{x} 112.81 kHz. Fundamental harmonic c. 61 kHz but rarely seen.

Comments: Further work is required to identify the bat making this call. Based on call characteristics, it is likely to be a small member of the Hipposideridae family. It is possible the call may belong to *Anthops ornatus*, being the only small Hipposiderid bat species known from Solomon Islands that we did not collect reference calls from. It may also represent an unknown call repertoire of a species we did record, or a cryptic species that has not yet been documented.

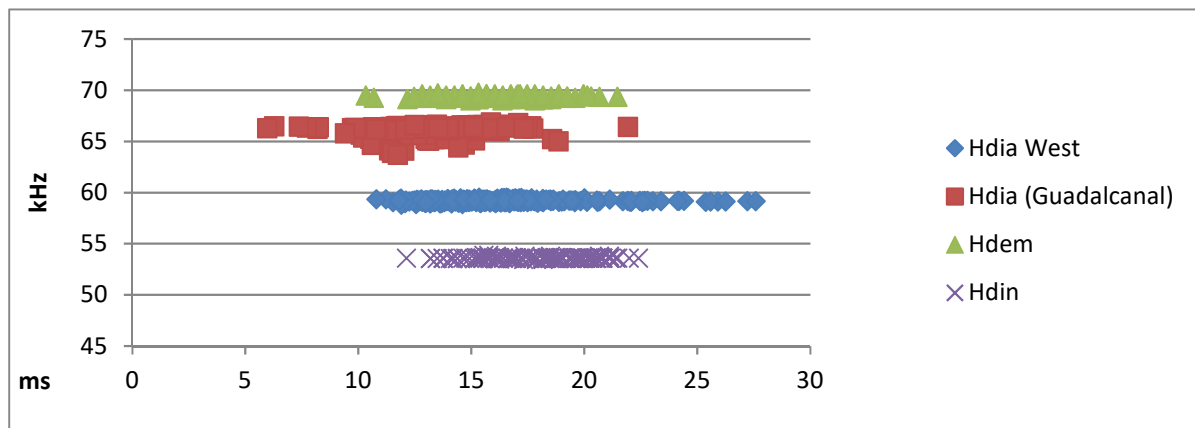


Similar species: Generally distinct from other calls based on unique peak frequency range (Fig. 17). The fundamental harmonic at 61 kHz could possibly be confused with calls from *Hipposideros diadema* in Choiseul or Western provinces, however the duration is less than half that of *H. diadema* (\bar{x} 16.20 ms). Calls strong in H1 (61 kHz) could be confused with calls from *Mosia nigrescens* above 60 kHz however these should be able to be separated by *M. nigrescens* generally being shorter in duration (\bar{x} 3.67 ms) and *Mosia* calls displaying H3 harmonics at c. 90 kHz.

GROUP 2 BATS WITH MID-FREQUENCY, LONG DURATION CF CALLS

This group is easily identifiable, consisting of long duration (>10 ms) constant frequency dominated calls at frequencies between 50 and 70 kHz. The 3 species (*Hipposideros diadema*, *H. dinops* and *H. demissus*) and 4 call types (*H. diadema* appear to 2 distinct call types - varied by region) are all easily distinguishable based on unique frequency ranges not occupied by other species with similar call types (Fig. 15).

FIGURE 18: FREQUENCY VS TIME PLOT OF GROUP 2 BAT CALLS BETWEEN 50-70 KHZ

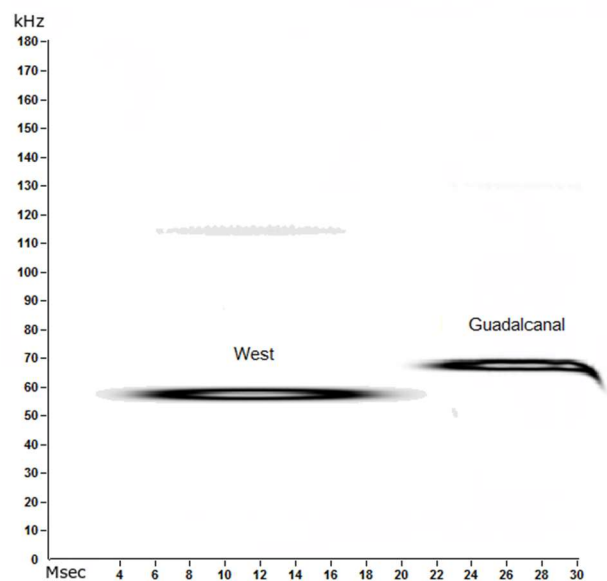


DIADEM LEAF-NOSED BAT (*HIPPOSIDEROS DIADEMA*)

Description: Regionally variable call.

Call is a long duration (\bar{x} 16.2 ms West and \bar{x} 13.19 ms in Guadalcanal), constant frequency tone with peak frequency of \bar{x} 59.18 kHz in West and consistently almost 7 kHz higher at \bar{x} 65.92 ms in Guadalcanal. Some calls have a very short frequency modulated tail dropping between 1 kHz (west) and 6 kHz (Guadalcanal). A widespread bat present in Bougainville and most Island groups in Solomon Islands, also Australia, S.E Asia and PNG.

Comments: *H. diadema* is a widespread bat, the calls from western province closely match those recorded in PNG and Australia (56-59 kHz). The calls from Guadalcanal are consistently higher around 66kHz, similar to calls of the species recorded in Java (64-70 kHz). There is substantial variation in echolocation calls over the species full range. It is not known if this is a response to occupying different habitat or acoustic niches, or underlying cryptic taxonomic variations.



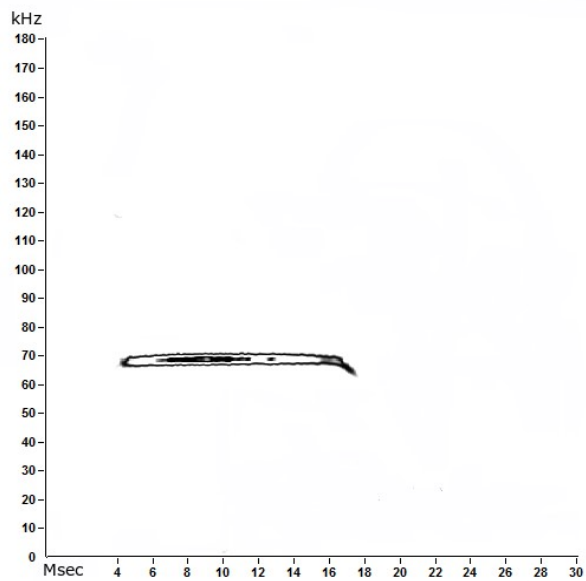
Similar species: Both call types are distinct from other calls based on unique peak frequency range and duration (Fig. 17). Calls could be confused with calls from *Mosia nigrescens*, which may sometimes overlap in frequency however these should be easily separated based on *M. nigrescens* calls being much shorter in duration (\bar{x} 3.67 ms) and having substantial frequency modulation.

MAKIRA LEAF-NOSED BAT (*HIPPOSIDEROS DEMISSUS*)

Description: A long duration (\bar{x} 15.99 ms), constant frequency tone with peak frequency of \bar{x} 69.32 kHz. Some calls have a frequency modulated tail dropping 10 kHz to minimum frequency \bar{x} 59.17. Endemic to Makira.

Comments: *H. demissus* is restricted to Makira, we recorded it in caves near Ngorangora and also flying freely along the river between Kirakira and Bwaunasugu.

Similar species: Call is distinct from other species calls based on unique peak frequency range and duration (Fig.17). Calls are unlikely to be confused with any other species. Could possibly be mistaken for the fundamental harmonic of *H. cervinus* (69.5 kHz), which typically calls around 139 kHz in Makira, however the call of *H. demissus*, is about triple the duration (c. 16 ms) of *H. cervinus* (5-6 ms).

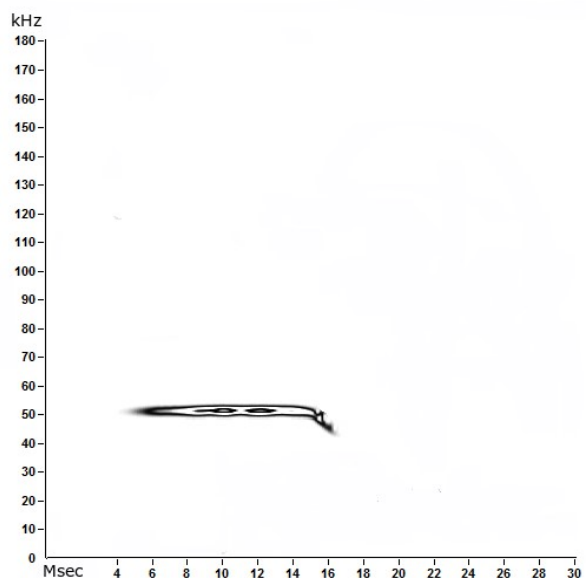


FIERCE LEAF-NOSED BAT (*HIPPOSIDEROS DINOPS*)

Description: A long duration (\bar{x} 17.99 ms), constant frequency tone with peak frequency of \bar{x} 51.99 kHz. Some calls have very short frequency modulated initial and/or tail of 1-2 kHz sometimes giving the calls a slight curved look (e.g. in Fig. 14)

Comments: Known from Guadalcanal, Malaita, Isabel, New Georgia and Bougainville. We also recorded this species flying freely in Guadalcanal and Choiseul. We found no evidence of regional variation in the call throughout the Solomon Islands.

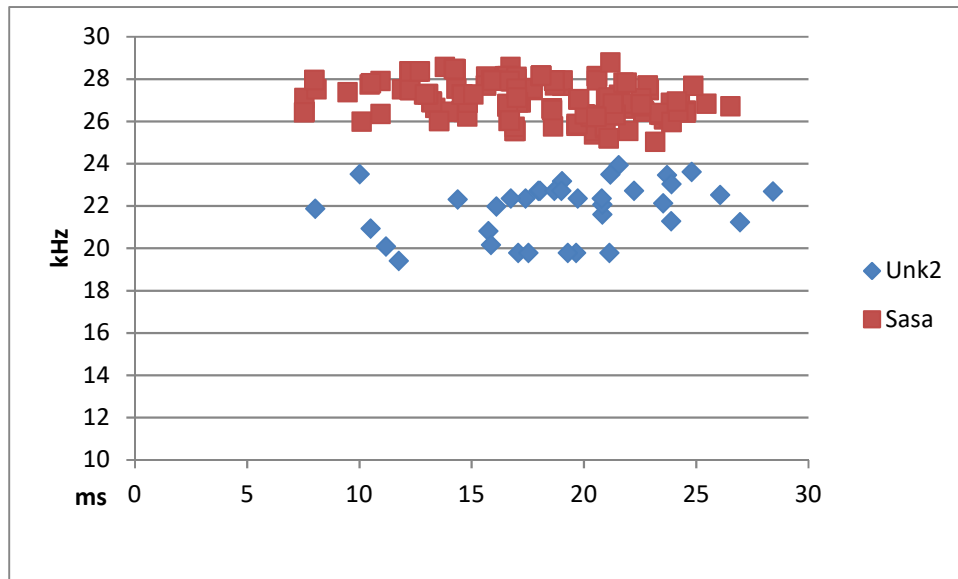
Similar species: Call is distinct from other species calls based on unique peak frequency range and duration (Fig. 17). Calls are unlikely to be confused with any other species.



GROUP 3 BATS WITH VERY LOW FREQUENCY, LONG DURATION FM CALLS

This group is distinct for having very low frequency (< 30 kHz) and very long duration (> 15 ms) calls. The group consists of *Saccolaimus saccolaimus*, calls from an unidentified bat from Guadalcanal, and probably *Chaerephon solomonis*, however we do not have reference recordings of *C. solomonis* call.

FIGURE 19: FREQUENCY VS TIME PLOT OF GROUP 3 BAT CALLS BETWEEN 10-30 KHZ

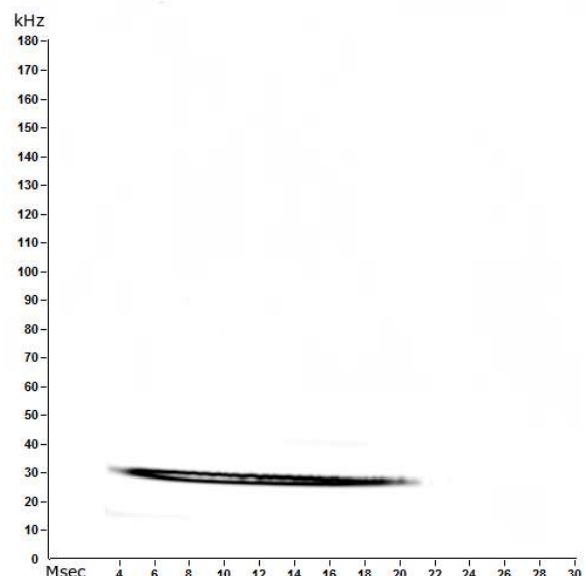


BARE-RUMPED SHEATHTAIL BAT (*SACCOLAIMUS SACCOLAIMUS*)

Description: A very long duration (\bar{x} 17.96 ms), shallow frequency sweep commencing at \bar{x} 30.48 kHz and dropping to \bar{x} 25.10 kHz, with gentle slope to almost flat appearance. Peak frequency in H2 at \bar{x} 27.08 kHz and characteristic frequency \bar{x} 26.46 kHz.

Fundamental harmonic (H1) 13 kHz often audible from a long distance. Loud call recordings often show multiple harmonics at c 13 kHz intervals

Comments: Known from Bougainville and Guadalcanal in Solomon Islands. Widespread elsewhere ranging from South Asia to Australia. We also recorded matching calls from free flying bats in Choiseul and Isabel. Possible regional variation if calls from unidentified bats (unk2) also belong to this species.



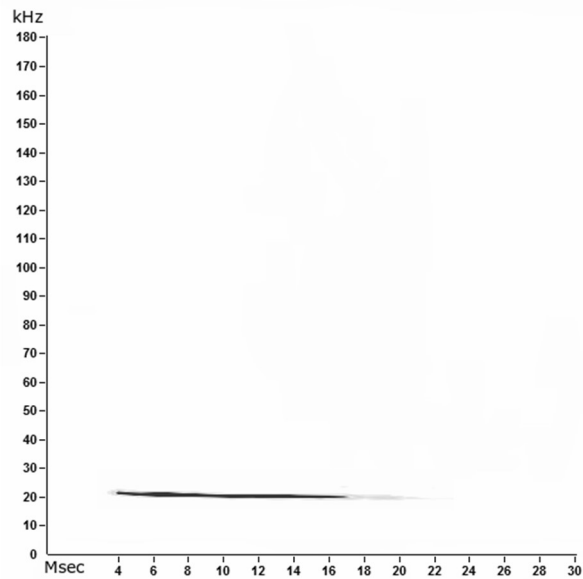
Similar species: Call is distinct from other species calls based on unique peak frequency range and duration (Fig. 17). Calls could possibly be confused with those of *Chaerephon solomonis* whose call is unknown, but is also likely to be a very long duration low frequency sweep.

UNIDENTIFIED BAT (UNK2)

Description: Very long duration (\bar{x} 17.94 ms), shallow frequency sweep commencing at \bar{x} 23.20 kHz and dropping to \bar{x} 20.37 kHz, with gentle slope to almost flat appearance. Peak frequency in H2 at \bar{x} 21.80 kHz and characteristic frequency \bar{x} 21.45 kHz. Average values mask that calls often alternate in frequency range between 22 and 19 kHz (Fig. 9).

Comments: A call similar to that of *Saccolaimus saccolaimus* in most characteristics but distinctly (x 4.7 kHz) lower and not overlapping in frequency range (Fig. 19). A series of these calls were recorded from free flying bats with audible calls at Ndoma in northwest Guadalcanal. The species was not identified. It could be possible the calls belong to a regionally distinct variation in the repertoire of *S. saccolaimus*, or potentially a different species. The only species we do not have reference calls likely to call in this range is *Chaerephon solomonis*. It may be possible the calls belong to *C. solomonis*, although *C. solomonis* has not previously been recorded on Guadalcanal. Alternatively the calls could belong to a cryptic undescribed species.

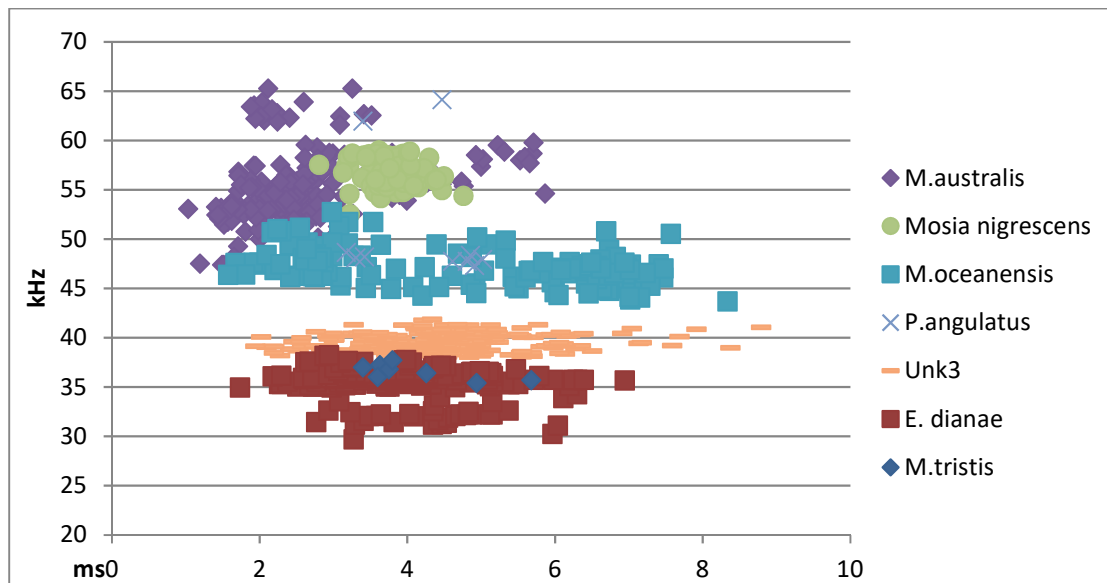
Similar species: Call is distinct from other species calls based on unique peak frequency range and duration (Fig. 17). Calls could possibly be confused with those of *Chaerephon solomonis* whose call is unknown.



GROUP 4 BATS WITH MID FREQUENCY SHORT DURATION FM CALLS

This group is made up of a mix of Vespertilionid genera (*Myotis*, *Miniopterus*, *Pipistrellus*) and Emballonurids (*Mosia*, *Emballonura*). The group has the most overlapping calls (Fig. 20), and species identification may not be resolved based on frequency and time parameters alone, additional parameters such as call shapes, harmonics and behavioural characteristics are required to separate out some – but probably not all- calls.

FIGURE 20: FREQUENCY VS TIME PLOT OF GROUP 4 BAT CALLS BETWEEN 20-70 KHZ

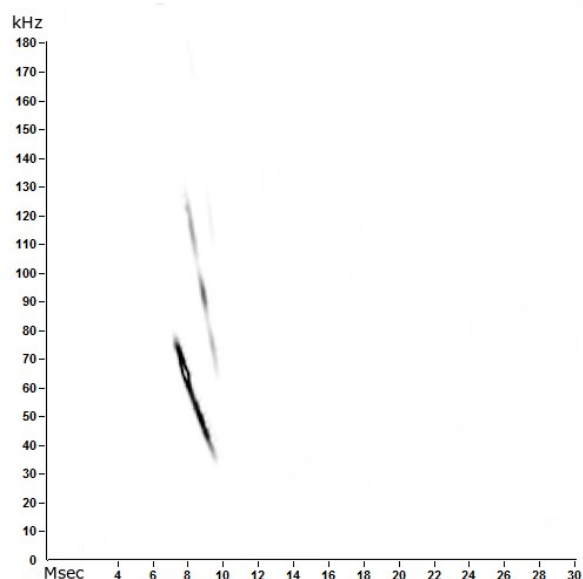


LARGE-FOOTED MYOTIS (*MYOTIS MOLUCCARUM*)

Description: A very distinctive call with steep near vertical very short duration (\bar{x} 2.8 ms), frequency sweeps. Peak frequency \bar{x} 58.22 kHz although standard call parameters not well suited to this type of call. Bandwidth (\bar{x} 46 kHz) and slope (\bar{x} 16.66 kHz/ms) far greater than calls from any other species in Solomon Islands.

Comments: We recorded reference calls from this bat at Matikuri Island, western Morovo Lagoon and from free flying bats foraging over the river between Kirakira and Bwaunasugu in Makira.

Similar species: Call is distinct from other species calls based on unique shape and duration (Fig. 17). Calls could possibly be confused with feeding calls from other FM species but the absence of search phase calls should resolve identification.

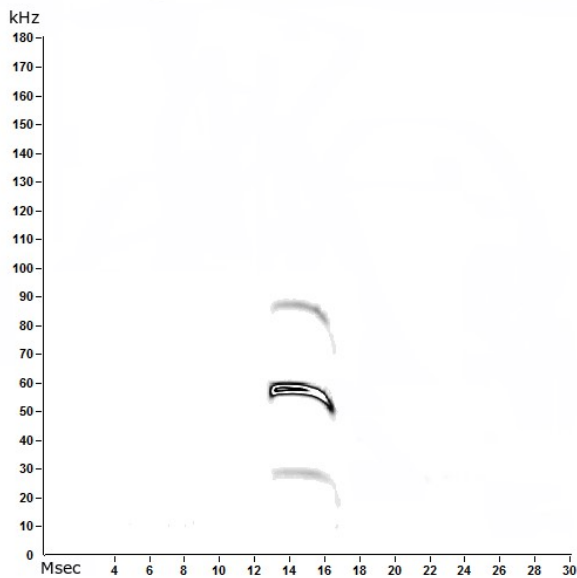


LESSER SHEATHTAIL BAT (*MOSIA NIGRESCENS*)

Description: A short duration (\bar{x} 3.6 ms) frequency modulated call that looks superficially like short duration CF bat call, starting with a flatter section around 55-60 kHz followed by a downsweeping tail (\bar{x} 8 kHz). Peak frequency in 2nd harmonic \bar{x} 57.05 kHz usually in the flattest section. Fundamental harmonic (H1) around 28-29 kHz. In louder calls upper harmonics at H3 (c. 85 kHz, and H4 (c. 114 kHz) may also be visible.

Comments: One of the most commonly recorded species. We recorded free flying bats from most provinces. Free flying calls tend to display long sequences with multiple Doppler shifts and sometimes feeding sequences reflecting the rapid circling and direction changes this species uses when foraging (e.g. Fig. 7)

Similar species: Call is generally distinct from other species calls based on unique shape and duration (Fig. 17). Overlaps in frequency with *Pipistrellus angulatus* and *Miniopterus cf australis* but is easily distinguished by its 'upside down' call shape. Calls could possibly be confused with some large Hipposideros species in group 2 but call duration much shorter. Could also be confused with fundamental harmonics of some small Hipposideros bats in group 1 but 28 kHz harmonic interval should distinguish.

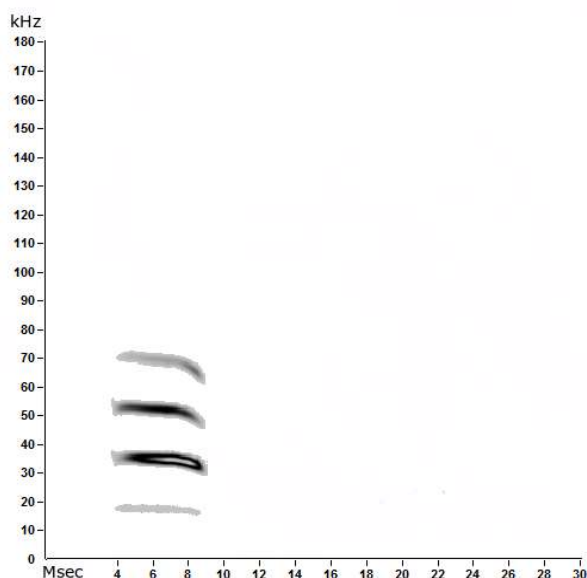


LARGE-EARED SHEATHTAIL BAT (*EMBALLONURA DIANAE*)

Description: A short duration (\bar{x} 4.06 ms) frequency modulated call that also looks superficially like short duration CF bat call, starting with a flatter section around 36 Hz dropping about 4 kHz in a gentle arc.. Peak frequency in 2nd harmonic \bar{x} 35.35 kHz usually in the flattest section. Fundamental harmonic (H1) around 17 kHz. In most calls several harmonics at H3 (c. 52-3 kHz, and H4 (c. 69-70 kHz) are visible (e.g. Fig. 14).

Comments: Known from Guadalcanal, Rennell, Malaita and Isabel. It is also found in Papua New Guinea. We only recorded reference and free flying bat calls from this species in the Kovi/Kongulai area of Guadalcanal near caves.

Similar species: Call is easily distinguished from other species calls based on unique shape and duration (Fig. 17). When our reference calls were compared with calls from free flying bats we identified a cluster of bat calls with similar characteristics but at higher frequencies than any calls we recorded, on average

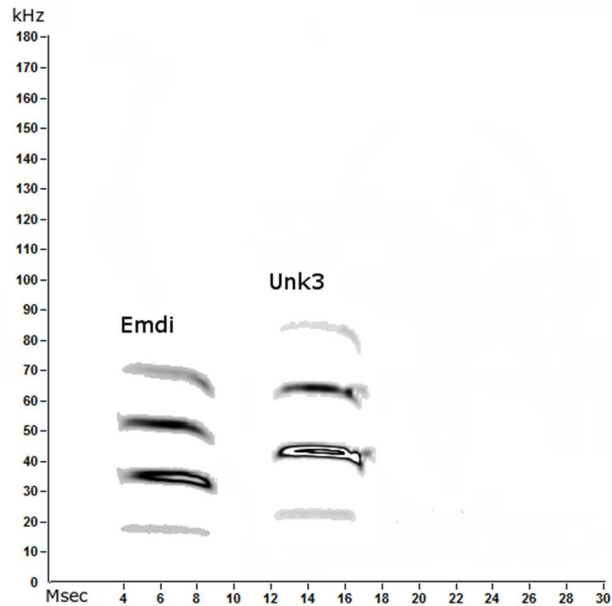


about 5 kHz higher on all parameters (Fig. 20, Unk3). This cluster of calls could represent a portion of the *E. diana* repertoire we did not record, or it could represent another species.

UNIDENTIFIED EMBALLONURID CALL (UNK3)

Description: A short duration (\bar{x} 4.49 ms) frequency modulated call very similar in most characteristics to *Emballonura diana* except being consistently about 4-5 kHz higher on most parameters, and outside the range of any reference calls we recorded for *E. diana* (Fig. 20). Peak frequency in 2nd harmonic \bar{x} 39.48 kHz usually in the flattest section. Fundamental harmonic (H1) around 20 kHz. In most calls several harmonics at H3 (c. 60 kHz, and H4 (c. 80 kHz) are visible (e.g. Fig. 14).

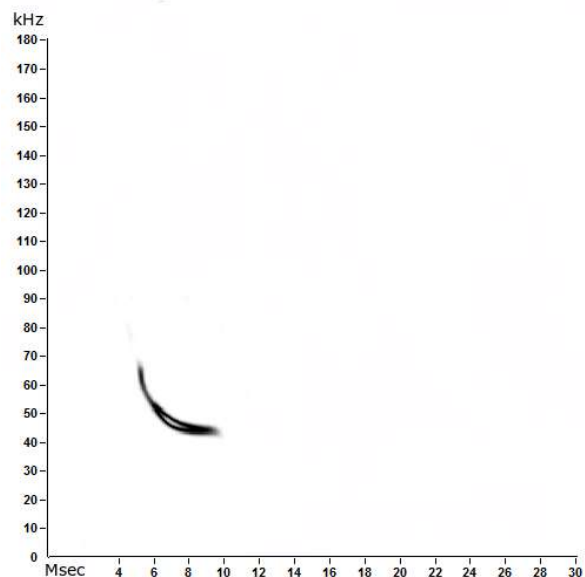
Comments: We recorded 270 of these calls from free flying bats on multiple islands. They do not match any reference calls we collected, we do not know which species made them. The shape and multi harmonic nature of the calls strongly suggest the bat that made them is an emballonurid. *Emballonura raffrayana* and *E. beccarii* are both recorded from the region, *E. beccarii* from Bougainville only, we do not have reference calls for either species. Further work is required to determine if these calls belong to *E. raffrayana*, *E. beccarii*, *E. diana* or another species.



NEW GUINEA PIPISTRELLE (*PIPISTRELLUS ANGULATUS*)

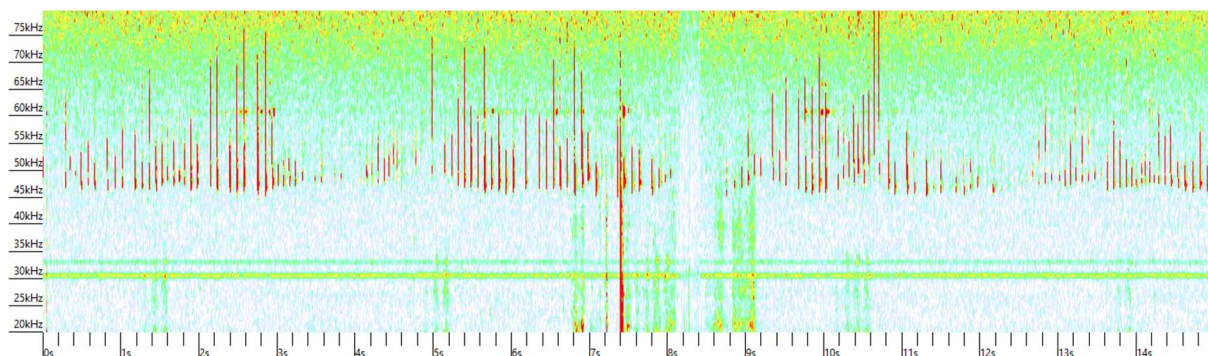
Description: A short duration (\bar{x} 4.16 ms) frequency modulated 'hockey stick' shaped call starting with a rapid frequency sweep dropping from about 70 kHz to 50 kHz and then transitioning to a less steep longer duration characteristic section around 45-46 kHz. Parameters from 452 free flying bat calls closely match calls from the limited number of reference calls; peak frequency is in H1 at the point the frequency sweep starts transitioning to a flatter decline \bar{x} 50.69 kHz, characteristic frequency \bar{x} 47.5 kHz.

Comments: One of the most commonly recorded species. We recorded free flying bats from Choiseul, Isabel, Tetepare, New Georgia and Vangunu Islands. Free flying calls tend to display long sequences with multiple Doppler shifts and sometimes feeding sequences reflecting the rapid circling and direction changes this species uses when foraging (as demonstrated in Figure 21). This pattern can help differentiate it from *Miniopterus* species with similar frequency calls. *Miniopterus* have fast flight patterns resulting in shorter duration sequences with a single Doppler trend.



Similar species: Overlaps in call shape and frequency with *Miniopterus cf australis* and *M. cf oceanensis*. Can be differentiated by peak and characteristic frequencies (\bar{x} 47.5, 50.69 kHz) being lower than *M. australis* (\bar{x} 51.62, 55.35 kHz), and a higher than *M. oceanensis* (\bar{x} 47.23, 44.07 kHz). Can also be distinguished by longer duration sequences (often >5 seconds) with multiple Doppler fluctuations (Fig. 21), *Miniopterus* sequences tend to be shorter with single Doppler trajectories. The feeding call pattern is also diagnostic, with minimum frequency of approach and buzz calls changing little or increasing in frequency (Fig. 8), whereas the minimum and maximum frequency of *Miniopterus* buzz calls drops substantially in frequency from surrounding search phase calls. Overlaps in frequency and shares similar call sequence foraging patterns with *Mosia nigrescens*, but easily differentiated by call shape. May overlap with *Pipistrellus papuanus* on Bougainville but *P. papuanus* call unknown.

FIGURE 21: 15 SECOND CALL SEQUENCE OF *P. ANGULATUS* SHOWING DOPPLER EFFECTS



GENUS MINIOPTERUS

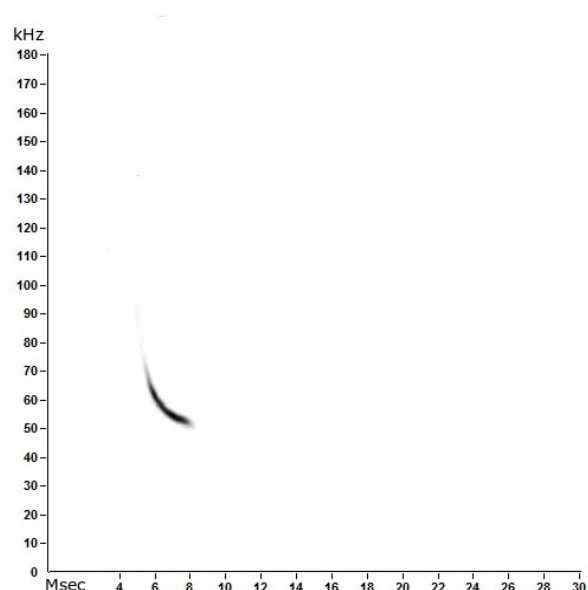
The taxonomy (Scientific naming) of bent-wing bats (genus *Miniopterus*) in Solomon Islands and New Guinea is uncertain. The actual number and names of species present in Solomon Islands is unknown. For the purpose of this guide we have named the three distinct morphological types of *Miniopterus* we captured after the species we felt best fitted the description, but we recognise that these names may not be correct.

LITTLE BENT-WING BAT (*MINIOPTERUS CF AUSTRALIS*)

Description A very short duration (\bar{x} 2.6 ms) frequency modulated 'hockey stick' shaped call starting with a rapid frequency sweep dropping from above 80 kHz (\bar{x} 82 kHz) to around 60 kHz (\bar{x} 59 kHz) and then transitioning to a less steep longer duration characteristic section just over 50 kHz (\bar{x} 51.6 kHz). Peak frequency is in H1 at the 'knee' after the frequency sweep starts transitioning to a flatter decline (\bar{x} 55.3 kHz), characteristic frequency \bar{x} 51.62 kHz.

Comments: Taxonomy of the species uncertain, but smaller than other *Miniopterus* on most measurements (\bar{x} forearm measured 38.9 mm).

Similar species: Call overlaps in shape and frequency with *Pipistrellus angulatus* but can generally be differentiated by having a higher peak



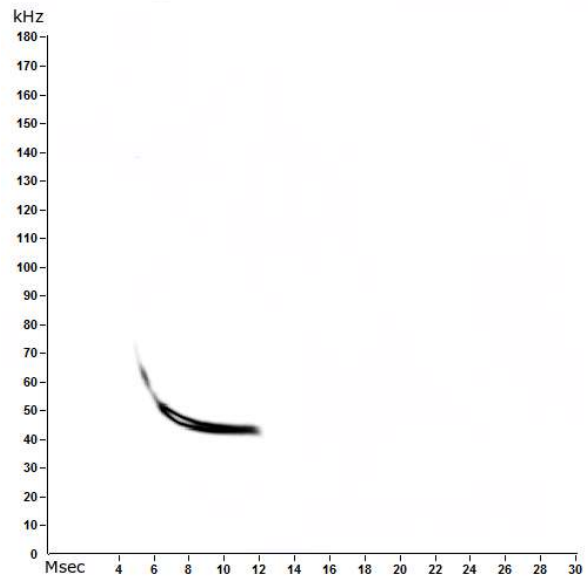
and characteristic frequencies. It also has a distinct feeding buzz that drops substantially in minimum frequency.

EASTERN BENT-WING BAT (*MINIOPTERUS CF OCEANENSIS*)

Description A short duration (\bar{x} 4.72 ms) frequency modulated 'hockey stick' shaped call starting with a rapid frequency sweep dropping from 70-80 kHz (\bar{x} 77 kHz) to around 53 kHz (\bar{x} 52.6 kHz) and then transitioning to a less steep longer duration characteristic section around 43-45 kHz. Peak frequency is in H1 at the 'knee', the point where the initial frequency sweep transitions to a flatter decline (\bar{x} 47.23 kHz), characteristic frequency \bar{x} 44.07 kHz.

Comments: Taxonomy of the species uncertain, larger than *M.cf australis* but smaller than *M. cf tristis* (\bar{x} forearm measured 46.4 mm).

Similar species: Call overlaps in shape and frequency with *Pipistrellus angulatus* but can generally be differentiated by having a lower peak (below 50 kHz) and characteristic frequencies. It also has a distinct feeding buzz that drops substantially in minimum frequency.

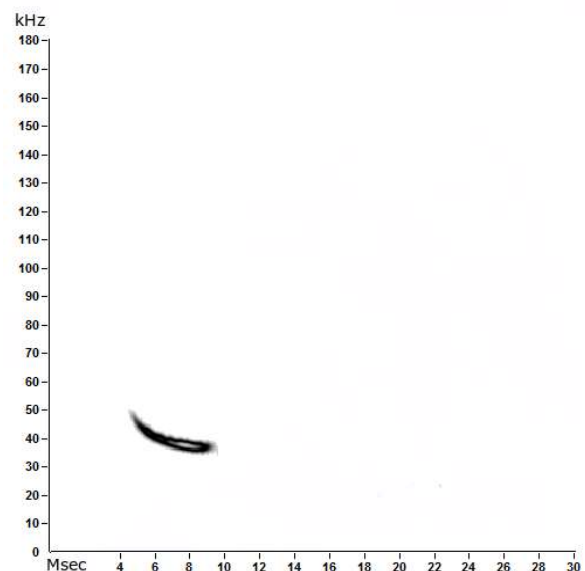


GREAT BENT-WING BAT (*MINIOPTERUS CF TRISTIS*)

Description A short duration (\bar{x} 4.13 ms) frequency modulated 'hockey stick' shaped call starting with a rapid frequency sweep starting between 70- 45 kHz to around 40 kHz (\bar{x} 39 kHz) and then transitioning to a less steep longer duration characteristic section around or below 40 kHz (\bar{x} 36.16 kHz). Peak frequency is in H1 at the 'knee', the point where the initial frequency sweep transitions to a flatter decline (\bar{x} 36.52 kHz), characteristic frequency \bar{x} 36.16 kHz.

Comments: Taxonomy of the species uncertain, but larger than other *Miniopterus* on most measurements (\bar{x} forearm measured 49 mm).

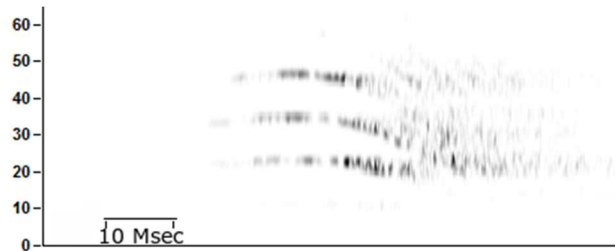
Similar species: Call overlaps in shape and frequency with *Miniopterus cf. oceanensis* but can be differentiated by having lower peak and characteristic frequencies below 40 kHz.



NON ECHOLOCATION BAT CALLS

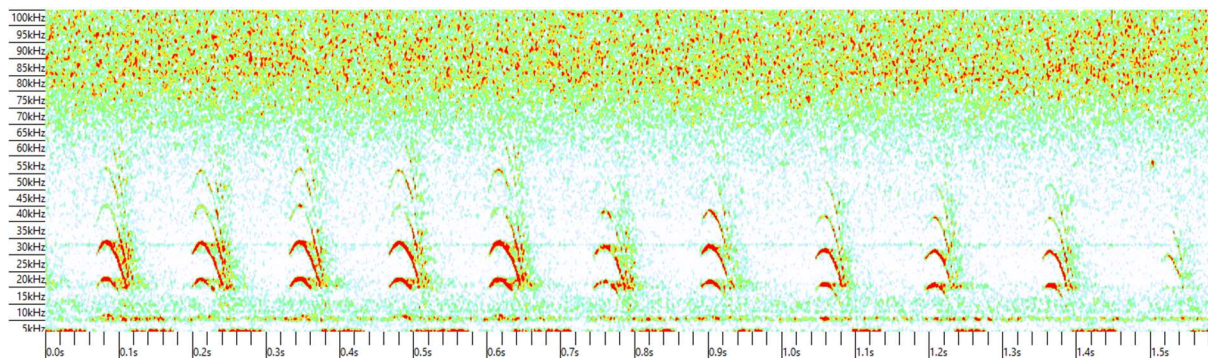
WOODFORD'S BLOSSOM BAT (*MELONYCTERIS WOODFORDI*)

We recorded multiple sequences of very unusual calls from free flying bats from Vakao Island, Isabel. The calls are very long duration (40-60 ms) and consist of multiple frequency sweeps at 11kHz harmonics. The loudest at H2 (22 kHz) and H3 (33 kHz). Calls are in sequences of approximately 10 or so pulses in a 1-1.5 second period, time between calls 70-80 ms (Fig. 22).



At the time of recording Woodford's blossom bats were observed flying between flowering trees and making high pitched bird like trilling social calls. It seems that these social calls include ultrasonic elements. This is very unusual for a pteropodid and warrants further investigation.

FIGURE 22: ULTRASONIC ELEMENTS IN CALL OF *MELONYCTERIS WOODFORDI*



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MORE INFORMATION

If you find an error, have any questions about this guide, or would like more information about mammal research and bats in Solomon Islands and Bougainville please email:

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