KEY TO THE BAT CALLS OF THE TOP END OF THE NORTHERN TERRITORY

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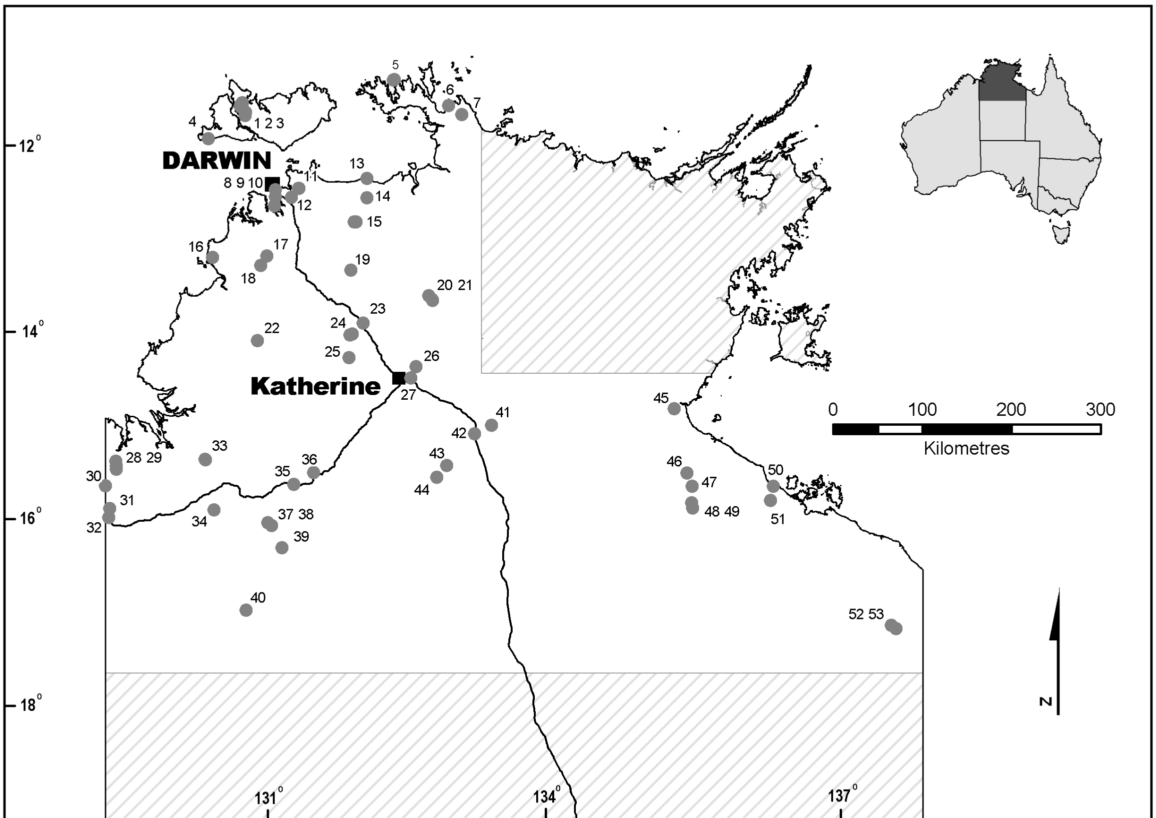
Contents

INTRODUCTION

Anabat detectors (Titley Electronic, Ballina, NSW) have been used with increasing popularity over recent years. Unfortunately, their use has resulted in species lists of bats being published based on Anabat calls without documentation of the characteristics used to separate species. The development of regional keys to bat calls, based on locally collected reference calls, defining the methods and parameters used to identify species is clearly required (Duffy *et al*. 2000). This guide provides such a key for the identification of the microchiropteran bat fauna that occurs in the Top End of the Northern Territory. These calls were obtained using Anabat detectors and analyzed using Analook software (Corben, 2000).

The area covered is north of the 18°S parallel in the monsoon tropics of the Northern Territory, excluding most of the Arnhem Land region where no reference calls have been collected (Figure 1). It is dominated by eucalypt savanna woodlands and encompasses an area of approximately 340 000 km^2 covering eleven bioregions. The area is generally referred to as the “Top End”.



Chaerephon jobensis (15 25 39 42 52), *Chalinolobus gouldii* (24 28 32 39 40 43), *C.nigrogriseus* (5 11 15 21 22 24 25 27 28 29 33 37 39 42 43 51 52), *Hipposideros diadema* (20), *H.ater* (24 27 31 48), *Macroderma gigas* (23) *Miniopterus schreibersii* (8 17 21 28 29 44) *Mormopterus loriae* (45), *Myotis macropus* (8 9) *Nyctophilus arnhemensis* (1 4 5 10 12 29 33 41), *N.bifax* (21 34), *N.geoffroyi* (14 22), *N.walkeri* (21 26 29 33 41), *Pipistrellus adamsi* (7 15 16 21), *P.westralis* (1 2 13 45), *Rhinonicteris aurantius* (18 25 47 52), *Saccolaimus flaviventris* (1 6 15 16 25 30 38 42 48 49 50 52 53), *Scotorepens greyii / S.sanborni* (1 2 5 11 14 16 21 24 32 33 36 40 46 47 50), *Taphozous georgianus* (21 47 53), *T.kapalgensis* (13), *Vespadelus caurinus* (17 21 24 30 35 48).

Figure 1. Locality map showing the area covered by the key (unshaded) and the locations of sites where reference calls were collected (gray dots). The attached text box lists the species that have been recorded and the sites where they were recorded from, according to the numbered sites on the map.

A reference collection of 205 call recordings, from hand identified bats from the Top End, was used to construct the key. The key is based primarily on call frequency, time and slope parameters of these reference calls. Only search phase call pulses of good quality that were unaffected by 'post-release stress' of hand released bats were used in the analysis.

For those species that could not be consistently identified from call frequency and shape of the call pulse, discriminant function analysis was used to test whether call parameters could mathematically differentiate between species. Discriminant function analysis is a powerful statistical tool, that can sometimes differentiate between the calls of two or more species that visually appear very similar. When parameters derived from ANALOOK (which will be described later) are analysed using discriminant function analysis it determines whether those parameters are able to form two or more naturally occurring groups (STATISTICA, 1999). These groups can then be described by a mathematical formula and the level of significance examined. The end result is a more robust and objective means for identifying bat calls.

A dichotomous key is provided to identify calls and includes illustrations to explain the terms used. A summary of characteristic frequency ranges for each species is shown in Figure 4. The range of all frequencies for each species are shaded depending on the method required to identify the call:

- white - the call can be identified based on frequency alone or distinctive call features;
- hatch - discriminant function analysis may be required for accurate identification of the call;
- black - identification to the level of species cannot be made with confidence.

The section on Species Call Descriptions then provides a summary of the average characteristic frequency and 95% confidence interval (= characteristic frequency range), the number and locations of reference calls used and other species that produce similar calls which can be confused with those of the target species. A brief description of the call for each species and one example of a reference call are also provided.

Earlier reference calls were collected using analog tape recorders and subsequently downloaded to computer. The majority of more recently collected reference calls have been digitally recorded from the Anabat detector to a laptop computer (via a ZCAIM unit). White and Gehrt (2001) found that calls recorded this way are of better quality and the parameters derived from ANALOOK can differ significantly between digital and analog recording methods. These parameters are critical in deriving reliable results from the discriminant function analysis. As more digitally recorded reference calls are collected, it is expected that using discriminant function analysis on species with similar calls will produce more reliable separation.

This key is designed to be used with the Analook software (Analook 4.8f - Corben, 2000), therefore a basic working knowledge of the software is required. Analook is a simple program that is easy to learn and freely available (http://www.titley.com.au/tdload.htm). Instructions are provided with the software or refer to "Anabat System Manual" (Corben and O'Farrell, 1999) for complete documentation.

The Anabat system is a non-intrusive means of detection and identification which avoids the need to handle and potentially cause injury to echolocating bats. However, the accuracy and reliability of the identification still depends, to some degree, on the experience and skill of the Anabat user. Inexperienced users should always err on the side of caution when identifying unknown calls. In some cases even expert users may identify to species level as few as 10% of Anabat call files collected during surveys (Duffy *et al.*, 2000). The bottom line…if in doubt, cross it out !

This guide follows many of the principles described in "Key to the bat calls of south-east Queensland and north-east New South Wales" (Reinhold *et al*., 2001). This publication should be referred to for more information on the technical aspects of identifying Anabat calls.

IDENTIFYING CALLS

TERMS USED IN THE KEY

The list below provides definitions of terms that are used in the key and are demonstrated in Figure 2. Definitions have been derived and/or modified from various sources in order to provide a simplified list of the characteristics of calls specific to the species of echolocating bats that occur in the Top End.

Call parameters [1]

Fc	Characteristic frequency, the frequency at the end or flattest portion of the call.
Fk	Frequency at the "knee" or the point at which the slope of the call abruptly changes from a downward slope to a more level slope.
Fmin	Minimum call frequency.
Fmax	Maximum call frequency.
DUR	Total duration of the call.
Tc	Time from the start of the call to Fc.
Tk	Time from the start of the call to Fk.
S1	Slope at the start of the call.
Sc	Slope of the call at Fc.

Sections of a call pulse [2]

Initial	Portion of call between the start of the call and Tk .
Body	Portion of call between Tk and Tc.
Tail	Portion of call between Fc and the end of the call.

Call Types [3]

Four different call types are recognised: flat, constant frequency, linear and curvilinear.

1 Definitions from Corben and O'Farrell (1999)
2 Definitions modified from Reinhold *et al.* (2001)
3 Modified from de Oliveira (1998a)

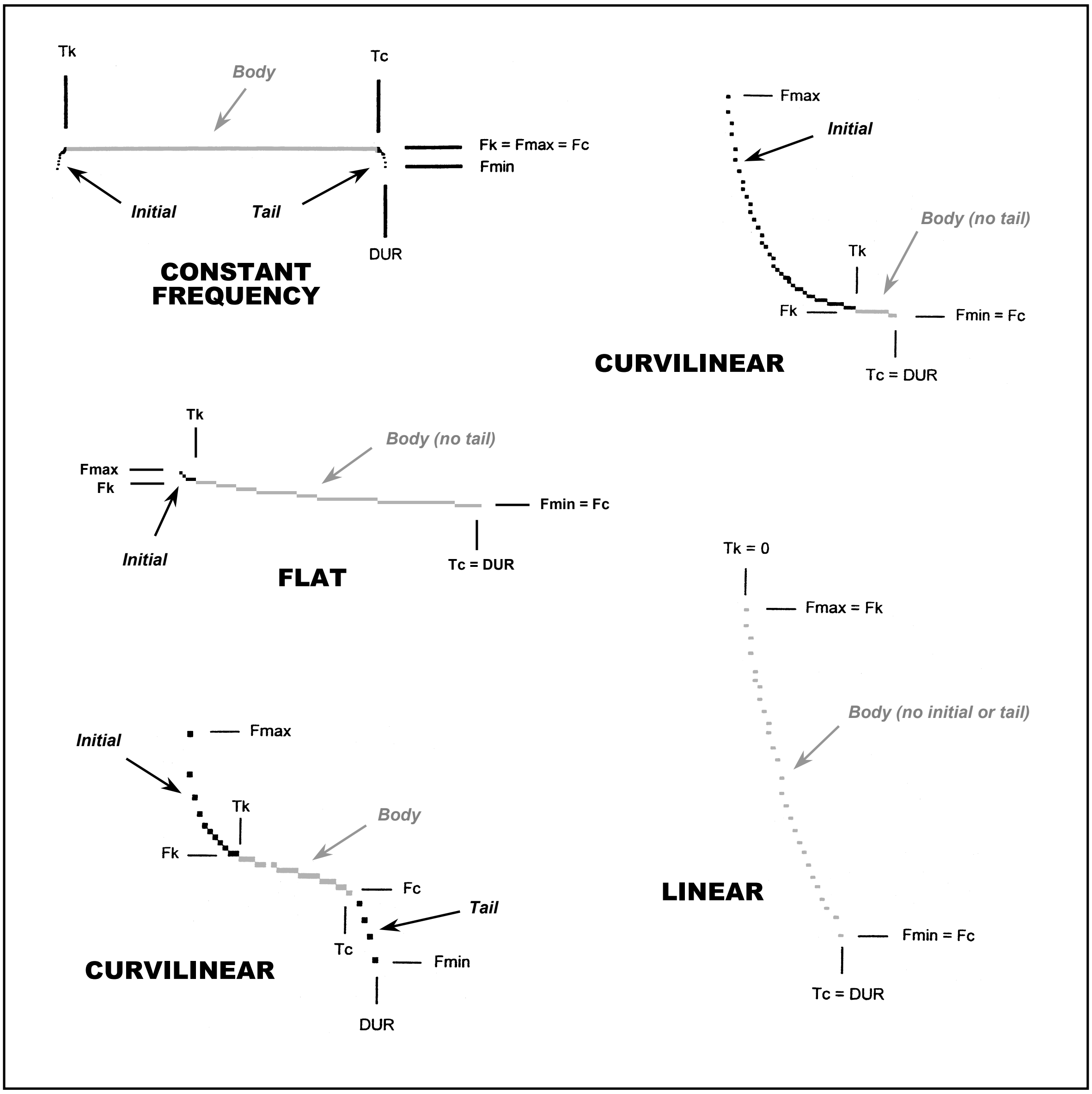


Figure 2. Various types of call pulses and their parameters. All images (except the “flat” call type) are modified from Corben and O’Farrell (1999)

CALL EDITING

To minimise subjectivity, the key is based primarily on measurable call parameters and clearly defined call characteristics of the search phase of calls. Therefore, some minor editing of call sequences is sometimes required to delete non-search phase calls before attempting identification. The following describes some of Analook's call editing techniques (editing the call does not change the original file and saving edits is not normally required).

Only calls based on search phase pulses should be used. Sections of calls containing attack phase pulses and feeding buzzes (Figure 3) should be deleted. Use the **MARK TO EXCLUDE** option to delete these pulses. A minimum of three consistent search phase pulses is required for call identification, but preferably longer call sequences should be used.

Fmin, Fmax and S1 will be affected by "noise" generated through the recording process above and below call pulses. Use the **MARK OFF POINTS** option to delete these points. Fc, Fk, Tc and Sc are affected by the position of the Body of the call. Analook automatically delineates this section (highlighted on screen by pressing "**m**"). However, it does not always do this consistently, particularly for poor quality and/or erratic call sequences. Use the **MODIFY BODIES** option to manually delineate this section of call pulse if required.

Parameters can be viewed at the bottom of the screen by pressing "**m**". They are the mean values for all pulses displayed on the screen, required for the discriminant function equations for the identification of some species. If the entire call sequence does not fit across the screen, reduce the horizontal resolution using the **F1-F10** keys. If the call sequence extends off the top of the screen, toggle the vertical resolution using the **+** and **–** keys.

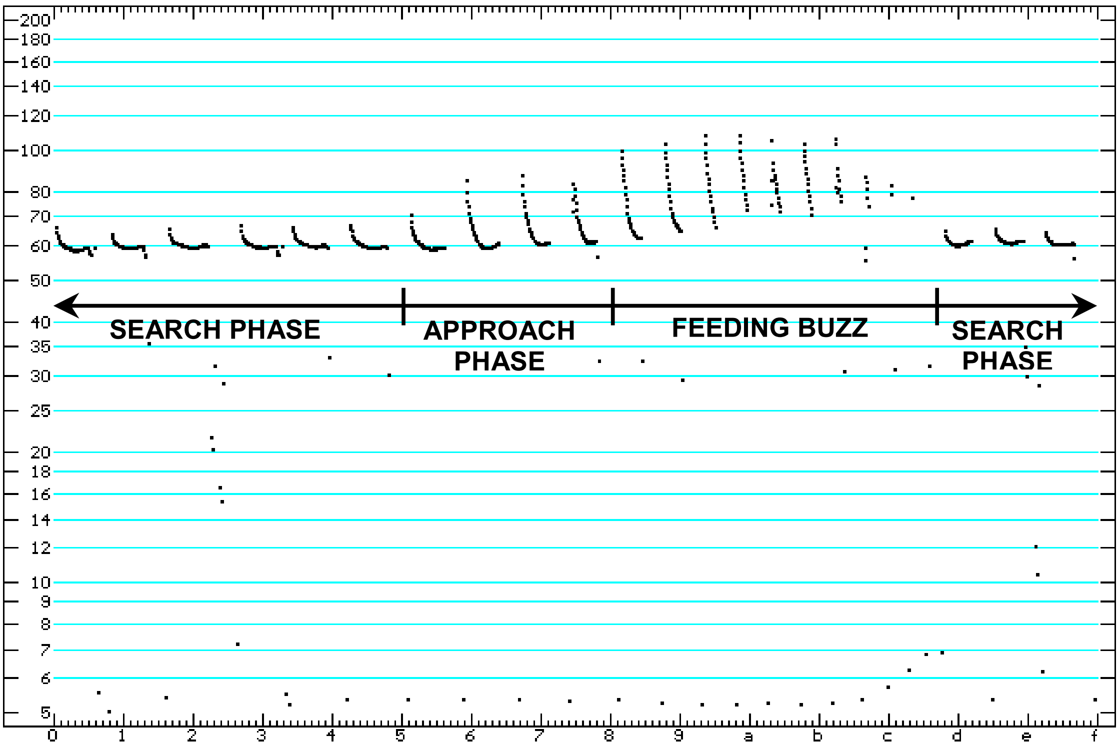
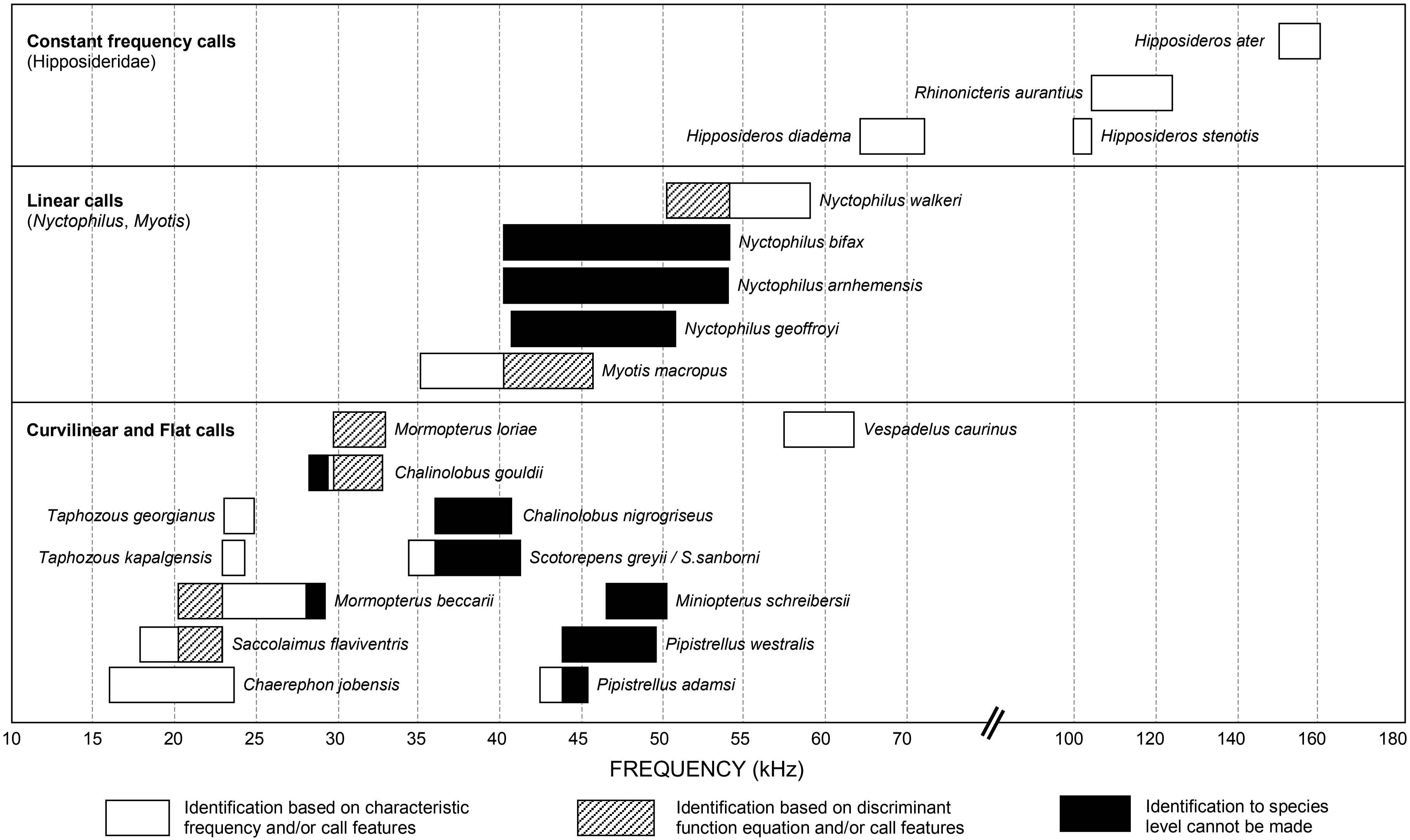


Figure 3. Different phases of a call sequence. Terminology of phases based on de Oliveira (1998b).

FIGURE 4. CHARACTERISTIC FREQUENCY RANGES



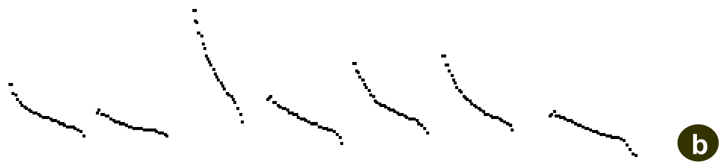
KEY TO BAT CALLS OF THE TOP END

1 a Characteristic frequency less than 33.1 kHz 2
b Characteristic frequency greater than 34.5 kHz 13

2 a Call harmonic (duel frequency) present (a) .... ***Saccolaimus flaviventris*** (page 14)

b Call harmonic absent 3

3 a Call sequence “messy” i.e. pulse shape variable and inconsistent with abrupt changes in frequency (b), ... ***Chaerephon jobensis*** (page 13)



b Pulses even smooth and consistent, changes are gradual (a) 4

4 a Characteristic frequency less than 20.3 kHz .... ***Saccolaimus flaviventris*** (page 14)
b Characteristic frequency greater than 20.2 kHz 5

5 a Characteristic frequency less than 28.2 kHz 6
b Characteristic frequency greater than 28.1 kHz 10

6 a Call duration (DUR) of all pulses (minimum 8 pulses) less than 8ms ....
.... ***Taphozous kapalgensis*** (page 16)
b Call duration (DUR) of any pulse greater than 8ms 7

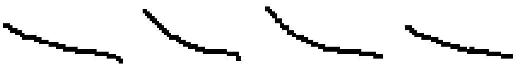
7 a Characteristic frequency less than 23.0 kHz 8
b Characteristic frequency greater than 22.9 kHz 9

8 a FK*7.101 + S1*0.0014 - 76.642 >
FK*8.658 + S1*0.026 - 114.431 .... ***Saccolaimus flaviventris*** (page 14)
b FK*7.101 + S1*0.0014 - 76.642 <
FK*8.658 + S1*0.026 - 114.431..***Mormopterus beccarii*** (page 15)

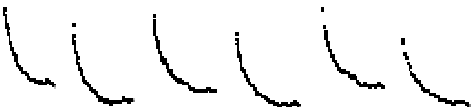
9 a Pulse type flat (c) .... ***Taphozous georgianus*** (page 17)


c

b Pulse type curvilinear (d) .... ***Mormopterus beccarii*** (page 15)


d

10 a Pulses alternate in characteristic frequency (e) .... ***Chalinolobus gouldii*** (page 18)


e

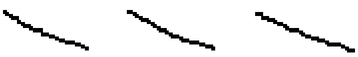
b Pulses do not alternate in frequency (a) 11

11 a Characteristic frequency less than 28.5 kHz ....
.... ***Mormopterus beccarii* or *Chalinolobus gouldii*** (pages 15,18)

b Characteristic frequency greater than 28.4 kHz 12

12 a Pulses predominantly curved (a)
FK*34.346 - FMAX*4.177 + TC*16.519 - 518.243 >
FK*37.662 - FMAX*5.178 + TC*17.791 - 597.869 .... ***Chalinolobus gouldii*** (page 18)

b Pulses predominantly straight (f),
FK*34.346 - FMAX*4.177 + TC*16.519 - 518.243 <
FK*37.662 - FMAX*5.178 + TC*17.791 - 597.869 .... ***Mormopterus loriae*** (page 19)


f

13 a Pulse type curvilinear (a) or linear (g), characteristic frequency less than 62 kHz 14


g

b Constant frequency pulse type (h), characteristic frequency greater than 66 kHz 25


h

14 a Pulse type curvilinear (a) 15

b Pulse type linear (g) 20

15 a Characteristic frequency less than 41.5 kHz 16
b Characteristic frequency greater than 42.4 kHz 17

16 a Characteristic frequency less than 36.1 kHz ....
.... ***Scotorepens greyii* or *S.sanborni*** (page 20)
b Characteristic frequency greater than 36.0 kHz ....
.... ***Scotorepens greyii* or *S. sanborni* or *Chalinolobus nigrogriseus*** (pages 20,21)

17 a Characteristic frequency less than 50.3 kHz 18
b Characteristic frequency greater than 57.4 kHz .... ***Vespadelus caurinus*** (page 25)

18 a Characteristic frequency less than 44.0 kHz .... ***Pipistrellus adamsi*** (page 22)
b Characteristic frequency greater than 43.9 kHz 19

19 a Characteristic frequency less than 46.7 kHz ....
....***Pipistrellus adamsi* or *P.westralis*** (pages 22,23)
b Characteristic frequency greater than 46.6 kHz ....
......................................***Pipistrellus westralis* or *Miniopterus schreibersii*** (pages 23,24)

20 a Characteristic frequency less than 40.1 kHz ....***Myotis macropus*** (page 26)
b Characteristic frequency greater than 40.0 kHz 21

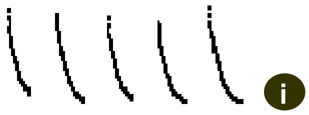
21 a Characteristic frequency less than 50.2 kHz 22
b Characteristic frequency greater than 50.1 kHz 24

22 a Characteristic frequency less than 45.6 kHz 23
b Characteristic frequency greater than 45.5 kHz ....
.... ***Nyctophilus geoffroyi* or *N.arnhemensis* or *N.bifax*** (pages 27,28,29)

23 a FC*6.040 + DUR*17.033 + SC*0.034 - 150.114 >
FC*7.135 + DUR*19.373 + SC*0.023 - 202.991 ....***Myotis macropus*** (page 26)

b FC*6.040 + DUR*17.033 + SC*0.034 - 150.114 <
FC*7.135 + DUR*19.373 + SC*0.023 - 202.991 ....
.... ***Nyctophilus geoffroyi* or *N.arnhemensis* or *N.bifax*** (pages 27,28,29)

24 a Some indication of a bend at the end of most pulses (i) when viewed with log scale
FC*8.311 - SC*0.028 + DUR*15.670 - 219.761 <
FC*9.701 - SC*0.062 + DUR*17.632 - 292.275 .... ***Nyctophilus walkeri*** (page 30)



b No indication of a bend at the end of most pulses (g) when viewed with log scale
FC*8.311 - SC*0.028 + DUR*15.670 - 219.761 >
FC*9.701 - SC*0.062 + DUR*17.632 - 292.275 ....
.... ***Nyctophilus geoffroyi*** **or** ***N.arnhemensis*** **or** ***N.bifax*** (pages 27,28,29)

25 a Characteristic frequency less than 72 kHz ....***Hipposideros diadema*** (page 31)
b Characteristic frequency greater than 101 kHz 26

26 a Characteristic frequency less than 107 kHz .... ***Hipposideros stenotis*** (page 32)
b Characteristic frequency greater than 107 kHz 27

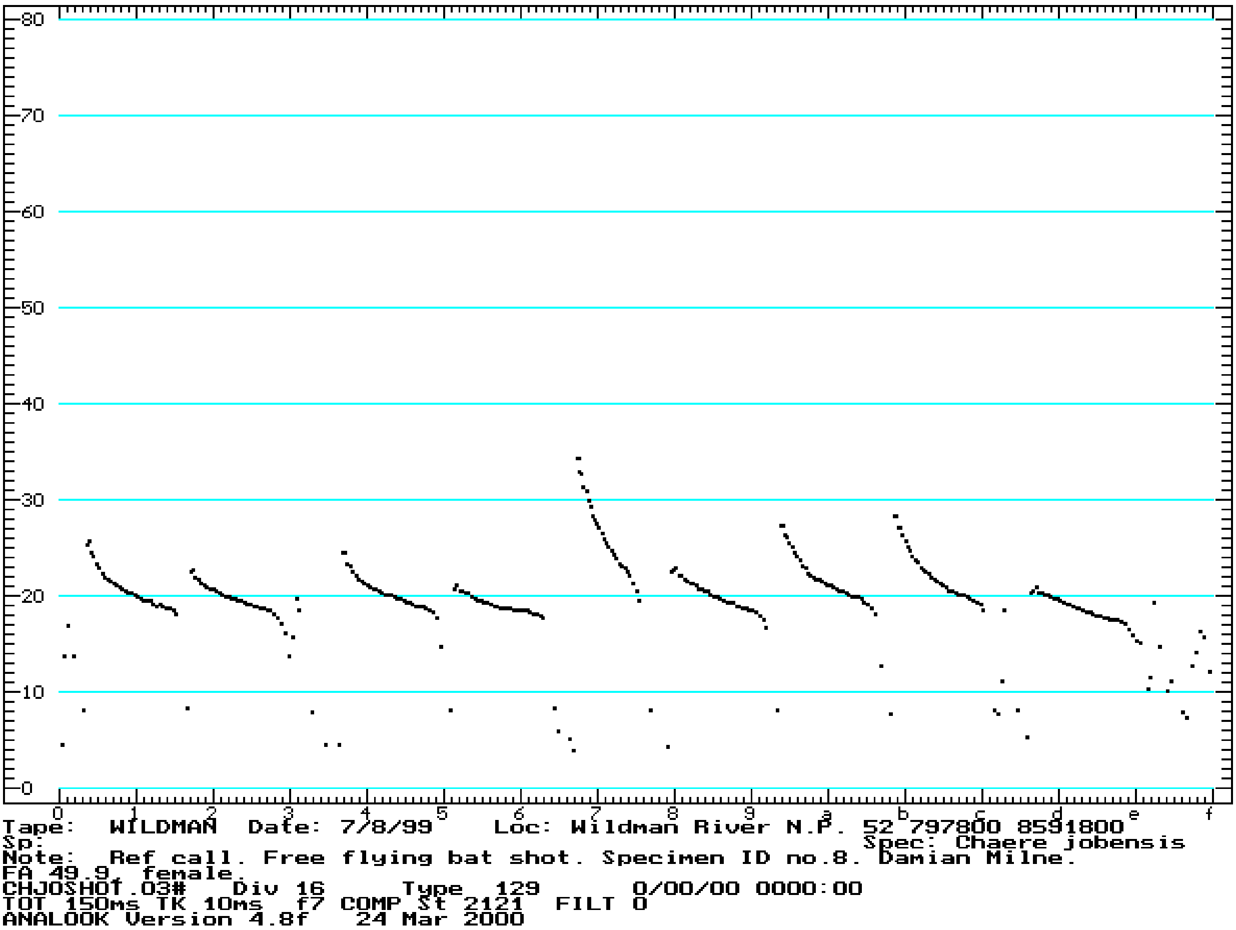
27 a Characteristic frequency less than 126 kHz ....***Rhinonicteris aurantius*** (page 33)
b Characteristic frequency greater than 150 kHz ....***Hipposideros ater*** (page 34)

SPECIES CALL DESCRIPTIONS

Chaerephon jobensis
Northern freetail bat

Characteristic frequency	19.8 kHz	(95% Confidence interval 16.1 - 23.6 kHz)
Number of reference calls	6	(Sites 15, 25, 39, 42, 52)
Similar calls	*Saccolaimus flaviventris*, *Mormopterus beccarii*	

C.jobensis often flies in pairs (T.Reardon pers. comm.). This behaviour tends to produce paired call pulses at alternating frequencies with intermittent, “excited”, linear pulses. This pattern is probably the result of bats interacting with each other. The calls of an individual *C.jobensis* are therefore likely to be difficult to identify from *S.flaviventris* or *M.beccarii*. So far all reference calls for *C.jobensis* have been produced by two individuals, whereas all reference calls collected for *S.flaviventris* (n = 18) have been of solitary animals. Reference calls from Queensland have shown this species to occasionally emit very flat low pulses just below 20 kHz.

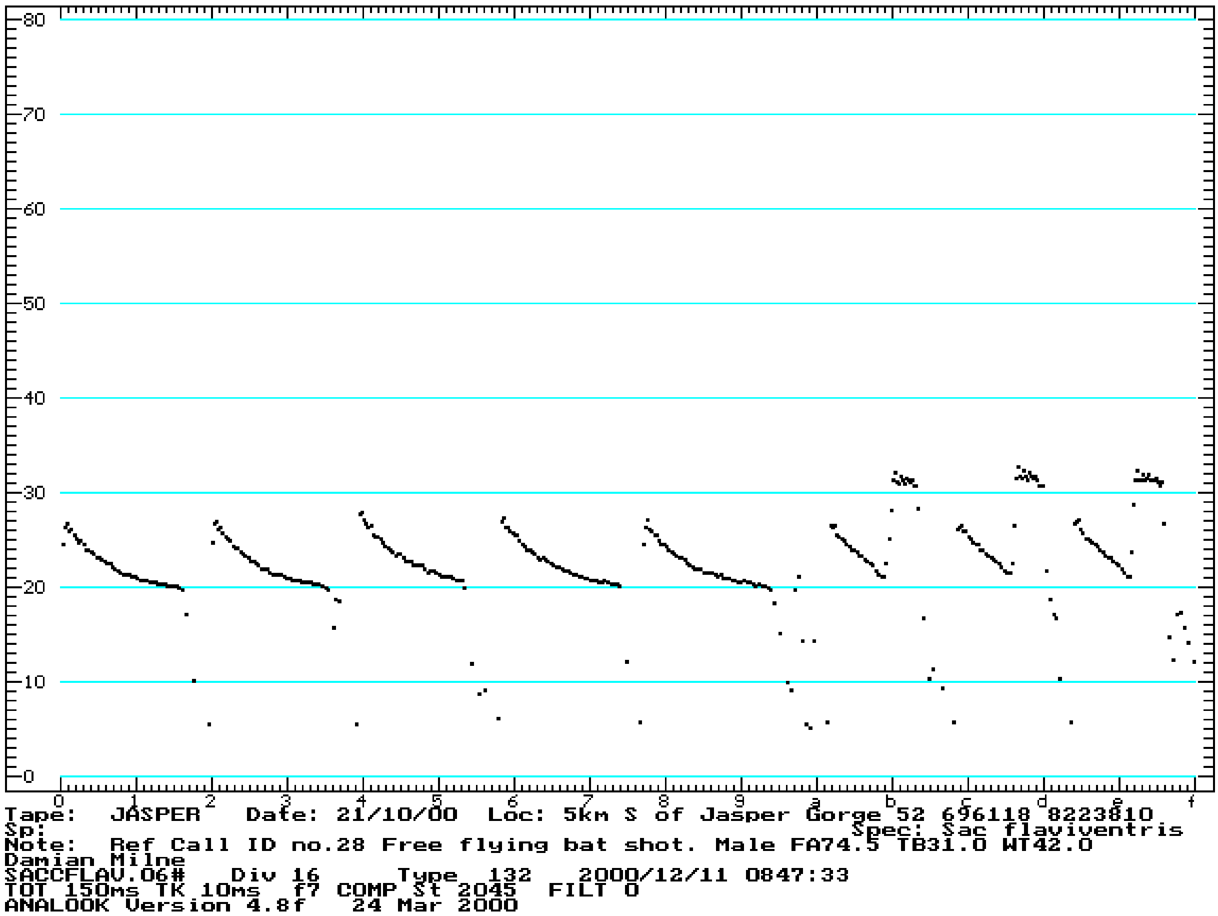


Saccolaimus flaviventris
Yellow-bellied sheathtail bat

Characteristic frequency	20.3 kHz	(95% Confidence interval 17.8 - 22.9 kHz)
Number of reference calls	18	(Sites 1,6,15,16,25,30,38,42,48,49,50,52,53)
Similar calls	*Chaerephon jobensis, Mormopterus beccarii*	

The search phase sonar pulses of *S.flaviventris* are always smooth, consistent and without abrupt changes in frequency between pulses. The curvilinear pulse shape is generally evenly curved, however it can sometimes be quite straight. In one reference call sequence, the pulse shape was flat and very long. *S.flaviventris* sometimes produces a harmonic call at around 30 kHz (shown below), which no other species around this frequency appears to produce. *S.flaviventris* overlaps with the characteristic frequency range of *Mormopterus beccarii* and can be identified if the following condition is satisfied:

FK*7.101 + S1*0.0014 - 76.642 > FK*8.658 + S1*0.026 - 114.431

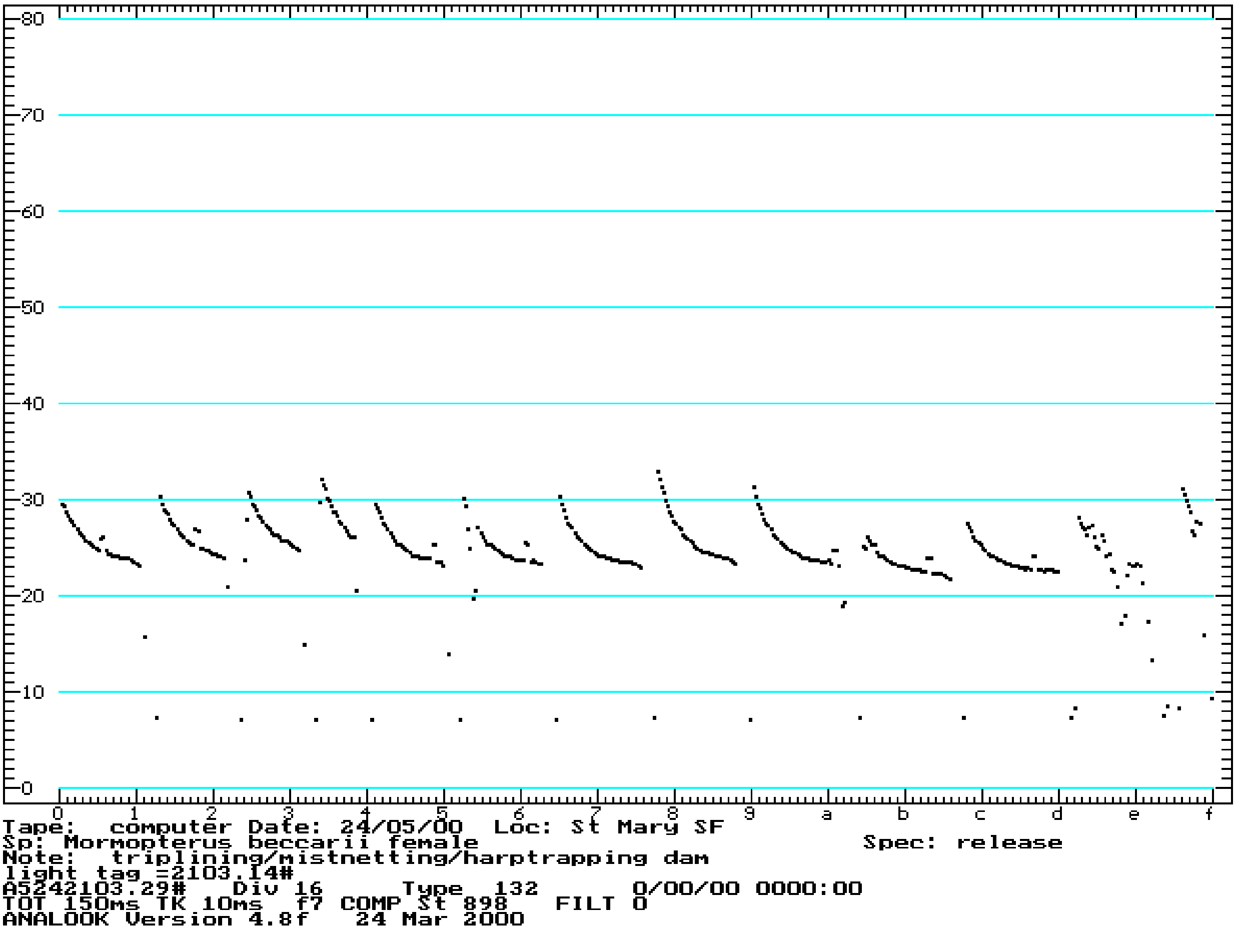


Mormopterus beccarii
Beccari's freetail bat

Characteristic frequency	24.3 kHz	(95% Confidence interval 20.3 - 28.4 kHz)
Number of reference calls	5	(all from Queensland)
Similar calls	*Saccolaimus flaviventris*	

Mormopterus beccarii produces curvilinear search phase call pulses. Where its characteristic frequency range coincides with *S.flaviventris*, and in the absence of call harmonics, it can only be confidently identified by satisfying the condition below. *M.beccarii* also just overlaps with the lower characteristic frequency range of *Chalinolobus gouldii* between 28.2 and 28.4 kHz. Reinhold *et al*. (2001) noted that the pulses of a feeding buzz of *Mormopterus* spp*.* go through a gradual change in pulse shape. This pattern is in contrast to the feeding buzzes for species such as *Saccolaimus flaviventris* where pulse change is very abrupt. No reference calls for this species have been collected for the Top End. Call parameters are based on reference calls provided by Terry Reardon and Linda Reinhold from bats recorded in Queensland.

FK*7.101 + S1*0.0014 - 76.642 < FK*8.658 + S1*0.026 - 114.431

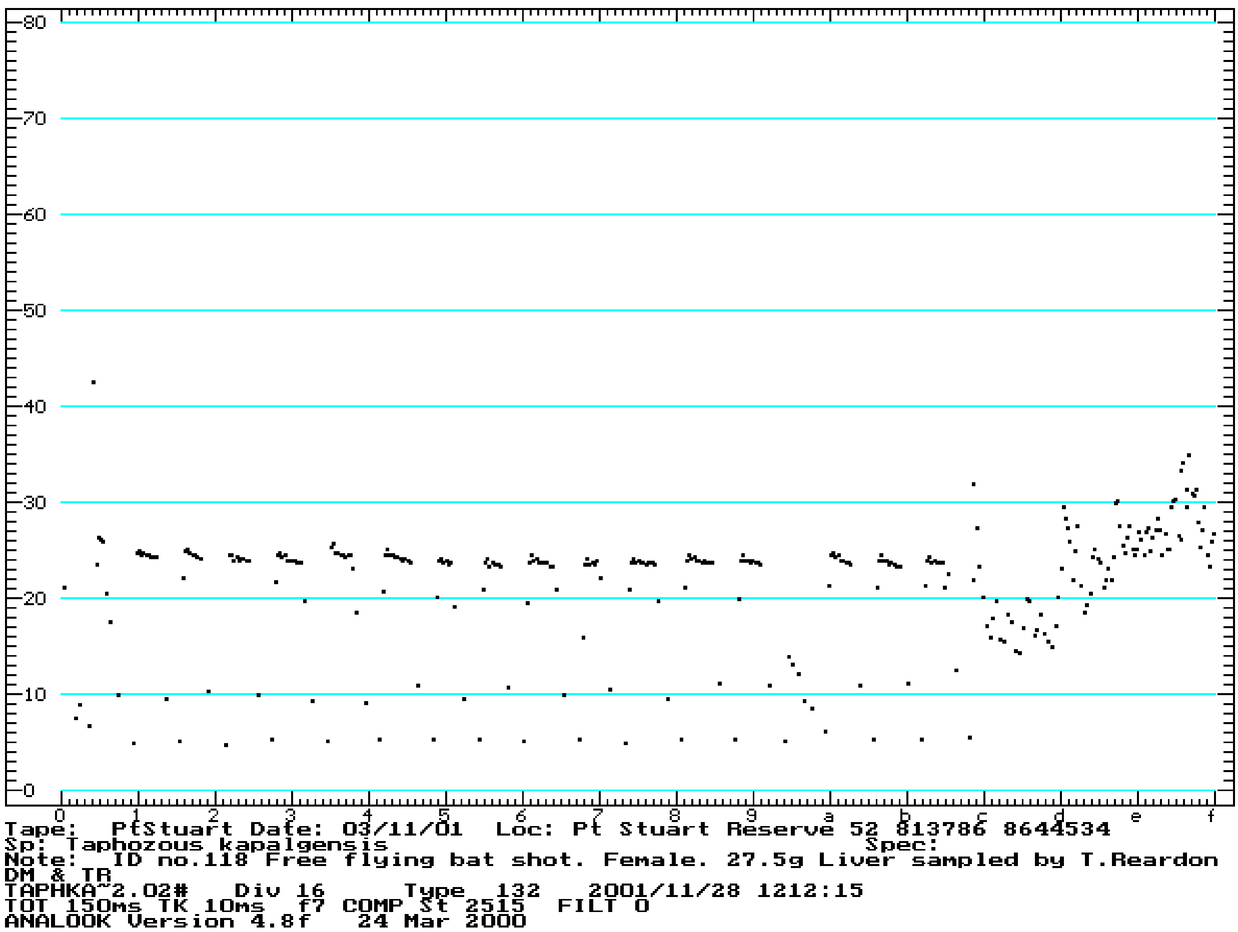


Taphozous kapalgensis
Arnhem sheathtail bat

Characteristic frequency	23.6 kHz	(95% Confidence interval 23.0 - 24.3 kHz)
Number of reference calls	2	(Site 13)
Similar calls	*Taphozous georgianus*, *Mormopterus beccarii*	

Only two reference calls have been obtained from this species, so a definitive description of its call cannot be made. However, one call sequence is of 20 seconds duration. Call pulses were consistent throughout the call sequence so it can be safely assumed to be a search phase call sequence for this species. This call is different to reference calls for other species. Therefore, even though the entire range of call characteristics may not have been obtained, calls detected of this type can be attributed to *T.kapalgensis*. The second reference call was recorded directly to computer and was consistent with the first.

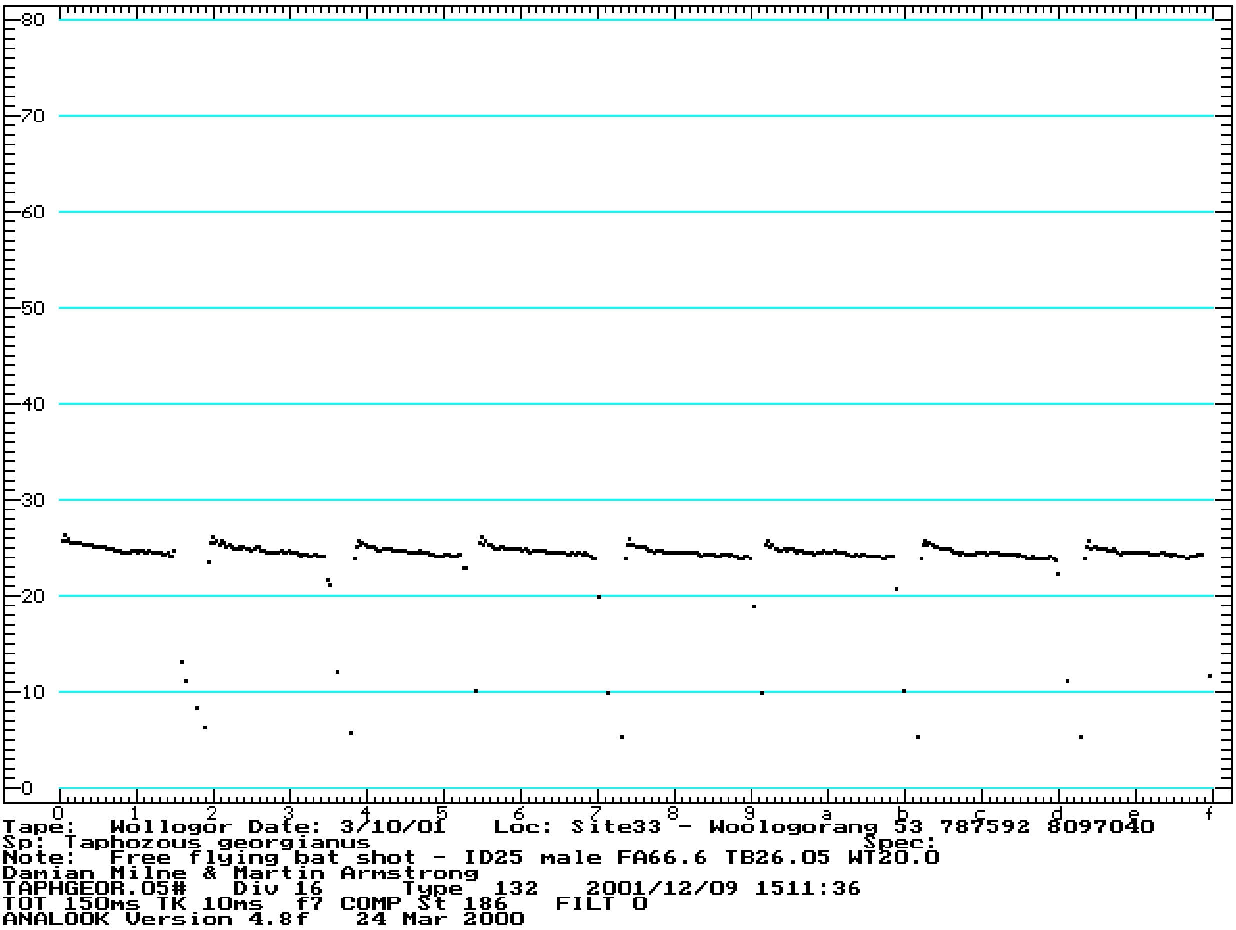
T.kapalgensis produces very short call pulses that are less than 8 ms in duration. This type of call could also be recorded for other “low frequency” bats but only if part of the pulse is recorded as a consequence of these bats flying at the limits of the distance at which the Anabat detector can detect their calls. However, it is unlikely that such pulses would remain consistent for more that three or four pulses as the distance of the bat from the detector will vary as the bat flies. In the key therefore, it is suggested that calls of this nature be attributed to *T.kapalgensis* only if the call sequence has at least 8 pulses.



Taphozous georgianus
Common sheathtail bat

Characteristic frequency	24.1 kHz	(95% Confidence interval 23.3 - 24.9 kHz)
Number of reference calls	6	(Sites 21, 47, 53)
Similar calls	*Taphozous kapalgensis*	

T.georgianus produces a flat type call pulse. It is typically long and straight or slightly curved and almost horizontal. These characteristics readily distinguishes this call from that of any other species. When recording reference calls from hand released individuals of this species, initially the pulse shape is curved, however this does not appear to be the typical pulse shape for this species when in normal "search mode" flight. *Taphozous*, *Chaerephon* and *Saccolaimus* all produce relatively low frequency echolocation calls that travel longer distances than higher frequency calls (Woodside and Taylor, 1985). This allows them to fly faster than most other species by having the capability to detect and avoid obstacles that are far ahead (Churchill, 1998). As a consequence of this signal system, these species tend to forage in open space.

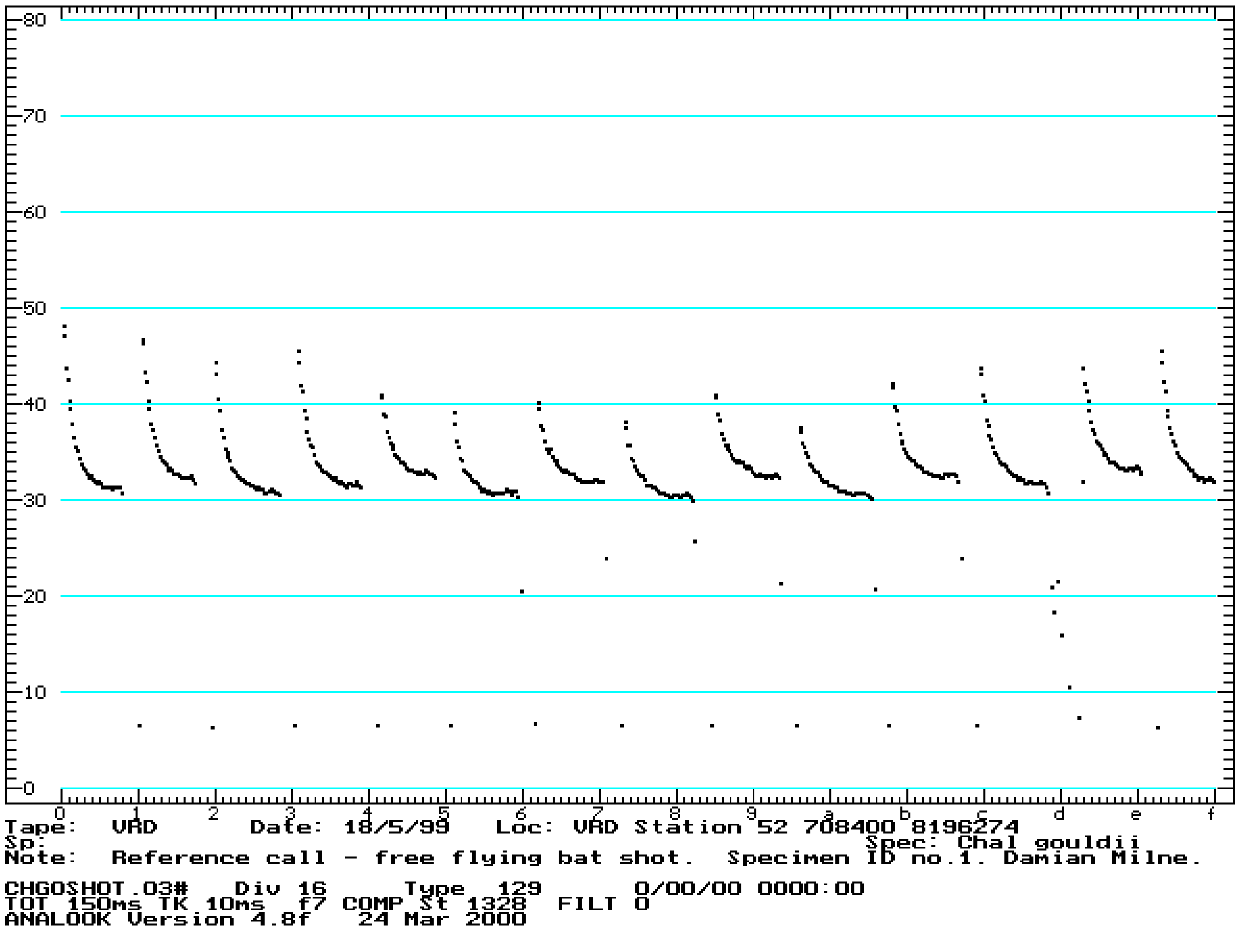


Chalinolobus gouldii
Gould's wattled bat

Characteristic frequency	30.5 kHz	(95% Confidence interval 28.2 - 32.8 kHz)
Number of reference calls	10	(Sites 24, 28, 32, 39, 40, 43)
Similar calls	*Mormopterus beccarii, M. loriae*	

C.gouldii produces a curvilinear pulse shape. In half of the reference call sequences collected, the calls show an alternating call pattern of higher and lower pulses. At the lower end of its characteristic frequency range, this species overlaps with *Mormopterus beccarii*. Above 30.4 kHz it coincides with *Mormopterus loriae* from which it can be distinguished by satisfying the condition set out below.

FK*34.346 - FMAX*4.177 + TC*16.519 - 518.243 > FK*37.662 - FMAX*5.178 + TC*17.791 - 597.869



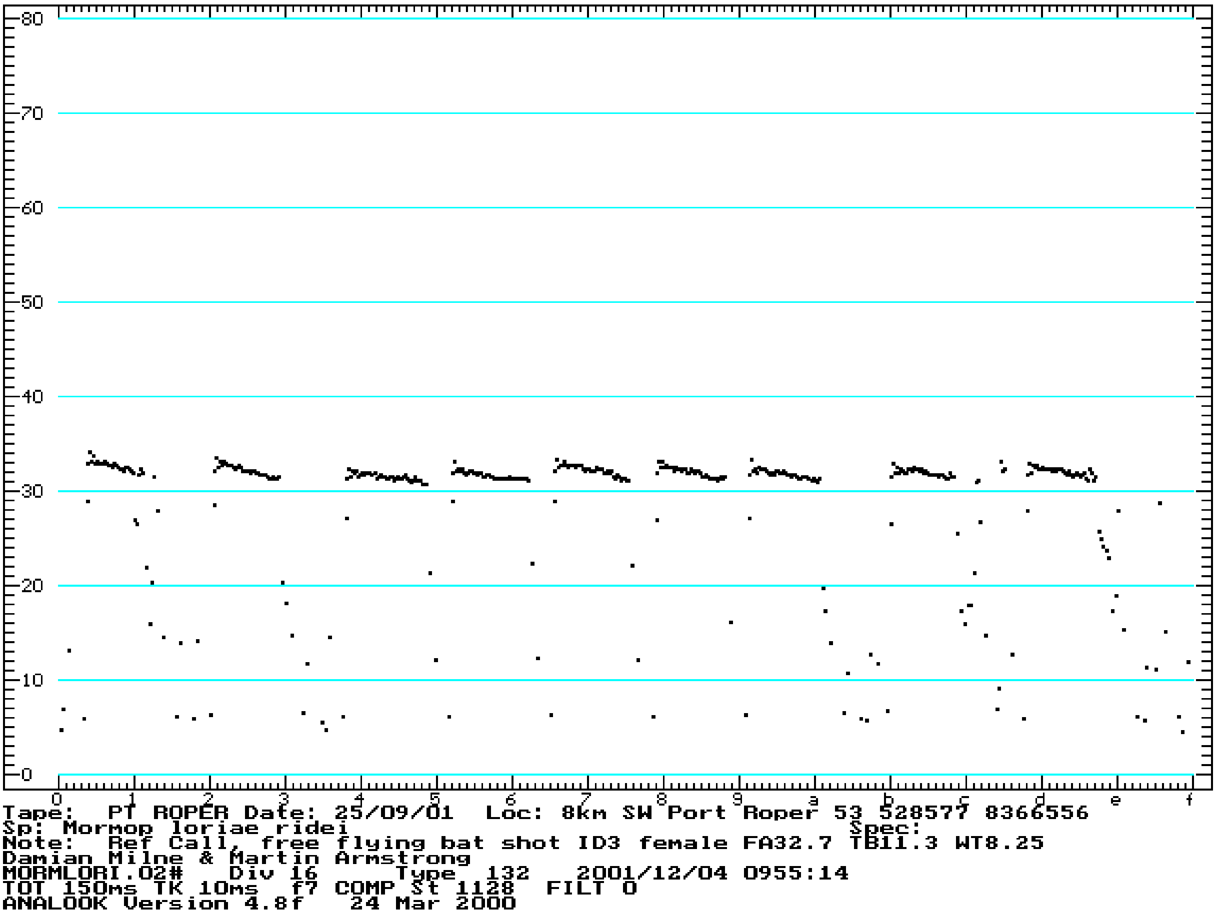
Mormopterus loriae ridei
Little north-eastern freetail bat

Characteristic frequency	31.7 kHz	(95% Confidence interval (29.5) 30.5 - 33.0 kHz)
Number of reference calls	2	(Site 45)
Similar calls	*Chalinolobus gouldii*	

The two reference call sequences collected for this species consist of relatively short, straight call pulses angled slightly above horizontal just above 30 kHz. Virtually its entire frequency range coincides with that of *Chalinolobus gouldii* from which it can be distinguished by having a straighter pulse shape. If there is any doubt over the identification, the discriminant function equation should be used. More reference calls need to be collected to assess the full range of call characteristics, however, calls from the Top End are consistent with those collected from Queensland (provided by Alex Kutt).

It is suspected that the characteristic frequency for this species may drop just below 30 kHz. This view is based on observations of several call sequences where the call pulses at the beginning of the sequence were identical to those described here but subsequent pulses gradually decreased in frequency to around 29.5 kHz by the end of the sequence.

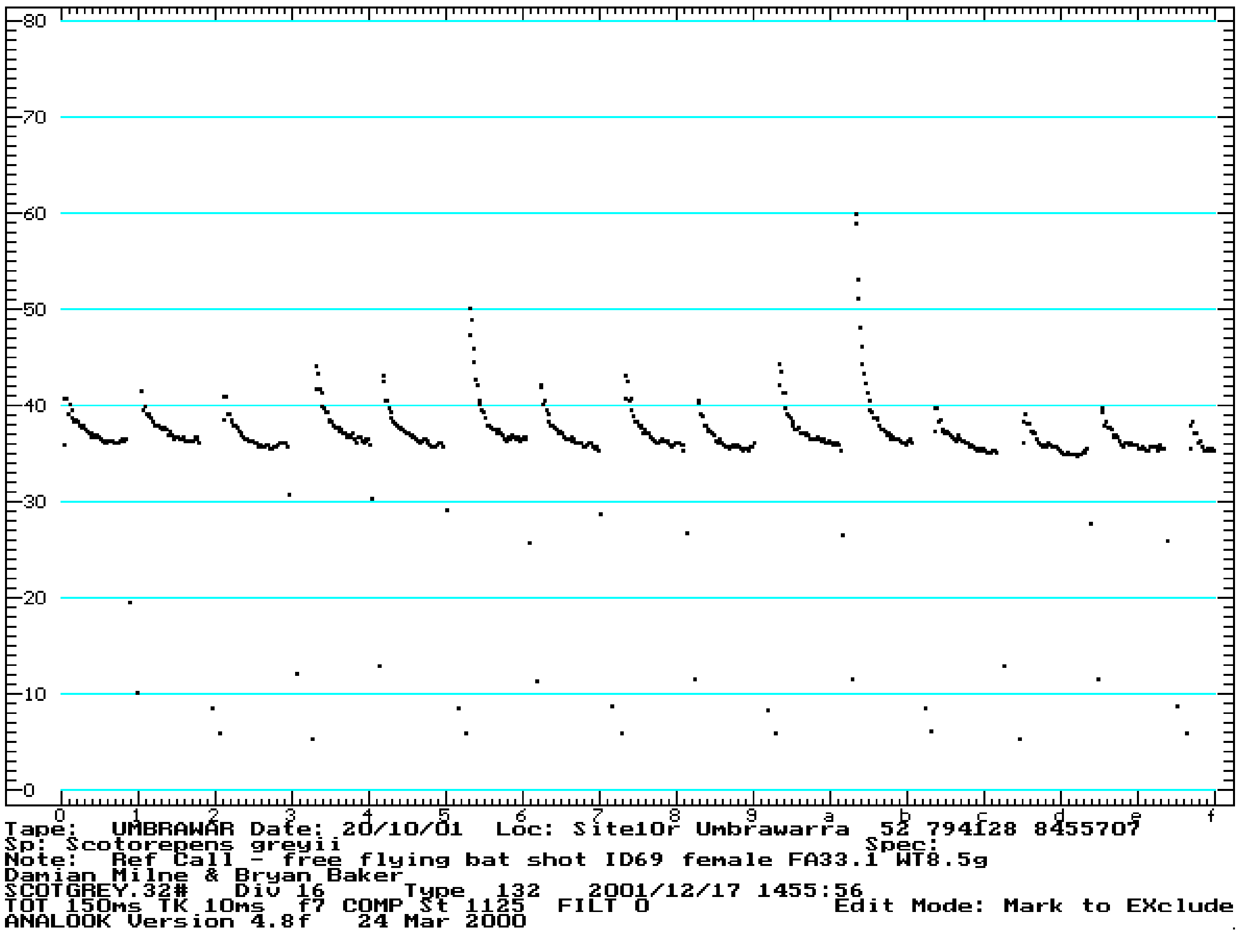
FK*34.346 - FMAX*4.177 + TC*16.519 - 518.243 < FK*37.662 - FMAX*5.178 + TC*17.791 - 597.869



Scotorepens greyii / S.sanborni
Little broad-nosed bat / Northern broad-nosed bat

Characteristic frequency	38.0 kHz	(95% Confidence interval 34.6 - 41.4 kHz)
Number of reference calls	30	(Sites 1,2,5,11,14,16,21,24,32,33,36,40,46,47,50)
Similar calls	*Chalinolobus nigrogriseus*	

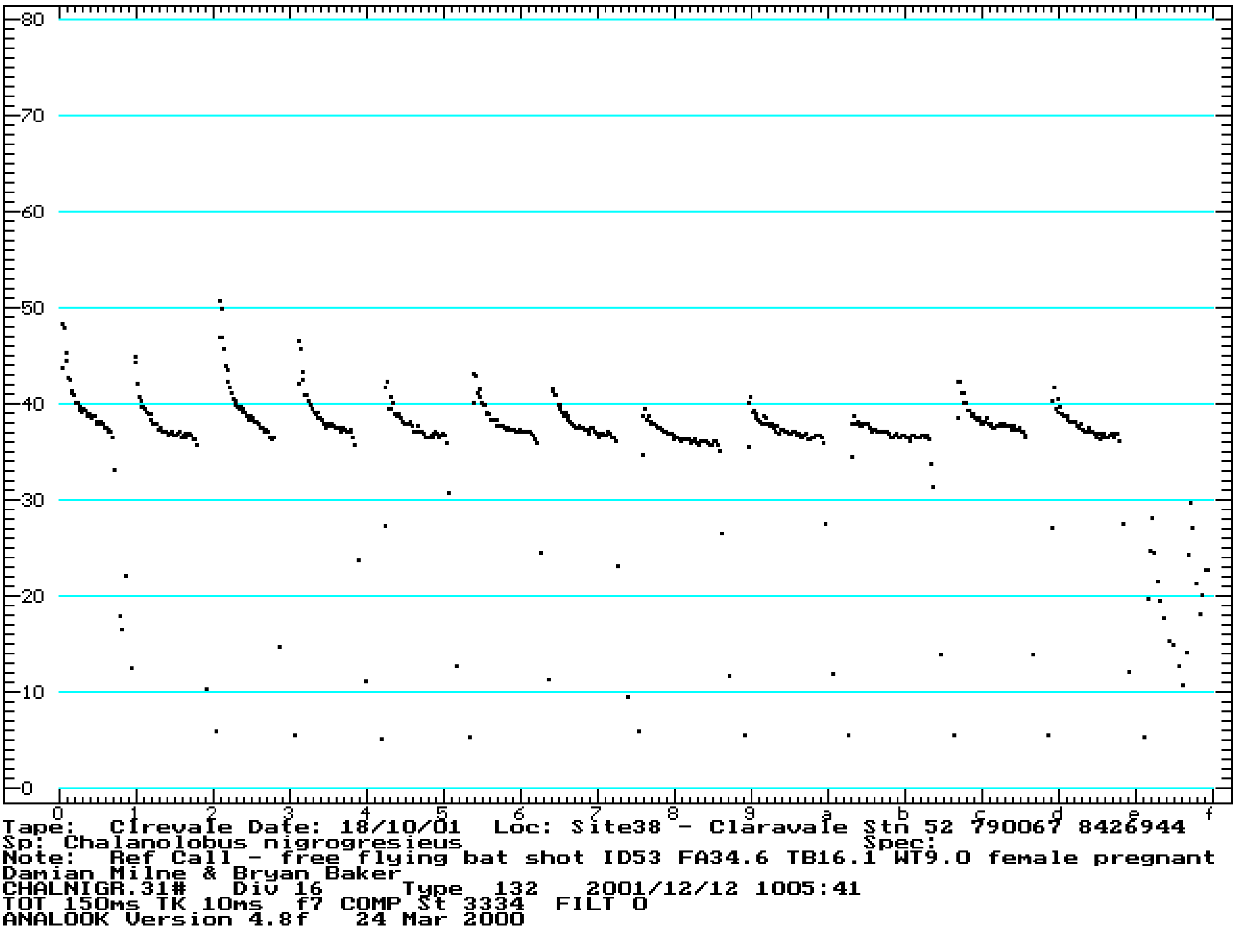
Because *Scotorepens greyii* and *S.sanborni* can only be accurately identified using protein electrophoresis (Churchill,1998) they were unable to be separated when collecting reference calls and are treated here as an amalgam. This probably accounts for the relatively broad characteristic frequency range. The call shape is curvilinear and the initial up sweeping portion of call pulses varies from distinct to non-existent. The call cannot be distinguished from that of *Chalinolobus nigrogriseus* except for a narrow frequency range below 36.1 kHz where the characteristic frequencies of the species do not overlap.



Chalinolobus nigrogriseus
Hoary wattled bat

Characteristic frequency	38.4 kHz	(95% Confidence interval 36.1 - 40.8 kHz)
Number of reference calls	33	(Sites 5, 11, 15, 21, 22, 24, 25, 27, 28, 29, 33, 37, 39, 42, 43, 51, 52)
Similar calls	*Scotorepens greyii / S.sanborni*	

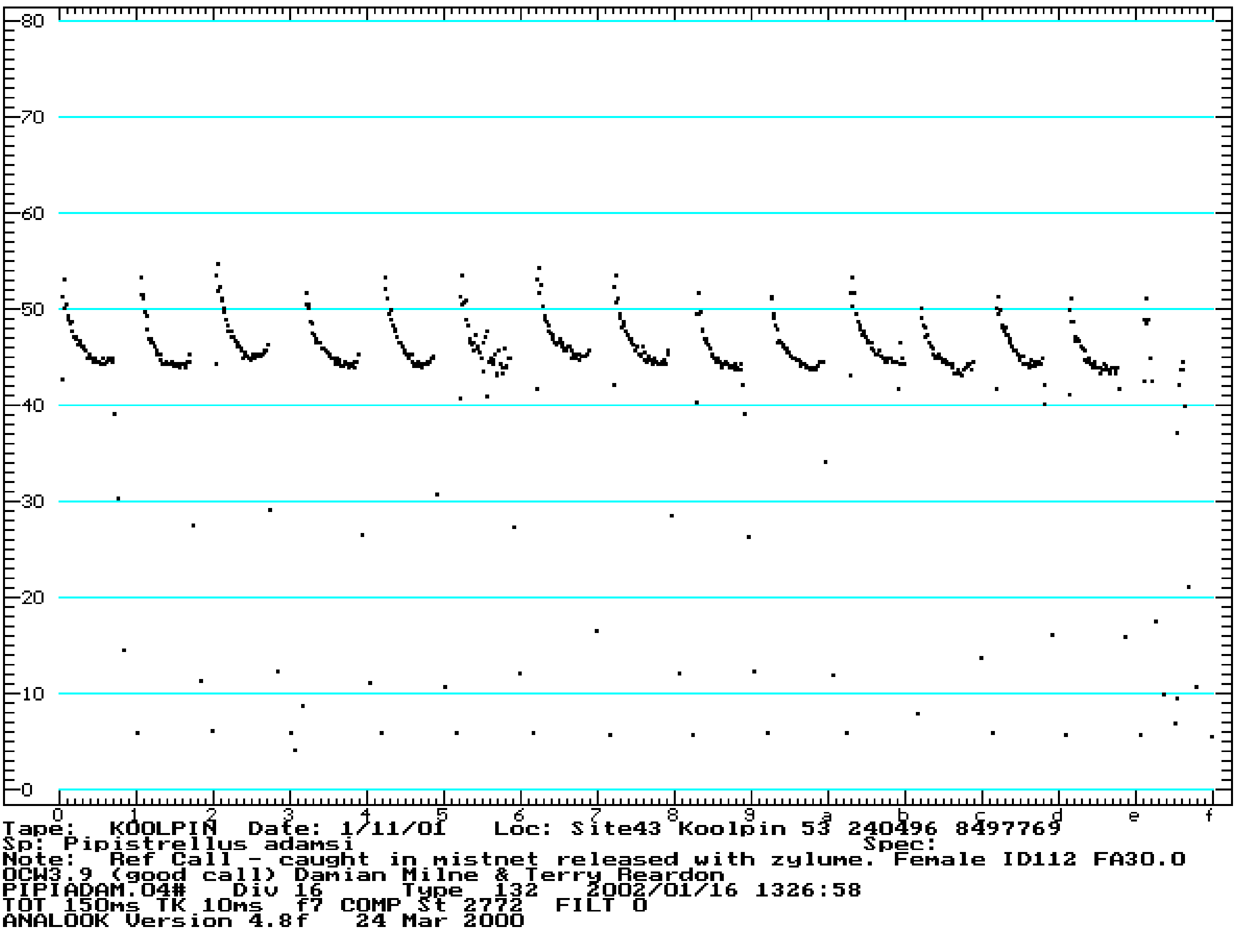
C.nigrogriseus has a call pulse shape that is curvilinear. Its characteristic frequency range falls entirely within the range of *S.greyii* / *S.sanborni*. As the Anabat call sequences for *C.nigrogriseus* are visually identical to *S.greyii* / *S.sanborni,* and discriminant function analysis of call parameters fails to discern between the two, these species cannot be reliably separated from each other.



Pipistrellus adamsi
Cape York pipistrelle

Characteristic frequency	43.9 kHz	(95% Confidence interval 42.5 - 45.3 kHz)
Number of reference calls	4	(Sites 7, 15, 16, 21)
Similar calls	*Pipistrellus westralis*	

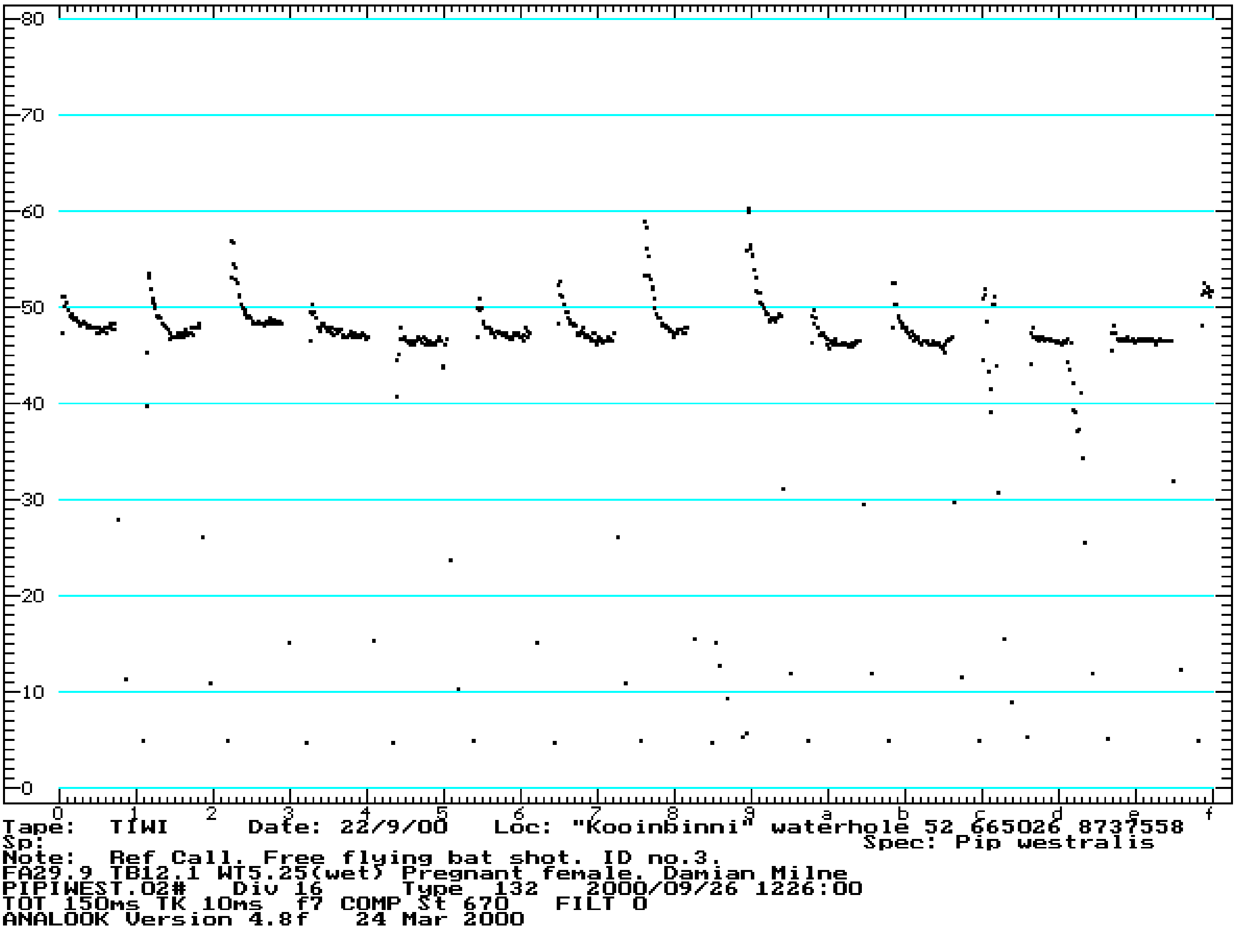
The pulse type of the calls of *P.adamsi* is curvilinear. Identification is based on its characteristic frequency, except above 43.9 kHz where its frequency range overlaps with *P.westralis*. Occasionally, the "feeding buzz" call pulses of *Scotorepens greyii* may creep up into the frequency range of *P.adamsi*, however, these pulses will appear very steep and erratic and can be readily distinguished from the consistent "search phase" call pulses of *P.adamsi*. Only four calls have been collected for this species, more calls are required to account for the full range of call characteristics.



Pipistrellus westralis
Northern pipistrelle

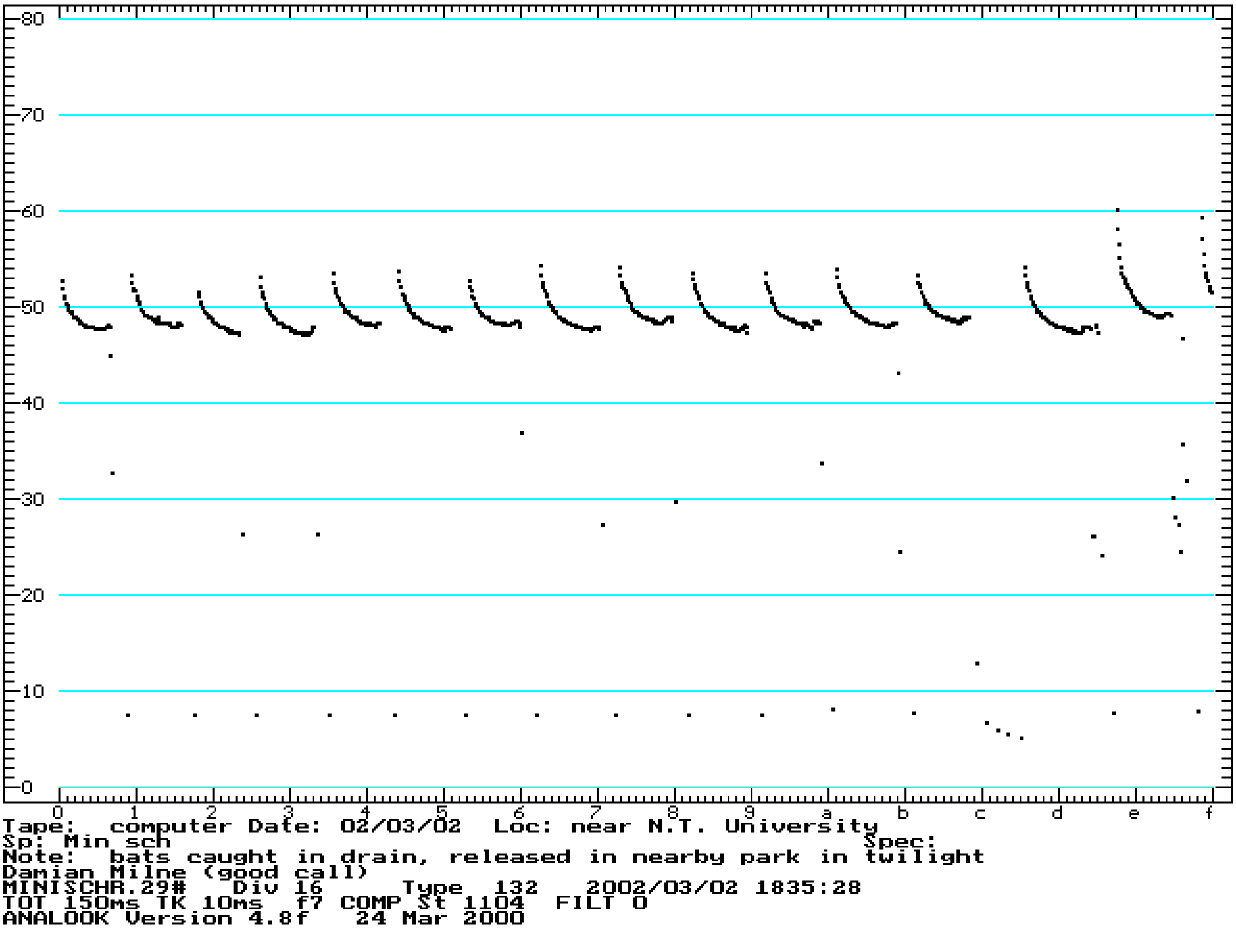
Characteristic frequency	46.6 kHz	(95% Confidence interval 44.0 - 49.3 kHz)
Number of reference calls	4	(Sites 1, 2, 13, 45)
Similar calls	*Pipistrellus adamsi, Miniopterus schreibersii*	

The Anabat call for *P.westralis* cannot be identified to the species level. Below 45.4 kHz it coincides with *P.adamsi* whereas above 46.6 kHz it occurs in the same frequency range as *Miniopterus schreibersii*. Calls detected between these two frequencies cannot be confidently attributed to *P.westralis* given the low number of reference calls collected for the two Pipistrelle species. The pulse type is curvilinear. The initial section is sometimes very short giving the call pulse a flat appearance. As more digitally recorded reference calls are collected for *P.westralis*, it may become possible to confidently identify this species from *P.adamsi* and *M.schreibersii*.



Miniopterus schreibersii orianae Northern bent-wing bat		
Characteristic frequency	48.5 kHz	(95% Confidence interval 46.7 - 50.2 kHz)
Number of reference calls	20	(Sites 8, 17, 21, 28, 29, 44)
Similar calls	*Pipistrellus westralis*	

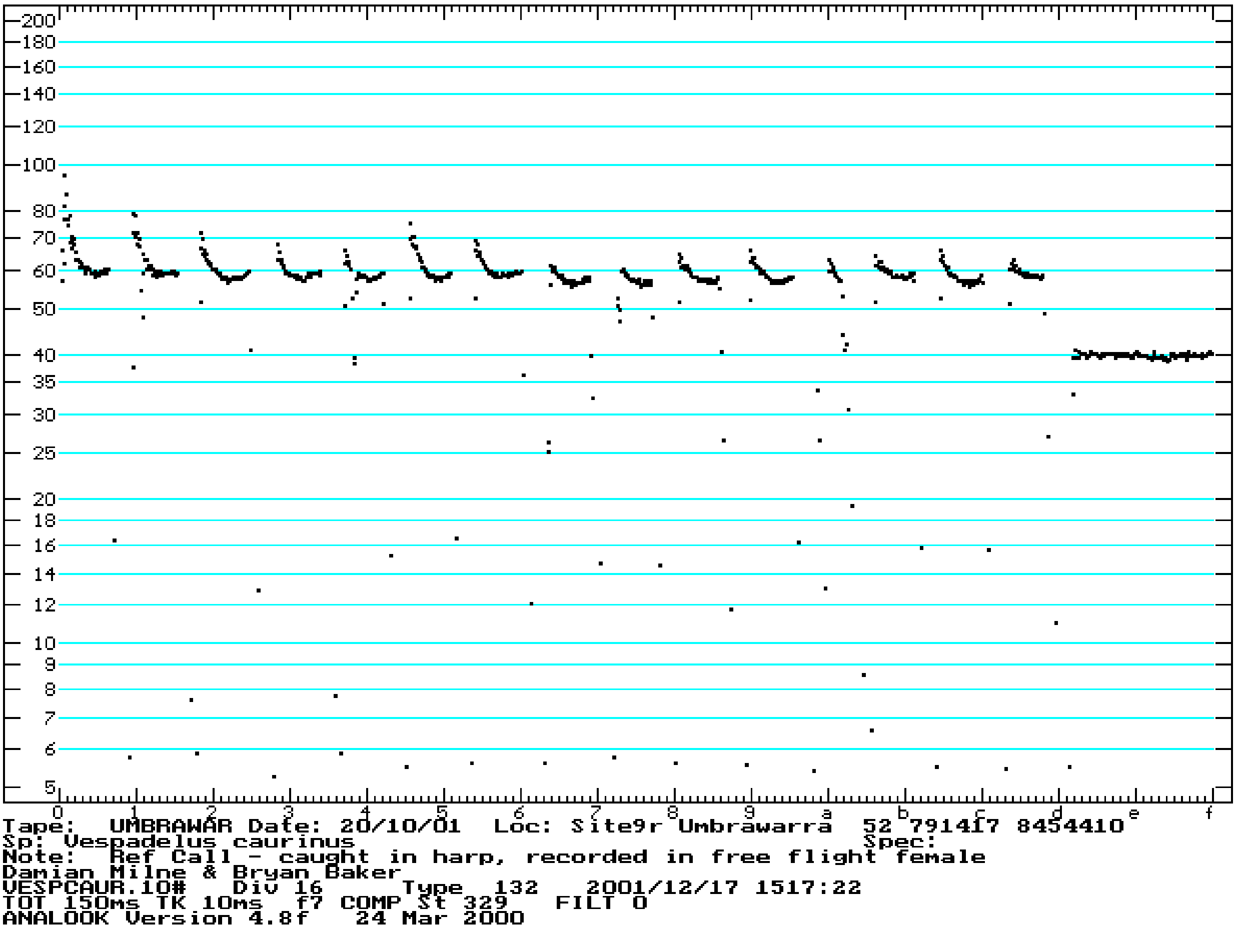
The pulse shape is curvilinear and has a relatively high initial section and usually no or at most a very short tail. Although the frequency range for *M.schreibersii* extends slightly higher than *Pipistrellus westralis*, it cannot be confidently separated given the limited number of reference calls collected for *P.westralis*



Vespadelus caurinus
Northern cave bat

Characteristic frequency	59.6 kHz	(95% Confidence interval 57.5 - 61.7 kHz)
Number of reference calls	29	(Sites 17, 21, 24, 30, 35, 48)

This tiny bat (less than 5 grams in weight) has the highest characteristic frequency of any of the vespertilonid bats in the Top End. It can be readily identified from its curvilinear pulse shape and a characteristic frequency above 57.4 kHz.

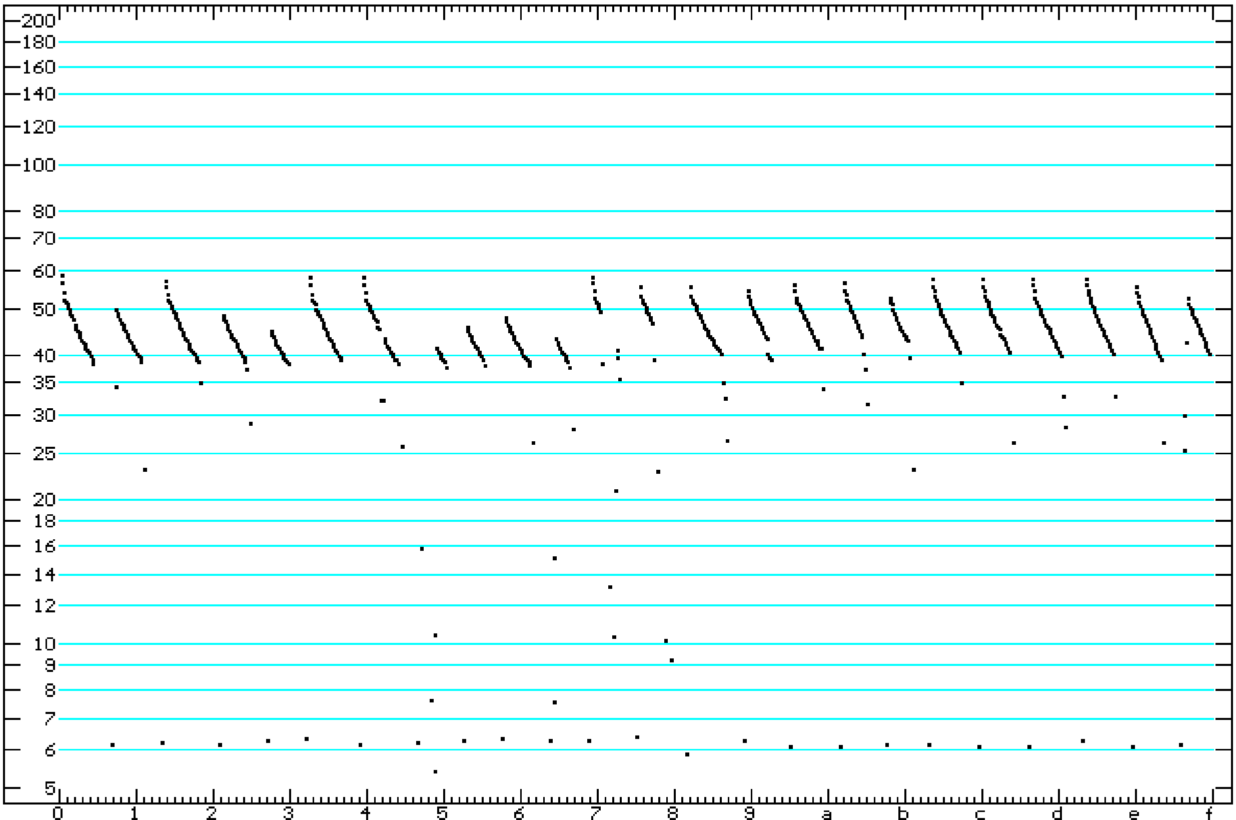


Myotis macropus
Northern myotis

Characteristic frequency	40.1 kHz	(95% Confidence interval 34.7 - 45.5 kHz)
Number of reference calls	6	(Sites 8, 9)
Similar calls	*Nyctophilus arnhemensis, N.bifax, N.geoffroyi*	

Myotis (like *Nyctophilus*) has a linear pulse shape. At frequencies of 40 kHz or lower, *Myotis* can be identified by its characteristic frequency. *Myotis* seems to maintain a relatively constant characteristic frequency when compared with *Nyctophilus*. Above a characteristic frequency of 40.0 kHz where it overlaps with the characteristic frequencies of *Nyctophilus*, *Myotis* can be identified by satisfying the condition:

FC*6.040 + DUR*17.033 + SC*0.034 - 150.114 > FC*7.135 + DUR*19.373 + SC*0.023 - 202.991

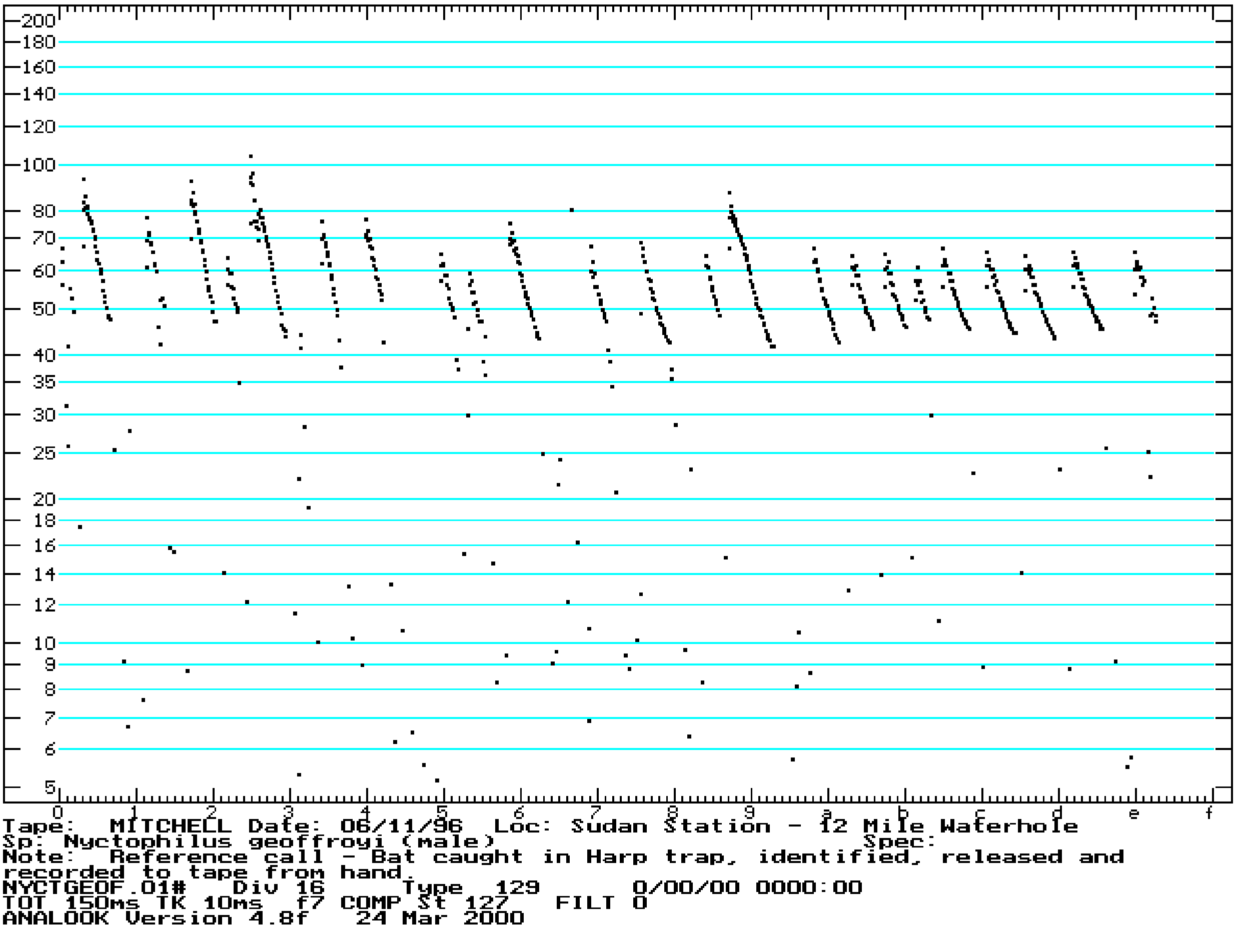


Tape: laptop Date: 29/1/01 Loc: Drainpipes near NTU Darwin
Sp: Myotis moluccarum Spec: My moll
Note: Laptop recorded reference call. Bat marked with cyalume and recorded in free flight (Good call). Damian Milne.
MYOTMOLU.05# Div 16 Type 132 2001/01/28 2032:03
TOT 150ms TK 10ms f7 COMP St 640 FILT 0
ANALOOK Version 4.8f 24 Mar 2000

Nyctophilus geoffroyi
Lesser long-eared bat

Characteristic frequency	45.8 kHz	(95% Confidence interval 40.7 - 50.8 kHz)
Number of reference calls	2	(14, 22)
Similar calls	*Myotis macropus, Nyctophilus arnhemensis, N.bifax, N.walkeri*	

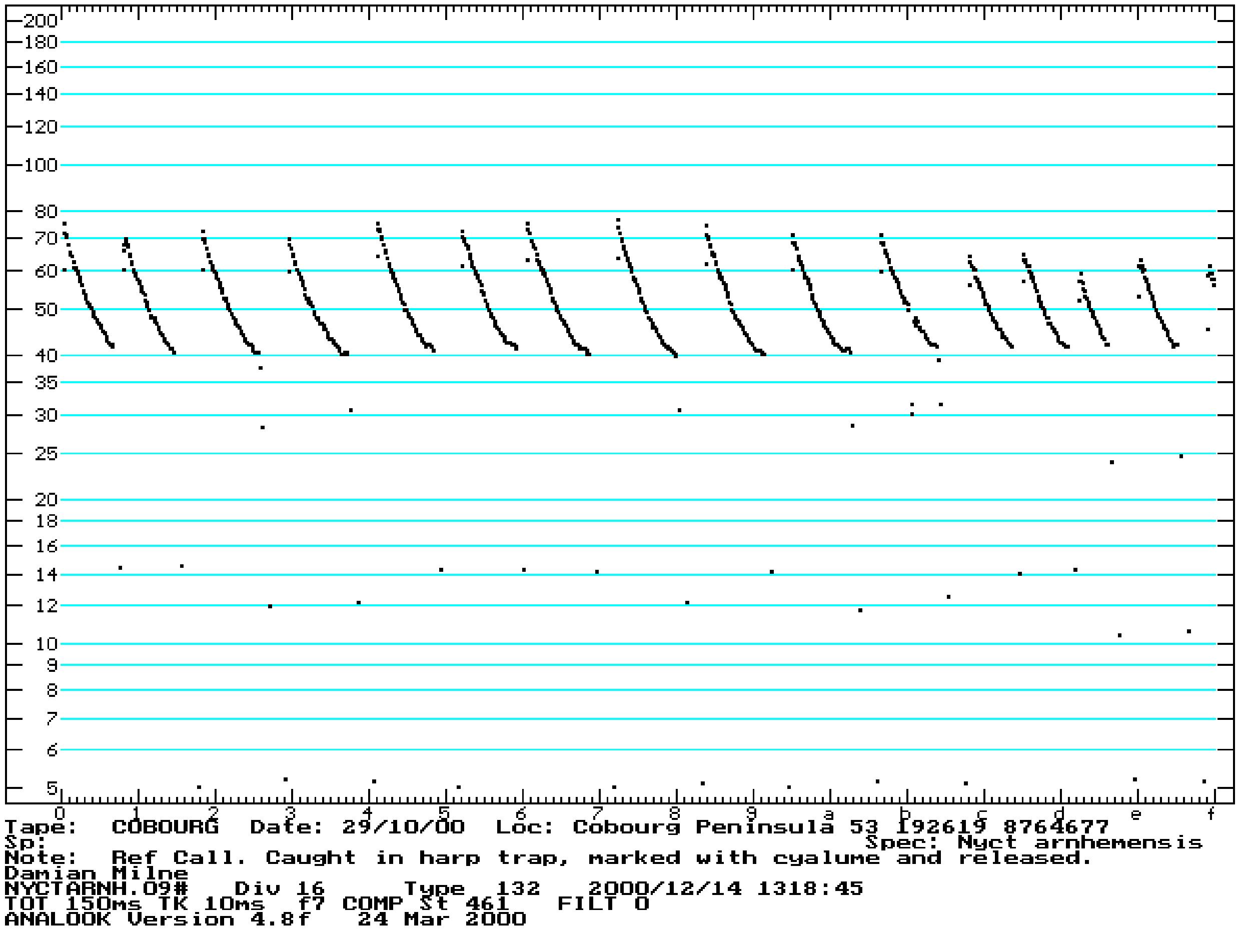
N.geoffroyi has linear call pulses. The characteristic frequency range appears to be much narrower than the other species of *Nyctophilus* species (refer Figure 2). However, as there have only been two reference calls collected for this species, it is doubtful the entire range of characteristic frequencies has been determined. Herr *et al*. (1997) report a characteristic frequency range (Fmin - Fmax) for *N.geoffroyi* from south-eastern Australia that extends much higher (39.5 kHz - 63.7 kHz, n = 11) than recorded for *N.geoffroyi* in the Top End. Therefore, based on the information available, *N.geoffroyi* cannot be confidently identified from *N.arnhemensis* or *N.bifax*.



Nyctophilus arnhemensis
Arnhem long-eared bat

Characteristic frequency	47.1 kHz	(95% Confidence interval 40.1 - 54.1 kHz)
Number of reference calls	8	(Sites 1, 4, 5, 10, 12, 29, 33, 41)
Similar calls	*Myotis macropus, Nyctophilus bifax, N.geoffroyi, N.walkeri*	

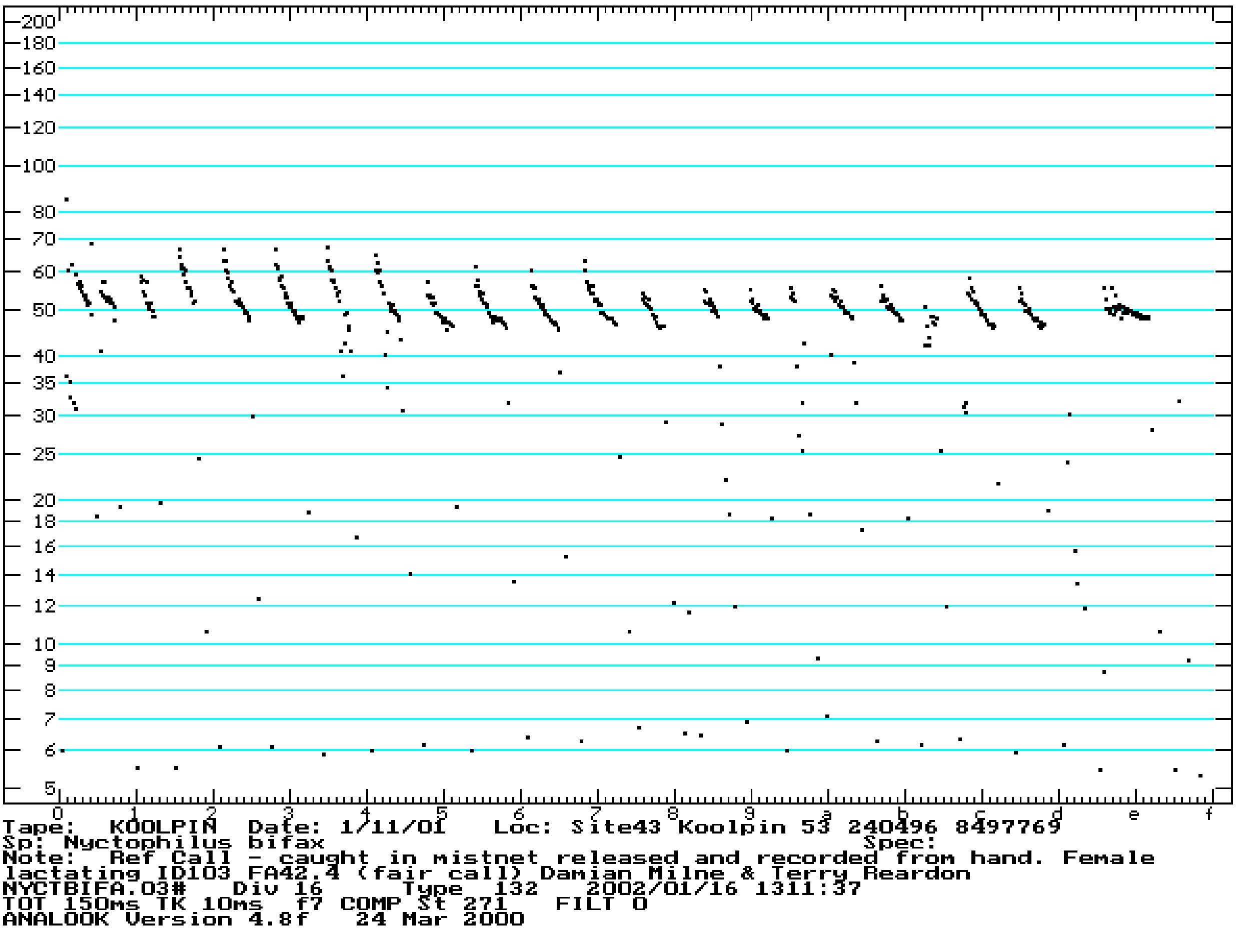
The pulse shape for *N.arnhemensis* is linear and, as with the other species of *Nyctophilus,* the frequency and length of each call pulse, within a sequence, can vary considerably. Being so variable and within the same frequency range of the calls of other *Nyctophilus*, it is impossible to identify *N.arnhemensis* to species level based on its Anabat call.



Nyctophilus bifax
Northern long-eared bat

Characteristic frequency	49.4 kHz	(95% Confidence interval 44.7 - 54.2 kHz)
Number of reference calls	3	(Sites 21,34)
Similar calls	*Myotis macropus, Nyctophilus arnhemensis, N.geoffroyi, N.walkeri*	

The same comments apply as presented for the previous two species of *Nyctophilus*. Based on three reference calls, it is unlikely that the entire range of call characteristics for this species has been sampled. The linear pulse shape of the *Nyctophilus* echolocation call allows these species to detect details of texture in their immediate environment such as a camouflaged moth perched on a leaf. It does not allow them to detect the speed and direction of flying insects. This echolocation technique is ideally suited for the gleaning mode of foraging used by long-eared bats (Woodside and Taylor, 1985).

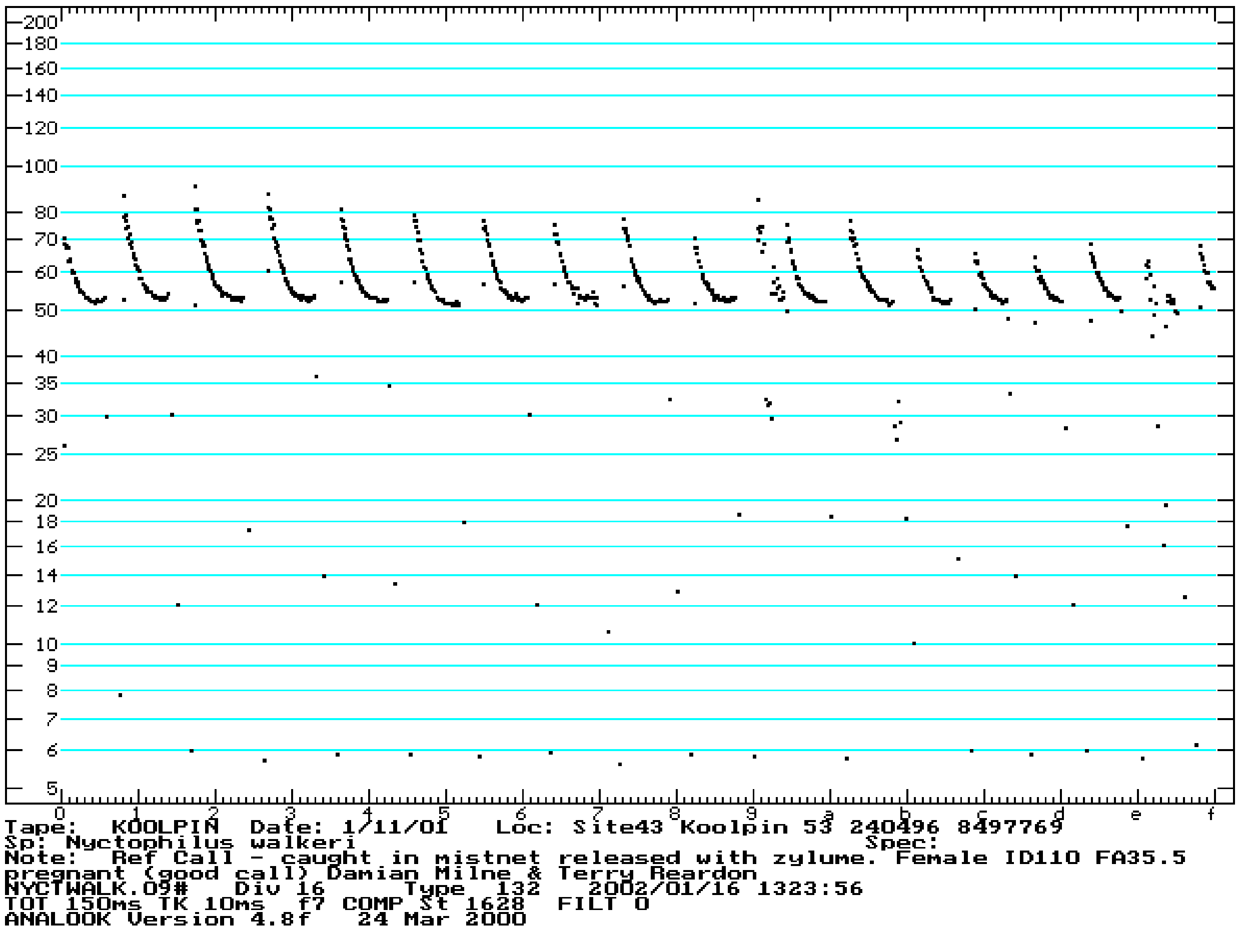


Nyctophilus walkeri
Pygmy long-eared bat

Characteristic frequency	54.7 kHz	(95% Confidence interval 50.2 - 59.1 kHz)
Number of reference calls	7	(Sites 21, 26, 29, 33, 41)
Similar calls	*Nyctophilus arnhemensis, N.bifax, N.geoffroyi*	

The call pulses for *N.walkeri* are linear, however when a call sequence for this species is viewed on a logarithmic scale with Analook, there is normally some indication of a "hook" at the bottom of each pulse. The hook varies from a small kink, to a complete 90° bend. If there is any doubt, the call sequence can be identified by satisfying the condition set out below.

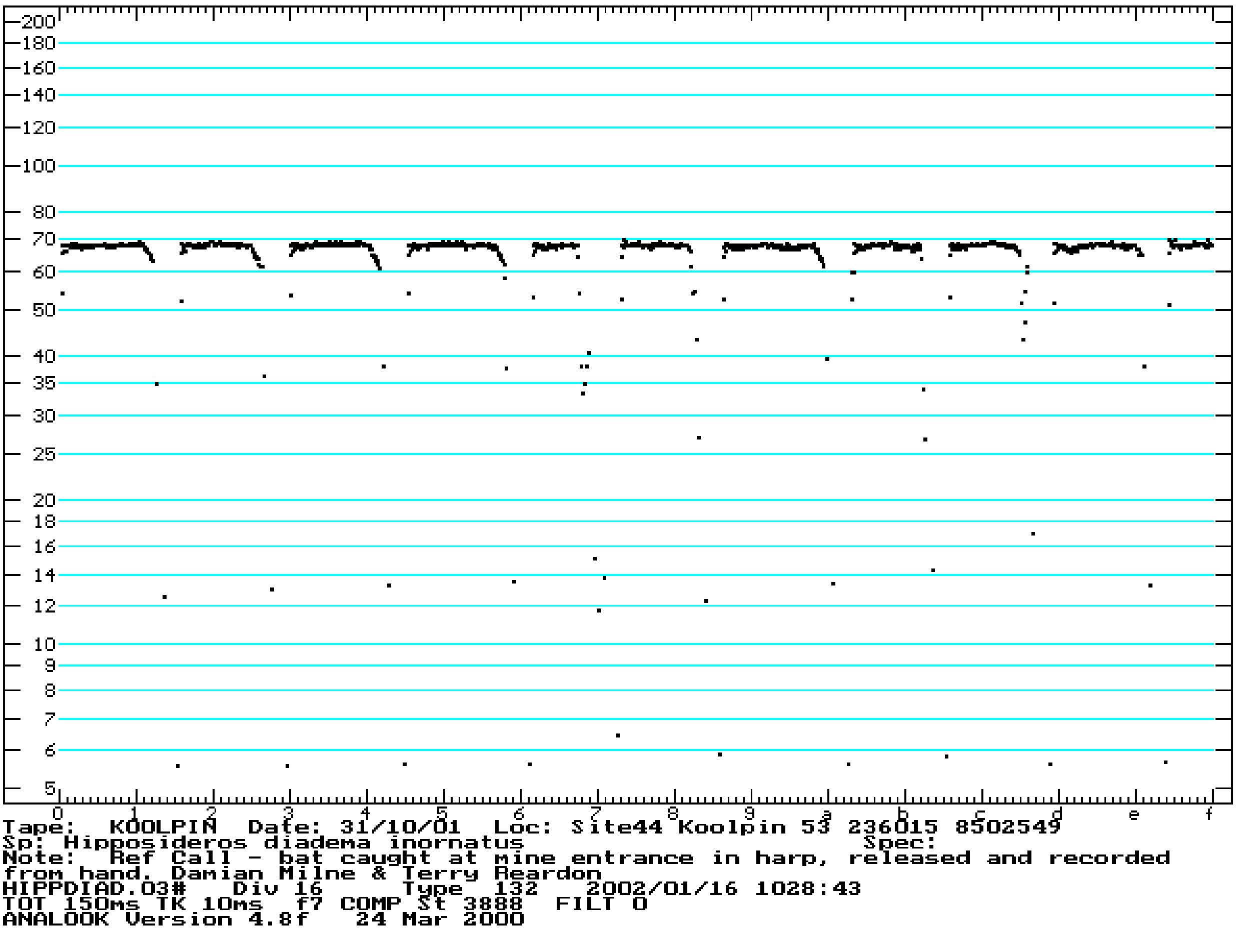
FC*8.311 - SC*0.028 + DUR*15.670 - 219.761 < FC*9.701 - SC*0.062 + DUR*17.632 - 292.275



Hipposideros diadema inornatus
Arnhem leaf-nosed bat

Characteristic frequency	69.1 kHz	(95% Confidence interval 67.1 - 71.2 kHz)
Number of reference calls	5	(Site 20)

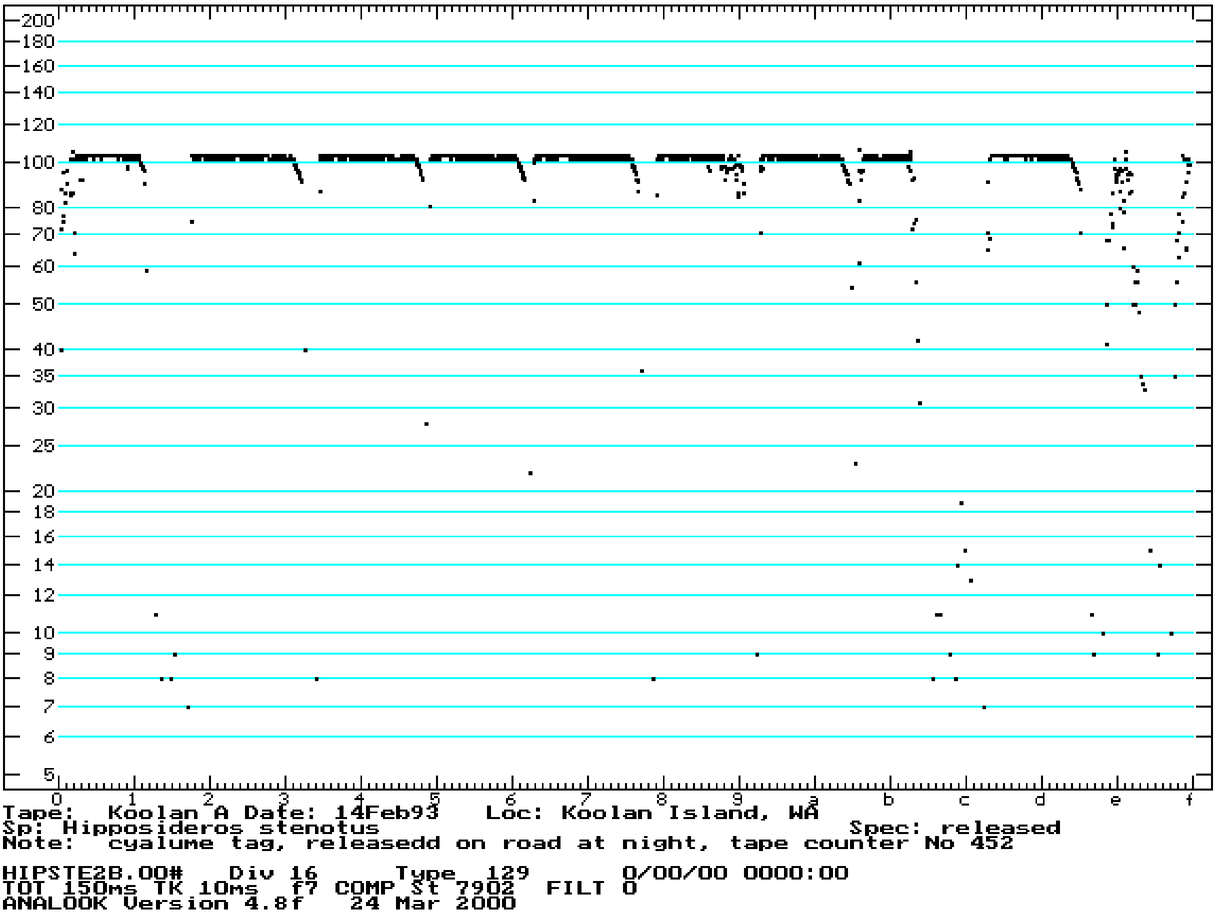
The largest of the four hipposiderid species that occur in the Top End, *H.diadema* has a much lower characteristic frequency than the other three species of leaf-nosed bats. The distance over which calls of this species can be detected by an Anabat detector is also greater than for other hipposiderid species, estimated at around 10 metres (with the detector sensitivity set between 7 and 8). Therefore, this species is likely to be detected using automatic Anabat detection techniques if there are individuals in the area.



Hipposideros stenotis
Northern leaf-nosed bat

Characteristic frequency	102-106 kHz
Number of reference calls	0

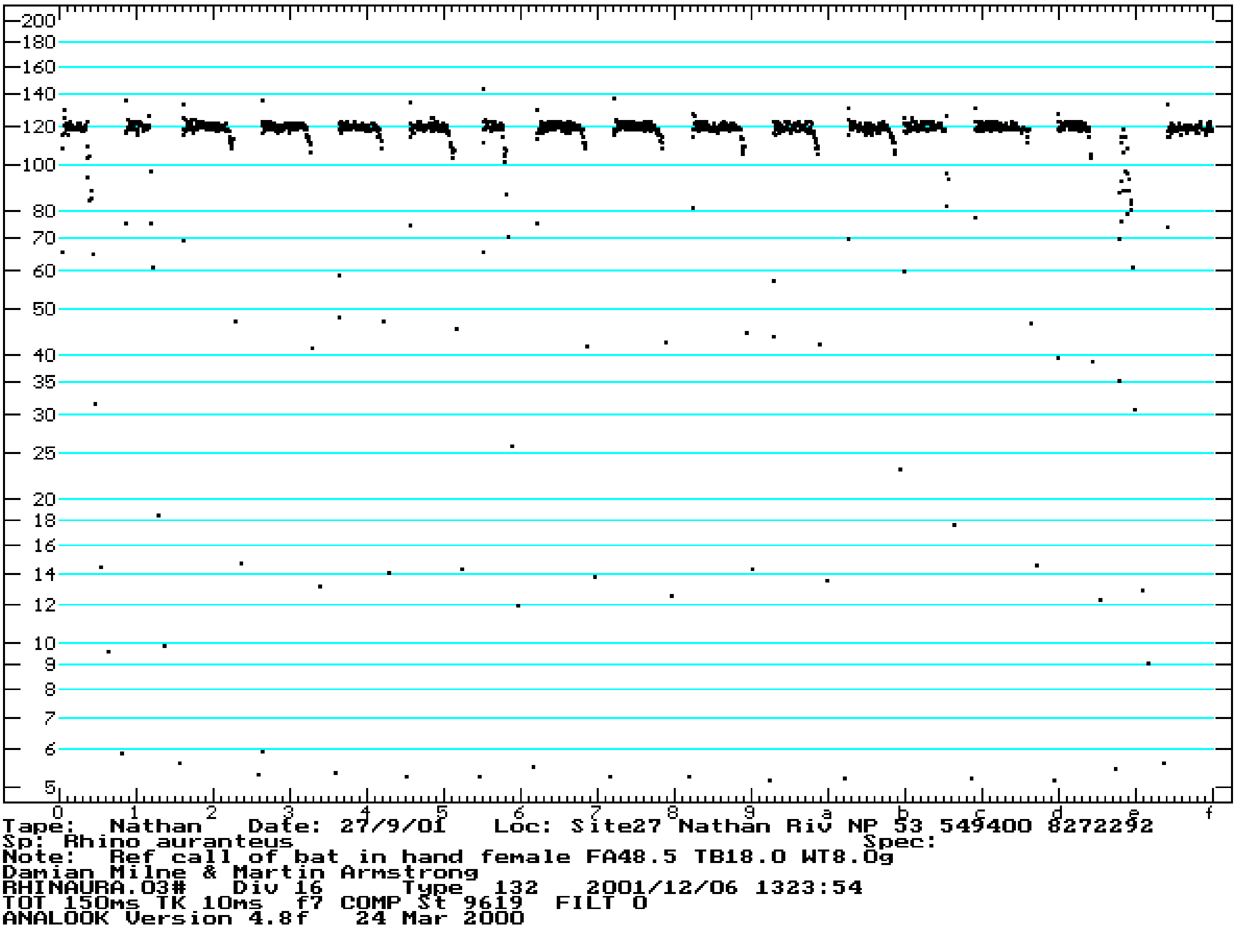
No Anabat recorded reference calls have been collected for this species in the Top End. Coles (1993) recorded *H.stenotis* at 106 kHz from the Top End using a U25 bat detector (Ultra Sound Advice, U.K.), whereas McKenzie *et al*. (1996) recorded this species at 102.5 kHz from northern W.A. using a D140 ultrasound detector (Petterson Elektronik, Sweden). Because these frequencies are very similar to those of *Rhinonicteris aurantius*, more reference calls need to be collected to confirm the characteristic frequency for this species in the Top End. The vertical resolution of Analook must be toggled to the logarithmic scale in order to see this call. The reference call shown was provided by Norm McKenzie.



Rhinonicteris aurantius
Orange leaf-nosed bat

Characteristic frequency	116 kHz	(95% Confidence interval 107 - 125 kHz)
Number of reference calls	6	(Sites 18, 25, 47, 52)

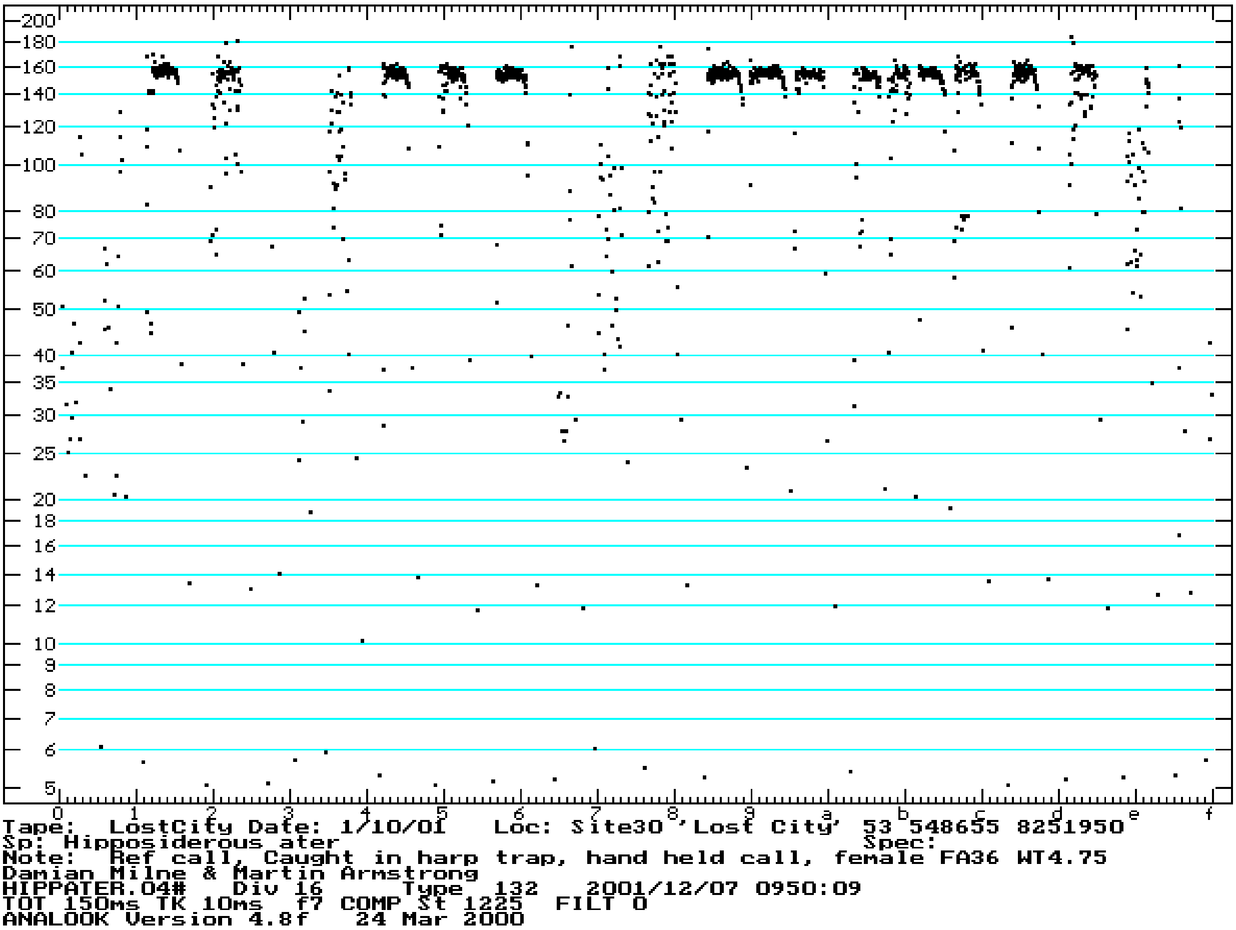
R.aurantius produces a constant frequency call type, with a slightly higher characteristic frequency than *H.stenotis*. Its characteristic frequency covers a relatively broad range. The detection range of calls of this species (as with the other small Hipposiderid bats) is very short (less than one metre) and free flying bats are only very occasionally recorded with the Anabat detector. When attempting to detect these species, the sensitivity of the Anabat detector should be set to at least 9. Even then, only one or two call pulses may result. The vertical resolution of Analook must be toggled to the logarithmic scale in order to see this call.



Hipposideros ater
Dusky leaf-nosed bat

Characteristic frequency	157 kHz	(95% Confidence interval 152 - 162 kHz)
Number of reference calls	4	(Sites 24, 27, 31, 48)

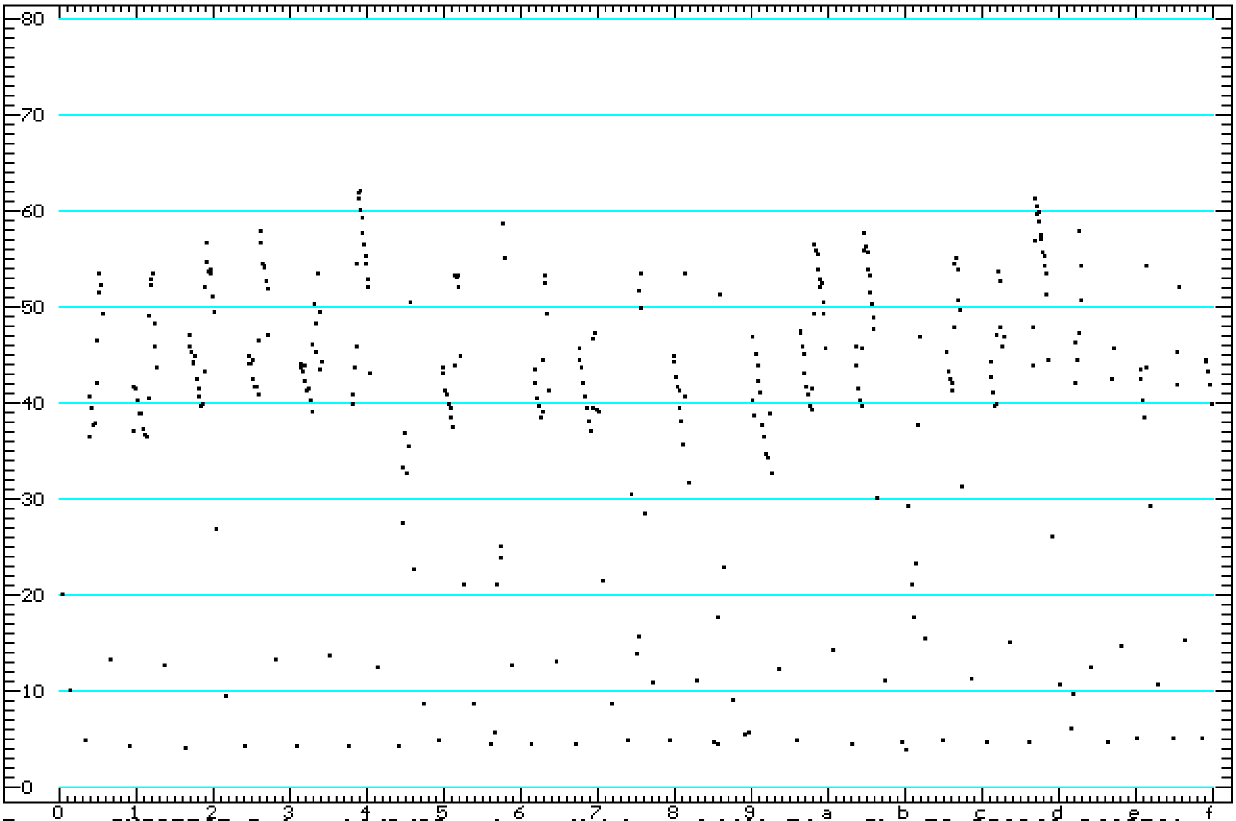
H.ater has a constant frequency search phase call type, much higher than any other bat. The vertical resolution of Analook must be toggled to the logarithmic scale in order to see this call. The constant frequency echolocation technique employed by the leaf-nosed bats allows them to detect the speed and direction of very small flying insects with great accuracy (Woodside and Taylor, 1985).



Macroderma gigas
Ghost bat

The calls of the ghost bat are so faint and poorly defined, the species would never be positively identified using Anabat during a general fauna survey. When in flight, this species regularly emits an audible “trill” from which it can be identified by a trained observer.

Identification of ultrasonic calls may be possible using better quality reference calls that are digitally recorded. However, this possibility has not been examined. The call sequence shown is the best quality call recorded (via tape recorder) from dozens of Anabat recordings of ghost bats flying near the exit of a mineshaft.




```
Tape:   GHOSTBAT Date: 14/9/99   Loc: Kohinor Addit Pine Ck. 52 806946 8468761
Sp:                                                  Spec: Macroderma gigas
Note:   Bats recorded in free flight circling above mine on exit.
Reference call. Damian Milne.
MACRGIGA.08#   Div 16      Type  129       0/00/00 0000:00
TOT 150ms TK 10ms  f7 COMP St 634   FILT 0
ANALOOK Version 4.8f   24 Mar 2000
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OTHER CALLS

The known geographic distributions of three other micro-bats come close to the Top End. The possibility of recording these species needs to be considered when examining the results of Anabat surveys close to the boundary of the area covered by this key.

- *Tadarida australis* occurs just to the south of the Top End. It has the lowest known characteristic frequency of any Australian bat species of around 10 - 13 kHz (Reinhold *et al*., 2001). Its call is therefore clearly audible to the human ear.

- *Scotorepens balstoni* also occurs just to the south of the Top End and has a characteristic frequency of 31-35 kHz (Reinhold *et al*., 2001).

- *Vespadelus finlaysoni* has a known distribution that extends into the south-east corner of the Top End (Churchill, 1998) and has a characteristic frequency of around 53 kHz (McKenzie and Muir, 2000).

Limitations

The call database on which this key is based has several limitations as detailed below. First, no reference calls were collected for *Saccolaimus saccolaimus* and therefore this species is not covered in this publication. Given that this species is the only bat recognised in Australia as critically endangered (Environment Australia, 2002) it may be a significant omission. Second, no reference calls were collected for either *Mormopterus beccarii* (call descriptions provided here are based on reference calls from Queensland) or *Hipposideros stenotis* (figures presented here were derived from frequencies reported in the scientific literature). Further, only two reference calls were collected from the region for *Taphozous kapalgensis, Mormopterus loriae* and *Nyctophilus geoffroyi*. Therefore, it is doubtful that the full variation of call parameters for each of these species is presented here. Third, although reference calls have been collected from across the Top End, reference calls for each species have not. Therefore, intraspecific geographic variation in echolocation calls, if it occurs, has not been fully described for all species.

Several factors also need to be considered when interpreting the results obtained from Anabat. The distance an ultrasonic call will travel varies considerable depending on the type of call produced by different species of bats (Woodside and Taylor, 1985). Therefore, some species will be detected by an Anabat unit more frequently than others. Furthermore, small Hipposiderid bats (e.g. *Hipposideros ater*) are rarely recorded by Anabat detectors but are more readily detected using harp traps. The environment in which bats are recorded can also impact on the results of Anabat surveys. Bats will be detected more readily in open areas that are free of obstructions as opposed to densely vegetated closed habitats. Tall forest environments may result in some species of bats flying higher and further away from an Anabat detector, when compared with a low woodland environment. This will also reduce the likelihood of calls being recorded (Law et al., 1999; Duffy et al., 2000). For these reasons, Anabat recordings cannot be used to directly measure bat abundances, nor can it be assumed that all echolocating bats will be detected using an Anabat detector during a survey.

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