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ORIGINAL PAPER

Psychoacoustic sampling as a reliable, non-invasive method to monitor orthopteran species diversity in tropical forests

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Abstract We evaluated trained listener—based acoustic sampling as a reliable and non-invasive method for rapid assessment of ensiferan species diversity in tropical evergreen forests. This was done by evaluating the reliability of identification of species and numbers of calling individuals using psychoacoustic experiments in the laboratory and by comparing psychoacoustic sampling in the field with ambient noise recordings made at the same time. The reliability of correct species identification by the trained listener was 100 % for 16 out of 20 species tested in the laboratory. The reliability of identifying the numbers of individuals correctly was 100% for 13 out of 20 species. The human listener performed slightly better than the instrument in detecting low frequency and broadband calls in the field, whereas the recorder detected high frequency calls with greater probability. To address the problem of pseudoreplication during spot sampling in the field, we monitored the movement of calling individuals using focal animal sampling. The average distance moved by calling individuals for 17 out of 20 species was less than 1.5 m in half an hour. We suggest that trained listener—based sampling is preferable for crickets and low frequency katydids, whereas broadband recorders are preferable for katydid species with high frequency calls for accurate estimation of ensiferan species richness and relative abundance in an area.

Keywords Acoustic monitoring · Ambient noise recordings · Crickets · Focal animal sampling · Hearing threshold · India · Katydids · Species diversity · Tropical forests

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Introduction

Both terrestrial and aquatic animals use acoustic signals for long distance communication. Birds, frogs, bats, cicadas, crickets, katydids, whales and elephants are some groups which use sound in the context of mate attraction, territorial defence and aggression behaviour (Alexander 1967). Among insects, mainly Orthoptera (crickets, katydids and grasshoppers) and Homoptera (cicadas) have the ability for sound production and reception in the context of long—distance communication. Crickets (Family: Grylloidea) have a simple song structure consisting of pulses with narrow—band frequencies in the audible range (Riede 1998).

Adult male crickets and katydids have specialised sound producing structures called the stridulatory apparatus on the forewings. Sound is produced by rubbing a row of teeth on the underside of one wing (the file) against a hardened edge called the plectrum on the other wing. This periodic rubbing of file over plectrum excites other parts of the forewing such as the harp in crickets and mirror in katydids that resonates at a particular frequency, determining the carrier frequency of the call (Bennet-Clark 1989). Songs are produced for conspecific mate attraction.

The highly stereotyped species—specific calling songs of ensiferan insects provide a very reliable clue for species identification and are used by taxonomists to distinguish morphologically similar species (Otte 1994; Riede et al. 2006; Walker 1964). Species-specific songs of Orthoptera can be used for acoustic monitoring of single species as well as communities, especially in tropical forests (Riede 1993, 1998). Species—specific song patterns can also be used to estimate and monitor population sizes (Forrest 1988; Fischer et al. 1997). The use of acoustic sampling to estimate species richness and abundance is widespread in studies on bird (Haselmayer and Quinn 2000), bat (O'Farrell and Gannon 1999 and references therein) and frog (Bridges and Dorcas 2000 and references therein) communities.

In tropical forests, large numbers of insect species are still unknown to science (Stork 1988). This immense tropical biodiversity is under threat because of habitat loss and destruction due to anthropogenic activities. As a result, a lot of these species may become extinct even before being described (Wilson 1989). Therefore, inventorying of biodiversity and identification of species—rich areas (hotspots) are important baseline data for conservation of tropical fauna. However, such field surveys are time consuming, costly and logistically difficult. Also, the sampling techniques employed to census insects such as pitfall and bait trapping and insecticidal fogging are invasive methods. Lack of taxonomic expertise for the identification of collected samples also hampers species inventories (Gaston and May 1992).

Acoustic sampling of ensiferan species could thus provide a rapid, reliable and non-invasive method to estimate and monitor orthopteran species diversity in tropical forests. The Ensifera (consisting of crickets, katydids and wetas) are ideal systems for long term acoustic monitoring of tropical forests because (1) they occupy most of the acoustic space, having both low frequency narrow—band (mainly gryllids or true crickets) and high frequency broad - band calls (katydids or bushcrickets), (2) the number of species calling at the same time is quite high (Riede 1993) and (3) some species of Orthoptera are sensitive indicators of habitat quality and change (Fischer et al. 1997; Nischk and Riede 2001).

Acoustic monitoring is typically carried out in two ways. The first consists of manual call surveys using line transects or point counts where trained listeners record calling individuals within defined areas in limited time periods. This is mainly used for acoustic monitoring of birds (Bibby et al. 1992) and frogs (Heyer et al. 1994). The second method uses automated systems that record ambient noise in the field. The data are then digitised and

analysed (Bridges and Dorcas 2000; O'Farrell and Gannon 1999; Riede 1993, 1997). The recordings can be used to monitor any sound producing groups such as birds, bats, frogs and Orthoptera.

The conventional method of trained listener - based call surveys is limited by lack of trained listeners and inter-listener variability in skill, age and hearing perception, that may cause wrong identification or failure to detect certain species, resulting in inaccurate species richness estimates. Acoustic recordings have been suggested to have advantages over the conventional call survey method in terms of (1) the possibility of extended sampling efforts which decreases the probability of missing species, (2) as a solution to the problem of listener variability, (3) permanence of sampling records that can be analysed later by other investigators and (4) less disturbance to calling animals. A number of studies have compared the two methods and have suggested advantages of using acoustic recordings over call surveys, point counts or capture / mist netting in birds, frogs and bats (Bridges and Dorcas 2000; O'Farrell and Gannon 1999). To the best of our knowledge, no such comparative work on the sampling methodology has been done so far on the Orthoptera.

Acoustic recordings no doubt have the above-mentioned advantages over the conventional method. However, we suggest that manual call surveys may be more feasible for monitoring and inventorying biodiversity of ensiferan species in tropical forests especially in developing countries in terms of logistics and cost-effectiveness. The cost of training individuals in fieldwork will still be less in developing countries than expensive audio equipment such as microphones, recorders and computers, which are needed for acoustic recordings. Audio equipment is also sensitive to the highly humid conditions of tropical rainforests. Also, in the species—rich environment of tropical forests a number of ensiferan species call together, resulting in high levels of background noise. Under these conditions, the calls of different species and individuals are difficult to resolve in spectrograms, particularly for the crickets (gryllids) that have overlapping call frequencies in the range from 3 to 9 kHz (Riede 1993).

Although acoustic sampling by trained listeners is a widely used method in biodiversity surveys, quantitative validation of the reliability of species identification by the listener is very rarely presented. Such quantitative validation of listener skill in identification is crucial to evaluate the reliability of species diversity estimation. In this paper, we aim to evaluate trained listener—based acoustic sampling as a reliable, non-invasive method for rapid assessment of orthopteran species diversity in tropical evergreen forests. This is done in two ways (1) evaluating the reliability of identification of species and numbers of calling individuals using psychoacoustic experiments in the laboratory and (2) by comparing psychoacoustic sampling in the field with ambient noise recordings made at the same time.

Materials and methods

Psychoacoustic tests

We assessed the reliability of correct identification of species and number of individuals of species by the listener (first author) who has four years of experience in localising and recording calls of species belonging to an acoustically communicating ensiferan assemblage of a tropical forest in Southern India. We have already described the calls of the twenty ensiferan species constituting the nocturnal acoustic community of Kudremukh National Park in the Western Ghats of South India (Diwakar and Balakrishnan in press; Nityananda and Balakrishnan 2006).

Of the twenty species in the ensiferan assemblage, ten belonged to the superfamily Gryllloidea. Gryllids (true crickets) mainly have narrow band calls with dominant frequencies ranging from 3 to 7 kHz. The superfamily Tettigonioidea was represented by nine species. Four of the tettigoniid (katydid or bush cricket) species, belonging to the genus *Onomarchus, Phyllomimus, Brochopeplus* and one unidentified genus that we called '15 kHz' have narrow band calls centered at 3, 9, 11 and 15 kHz respectively. The other five species, *Mecopoda* 'Two part', *Mecopoda* 'Train', *Mecopoda* 'Helicopter' (frequency bandwidth: 2–70 kHz), *Pirmeda* (frequency bandwidth: 12–28 kHz), and *Elimaea* (frequency bandwidth: 8–25 kHz) were broadband callers. The superfamily Gryllacridoidea was represented by one species belonging to the genus *Gryllacropsis* with a dominant frequency of 1.7 kHz (Diwakar and Balakrishnan 2006).

Experimental design

A series of tests were conducted on the trained listener (first author) by the second author in an anechoic chamber (2.2 m × 2.4 m). Six speakers were used for playback (two Avisoft Ultrasonic Scanspeak loudspeakers, frequency range: 1–120 kHz and four Creative speakers-SBS20, frequency range: 50 Hz–16 kHz). The listener was made to sit equidistant from the six speakers. The speakers were placed on the ground. The distance between the listener and each speaker was close to 1 m. The experiment was designed to produce maximum masking conditions, with calls being played out such that the sound level of each call at the position of the listener was 60 ± 2 dB SPL, which is around 10 dB higher than the ambient noise level in the forest during the peak calling period (49.6 ± 9.31 dB SPL). The sound levels at the listener's position were verified using a sound level meter (CEL 414 Precision Impulse with a Larson Davis 2540 microphone, frequency range: 32 Hz–40 kHz). Calls were played out from the six speakers simultaneously and the listener's task was to identify the calls and the number of individuals of each call.

Synthesis of stimuli and playback

Calls of all twenty ensiferan species that were previously recorded from the forest were used for playback (Diwakar and Balakrishnan in press; Nityananda and Balakrishnan 2006). Four stimuli were synthesized for each species call wherein delays of 0, 1, 2 and 3 s respectively were added in the beginning of the call. This was done to simulate field conditions where the calls of individuals of species occur randomly in time without fixed phase relationships. Each species was randomly and non-repetitively assigned a code from 1 to 20. For each trial, each of the six speakers was pseudo-randomly assigned a number from 1 to 20 (species code). The call played out from each speaker corresponded to the species code assigned to it for that trial. Delay files for each species were also assigned randomly for each trial.

Hence, during each trial all six speakers played out calls of species assigned to them pseudo-randomly with random delays and at intensities such that the sound levels of the six calls were equal at the position of the listener. The design of the experiment resulted in some trials for each species where calls of four, three, two or one individual of the same species were played out. This simulates the field situation where variable numbers of individuals of the same or different species call together at a given point in space and time.

The playback was carried out using Matlab (1997, Version 5.1.0.421, The Mathworks Inc., Natick, MA) through a laptop computer (IBM® ThinkPad® R40 type 2682) and D/A

output card (National Instruments DAQ 6715) via six channels using the six speakers. Each trial lasted for 50 s and was repeated once. Eighty trials were conducted on the listener to assess the reliability of identifying species and number of individuals of species correctly. Reliability of correctly identifying species was calculated as number of correct species identifications/total number of times species appeared in separate trials and expressed as a percentage.

Listener – instrument comparison

Hearing threshold of the trained listener

Sine waves of 1–20 kHz were synthesised using Matlab at a sampling rate of 100 kHz. Sine waves were played out one at a time using the software Matlab via a laptop computer (IBM® ThinkPad® R40 type 2682) and D/A output card (NI DAQ 6715) using an Avisoft amplifier and Avisoft Ultrasonic Scanspeak loudspeaker (Frequency range: 1–120 kHz). A sound level meter (Brüel and Kjaer 2260 Observer with ½'' condenser microphone 4189, frequency range: 6 Hz–20 kHz) was kept at a distance of 60 cm from the speaker in an anechoic chamber of 75 cm x 75 cm dimension. Measurements were made using a 1/3rd octave filter with the centre frequency being changed for each frequency measured. The volume knob of the amplifier was kept at minimum in the beginning and slowly increased till the listener just heard each sine wave. The sound pressure level was noted at that instant and was considered as the hearing threshold in dB SPL (P_{ref}: 2×10^{-5} Nm^{-2}) of the listener's ear for that frequency. The process was repeated two or three times till we got a constant reading. The distance of the loudspeaker to the listener's ear and the sound level meter was 60 cm.

Sensitivity of the ultrasound detector

The same frequency range of 1–20 kHz of sine waves and set up for output of sine waves described above were used. The ultra sound detector (D 980, Pettersson Elektronik AB, Sweden, custom—built microphone with frequency range: 2–200 kHz) was placed next to the sound level meter and both were at a distance of 60 cm from the loudspeaker. The output from the ultrasound detector was digitised using a data acquisition card (NI-DAQ AT-MIO-16E-2) and NI MAX version 2.0 software at a sampling rate of 100 kHz. The volume knob of the loudspeaker amplifier was slowly increased till the sine waves just started registering in the test panel. The value of SPL registered by the sound level meter was taken as the sensitivity threshold of the ultrasound detector.

Comparison between psychoacoustic spot sampling and ambient noise recordings

Psychoacoustic spot sampling: Based on high diversity and abundance of calling ensiferans, two transects of similar evergreen vegetation and elevation of 500 m were selected in the Kudremukh National Park in the Western Ghats in Southern India. In each 500 m transect, ten spots were marked that were 50 m apart from each other. Psychoacoustic spot sampling was carried out by the first author by standing on each of the marked ten spots in each transect for five minutes and listening to the calls. The number of different call types heard, number of individuals of each type of call, direction, approximate distance and height from which the call type was heard, were recorded. Sampling was carried out after sunset between 1800 h in the evening till midnight when the calling activity of insects is at

peak (Diwakar and Balakrishnan in press). Six replicates of the psychoacoustic spot sampling were carried out in each transect between December 2004 and March 2005.

Ambient noise recordings were made simultaneously with the psychoacoustic spot sampling. Ambient noise recordings were made in the forest by using an ultrasound detector (D 980, Pettersson Elektronik AB, Sweden, custom built microphone with frequency range: 2–200 kHz) at the highest microphone sensitivity. The single channel input was digitised on to a laptop computer (IBM® ThinkPad® R32) using a data acquisition card (DAS 16/380 Measurement Computing) into binary format at a sampling rate of 200 kHz using software Lab view version 6.0. The binary files were then converted to wave files using Matlab (1997, Version 5.1.0.421, The Mathworks Inc., Natick, MA). Five ambient noise recordings were made during each three - hour sampling period in each transect. Each recording was for a duration of five minutes which was carried out simultaneously with the psychoacoustic spot sampling.

Spectrograms were computed using the Demo version of Raven software (1.2.1 version). Spectrograms were computed with FFT size of 1024, Hanning window, 90% window overlap and average block size of 20 to get sufficient resolution in both time and frequency. *A posteriori*, we selected psychoacoustic sampling spots in which *Onomarchus* sp., 'Whiner', *Phyllomimus* sp. and *Mecopoda* 'Two part' were heard. The spectrograms of the corresponding ambient noise recordings were visually inspected to check whether these species could be identified. Another set of ambient noise recordings was also selected where the above-mentioned species were not heard during psychoacoustic spot sampling. The spectrograms of the corresponding ambient noise recordings were visually inspected to check whether the signals from these species were recorded.

Focal animal sampling

It is important to know the extent of movement of individuals of different ensiferan species during calling to correctly estimate abundance and population sizes in an area. In order to do this, a calling individual of a species was located either visually or acoustically in the field. The initial calling site and position were noted. The individual was then observed for 30 min for its movement. After 30 min, the final position of the observed individual was noted and the distance between initial and final position was determined using a measuring tape. Focal animal sampling was carried out on five individuals for most species.

Results

Psychoacoustic tests

In 80 six-speaker trials, the reliability of correct species identification was 100% for 16 out of 20 species (Table 1). Identification errors occurred only for four species: *Landreva* sp., *Phyllomimus* sp., *Xabea* sp. and *Mecopoda* 'Helicopter' sp. The reliability of correct identification was 85% for *Landreva* sp. and *Phyllomimus* sp. and 93% for *Xabea* sp. and *Mecopoda* 'Helicopter' sp. The reliability of identifying the number of individuals correctly was 100% for 13 out of 20 species. The number of individuals was underestimated by 5% for *Mecopoda* 'Helicopter' and *Xabea* sp. and by 12% for *Landreva* sp. The number of individuals was overestimated by 4–8% for *Scleropterus* sp.,'15 kHz', *Mecopoda* 'Train' and *Ornebius* sp. (Table 1). The identification of both species and numbers of individuals was thus correct 85–100% of the time.

Table 1 Results of the laboratory psychoacoustic tests showing the total number of correct identifications of species and numbers of individuals

Species code	Species	Number of trials in which the species call was played	Number of times species correctly identified	Total number of individuals presented	Total number of individuals recorded by the listener
1	*Brochopeplus* sp.	17	17	24	24
2	'Whiner'	20	20	27	27
3	*Elimaea* sp.	13	13	19	19
4	*Callogryllus* sp.	15	15	22	22
5	*Pirmeda* sp.	14	14	20	20
6	*Mecopoda* 'Helicopter'	14	**13**	22	***21***
7	*Mecopoda* 'Train'	19	19	26	**28**
8	'15 kHz'	10	10	17	**18**
9	*Gryllitara* sp.	19	19	26	26
10	*Micrornebius* sp.	21	21	28	28
11	*Mecopoda* 'Two part'	20	20	28	28
12	*Scleropterus* sp.	16	16	23	**24**
13	*Ornebius* sp.	17	17	23	**25**
14	*Phaloria* sp.	22	22	31	31
15	*Xabea* sp.	15	**14**	22	***21***
16	*Onomarchus* sp.	16	16	25	25
17	*Landreva* sp.	26	**22**	33	***29***
18	*Phyllomimus* sp.	13	**11**	19	19
19	*Scapsipedus* sp.	16	16	23	23
20	*Gryllacropsis* sp.	15	15	22	22

Listener—instrument comparison

Threshold curves

The hearing threshold of the trained listener and the sensitivity of the ultrasound detector are shown in Fig. 1. The hearing threshold for low frequency signals was lower by up to 20 dB for the human listener as compared to the instrument up to 6 kHz. Hearing threshold of the human listener and the sensitivity of the ultrasound detector were similar between 7 kHz and 10 kHz. However, for the frequencies above 10 kHz, the instrument showed lower detection thresholds and as expected, the listener's hearing sensitivity declined. Sounds above 19 kHz could not be heard by the human listener.

Comparison between psychoacoustic spot sampling and ambient noise recordings

Among the acoustically communicating ensiferan species of Kudremukh National Park, there is a high overlap of temporal pattern and frequencies from 3 kHz to 7 kHz mainly due to gryllid calls (Diwakar and Balakrishnan in press). There are also tettigoniid species in the tropical forest that have broadband calls ranging from 2 kHz to 70 kHz (Nityananda and Balakrishnan 2006). Because of the overlapping gryllid and tettigoniid calls, it was not possible to separate all twenty species in the spectrogram (example shown in Fig. 2). We decided to pick four species with unique temporal patterns and frequencies, which had motifs that could be identified clearly and unambiguously in the spectrogram (Fig. 2) by eye to compare the efficiency of instrument recordings with psychoacoustic spot sampling.

In comparison with the human listener in the field for the selected species, the instrument was slightly less effective at detecting the species (Fig. 3 grey bars). The instrument was 100% effective in recording *Phyllomimus* sp., which has a dominant frequency of 9 kHz but could detect *Onomarchus* sp. (dominant frequency: 3.2 kHz) only 79% of times in which it was heard by the human listener. For 'Whiner' and *Mecopoda* 'Two part', the instrument recorded the call 93.33% and 90.91% of the times respectively. The trained

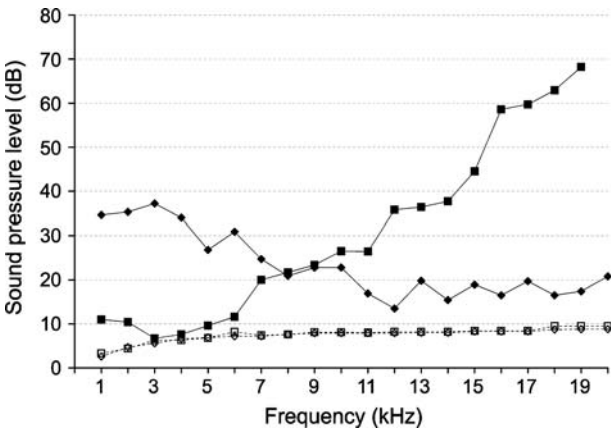

Fig. 1 Human and instrument detection thresholds for audio signals. Hearing threshold curve of the trained listener (solid squares) and detection threshold curve of the ultrasound detector (filled diamonds). Empty squares and diamonds represent the ambient noise level at the centre frequency in the anechoic chamber during human listener and instrument hearing curve generation

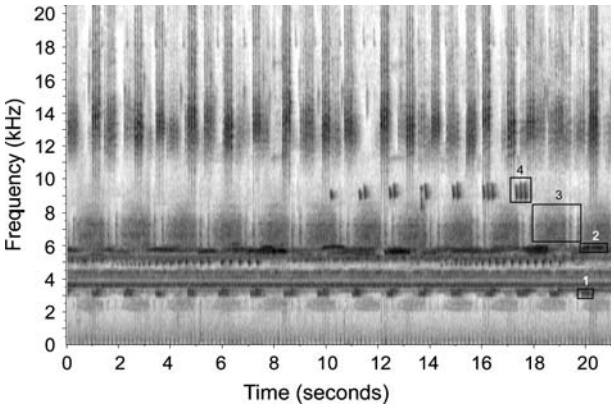

Fig. 2 Spectrogram showing the distinct temporal patterns and frequency bands for four selected species: (1) *Onomarchus* sp. (3 kHz), (2) 'Whiner' (5.5 kHz), (3) *Mecopoda* 'Two part' (broadband call with dominant energy band between 6 kHz and 7 kHz) and (4) *Phyllomimus* sp. (9 kHz)

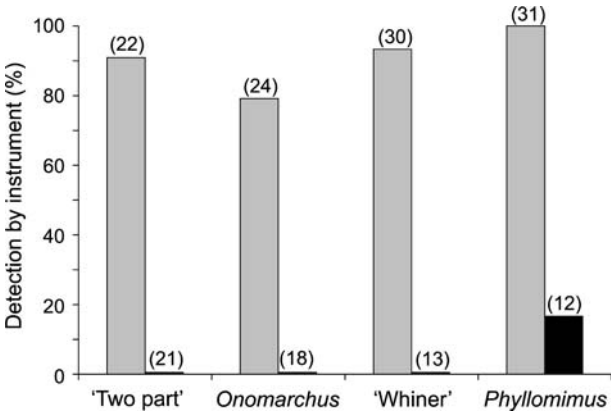

Fig. 3 Comparison of psychoacoustic and instrument sampling in the field. Detection by the instrument (in %) when the selected species were heard in the psychoacoustic spot sampling (grey bars) and when the species were not heard in the psychoacoustic spot sampling (black bars). Numbers in brackets indicate the numbers of psychoacoustic sampling spots and ambient noise recordings analysed

listener's tendency to miss out on species that were picked up by the recorder was nil for three out of four species (Fig. 3 black bars). For *Phyllomimus* sp., the instrument's ability to detect the signal was 16.67% higher. Overall, there was at least 80% agreement between human and instrument sampling for the four selected species.

Focal animal sampling

Individuals of five species of gryllids belonging to *Callogryllus* sp., *Scapsipedus* sp., *Scleropterus* sp., *Landreva* sp. and *Xabea* sp. and four species of tettigoniids namely, *Mecopoda* 'Two part', *Phyllomimus* sp., *Pirmeda* sp. and *Onomarchus* sp. essentially did not move for thirty minutes from their calling positions (Fig. 4). The average distance moved by individuals of *Micrornebius* sp., *Gryllitara* sp., *Phaloria* sp., *Brochopeplus* sp., '15 kHz' and

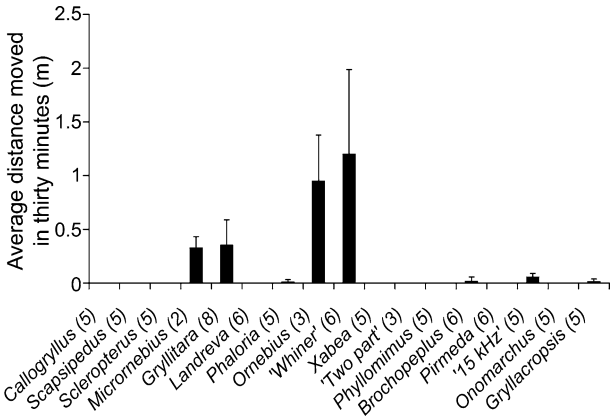

Fig. 4 Focal animal sampling to measure movement of calling individuals. Numbers in brackets indicate the number of individuals sampled

Gryllacropsis sp. was limited to less than 0.5 meters. *Ornebius* sp. and 'Whiner' moved most among gryllids with the average movement being 0.95 ± 0.43 m and 1.2 ± 0.79 m respectively. Their movement, however, was restricted to different branches of the same shrub on which the individuals were first located. Three species *Mecopoda* 'Train', *Mecopoda* 'Helicopter' and *Elimaea* sp. moved to greater distances but since the animals were not marked it was not possible to measure the distances reached after 30 min of sampling. For the species that moved more than 1.5 m and could not easily be relocated, we measured the average amount of time the animal stayed at the same place. The average amount of time that calling individuals of *Mecopoda* 'Train', *Mecopoda* 'Helicopter' and *Elimaea* sp. stayed at one spot was found to be 14.2 ± 3.35, 12 ± 1.4 and 11 ± 5.6 min respectively.

Discussion

Performance of the trained listener

We have quantitatively validated the reliability of human listener—based psychoacoustic sampling as a technique to monitor species richness and relative abundance of acoustically communicating ensiferan species that are within the human hearing range. We have shown using controlled psychoacoustic tests in the laboratory that a trained listener is capable of identifying the species as well as the number of individuals of Ensifera with very high accuracy. The psychoacoustic tests presented a difficult task as compared to the field conditions as the calls were played at equal sound intensities, presenting high masking conditions and all the calls were played out at the same height. We argue that if the listener is able to correctly identify species and individuals in such high masking conditions then accuracy should be equally high or better in the field where individuals of different ensiferan species are calling at different heights, distances and at different intensities.

Comparisons between trained listener—based call surveys and automated recordings

Comparative studies on the two acoustic monitoring techniques of conventional call surveys by trained listeners and acoustic recording systems in bats (O'Farrell and Gannon

1999), anurans (Bridges and Dorcas 2000) and birds (Haselmayer and Quinn 2000) have found that more species were detected using acoustic sampling by instruments than by capture methods, point counts or call surveys. Acoustic recordings were capable of detecting bat and frog species that were missed in mist net captures and psychoacoustic sampling. In a study of acoustic monitoring of anuran calling (Bridges and Dorcas 2000), it was found that due to inter-specific differences in calling activity and breeding seasons, traditional call surveys missed detection of some species. The study suggested the use of automated recording systems to monitor anuran populations for extended time periods, with fewer disturbances to calling anurans.

New techniques have been developed for automated recognition and identification of signals from ambient recordings in bats (Parsons and Jones 2000; Vaughan et al. 1997), birds (Anderson et al. 1996) and crickets (Brandes et al. 2006; Riede et al. 2006). Brandes et al. (2006) have developed an automated call recognition (ACR) method that can detect and classify narrow band cricket and frog calls from the spectrogram images of the ambient noise recordings from tropical forests using image-processing techniques. This method has high accuracy of detecting unique calls even at a high background noise level and can be effectively used for monitoring cricket populations. However, the efficiency of this technique is dependent on the availability of cricket call characteristics from an area of interest and also the extent of overlap of call features of different species. The technique is effective to monitor presence or absence of narrow band calls that have non-overlapping spectral and temporal patterns.

In the acoustically communicating ensiferan assemblage in our study area however, there is a considerable overlap of frequencies and temporal patterns of gryllid species especially between 3 kHz and 7 kHz and broad band tettigoniid calls that smear the spectrogram ranging from 2 kHz to 70 kHz (Diwakar and Balakrishnan 2006, in press; Nityananda and Balakrishnan 2006). The species—specific temporal patterns were not resolvable visually in the spectrograms when many species were calling at the same time. The human listener however, is able to distinguish between different species based on frequency as well as species-specific temporal pattern such as call duration, period and duty cycle.

Acoustic recordings are limited in estimating relative abundance of each species using spectrograms when many individuals of the same or different species call together. On the other hand, resolving the numbers of individuals is relatively easy for a trained human listener, since the mammalian brain has excellent auditory processing capabilities. A trained listener can simultaneously obtain information about the stratum (ground, understorey or canopy) occupied by the calling species that is not possible with single microphone recordings. We suggest that trained listener—based psychoacoustic sampling may be preferable to carry out rapid assessments and species inventories of gryllids and low frequency katydid species in tropical forests.

Comparisons between the hearing threshold of the trained human listener versus the sensitivity of the ultrasound detector and the ambient noise recordings with the psychoacoustic spot sampling showed that while the trained human is better at detecting species for the low frequency gryllid calls, ambient noise recordings can pick up high frequency tettigoniid signals that are missed by human ears. Ultrasonic calls can only be picked up by an ultra sound detector as human hearing is limited to 20 kHz. We therefore suggest that acoustic monitoring of Orthoptera should be done using both the trained listener—based spot sampling and ambient noise recordings using ultrasound detectors for accurately estimating species richness and relative abundance in an area.

Pseudoreplication and density estimation in acoustic monitoring

An important aspect in monitoring and estimating ensiferan populations is to know how mobile calling animals are. Pseudoreplication by counting the same animals twice if animals are changing positions can overestimate the population sizes and cause errors in abundance estimates. Using focal animal sampling, we have shown that this is not a problem for calling crickets and katydids. Most species in the tropical forest ensiferan assemblage of Kudremukh National Park did not move more than a metre in a span of half an hour. Three species that moved either due to disturbance by the listener or perhaps a 'call and fly' mating strategy stayed at one spot for more than ten minutes. So the acoustic sampling should be designed in such a way as to cause minimal disturbance to the calling animals and could be limited to ten minutes to avoid re-counting individuals.

Acoustic recordings with single microphones and psychoacoustic sampling are limited by the inability to estimate distances over which the calling animals are recorded. The detection distance for each species may differ. If the range within which each call can be detected is known, it will be possible to obtain absolute density estimates from acoustic sampling. Hence, it is important to get hearing distances for each species to accurately estimate ensiferan populations in an area.

By evaluating the reliability of a trained human listener in correctly identifying species and numbers of individuals using laboratory psychoacoustic tests and the comparisons between ambient noise recordings and psychoacoustic spot sampling in the field, we have validated the use of psychoacoustic spot sampling as a reliable and non-invasive method to monitor ensiferan species in tropical rainforests.

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References

Alexander RD (1967) Acoustical communication in arthropods. Ann Rev Entomol 12:495–526

Anderson SE, Dave AS, Margoliash D (1996) Template-based automatic recognition of birdsong syllables from continuous recordings. J Acous Soc Am 100:1209–1219

Bennet-Clark HC (1989) Song and the physics of sound production. In: Huber F, Moore TE, Loher W (eds) Cricket Behavior and Neurobiology. Cornell University Press, Ithaca and London

Bibby CJ, Burgess ND, Hill DA (1992) Bird census techniques. Academic Press, London England

Brandes TS, Naskrecki P, Figueroa HK (2006) Using image processing to detect and classify narrow – band cricket and frog calls. J Acous Soc Am 120:2950–2957

Bridges AS, Dorcas ME (2000) Temporal variation in anuran calling behaviour: Implications for surveys and monitoring programs. Copeia 2:587–592

Diwakar S, Balakrishnan R (2006) Male and female stridulation in an Indian weta (Orthoptera: Anostostomatidae). Bioacoustics 16:75–85

Diwakar S, Balakrishnan R (in press) The assemblage of acoustically communicating crickets of a tropical evergreen forest in Southern India: call diversity and diel calling patterns. Bioacoustics

Fischer FP, Schulz U, Schubert H, Knapp P, Schmöger M (1997) Quantitative assessment of grassland quality: acoustic determination of population sizes of orthopteran indicator species. Ecol Appl 7:909–920

Forrest TG (1988) Using insect sounds to estimate and monitor their populations. Fla Entomol 71:416–426

Gaston KJ, May RM (1992) Taxonomy of taxonomists. Nature 356:281–282

Haselmayer J, Quinn JS (2000) A comparison of point counts and sound recording as bird methods in Amazonian southeast Peru. Condor 102:887–893

Heyer W, McDiarmid RW, Donnelly M, Hayek L (eds) (1994) Measuring and monitoring biological diversity – standard methods for amphibians. Smithsonian Institute Press, Washington, DC

Nischk F, Riede K (2001) Bioacoustics of two cloud forest ecosystems in Ecuador compared to a lowland rainforest with special emphasis on singing cricket species. In: Neider J, Barthlott W (eds) Epiphytes and canopy fauna of the Otongan rainforest (Ecuador), vol 2. Results of the Bonn-Quito Epiphyte Project, funded by Volkswagen Foundation. pp 217–242

Nityananda V, Balakrishnan R (2006) A diversity of songs among morphologically indistinguishable katydids of the genus *Mecopoda* (Orthoptera: Tettigoniidae) from Southern India. Bioacoustics 15:223–250

O'Farrell MJ, Gannon WL (1999) A comparison of acoustic versus capture techniques for the inventory of bats. J Mammal 80:24–30

Otte D (1994) The crickets of Hawaii. Origin, systematics and evolution. The Orthopterist's Society at the Academy of Natural Sciences, Philadelphia

Parsons S, Jones G (2000) Acoustic identification of 12 species of echolocating bats by discriminant function analysis and artificial neural networks. J Exp Biol 203:2641–2656

Riede K (1993) Monitoring Biodiversity: Analysis of Amazonian rainforest sounds. Ambio 22:546–548

Riede K (1997) Bioacoustic monitoring of insect communities in a Bornean rainforest canopy. In: Stork NE et al (eds) Canopy Arthropods. Chapman and Hall, London, pp 442–452

Riede K (1998) Acoustic monitoring of Orthoptera and its potential for conservation. J Insect Conserv 2:217–223

Riede K, Nischk F, Dietrich C, Thiel C, Schwenker F (2006) Automated annotation of Orthoptera songs: first results from analysing the DORSA sound repository. J Orth Res 15:105–113

Stork NE (1988) Insect diversity: facts, fiction and speculation. Biol J Linn Soc 35:321–337

Vaughan N, Jones G, Harris H (1997) Identification of British bat species by multivariate analysis of echolocation call parameters. Bioacoustics 7:189–207

Walker TI (1964) Cryptic species among sound – producing ensiferan Orthoptera (Gryllidae and Tettigoniidae). Q Rev Biol 39:345–355

Wilson EO (1989) Threats to biodiversity. Sci Am 60:60–66