Acoustic monitoring of Orthoptera and its potential for conservation

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Songs of Orthoptera can be used for inventorying and monitoring of individual species and communities. Acoustic parameters such as carrier frequency and pulse rates allow the definition of recognizable taxonomic units (RTUs) which help to overcome the taxonomic impediment due to our scanty knowledge, particularly of tropical faunas. Bioacoustic diversity is a first estimate for species richness and provides baseline data which can be a prerequisite for conservation. Additional ecological and behavioural information such as habitat preference and singing schedules can be inferred. Many Orthoptera are sensitive indicator species for habitat quality in temperate and tropical ecosystems. Examples are given for evaluation of habitat quality and deterioration by acoustic detection of Orthoptera.

Keywords: conservation monitoring; bioacoustics; biodiversity; Orthoptera; tropical forests.

Introduction: acoustic communication in Orthoptera

The rich and complex soundscapes, particularly of tropical rainforests, are testimony to orthopteran and homopteran diversity, but only species numbers can be estimated. Estimates of tropical arthropod diversity are continuing to be debated, but there is a general minimal consensus that for each described insect species two undescribed taxa can be found (Gaston, 1991; Hawksworth and Kalin-Arroyo, 1995). Based on 24 000 described Orthopera contained in the *Orthoperan Species File* (Otte and Naskrecki, 1997), there may be a total of 70 000 orthopteran species. This diversity is threatened by habitat destruction which leads to extinction of whole animal communities, particularly in sensitive tropical biota, where many species show localized occurrence. However, the ranges of most tropical arthropods are unknown and speculations on extinction rates by habitat loss are the theme of another, more serious debate (Wilson, 1989). This ignorance led to the development of 'Rapid assessment programmes' (RAPs, Tangley, 1992), to identify hot spots of biodiversity and to inventory certain key groups in such critical areas. However, these few taxonomic groups are by no means sufficient, because different groups react differently to disturbance (Lawton *et al.*, 1998). Therefore, acoustic surveys of Orthoptera are an additional window for quick biodiversity assays, particularly in tropical habitats.

Orthoptera exhibit a great variety of stridulatory mechanisms which basically consist of files and scrapers localized on movable appendages. Antennae, mandibles, wings and legs are rubbed against each other or against body parts acting as resonators. Some crickets even incorporate external structures such as cavities or leaves as acoustic amplifiers (Forrest, 1982; Bennet-Clark, 1987). For the reception of airborne sound, mechanoreceptors and tracheae provide the substrate for the evolution of sophisticated ears. These tympanal organs are located in foretibia (Ensifera) or the first abdominal segment (Acridoidea) (see Bailey (1990) for Ensifera and Mason (1968) for Acridoidea).

A considerable number of in-depth studies have dealt with acoustic communication in Orthoptera from various points of view, including bioacoustics of sound production (Bennet-Clark, 1989), the underlying neuromuscular mechanisms (Kutsch and Huber, 1989), sound reception (Larsen *et al.*, 1989), neural processing of sound signals (Elsner, 1994), genetics and behavioural responses (von Helversen and von Helversen, 1994) and sound transmission in the field (Römer, 1993). These studies have enriched such fields as bioacoustics, neurophysiology and behaviour and often profit from creative encounters with very distinct research traditions from physics and biology. Some Orthoptera have become model organisms for entire lines of research in neuroethology, such as *Gryllus* spp. (Huber *et al.*, 1989), several European gomphocerine grasshoppers (Elsner, 1994) and a variety of Tettigoniidae (Heller and von Helversen, 1993).

In most species, male songs are used by females for mate recognition. Such species-specific songs have been used by taxonomists for the detection and description of morphologically similar, but behaviourally different, cryptic species (Walker, 1964). Even in the absence of taxonomic expertise, songs are excellent features for classification of recognizable taxonomic units (RTUs) which can be used to measure Orthopteran diversity in a non-invasive way.

Methods: characterization of Orthopteran songs

The unaided human ear neither resolves the temporal structure nor the full frequency range of insect songs. Even so, it is an excellent frequency analyser, and an observer-based terminology of song components is still useful (Table 1).

Graphic representation of recordings is a prerequisite for analysis of the temporal structure and frequency composition of Orthoptera songs. Historically, it started with the use of the spectrograph and temporal analysis was accomplished by filming oscilloscope tracks (Pierce, 1948). The advance of computer technologies allowed digital analysis, mainly using fast Fourier transform to calculate spectrograms. During the last decade, expensive hardware and software has been replaced by personal computers with soundcards and cheap but fully functional software, making this technology financially accessible even for very low research budgets.

Figures 1–4 give some examples of graphical displays of songs for typical representatives of major orthopteran groups.

The Tettigonioidea exhibit the greatest diversity of song structures, covering a wide spectral range which often reaches far into the ultrasound. Narrow carrier frequencies ('musical quality') are observed among the Pseudophyllinae, but lie outside the human hearing range for Neotropical species. In contrast, several genera from the Palaeotropics produce the lowest carrier frequencies found among insects (Fig. 2; see also Heller, 1995) and might easily be confused with the sympatric frog species *Metaphrynella sundana* (Peters, 1867) or crickets (Riede, 1996).

Crickets (Grylloidea) are characterized by a rather homogeneous song structure, made up of trills with narrow carrier frequencies between 1 and 11 kHz. This simple structure permits easy classification within a parameter space made up of frequency and pulse repetition rate (Fig. 3).
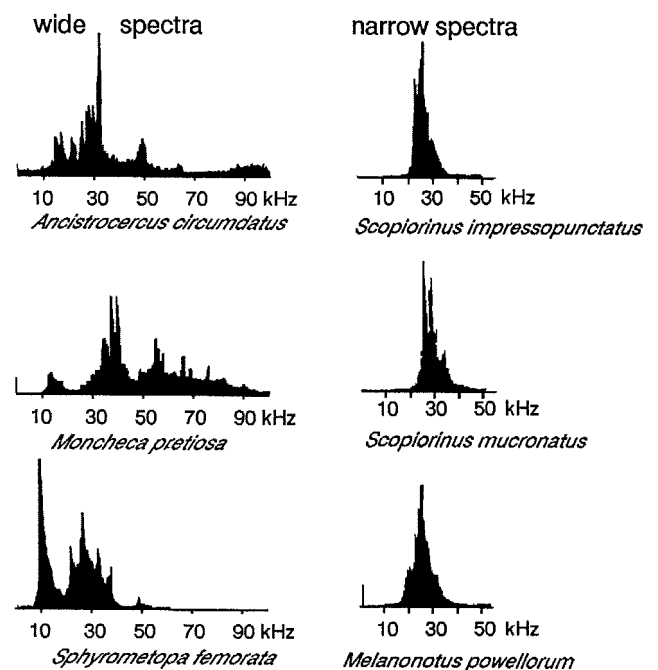

Figure 1. Power spectra of Neotropical Tettigonioidea (rearranged after Morris and Beier (1982)). Sound amplitude (in relative units on linear scale) is plotted against frequency. Species on the left are characterized by wide frequency spectra, reaching far into ultrasound, and belong to different groups such as Pseudophyllinae (*Ancistrocercus circumdatus* (Walker)), Copiphorini (*Moncheca pretiosa* (Walker)) and Agraecini (*Sphyrometopa femorata* Carl). Their songs contain higher harmonics, perceived as formants by humans and allowing onomatopoetic descriptions of songs (see Table 2). Species on the right exhibit narrow carrier frequencies and all belong to the Pseudophyllidae (*Scopiorinus impressopunctatus* Beier, *Scopiorinus mucronatus* (Saussure and Pictet) and *Melanonotus powellorum* Rentz). Note that the song of the Old World pseudophylline *Tympanophyllum* sp. (Fig. 2) also has a narrow spectrum, but an extremely low carrier frequency.

Table 1. Terminology of song components description based on the unaided human ear

| Infrastructure	Duration	Noisy	Musical
Absent	<1s	Tick	Note
Present	<1s	Zip	Chirp
Absent	>1s	Buzz	Tone
Present	>1s	Rattle	Trill

Summary of 'human ear terms', based on the temporal infrastructure and spectral properties (noisy, containing many different carrier frequencies and musical, dominated by only one frequency). From Morris *et al.* (1989, p. 217).
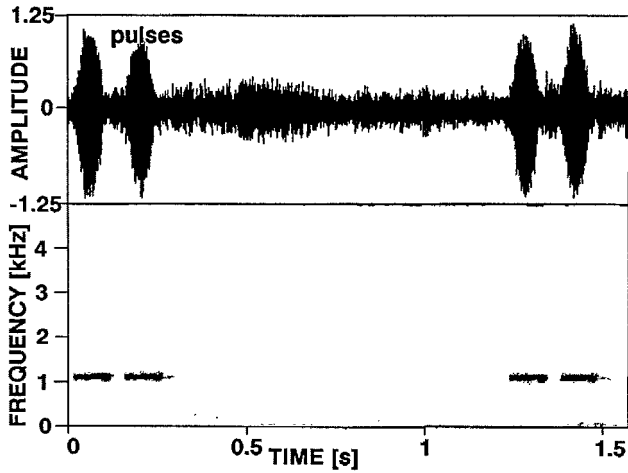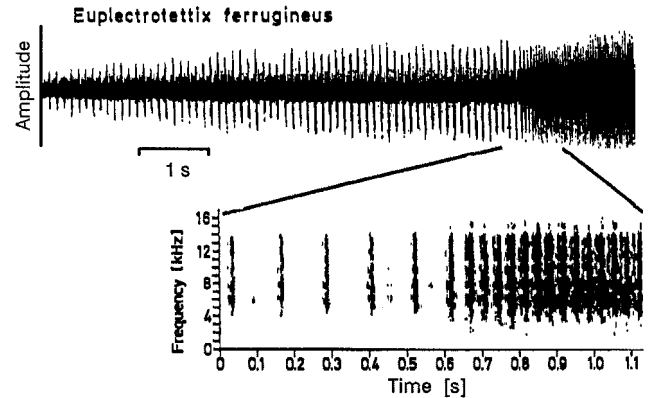
Figure 2. Oscillogram and sonagram of *Tympanophyllum* sp. (Tettigoniidae: Pseudophyllinae) from Bornean rainforest (see Riede, 1996), with a low carrier frequency and a cricket-like 'chirp' containing two pulses each.

Among the Acridoidea, the Gomphocerinae exhibit greatest song diversity (Fig. 4). This subfamily is species rich in grasslands outside the tropics. Interestingly, most tropical Acridoidea are silent, although the Romaleinae have remarkable songs (Riede, 1987).

The properties of orthopteran songs can be roughly categorized for higher taxonomic units. Table 2 summarizes the characteristics of the major orthopteran
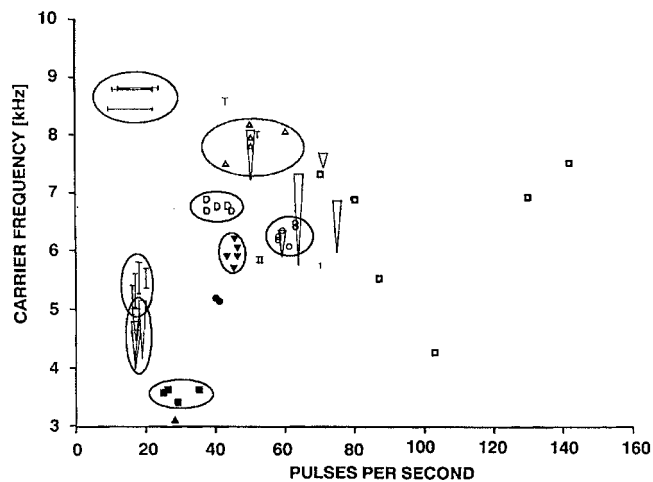
Figure 3. Distribution of Neotropical cricket songs, showing clusters in a parameter space made up of pulse interval (as defined in Fig. 2) and carrier frequency (from Riede, 1993). Preliminary results by Nischk (1998) indicate that songs can even be categorized at the subfamily level.

Figure 4. Oscillogram and sonagram of the gomphocerine grasshopper *Euplectrotettix ferrugineus* Bruner 1900 (Acridoidea). Acridid songs have a complex time structure, but their spectral properties can simply be described as wide-band noise.

groups, using the categories in Table 1. Computer-aided analysis of songs is time-consuming and, to date, impractical in the field. Therefore, detection and recognition of species in the field is often only attained by trained observers. As shown in Table 1, humans can categorize insect songs reliably. Bellmann (1993) designed an acoustic key based on time-domain categories for the determination of European Orthoptera. Additional characteristic features are higher harmonics which are perceived as formants, and add vocal-like quality, allowing onomatopoetic descriptions of insect songs. For insects communicating in the ultrasound, bat detectors have been used to transform songs down to human hearing range. In the future, songs could be slowed down electronically in the field, adapting their temporal structure to human time resolution, which would be useful for cricket identification.

Bioacoustics, documentation and taxonomy

Bioacoustic analysis of species-specific songs already forms an integral part of species descriptions for many Orthoptera (Ingrisch, 1997). Usually, but not always, these recordings are deposited in phonotheks, ideally with a cross reference to the recorded specimen. Publications as discs or CDs are still the exception: major revisions and compilations including song only exist for European gomphocerine grasshoppers (Ragge and Reynolds, 1997) and Tettigoniidae (Rentz, 1993). Today, new information technologies for digital sound processing and data exchange allow much more efficient ways of storage, organization, publication and access-

Table 2. Song characteristics for major taxa of Orthoptera

Taxon	Spectrum	Frequency range (kHz)	Infrastructure (human ear terms)
Tettigonioidea	Wide	5–101	Any
	Narrow	1-101	Note and chirp
Grylloidea	Narrow	1–11	Trill
Acridoidea			
Gomphocerinae	Wide	2–40	Zip, buzz and rattle
Oedipodinae	Wide	2–40	Tick and rattle
Acridinae	Wide	2–40	Tick and rattle
Hyalopterix spp.[a]	Narrow	3-5	Trill
Romaleinae	Wide	2–40	Rattle
Pneumoridae	Wide, narrow	1–8	Rattle and trill

[a] Some Acridinae have narrow carrier frequencies, such as *Hyalopterix rufipennis* Charpentier 1843 (see Riede, 1987).

ibility of acoustic data, but also signify new problems with respect to data formats, safety and intellectual property rights. The *Orthopteran Species File* (Otte and Naskrecki, 1997) is the first step towards making songs available via the World Wide Web. An efficient and coherent system of databasing is the prerequisite for the wider use of bioacoustics in conservation, as described below

Results: bioacoustic monitoring and conservation

Some case studies are used here to illustrate the under-exploited potential of acoustic monitoring. Basically, they can be divided into simple detection of presence/absence of certain species or an analysis of whole communities, including quantitative data. These community data are used to evaluate habitat quality and deterioration.

In central Europe, many Orthoptera live at the northern or eastern margin of their distribution area and most of the species on the *German National Red List* (Binot *et al.*, 1998) are threatened by habitat destruction. However, several species are difficult to find and identify and have probably been overlooked during visual surveys. The southern element *Isophya pyrenaea* (Serville) was mapped acoustically for the first time as far north as Germany and the threatened tettigoniid *Barbitistes serricauda* (Fabricius) was easily detected with a bat detector at several new sites (Froehlich and Holtzem, 1987). For many taxa, conspicuous calls are the only means for detecting otherwise cryptic animals. The loud songs of the South African bladder grass-

hopper *Bullacris membracioides* (Walker) can be heard within a range of 1.5–1.9 km at night (van Staaden and Römer, 1997). These examples illustrate that acoustical surveys provide quantitative data which could be used for a population viability analysis of threatened populations.

Some Orthoptera are sensitive indicators of habitat quality. By acoustic scanning of grasslands, Fischer *et al.* (1997) measured the composition of acridid communities and used them as an indicator of eutrophication in Bavarian heathlands.

In tropical environments, bioacoustic diversity is overwhelming. It is difficult to localize and identify songsters which often belong to scarcely known taxa, waiting for revision and description. A preliminary classification, using acoustic parameters to define RTUs, helps to estimate and compare the diversity of tropical Ensifera. Cricket songs can be classified by carrier frequency and pulse rate. A graphic representation of these song parameters shows cluster which can be attributed to RTUs (Fig. 3). During a preliminary study, Riede (1993) classified 20 RTUs at one locality in an Ecuadorian lowland forest. At the same site, Nischk (1998) recorded and captured 34 cricket species and showed that acoustic RTUs coincide with morphospecies, which could be identified to subfamily level. The majority consisted of undescribed species of Phalangopsinae and Trigonidiinae. Nischk (in press) used the same method in two mountain forests of different elevation and measured a considerable reduction down to only four species (mainly Phalangopsinae) at 2000 m above sea level. These examples illustrate that acoustic

methods allow ecological analysis such as evaluation of diversity along environmental gradients, patterns of beta diversity and species turnover. However, certain precautions are necessary. In tropical rainforests in particular, acoustic transmission channels could be considered as a resource divided up between distinct taxa. Resource partitioning is achieved by spatial segregation, diel periodicity and mutual inhibition of song activity (Riede, 1997). Several species of tropical mole crickets only sing within a small time window of less than 30 min at dusk (Walker and Whitesell, 1982; Riede, 1997). Considerable intraspecific song diversity is observed in some cricket species such as *Noctitrella plurilingua* Ingrisch (Ingrisch, 1997) or some species of *Teleogryllus* spp. (Otte, 1992). Therefore, bioacoustic diversity assays have to take into account singing schedules and intraspecific variablity of song patterns.

Perspectives for acoustic surveys and conservation

Acoustic inventorying and monitoring of Orthoptera could provide the necessary data for the development of conservation strategies and for monitoring their successful implementation. In contrast to fogging, sound recording is a non-invasive method, accepted widely by the public and conservation agencies. Once identified, songs are highly reliable taxonomic features and allow determination down to species either in the field (after some training) or in the laboratory. Computer-aided sound analysis is becoming cheaper and more flexible. It is now possible to use such techniques in the field, even in remote habitats. As crickets do not sing higher than 11 kHz, a cheap cassette recorder and a laptop with a simple, freeware sound analysis programme are sufficient to start a productive cricket project for several years anywhere in the tropics.

In spite of these advantages, the potential of acoustic surveys is still underexploited. One reason might be the poor state of insect song documentation. In most cases, orthopteran songs are published as spectrograms and/or oscillograms, revealing the spectral and temporal characteristics of songs, but scales of temporal and spectral resolution differ widely. In many cases it might be necessary to reanalyse original sound records, but these are rarely accessible. Some zoological museums harbour sound archives (e.g. London, Natural History sound collection). Ideally, songs should be cross-referenced to the recorded specimens which often are undescribed species. The Australian Phonothek (CSIRO) fulfils these requirements and has a preliminary labelling system which assigns number codes for species with uncertain taxonomic status (Rentz, 1987; Rentz and Balderson, 1989). One should think of a worldwide introduction of this system, particularly as there is such a high number of undescribed tropical Orthoptera species.

Digitized sounds still require considerable storage space, but with decreasing storage costs it will be possible to computerize whole sound archives. Such distributed digital archives could be connected to one huge 'virtual phonothek'. The multimedia features of the *Orthopteran Species File* are still in their infancy, but are a first step towards such a project. The value of the Virtual Phonothek can be enhanced by incorporation of descriptive parameters in a standard database format, containing a set of acoustical (e.g. carrier frequency and pulse rate) and biological data (e.g. locality, time). Together with the actual sound file, such data sets make up a multimedia database which allows one to answer completely novel, otherwise intractable, questions. In the future, more complex searching algorithms will allow pattern recognition even within original sound files. Software for human speech recognition is now widely available and could be adapted for automated classification of insect songs (Chesmore *et al.*, 1998). The implications for conservation are clear.

Acknowledgements

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