Minireview Article

Calls for Conservation: A review of bioacoustics monitoring with case studies from India

ABSTRACT

With recent technological advances and greater accessibility of equipment, bioacoustics monitoring has emerged as a valuable method that utilises biologically-produced acoustic signals to gather information on the presence and absence of animals, as well as their behavioural and ecological features. A wide range of microphones and recorders can be employed to collect acoustical data, allowing for the selection of equipment suitable for the specifics of the study. Data analyses can be conducted using software packages that facilitate visualisation of acoustic emissions. This essay provides an overview of the methods involved in bioacoustics monitoring, followed by advantages, disadvantages, and ethical considerations illustrated through examples of its application to collect data on a wide range of species from varied habitats in India. The case studies reveal that bioacoustics monitoring can be applied to a wide range of studies owing to its passive, non-invasive and increasingly inexpensive methods. As the field is at its nascent stage, it suffers from drawbacks arising from the limited expertise and availability of baseline data, because of which it has not been deployed extensively. Despite this, it holds potential as an emerging tool that can significantly advance the field of conservation research.

Keywords: Bioacoustics Monitoring, Conservation Research, Acoustic Signals, Recording, Spectrograph

1. INTRODUCTION

The global scientific community has highlighted the advancing widespread defaunation, that has been termed “the sixth mass extinction”, in which many current species could be extirpated or are headed for extinction by the end of the century [1]. This period is also described as the “Anthropocene Defaunation”, in relation to the human-induced factors that have triggered the wave of decline in wildlife species and populations [2]. Considering the rapid rate of loss and its cascading effects within ecosystems, urgent action is essential to mitigate the anthropogenic damage to the environment. These efforts are, however, limited by the lack of baseline species/population data and background rates of extinction, because of which accurate diagnoses of the status of many species and identification of appropriate conservation actions are impeded [3, 4, 5]. It is essential to conduct empirical research to evaluate drivers and trends in population levels and thereby inform evidence-based conservation responses [4]. While traditional survey methods can be resource-intensive, biased, and invasive, the information revolution and rapid advances in technology have improved the feasibility of biodiversity monitoring through the passive collection, storage, and analysis of acoustical data [6].

Bioacoustics monitoring is a biodiversity and conservation research method which employs sound technologies to collect, store, and analyse biologically produced acoustic signals and, thereby, gather information about the presence or absence of animal species along with parameters of their ecology and behaviour [7, 8]. Animals primarily generate sound to facilitate intra- and inter-specific communication, and these acoustic emissions carry encoded information that can be harnessed by researchers to gather data with minimal intrusions [7]. Animal vocalisations have previously been used by traditional trackers and hunters on land [9, 10, 11], and sonar technology by fisherfolk to detect fish species and abundance [12]. Contemporary researchers have adopted the concept to collect data and inform conservation, with development of portable tape recorders and digital audio recorders as well as spectrographs (for the visualisation and analysis of vocalisations) in the latter half of the 20th century allowing researchers to employ technology to record and store animal sounds from the field [13]. While such equipment was previously prohibitively expensive, technological advancements have made them more affordable and efficient, thus, leading to their increased use [6, 8, 13]. With changing research priorities, the applications of bioacoustics monitoring have also shifted from basic identification of species to collection of crisis data and recording information on biodiversity and biological variation for environmental monitoring [8]. Considering its potential to collect data with minimal intrusions and field access requirements, this research method has been applied to a wide range of species and ecosystems, using different monitoring devices and analytical software. With increasing advancements in technology, bioacoustics has become more efficient and accessible, providing for greater application to ecological studies. In this paper, we provide an overview of the emerging tool of bioacoustics monitoring in terms of the methods involved, advantages and limitations, as well as specific case studies demonstrating its application for different animal taxa in India.

2. APPLICATION OF BIOACOUSTICS MONITORING

2.1 Data collection

The mechanism behind auditory communication among animals involves the production of sound or oscillating pressure waves by the sender which are transmitted across the medium (air, water) to the receiver's hearing organ where it is received as an auditory impression [7, 8]. The collection of acoustic data from animals primarily requires a microphone and a sound recorder. Microphones utilise mechanical transducers to convert sound energy into electrical signals that can later be visualised, amplified, recorded, analysed, and/or converted back to sound using other devices. Microphones primarily differ in terms of their transducer type, self-noise, frequency range or response, sensitivity or efficiency, and polar pattern. The selection of the microphone type- dynamic, condenser or capacitance, piezo-electric transducer, solid-dielectric, electret, directional, or hydrophone- would depend on the specific objectives of the study and would require consideration of factors including the species in focus, the accessibility of the study site, the type of habitat, and the frequency and intensity ranges of expected sound etc [7, 12].

Dynamic microphones are reliable, robust, and are powered by electromagnetic induction, because of which they do not require an external power source. However, they have rudimentary sensitivity, and are, therefore, more suited to a closer range from the sound source or in loud environments. Condenser or capacitance microphones are more suited for general conditions as they have a wider frequency response range and are more sensitive. They require a power source through an internal battery or an external cable for movements in their diagraph to change the capacitance in the condenser. For studies that require detection at higher frequencies (for example, research on bats), piezo-electric transducer microphones are suitable as they detect frequencies in the ultrasonic range. Solid-dielectric microphones are also suitable for such studies; however, they require a higher-voltage energy supply and are more mechanically delicate. They are also highly sensitive to environmental conditions, because of which high humidity introduces noise in their detections. Electret microphones are suitable to detect a wide range of frequencies with recent models providing improved features. These microphones are also electrically pre-charged, cheaper, inconspicuous, and omni-directionally sensitive. In contrast, directional microphones are configured to detect sound originating either from a single source or a single direction and can be used to conduct ambience recordings to understand the sound characteristic of a specific environment, or to selectively detect sound from a single species or individual with limited noise disturbances. Hydrophones are available to detect sound underwater. They can either be installed in a specific location or can be towed across a specific region to collect data from a wider spatial range. Depending on the depth at which intended recordings are to be collected, the microphone would require a pressure resistant container [7, 12]. Bioacoustics monitoring can also be performed using microphone arrays, i.e., the deployment of multiple microphones in the same region to triangulate the position of vocalising animals. This arrangement can be used to study animal movement patterns and behaviour in habitats that may be inhospitable [14].

In order to ensure that the sound detected by the microphone can be accurately analysed, the recording device must record the electrical signal detected without distortion, preserving features like the frequency and amplitude. Earlier studies employed analogue (tape) recorders; newer digital recorders are capable of capturing more exact details of the sound. To further ensure that the data is precise, it must be stored in uncompressed wave formats (.wav file) so the device requires suitable storage capacity. In addition to sound, recorders also allow for meta-tagging with information like location and time stamps. The data can be stored on an internal hard disk or portable external device like Secure Digital (SD), SD High Capacity (SDHC), or Compact Flack (CF) memory cards. For long-term studies, recording devices require periodic visits to ensure that the power supply and storage capacity are not exhausted. In cases where there is sufficient access to power and wireless networks, the data can be streamed from the devices, allowed for remote, real-time recording. The data can later be archived on Compact Disks (CDs), Digital Versatile Disks (DVDs), or BluRay discs [7, 12].

2.2 Data analysis

To analyse the detected and recorded sound, researchers use software to graphically visualise the acoustic signals and, thereby, examine their structure or compare it with a database of previously recorded species. Free (e.g., Ishmael, Praat, Raven Lite), open-sourced (e.g., Audacity, BioAcoustica), and commercial (e.g., Adobe Audition, Raven Pro) software packages are available to convert the digitally recorded sound into graphs and quantify important parameters like temporal and spectral structure [7, 15]. Prior to analysis, it is important to filter the recordings to ensure that only relevant data is used. In cases where the expected range of frequencies is known, high-pass, low-pass or band-pass filters can be applied as needed. A high pass-filter allows for the removal of sound below a specified frequency while a low-pass filter removes sounds above a specified frequency. A band-pass filter can be applied to remove sounds within a predefined frequency range, which is particularly valuable in cases where the recordings include frequent sounds produced by sources other than the species of focus [16]. Additionally, other 'noise' or unwanted background sounds and disturbances in the recordings should be minimised. While noise can be avoided through methods such as shielding the microphone or avoiding placement in windy areas, some degree of noise is inevitable in outdoor recordings. Noise can be processed and removed using sound enhancement methods or de-noising filters available within the audio analysis software [12, 16].

The two main visualisation tools used in bioacoustics monitoring are oscillographs and spectrographs. Oscillographs display temporal changes in the sound pressure in terms of amplitudes and voltages. Spectrographs are more commonly used as they present three parameters of the recordings: time, frequency, and amplitude. They can also reveal sound features that are imperceptible to the human ear, allowing for analyses of infrasound (from whales or elephants) and ultrasound (from bats). The spectrograms can either be analysed manually, or using automated algorithms for detection of specific features or comparisons with prior databases [7, 12, 13].

2.3 Commercial devices

Increasing demand and technological innovations have led to the development of commercially-available consolidated devices that record, store and filter audio signals. AudioMoth is a compact acoustic monitoring device that has recently emerged as a low-cost, power-efficient, and user-friendly alternative to earlier Passive Acoustic Monitoring (PAM) devices [17]. A distinguishing feature of this device is its ability to perform real-time analysis of acoustic signals, which allows for classification and filtering of data before storage. It can also be programmed to record only when a predefined acoustical signal (such as a gunshot or the call of a target species) is detected. This significantly reduces the storage requirements, power usage and post-processing time. While AudioMoth devices can run using existing open-source software, the researcher/s can also design their own software using the C programming language for real-time classification of sounds to tailor it to the requirements of the project. AudioMoth also has a cost-advantage over other PAM devices, as its manufacture involves the use of simply-constructed hardware with minimal fabrication steps. The distribution method employed for the sale of AudioMoth benefits from economies of scale through an online collective purchasing group called GroupGets, wherein the researcher/s can place orders which will only be manufactured and dispatched once the total order requirements are fulfilled. While a single AudioMoth device costs about US$43 to build, group purchasing allows an order of 500 devices to be built at $30 apiece. As a result, it provides an accessible and efficient alternative to conducting bioacoustics monitoring studies.

In addition to commercially available devices like AudioMoth, biologists are now taking advantage of the availability of low-cost, single-board computers (SBCs) to build devices for bioacoustics monitoring. Raspberry Pi is one such SBC which contains a central processing unit (CPU), a graphics processing unit (GPU), power input, and on-board memory, all within a palm-sized computer. These devices can be programmed with custom scripts to collect data specific to the study. They also have multiple ports that can be used to attach other devices such as an external power source, an additional storage device, an external microphone, an audio card etc. Most models of Raspberry Pi also carry Ethernet, Bluetooth, and Wi-Fi connectivity, allowing for remote deployment of acoustic recording devices. The use of SBCs for bioacoustics monitoring requires a basic level of programming ability, and Raspberry Pi offers a user-friendly interface with extensive online resources and tutorials available for first-time users [18]. The Solo audio recorder, a bioacoustics monitoring device, was constructed from the Raspberry Pi SBC [19], and is an inexpensive, robust, and highly customisable device that can operate in remote locations across large durations without the need of use interference. This device can be easily constructed by researchers using commercially available components (Raspberry Pi, a sound card, a clock, a memory card, a battery bank and a waterproof box), following online resources provided by the developers of Solo [20]. While it is more expensive than AudioMoth, it provides greater scope to customise data retrieval for the specific needs of the study.

2.4 Combination of bioacoustics with other field methods

Audio recorders can be combined with other devices to enhance the scope of bioacoustics monitoring. One such example is pairing camera traps (autonomously triggered cameras) with passive acoustic monitoring to assess the ecological impact of human disturbances [21]. Camera traps can be used to record medium to large terrestrial animals, document habitat conditions, and record visible human disturbances. Complementary acoustic recording units can be used to detect vocalising animals (like birds and insects) that may not be captured using camera traps due to their size. The latter can also provide a measure of anthropogenic noise pollution. Combining these two techniques can, thus, allow studies to monitor a wide range of species and stressors [21]. Bioacoustics monitoring can also be combined with drones or unmanned aerial vehicles (UAVs) to collect recordings from remote/inaccessible regions or over longer distances than a fixed recording device [22].

3. CASE STUDIES

3.1 Avian diversity

Buxton and colleagues [23] employed bioacoustics monitoring to assess the potential of using acoustic indices to evaluate the diversity, richness, and total number of animal vocalisations in the Western Ghats, a biodiversity hotspot region in southern India. They deployed acoustical recorders called Song Meters (manufactured by Wildlife Acoustics Inc.) in different locations and programmed them to record at pre-defined intervals and analysed data using spectrographs. The Raven Pro 1.5 software developed by the Cornell Lab of Ornithology was used for visualisation of spectrograms, tagging of vocalisations and to listen to the audio recordings. R software (version 3.4.1) was used to analyse the recordings to estimate species richness, diversity, and number of bird vocalisations based on acoustical indices. Buxton et al. [23] compared this with analysis manually conducted by a trained technician and a bird song expert, and found that while weekly acoustic indices predicted species richness and number of vocalisations with high accuracy, demonstrating the benefits of employing acoustical tools to monitor biodiversity. This finding indicates great potential for large-scale monitoring through rapid and standardised methods that can effectively extract valuable information from large data-sets through automated processes.

3.2 Indian purple frog

Bioacoustics monitoring was used by Thomas and colleagues [24] to study the calls of the elusive Indian purple frog to understand their vocalisation behaviour. This species is fossorial and is believed to be earless. Hence, the reason for their production of acoustic signals is of particular interest. The researchers placed acoustic recording devices in Idukki Wildlife Sanctuary, Kerala, typically after heavy rain when the target frogs were most active. To collect audio from specific individuals, they used a Sennheiser MKH 416 (directional microphone) mounted in a Rycote WS4 windshield (to prevent distortion) and stored the recordings onto a Fostex FR2LE solid-state recorder. Data on body size and soil temperature was also recorded when frogs were captured, and Thomas et al. [24] found that variations in the vocalisations were related to these factors. They also observed that the calls emitted by purple frogs beneath the surface of the soil were acoustically similar to those produced when an individual was induced to call while above the soil. This implies that these frogs can remain under a thin layer of soil, which does not obscure their calls. Additionally, the males engaged in antiphonal calling with vocalisations overlapping with nearby neighbours. This study thus catalogued the elusive purple frog's acoustic signals, which can be used to conduct non-invasive surveys of their population and further understand their vocalisation behaviour.

3.3 Ensiferan suborder of insects

Diwakar and Balakrishnan [25] employed bioacoustics monitoring to study the call structures and taxonomic diversity of the ensiferan assemblage of arthropods in Kudremukh National Park of the Western Ghats. The recordings were produced using a handheld Sony (ECM-MS957) microphone held near the calling animal and stored on a cassette recorder (Sony WM-D6C Professional Walkman) or an ultrasound detector (D 980 Pettersson Elektronik AB). The recorded analogue audio files were later digitised using the Matlab (1997, Version 5.1.0.421) software and spectrally analysed using Spectra Plus Professional (1994, Version 3.0), a signal processing software. The individual was also captured and preserved through taxidermy for later identification of the species. Through this study the researchers catalogued the spectral and temporal features of the acoustic signals of 20 species of ensifera. They also noted the peak timings of these calls, during which they can be recorded with minimal disturbance. Bioacoustics monitoring using this baseline data could be particularly valuable to study this nocturnal taxon as they will be difficult to observe without artificial light.

3.4 Buffalo Calves

Devi and colleagues [26] conducted a study to identify specific acoustical features from buffalo calves that could serve as early indications of pneumonia. Pneumonia causes inflammation of the lungs and physiological changes and alters the normal voice patterns produced by the animal. The researchers regularly recorded the voices of calves that were showing signs of respiratory distress at a livestock research centre in Karnal, Haryana. They placed a Sony ECM674 microphone attached to a Sony HDV FX7E handicam in the pens of individual calves for fixed periods of time, after which the audio signals were transferred from the handicam to a computer. The audio-visual editing software Adobe Premium Pro-1.5 was then used to observe the spectrograms of each signal and eliminate the environmental sound signals and other superimposed signals from the recordings. Following this, the PRAAT 5.1.36 software package was used to extract eight acoustic features from the signals, including call duration, intervals, maximum frequency, minimum frequency, peak frequency, band width, and peak amplitude. This was compared with clinical diagnostic tools to study the corresponding changes in their vocal signals through their infection and recovery. Devi et al. [26] studied the wave forms of these vocalisations to identify characteristic features of the infections which would allow for early diagnosis of the infection. This study provides a basis for further studies and the possibility of developing automatic detectors that can be used by livestock farmers to prevent pneumonia outbreaks in buffalos.

3.5 Humpback whale

While acoustical monitoring in the aquatic ecosystems of India have been relatively few, Madhusudhana and colleagues [27] conducted a systematic study of the vocalisations of humpback whales from a near-shore site in the Arabian Sea off the coast of Goa. The data for this study was collected with a SongMeter 3 marine autonomous recorder (manufactures by Wildlife Acoustics Inc.) suspended at a specific depth below the surface using weights and floatation buoys. The collected recordings were analysed both aurally and visually (using a spectrograph) with Matlab programs that were developed in-house. An automatic detector was employed to isolate the frequencies within the range characteristic of the target species. Through this study they catalogued the vocal repertoire of the humpback whales of the eastern Arabian Sea. The data gathered can be compared with recordings produced by future studies to gain insight into migration patterns and behavioural aspects of humpback whales. Bioacoustics monitoring is particularly valuable for this as previous knowledge of this species was dependent on stranding and beaching records which were based on visual surveys.

4. DISCUSSION

The case studies summarised in this paper illustrate the wide applicability of bioacoustics to conservation research. There are a number of microphones and recorders with varied features, providing for the application of this method to different species and habitats. Additionally, the software packages highlighted in the “Data analysis” section indicate the possibility of simplified analysis through the use of automated methods. The case studies illustrate the diverse applications for this method, such as predicting avian biodiversity in a specific habitat [23], detecting acoustical features of an elusive frog species and analysing the potential reasons behind their vocalisation behaviour [24], identifying insect species diversity in a region and cataloguing features of their acoustic signals [25], using sound for early diagnosis of pneumonia in buffalo calves [26], and documenting the vocalisations of humpback whales [27]. The range of equipment and software used across different studies also indicates the diverse range of options available for bioacoustics research in India.

An important advantage of bioacoustics monitoring is the possibility of passive and non-invasive data collection which limits intrusions that could introduce bias in the data or harm the animals in the study site. As a result, it is suitable for data collection involving elusive or threatened species. As audio signals can travel across large distances and through many obstructions, bioacoustics techniques can monitor remote locations, areas with low visibility, and hostile environments. It also allows for the detection of signals from small species as well as nocturnal animals. Additionally, bioacoustics monitoring is spatially and temporally scalable, and can produce long-term monitoring data as well as statistically significant insights into animal behaviour and ecology. As the collected data is archivable, the data analysis can be repeated by multiple researchers, reducing the likelihood of biases. Increasing technological innovations have made the hardware and software required for bioacoustics monitoring inexpensive and accessible, paving the way for greater use of this method. Access to inexpensive devices like AudioMoth, along with widespread ownership of mobile phones with in-built recording devices, carries great potential for combining bioacoustics monitoring with citizen science projects to involve communities in conservation research initiatives while collecting large volumes of data [16, 28].

Bioacoustics monitoring must also consider ethical issues that may arise from the research. The recording devices must be deployed in a manner that causes minimal disruptions in the study site. Researchers should also make sure that the devices are not inadvertently invading the privacy of people living in the region by informing local communities about the installed devices. While bioacoustics monitoring devices are unlikely to record human conversations, it is important to keep the potential for this to occur in mind while collecting and storing audio recordings from devices deployed in areas frequented by people. Another potential issue could arise from the data storage method. As bioacoustics data recorded from these studies might indicate the regions inhabited by threatened species, public availability of recordings data could lead to increased rates of hunting and illegal take. In situations where this is a possibility, care must be taken to ensure that the data is secure and identifying features of the location (such as GPS co-ordinates) should not be freely available.

5. CONCLUSION

Bioacoustics monitoring has the potential to address gaps in baseline biodiversity data that hinder effective conservation actions. By tapping into the auditory communications between animals, it allows for the non-intrusive collection of data about elusive, nocturnal, cryptic, and threatened species from a variety of habitats that may be inaccessible through traditional field research methods. A major factor that could limit the use of this method is the high initial investment required to purchase the necessary equipment, however recent innovations have made acoustic monitoring devices more efficient and inexpensive, paving the way for more monitoring projects and large-scale data collection. Greater accessibility of acoustic monitoring devices could also facilitate more citizen-science projects wherein the local community is involved in monitoring biodiversity in their environment.

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