VARAD GIRI

THE MUSICAL WORLD OF FROGS

Are We Listening?

By Dr. Seshadri K. S.

One of the surest signs of the onset of monsoon is the incessant croaking of frogs and toads. The hot and humid day gives way to a cool evening and with even the slightest trickle, myriad sounds fill the air. Soon, the trickle becomes a downpour and all one can hear is the thunder and the pounding of rain. It is thus a simple association that frogs are the harbingers of rain. The association of anuran (frogs and toads) calls and the rains have been made as far back as the times of the *Rig Veda*. The frog hymn in the seventh *mandala* (book) of the *Rig Veda* outlines how frogs lay in wait for the rains and begin to talk to each other, just like people. It goes on to describe how one frog bellows like a cow and another bleats like a goat. In present times, the Vedic hymn has been interpreted as evidence of people having known the connection between rain and anurans, and of their keen ability to observe nature. Yet, little remains known about why anurans vocalise, and what they mean to them and us.

ANIMAL COMMUNICATION Animals communicate for a variety of reasons ranging from marking territories to attracting a mate. In every form of communication, there are two participants, one that sends out a signal and the other that receives it. Communication can take many forms: a peacock spreads out its wings and struts in front of a female – this is a form of visual communication. A male bushlark flutters up into the air and descends, singing an elaborate song, combining a visual and an auditory signal. A male toad sits in a small puddle of water and emits a loud, repetitive call, using sounds to possibly woo a female.

Communication is a costly affair. One must expend energy to produce sounds. An added cost comes from the increased risk of predation. Predators can easily eavesdrop on an animal that is perched in the open and singing away. To be effective communicators, organisms would need to overcome these challenges. One way to do this is to have calls for different purposes and use them to contextualise information. For instance, a langur produces a loud "*haark*" call upon spotting a potential threat and other langurs as well as other animals nearby pause, becoming vigilant of their surroundings. In contrast, the langur has a different set of calls for social contexts such as mating or foraging. Another way of achieving efficiency is to string together signals in temporal patterns, resulting in complex sequences. Birds do this to make elaborate songs, and perhaps there is no better example of syntactic structure in communication than humans.

ANURAN VOCALISATIONS Anurans vocalise primarily to attract mates. Typically, males are vocal, and females tend to produce little or no sound. Anuran vocalisations have a wide range of functions from indicating the quality of the mate, advertising position, and warding off competitors of the same sex. Male anurans produce sounds by pumping air through their vocal cords into vocal sacs, which act like reverberation chambers. Unlike most other vertebrates, anurans have a closed system, where the air is recirculated between the lungs and the vocal sacs. Researchers have observed anurans to possess a repertoire of vocalisations, which are classified into different 'call types'. Each call can comprise many 'notes', and the notes can be of many types. For example, the common toad *Duttaphrynus melanostictus* has a multi-note call that goes "*turr turr turr turr turr…*", whereas the Kalpetta waterdrop frog *Raorchestes nerostagona* has a single-note call that goes "*tuckk!*". Describing anuran vocalisations using words would be challenging. An efficient technique would be to use spectrograms, where the frequency (number of waves) and amplitude (height of a wave) of a call can be plotted against time. The result will help determine the overall frequency of calls, visualise the number of notes in a call, and measure a set of parameters such as call duration, note length, number of notes, inter-note length, and so on.

Anurans have a repertoire of vocalisations or call types, each of which has been attributed to some function. The classic example is the Tungara frog, found in parts of Central and South America. Males of this species can produce two calls: a simple call where only a long-drawn 'whine' is produced, and a complex call where up to seven, short, high amplitude 'chuck' sounds are added to the whine. Do the two calls have varying functions? Indeed. The whine helps the female locate the calling male in a process called 'phonotaxis', and the chuck enhances the attractiveness of the male to the female. Vocalising males put themselves at risk by being susceptible to eavesdropping by unintended receivers such as predators. If a male vocalises consistently, it may indicate a higher level of genetic fitness, and the female uses multiple such cues to decide on a mate. Mating, however, is one of the contexts where anurans vocalise.

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ABOVE *The Amboli bush frog* Pseudophilautus amboli *is widespread in the central Western Ghats. The males can be found calling among leaves. Vocalising males have a yellow hue to their vocal sac.*

FACING PAGE *The Humayun's wrinkled frog* Nyctibatrachus humayunii is *endemic to the northern Western Ghats. Males vocalise from leaves overhanging first-order streams and females lay eggs on the same leaves. The tadpoles hatch and drop down into the water where they continue metamorphosis. Most species of wrinkled frogs have a pair of vocal sacs on either side of their head.*

Anurans may be able to produce complex calls by either repeating the same notes in a temporal sequence or having a different set of calls according to context. Anuran vocalisations are crucial in mate choice. The female assesses male quality by evaluating the calls.

STUDYING FROG CALLS IN THE WESTERN GHATS In the summer of 2019, Ananda Shikhara Bhat, an enthusiastic student of biology, reached out to me with some fascinating observations on frogs he had made with his colleague Varun Sane. They had gone out into the night in the Western Ghats and had seen the Humayun's night frog *Nyctibatrachus humayuni* producing different types of calls. Making these observations in Tamhini Ghat of Pune, he had observed that the male frogs produce a seemingly simple

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ABOVE *The yellow bush frog* Raorchestes luteolous *has a relatively long-drawn call. The male starts with a short "*trrr*" and switches to a series of "*tick tick tick tick*" with up to 40 ticks! The vocal sac acts like a reverberation chamber.*

call with one note and a complex call with multiple notes added. The complex call appeared to be made in the proximity of another conspecific (same species) male. He had a whole bunch of recordings, including information of the presence of a conspecific nearby and if it was vocalising too.

Shikhara's observations were fascinating. We sat down at the canteen in the Indian Institute of Science, Bengaluru, discussed ideas over lunch, and got in touch with his supervisor Dr. Anand Krishnan, who studies animal communication, at the Jawaharlal Nehru Centre for Advanced Scientific Research, among other things. Shikhara was a student (now in the University of Mainz, Germany) and Anand was his advisor at the Indian Institute of Science Education and Research (IISER) in Pune. We had our work cut out for us in the form of a slew of research questions. Do other members of the genus *Nyctibatrachus* also have a repertoire of calls? Do frogs use different call types to convey context-specific information? If they are vocalising in the presence of a conspecific male, do they change the sequence of their call or switch to a completely different call type? Are the calls randomly strung together or is there a syntactic (syntax-related) pattern to it? Soon, we outlined things we would do in the field, and Shikhara set off with a recorder and a camera to make observations.

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Just about the time he was to head back to the field in 2020, the COVID19 pandemic took the world by storm and all research work was grounded. When the lockdowns were partially lifted, Shikhara managed to get to Sirsi in Karnataka to make recordings, but the locals were hesitant to let an outsider into their town and he was confined to the homestay. At night, he began to wander about the property and realised that there was another frog that was vocalising, and it appeared to have a repertoire of calls. The Amboli bush frog *Pseudophilautus amboli* is a small frog, measuring about half the size of a human thumb, and is found in the central Western Ghats. Observing them for a couple of nights, Shikhara was able to discern that the frogs had a repertoire of calls, which would vary depending on the context. This discovery came as a blessing in disguise. Instead of comparing the vocalisations of two species within the genus, we were now able to ask questions across two families of frogs that separated from their ancestors nearly 60 to 100 million years ago.

ANURANS CAN CONVEY CONTEXT Shikhara returned to Bengaluru after several nights of recordings and observations. The pandemic-related restrictions on movement were still in place and we would meet online to analyse data. We found that both species *Nyctibatrachus humayuni* and *Pseudophilautus amboli* had a repertoire of calls. When compared to the existing classification of frog calls *N. humayuni* was comparable to other species, where only the frequency is modulated while the notes remain uniform. The males produced an 'ascending' note, and a 'descending' note after the ascending note. The notes are ascribed as ascending or descending based on the energy distribution in a spectrogram, which to the human ear appears as if the call is increasing or decreasing in amplitude. However, the other frog *P. amboli* belonged to a category of frogs modulating the notes. They produced six different note types at varying frequencies. Some notes were uttered more often than others. Despite different repertoire sizes, the frogs were contextualising their vocal signals. Having listened to the recordings and extracted information by annotating the calls on computer software, we were able to conclude that males of *N. humayuni* produced only the ascending note when alone, and added up to eight descending notes when in the presence of another male. The males of *P. amboli* in contrast, produced two sets of note types. One set, comprising three different notes, was produced when the males were alone, and the other set of two notes was produced when they were in the presence of another male. One of the six notes was so rarely produced that we did not consider it for statistical analysis.

SIMPLE OR COMPLEX? While it was clear that the two species could contextualise their signals, were they modulating the information being conveyed in different contexts as well? The Shannon diversity index is a measure used often to quantify biological diversity. It uses information about how many species are found and how often they are found.

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ABOVE *The Malabar tree toad* Pedostibes tuberculosus *was an enigma from the Western Ghats. Recent citizen-sourced data suggests that the toad is fairly common. Most people may have missed it because they vocalise before the onset of monsoon and make a rasping call that is hard to associate with a toad. They live among tree tops.*

Having measured the number of note types and how often they are produced, we used the Shannon entropy framework to infer if the information is of higher or lower diversity depending on the context. Males of *N. humayuni* added a descending note to their vocalisation in the presence of a male, and this increased the Shannon entropy. However, the males of *P. amboli* switched to different note types and repeated them; this did not change the Shannon entropy value and the vocalisations were stereotypical.

SYNTACTIC COMMUNICATION Frogs were always thought to be simple creatures that mindlessly croak. In statistical terms, they were thought to follow a Markov-chain where the next event is dependent on the current state. Thus, if a frog were to produce one note at one time interval, it would be expected to continue producing the same note the next time it croaks. Markov-chain models are extensively used in a variety of applications because they use information about the probability of events occurring. In our case, the frog vocalising presents a case that could be compared against a Markov-chain expectation. Since we had calls from multiple individuals of

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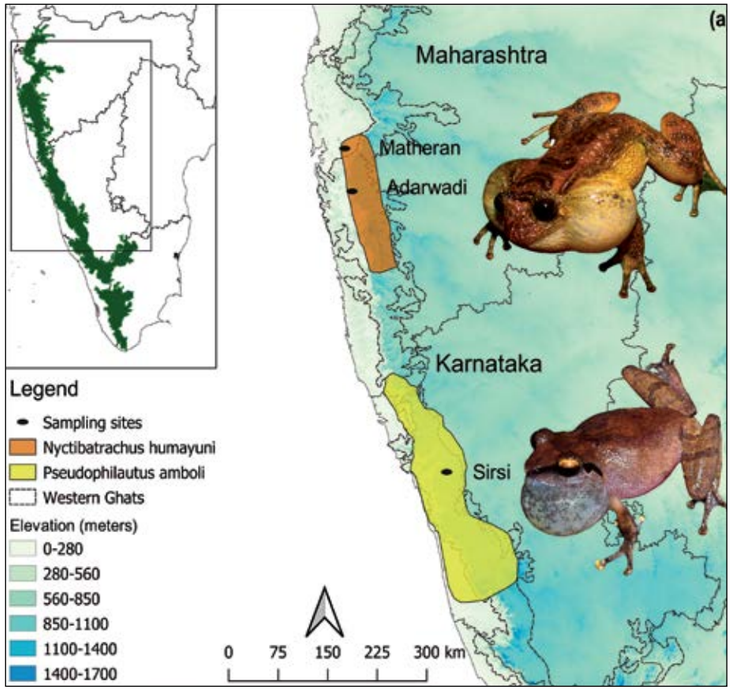

ABOVE *A map of the Western Ghats showing the distribution of the two species that were studied,* Nyctibatrachus humayuni *and* Pseudophilautus amboli.

both species, we annotated the calls to note types and compared them. To our surprise, we found that both species had a syntax in their vocalisation, and each note type had different probabilities. When alone, males of *N. humayuni* were likely to remain silent if they were silent, to begin with, or produce one ascending note and then go silent. When in the presence of a conspecific male, the probability of a descending note following an ascending note was much higher. In contrast, the vocalisations of *P. amboli* could be categorised into two groups. One set of calls contained three notes and the other contained two notes. When vocalising alone or in the presence of conspecific males, the frogs produced two distinct note types more often than the others, and when in a territorial dispute where two males engage in a physical fight, they produced a note belonging to the second note type. Overall, the pattern of these note occurrences was different from what would have been expected by chance, thus suggesting that they were using syntax in their communication.

DO THE CALLS MEAN ANYTHING? Often, we humans take pride in our ability to communicate syntactically. Our work cuts our ego and puts us in place by showing that anurans that are half the size of our thumb are also able to do this. They seem to have evolved this ability to communicate much before us on the evolutionary timescale. Our work shows that anurans can convey contextual information despite having a limited repertoire. It also suggests that the ability to effectively communicate was likely present in the common ancestor of the two endemic species belonging to the families *Rhacophoridae* and *Nyctibatrachidae*. While we have made some significant discoveries, we are again at a point where we have more questions than answers. What do the females make of the different note types? Are the different note types intended to address both conspecific males and females? Is there a differential risk of predation to each note type and is that why some notes are rarely produced?

ANURAN VOCALISATION IN THE WESTERN GHATS The Western Ghats is a renowned hotspot of biodiversity. Recent research has uncovered that there has been a long history of speciation in the Western Ghats. Despite the abundance of anurans and their vocalisations, existing studies were all limited to using vocalisations to identify

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Vocal Climate Challenges

Scientists from the University of California Los Angeles (UCLA) recorded changes in the vocalisations of the coqui frog, native to Puerto Rico. Known for the male's unique two-note "*co-qui*" call, the frogs exhibit differences in size and call characteristics based on their habitat location. Those found on colder mountain peaks are larger than those in the warmer valleys. Those living in mountain bases produced short, high-pitched calls at high rates while those on the peak had longer, lower-pitched, less frequent calls. However, over two decades, the scientists found that the calls of every frog had become higher in pitch. The scientists also had to move higher up in the mountain to record calls with certain characteristics. They attributed such upward habitat shifts to temperature changes as a result of climate change. Lead researchers Peter Narins and Sebastiaan Meenderink worry that if such temperature changes persist, it could lead to a collapse of the coqui population and spell disaster for the Puerto Rican ecosystem.

Similar changes are being seen in other parts of the world. In Alaska, USA, warming temperatures are causing rapid changes to the subarctic wood frog's habitat. Scientists used passive acoustic monitoring paired with semi-automated detection of wood frog calling to create an accurate method for tracking changes in population-scale wood frog breeding. They found that less snow cover and warmer air temperatures are changing spring runoff amounts and causing a decline in habitat availability for *Lithobates sylvaticus*, and impacting its breeding phenology that is closely tied to spring onset.

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ABOVE *The first time the author encountered this Jog wrinkled frog* Nyctibatrachus jog *was in the year 2008 in Katthalekan, Karnataka. These endemic frogs are semi-arboreal and produce a whistle-like call. Back then, the author did not believe his colleague who said it was a frog!*

species and use them as characteristics to describe new species. Anurans are facing the onslaught of development and as natural spaces continue to be fragmented and destroyed, there will be cascading effects on them. Anuran vocalisations play an important role in how humans perceive natural landscapes as well. Those of us who have been around for more than two decades will recall the monsoon night filled with a cacophony of anuran vocalisations. Today, that has slowly been replaced by traffic noise or dreadful silence. With the loss of species, we are also going to lose out on the rich insights one can get by studying aspects such as animal communication.

Anurans can serve as excellent indicators of change. One could monitor anurans just like a teacher takes attendance. Listening and noting down when a species is calling over multiple years can give us incredible insights into how the anuran community is changing. There are several such efforts in the United States as well as Australia, where crowd-sourced data is being used to track changes. While there are some efforts at monitoring amphibians in India, there is a need to scale up the effort. Perhaps our work is one example that can inspire people and help them realise that there is more to anuran vocalisations. The next time you hear a sound in nature, pause, take a moment, and listen. There might be figurative pearls of wisdom that could help draw us out of the well of ignorance. If not, I am afraid, we may continue to remain a proverbial *kupa mandooka* – the frog in the well.

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Seasonal Sounds

Most frogs only call during the breeding season, which is triggered by changing seasons, temperature and rainfall. Mating seasons vary for different species – some are winter breeders, yet others early and mid-spring breeders, and some are summer breeders. This staggering of breeding seasons allows each species its time of acoustic space to call, breed and ensure sufficient food for tadpoles. As frogs begin calling earlier than their expected timeline, and seasons shift, merge and overlap, there could be a cascading effect with competition over resources such as water, food, and space, which threatens their very survival.

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