Surrounded

A Series of Sound Installations That Combine Plant Electrophysiology and 3D Sonic Art

AUGUSTINE LEUDAR

ABSTRACT

This paper discusses a series of sound installations that combine plant electrophysiology with 3D sonic art. A brief introduction to plant electrophysiology is given. The sonification of electrophysiological signals in the mycorrhizal network is discussed, explaining how art and science are combined in this project in a way that differs from the simple sonification of data. Novel 3D audio spatialization techniques, the 3D audio mapping of natural environments and immersion are also discussed, along with technical details of how to read the electrical signals in plants known as *action potentials*. Other topics addressed include acoustic signaling in the forest, spectral composition and interaction with forest flora and fauna.

Surrounded (Fig. 1), *The Code* and *El Bosque Encantado* were a series of site-specific multichannel 3D sound installations that took place in three wooded locations—the Botanic Garden of La Paz, Bolivia; the 4th Computer Art Congress in Rio de Janeiro; and the Botanic Garden of Quito, Ecuador. As a triptych they form three aspects of one continuously evolving work.

The work combines science (plant electrophysiology) and sound art (3D experimental audio) and aims to avoid merely sonifying data (for example as with an ECG machine). Any electrophysiological data incorporated into the soundscape was based on established electrophysiological principles and technically robust equipment, using a control to calibrate equipment where necessary. Sounds and video accompanying the article are listed by name where appropriate.

The original inspiration for this work came about after moving to the Peruvian jungle town of Pucallpa in 2001, where I have lived on and off for twelve years. Until recently, medicine in the Peruvian Amazon has been based mainly on plants. Those who work with plants are considered to be doctors and fulfill the same function as a doctor in the developed world. Many of these practitioners are of course charlatans, but others do know a great deal about plants, and their knowledge is actively sought out by pharmaceutical companies.

Augustine Leudar (sound artist, PhD). Email: <augustineleudar@gmail.com>. Web: <www.augustineleudar.com>.

See <mitpressjournals.org/toc/leon/51/5> for supplemental files associated with this issue.

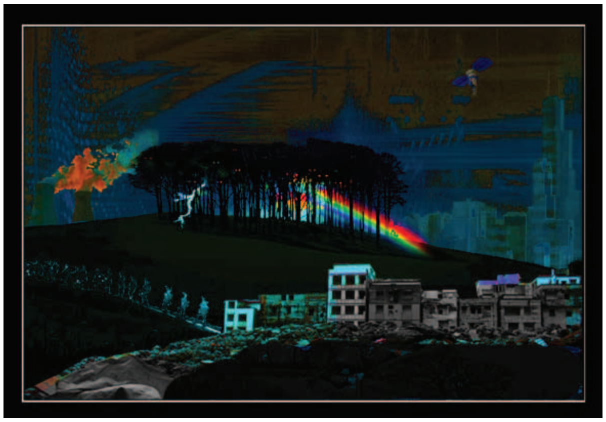


Fig 1. Artwork for *Surrounded.* (© Augustine Leudar)

They say they discover new cures for illnesses by communicating directly with the plants and that sound plays an important role in the process [1]. Rather than dismiss this claim out of hand, I wanted to see if there was any scientific evidence at all to support the view that plants could be conscious or that they responded to sound. It turns out there is quite a lot. The idea that plants had their brains underground was first described by Charles Darwin [2] shortly after he worked with the electrophysiologist Burdon-Sanderson, who was the first to discover that plants exhibited electrical signaling similar to the nerves found in animals [3]. After a long lull in the field due to discredited pseudoscientific experiments in the 1970s as described in "The Not-So-Secret Life of Plants" [4], research in the area of plant intelligence, memory and communication is blooming [5]. Our consciousness, or at least our thoughts, from the most reductionist viewpoint could be described as electrical activity in the brain. Such complex electrical activity has been discovered in plants including their roots and the fungal mycelium that connect them [6]. Although there is strong evidence to suggest that there is communication across this network [7], it is not known if such signaling is chemical, electrical or even acoustic [8].

 doi:10.1162/LEON_a_01338

PLANT NEUROBIOLOGY

Current research suggests that plant roots are analogous to an underground brain and, in terms of complexity, an entire forest network is many times more complex than the human brain. Aside from electrical signaling, when chemical signaling, both airborne and underground, and the possibility of acoustic signals (including that of insects that interact symbiotically with plants) are taken into account, it is clear that the forest as a whole could be a vast and highly complex signaling system at least as sophisticated as a mammalian nervous system.

Some of this is of course highly speculative, but some of the top scientists in the field believe that plants' root systems do act in a way similar to neurons [9] and plants have even been shown to exhibit forms of long-term memory [10] and swarm-like behavior [11]. Such research has even influenced popular culture such as the film *Avatar*, but the idea that the forest itself could be a form of neural net may not be as far-fetched as it seems. There are of course dangers of anthropomorphizing the processes involved, and the fledgling field of "plant neurobiology" is not without its critics [12]; however, many of the experiments have been repeatable, and it is gaining increasing mainstream scientific acceptance [13].

I believe that because of the current ecological disaster the world is undergoing, any attempts to enrich our understanding of the natural world is valuable, and art has a role to play. The findings of scientific research can have profound implications, but the public may be unimpressed by a research paper, and I have had many conversations with scientists about how this research could be brought to life through art. My intention for this body of work is therefore to create art installations incorporating current research, to investigate the possibility of increasing scientific understanding through art and to create tools for future development. By using networks of electrodes, audio spatialization and artistic techniques, I decided to try and make activity in this network tangible through sound in real time and immerse the public in the complexity of these processes. I make no grand claims of "consciousness" for the forest—we can barely define the basis of consciousness in humans—I simply make these processes tangible, incorporate them into works of art and allow people to draw their own conclusions.

LOCATION

Bosque Encantado and *Surrounded* were composed in virgin rainforest at a biological research center at Jatun Sacha [14]. *The Code* was composed at Omaere reserve on the edge of Puyo [15]. Both of these locations are in the Ecuadorian Amazon.

Jatun Sacha (Kichwa: "Great Forest")

Composition took place in a garden of medicinal plants set in virgin rainforest in a temporary open-air multichannel studio protected by a mosquito net and waterproof plastic (Fig. 2). The speakers were mounted in trees over a large area around the forest. Initially, composition took place mainly at night, although due to the effect of "playback" (described below) this shifted toward the day.

Once the composition was complete, I transplanted it to the site of the exhibition, where the exact same speaker configuration was replicated. There I made fine adjustments to the installation to tune it to the particular acoustics of the space.

SOUND PROCESSING TECHNIQUES AND CHOICE OF SOUNDS

When converting electrical signals in plants, or in fact any data, into sound, one is faced with a simple yet important choice: What kind of sounds should the signals control? Reading electrical signals in plants is quite similar to EEG readings of a person's heart in a hospital. In the case of an EEG machine, a simple beep is mapped to an electrical signal in the heart. This however is purely functional—the straightforward sonification of data, with no intention of being artistic. Within the context of sound art, this mapping becomes a creative decision and is a place where art and science can truly combine.

Common choices made by artists in the past with this kind of work were stereo and used signals to trigger MIDI piano notes [16]. Others have used random sine and saw waves whereby the oscillators become especially chaotic and high pitched when there is a signal [17]. Aside from serious technical concerns about whether the signals being read are artifacts or not, to me these choices seemed either not very revealing, not aesthetically pleasing or both. The piano sounds seemed to anthropomorphize the processes involved far too much: Why would plants play piano? Why should they be restricted to equal temperament and MIDI instruments? Would anyone

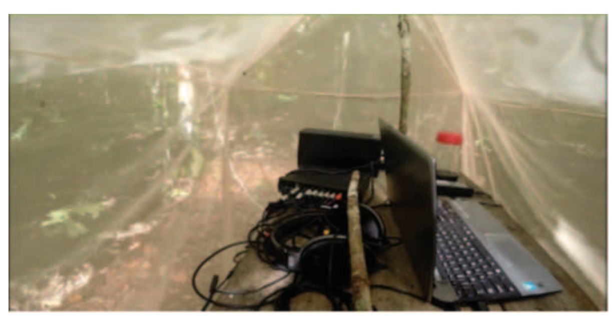


Fig. 2. Open-air 12-channel studio connected to speakers over an area of around an acre. (© Augustine Leudar)

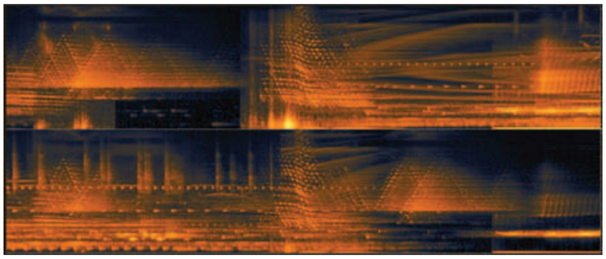


Fig. 3. Excerpt from spectrogram of composition *El Bosque Encantado*. Sound: "spectral canopies" in the supplemental files at <mitpressjournals.org/toc/leon/51/5>. (© Augustine Leudar)

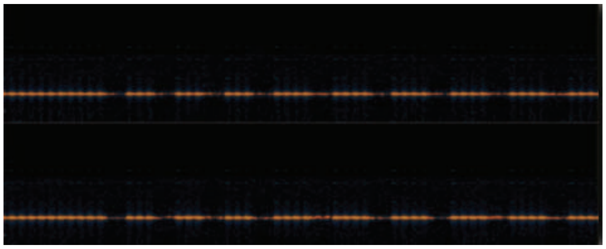


Fig. 4. Cricket and insect sounds when isolated exhibit Morse-like discrete sequences of pulses. The Morse-like sounds were isolated and formed the core of the sound sources in the installation *The Code* in Brazil. Sounds: "Cricket Code" and composition *The Code* at <www.augustineleudar.com/Offline%20 Website/page13.html>. (© Augustine Leudar)

listen to this as a piano piece in its own right? The randomized synth sound revealed more about the signals in the plants, but if presented as a piece of sound art in its own right it also seemed unlikely to would fare well, with its only merit being the idea that somehow "the plants were making the sounds." For me then, the challenge was to create a work that could stand alone as a piece of sound art even if the listener was completely unaware of the scientific side of the piece.

Combining Scientific Data and Artistic License

In multidisciplinary work that mixes scientific data and art, I would argue that not all sounds necessarily need to be controlled by the data. Otherwise the art would become little more than an ornate ECG machine. I would therefore argue that some sounds can be used simply because the artist feels inspired to use them in a particular context. Some works, especially those that use scientific data, seem to me to neglect the aesthetics of the piece, something that would be less likely if they were making a purely artistic or musical work. Adopting a flexible approach means that a work can become a true integration of science and art as opposed to art being reduced to the role of puppet animated by strings of data. It must be stressed, however, that if the composition uses no data at all, or if the data is so mangled that it bears no relation to the original input, then it becomes a purely artistic endeavor, and at this point all claim to it being in any aspect a scientific project should be abandoned. In the case of the installations discussed here, a difficult balance had to be struck. The composition had to be aesthetically pleasing, but it also had to make tangible bioelectrical activity in plants. In the case of the current work, scientific data radically changed elements within the composition but were not the whole composition. I wanted the artistic side of the work to be free to indulge the most far-flung reaches of the imagination but the scientific side to be strictly controlled and have a robust technical basis.

Ultrasonic Jungle

One of the principal choices of sound sources used in this work was discovered by accident while staying on an ecological reserve that had lost most of its fauna. Omaere has done a commendable job of turning many acres of sugarcane plantations back into rainforest, but most of the animals found in primary forest have not returned yet, leaving a lack of material to record there, at least in the audible frequency range. I usually left an SD card microphone running overnight deep in the forest as a kind of sound trap, in the hope of recording unusual sounds. After another disappointing scan of the previous night's spectrogram, I decided to examine some of the ultrasonic sounds, which were well beyond the range of human hearing. The spectrograms revealed curious shapes that I began to isolate, noise-reduce and pitch down (Color Plate D). This process revealed some extremely haunting sounds, and they formed the basis of much of the sound material in the installations, especially after they had been manipulated by data being read from the plants. While hearing individual ultrasonic wildlife sounds slowed down may be interesting and even form the basis of a stereo composition, when surrounded by these sounds in full 3D audio, and when sounds are selected as elements of a 3D audio collage in a forest, this ultrasonic jungle pitched down into the range of human hearing provides an unusual insight into a world normally hidden from us.

Spectral Composition

Eventually it became possible to recognize which sound sources suited the composition merely by looking at the spectrogram. Synthesized sounds with "geometric-like" shapes and natural sound sources that exhibited complex patterns usually turned out to both sound and look interesting. An important visual aspect entered the compositional process. When a section of the installation was bounced down to stereo, it was interesting to see that it exhibited many geometric and graceful forms even when they had been originally picked by ear (Fig. 3).

Further explorations revealed that the high-pitched twittering of birds made a sound akin to laughter when pitched down. Ornithologist Chris Canaday, author of *Common Birds of Amazonian Ecuador* [18], noted after listening to some adjusted recordings that some birds' high-pitched calls when slowed down were almost identical to the audible cry of completely different species of birds. In the included example, an Ecuadorian bird (*Thamnophilidae*) sounds like the call of various owls, such as the mottled owl, when slowed down (sound: "birdslowed" in the supplemental materials). Perhaps strangest of all was the Morse code–like calls of crickets and other insects. The pulses of these calls are organized into discrete packets, each of which contained varying numbers of pulses (Fig. 4). These sequences of pulses appear

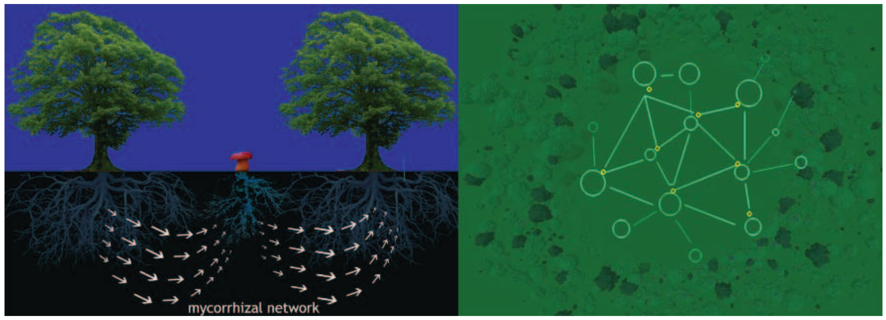


Fig. 5. The mycorrhizal network (left) is a network of tree roots and fungal mycelium through which trees communicate. Larger trees, represented here by larger circles, act as nodes in the network and generally have more connections (right). (© Augustine Leudar)

so complex and varied that it is hard not to speculate that they form a kind of syntax and communication beyond mere reproductive or territorial signaling.

Synthesized Sounds

I also used synthesized sound sources in the composition. These were modulated by the electrical signals in the plants in various ways apart from pitch shifting. The parameters of granular synthesis could also be changed by plant signaling. For example, grain spacing, grain size and grain shape were all possible to modify in real time. Other objects such as filters were also employed as well as more conventional effects such as delays and reverbs. Using unconventional sound processing techniques allowed texture as well as pitch to sonify signaling.

SONIFYING THE FOREST NETWORK

By converting electrical signals in a network of plants, known as “action potentials” and “variation potentials,” at different points in the forest, the work incorporates electrical activity in forest networks such as the mycorrhizal network. Action potentials in plants are usually quite fast signals, lasting no more than a few milliseconds. Variation potentials change slowly over much longer periods of time, such as minutes or even hours.

The Mycorrhizal Network

The forest communicates underground via a system of tree roots interfaced with fungal mycelia known as the “mycorrhizal network” (Fig. 5). The exact nature of signaling across the mycorrhizal network is poorly understood. Current scientific consensus maintains that it is most likely to be chemical signaling, though electrical signaling between plants is also possible. Aside from action potentials in individual plants, some studies show that electrical activity has been found in the mycelium of fungi [19] and the roots of plants [20]. I wanted to create a prototype system that could sonify signaling in the mycorrhizal network and the forest network as a whole. The system described here would work equally as well for chemical signaling as electrical signaling, although electrodes would have to be replaced by the equivalent chemical sensors.

Localization of Electrical Activity in the Network

Spatial audio is extremely applicable to sonifying biological networks in situ. Networks of communication in the forest are by their very nature spatial or “3D.” Larger trees form “nodes” in these networks [21] (Fig. 5). Therefore it seemed logical to space speakers around the forest at key nodes that, in combination with electrodes, could act as indicators as to where such activity was taking place (Fig. 6).

Broadly speaking, if there is a signal in a particular tree, a sound comes from that tree. If a signal appears in one tree and then shortly afterward at another nearby, then the sound should pan along the route between those two trees, mimicking the journey of the signals in both speed and intensity. In this way, by panning sounds between trees as they exhibit activity, the audio spatialization can give some sense of the network at play.

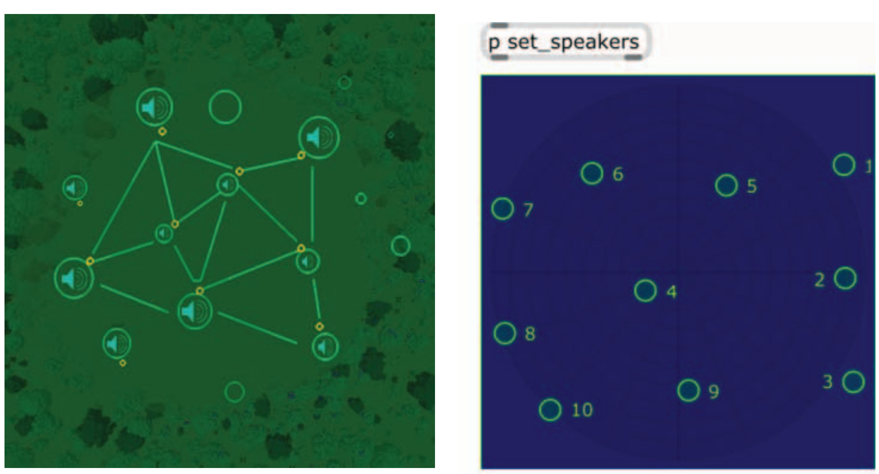


Fig. 6. (left) Dots at icons indicate electrodes. Next to them are small speakers at key nodes of the network. Lines show the directions that signals can take between trees and that audio is panned. (right) A map of speakers is entered into the software (ICST/MaxMSP); sounds can then be panned around the forest. (© Augustine Leudar)

There have been no scientific studies using multielectrode arrays in these forest networks, let alone attempts to sonify these arrays spatially in real time. This, therefore, is an area in which artistic practice can help illustrate scientific phenomena and perhaps even further scientific research and understanding.

Although in its early phases, with developing technology, sonifying these networks could become a lot more accurate in the future and will be able to indicate with more exactitude if, where and when signaling is taking place between trees. For the work described here, there was a maximum of 16 electrodes in the forest. Interpolation between key nodes can give an idea of how signals may be traveling in the network, although obviously the more points on the network that can be measured the greater the resolution and more revealing the sensor system becomes. This work, which is still being developed, represents a fairly basic prototype for such a technique; however, the system is robust and can be easily adapted to incorporate more electrodes should more portable data acquisition devices with more channels become available.

SPATIALIZATION TECHNIQUES AND IMMERSIVENESS

Originally I started working with peripheral speaker arrays whereby the speakers surrounded the listener, such as those used in ambisonics and wave field synthesis (WFS). I soon realized that peripheral speaker arrays were not suitable for the current application. They could not recreate the fully immersive effect desired nor the 3D audio that we all experience in day-to-day life. In particular, peripheral speaker arrays are not very effective at getting sounds to appear close to the listener (*focused sources*) and cannot create the sensation of sounds traveling between discrete objects within the space convincingly. There are reports of high-end WFS systems and very high-order ambisonics being able to do this better but, even if enough speakers were available, the regular arrays required would still make them unsuitable for much site-specific work. Therefore, I used fewer speakers in much more irregular arrays with disguised speakers close to the listener and indeed around which the listener could walk (*Around Sound*) (Fig. 6).

Trajectories through the Forest

As well as static sound sources that stayed by particular trees, I wanted to have sounds that would appear to "float" and wind their way through the forest, not just the sounds that mimicked the paths of electrical or chemical signals, but also sound that fitted with the space and the composition. The panning used to achieve this bore more in common with DBAP (distance-based amplitude panning) than ambisonics or WFS. I used ICST's Max ambisonics equivalent panners, with low directivity so that their activity was closer to normal amplitude panning in terms of accuracy of localization. I entered a map of the speaker array in the forest into ICST; sounds could then be automated on a trajectory around this map or be controlled by bioelectric potentials in the plants (Fig. 6).

Multiple Moving Sound Sources and Automation

I used many samples, and several were always playing simultaneously. As mentioned, each sound had its own trajectory through the forest. This was accomplished using multiple ICST objects in poly objects in MaxMSP. As these trajectories passed along different routes through irregular speaker arrays, and because there were hidden speakers close to the listener, it gave the impression of sounds coming very close to the listener. Reverbs, delays and granular artifacts on the sounds were panned slightly behind the principal sound source, to give the effect of "sonic trails" being left behind them.

READING THE SIGNALS

Numerous attempts by artists to sonify electrical activity in individual plants have been undertaken, although technical details are hard to come by and technical flaws are often apparent. For example, crocodile clips are used, or the artist touches the plant, claiming a response, when in fact their own electrical field is causing the signal in the electrodes, not the plant.

It is extremely difficult to read electrical signals in this network as roots are, obviously, underground, and placing electrodes accurately beneath the earth presents considerable technical challenges. Action potentials and variation potentials are found throughout the plant, so if inserting electrodes into the roots proves impractical, then placing electrodes elsewhere in the plant may still give some idea of how bioelectric signals are propagating throughout the forest network. For invasive or noninvasive electrodes, nonpolarizable AgCl or graphite electrodes should be used. Crocodile clips are not suitable. Wounding potentials can be generated when invasive electrodes are inserted, so it is best to wait some time for them to subside. It is also important to realize that scar tissue may form and after some time may begin to insulate the signal from the electrodes. To offset this, ECG electrode gel or some other form of conductive liquid that does not damage tissue may be useful. ECG electrodes can also be used on the surface of leaves, although signals are likely to be weaker. The data acquisition device used here was a Labjack U3 LV. The sampling rate should be sufficiently fast to register an action potential that can be as short as 100ms (some say shorter), so normal multimeters are not suitable (they read sometimes only four times a second), and Nyquist should be considered when selecting sample rates. To read a signal of duration 100ms, 20 samples/s should be sufficient. As a Faraday cage cannot be used easily in the field, installations should be done as far away from mains electricity as possible to prevent electrical interference, and signals should be filtered to further clean the signal and wherever possible equipment should be run by battery. Great care should be taken to connect the ground correctly. Further technical details on how to read electrical signals in plants can be found in the paper "An Artist's Guide to Plant Electrophysiology" [22].

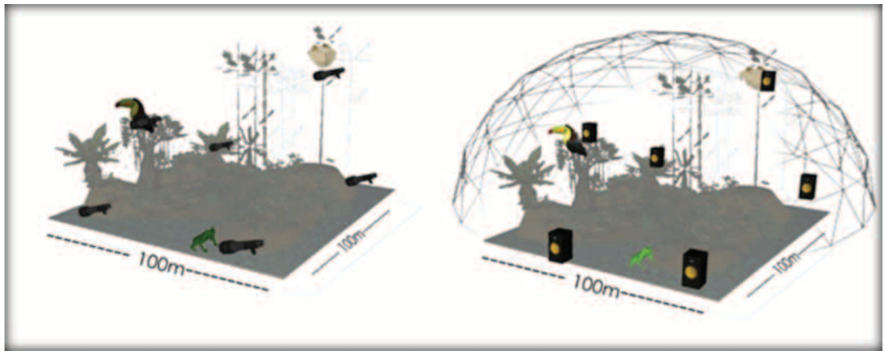


Fig. 7. 3D audio recording and reproduction. (© Augustine Leudar)

3D AUDIO MAPPING

In this alternative approach to 3D audio recording/reproduction, speakers are placed in a botanic garden in exactly the same relative positions that several SD card microphones were placed originally in the jungle (Fig. 7). Having lived in the jungle for several years, I have a good idea of how it should sound, and this technique, which was developed through trial and error, is one that I found to be far more effective at recreating 3D sound-scenes than other 3D sound recording techniques. It also allows for relatively large recorded areas to be scaled down or "miniaturized" [23]. These 3D sound scenes have several uses. Firstly, they can be used to test how a plant responds to its native soundscape (being the closest artificial recreation of the authentic soundfield). It also creates 3D audio documents; such documents may act as indicators of the current state of rainforest biodiversity as well as being documents for future generations to hear how the rainforest actually sounded in the past. Finally, such 3D recordings can be altered creatively to make unusual collages from original recordings that would not be found naturally.

INTERACTING WITH THE FOREST

The Effect of Sound on the Forest Fauna and Flora

Ornithologists and even hunters are known to use a technique known as "playback" [24] to call sought-after birds or animals so they can be photographed or hunted. This works by reproducing the call of a certain animal or bird so that it will come to find a mate or investigate who is impinging on its territory.

Spectrograms show that sounds in the jungle have evolved to occupy different frequency bands, almost like the different frequencies of broadcast radio waves, with a surprising degree of separation both in the frequency and time axes, perhaps to avoid interference with each other's "broadcast range" (Fig. 8). Many of the sound sources used in these installations were originally field recordings from the Amazon that I transformed in the various ways already described. Although radically altered, they still occupied the same frequency bands, so it is perhaps not surprising that many creatures seemed to be attracted to the area during composition. Further studies might indicate how similar to the original call that playback has to be to elicit a response.

The Effects on Flora—Plant Responses to Composition

Different sound sources did not appear to immediately affect electrical responses in the plants at any point, and laboratory experiments that I performed at the International Laboratory of Plant Neurobiology in Florence [25] appeared to confirm this. That is not to say that sounds do not affect plants; in fact several experiments strongly suggest that they do [26], but a thorough investigation into this phenomenon would involve testing thousands of species and is beyond the scope of the current work.

CONCLUSION AND FUTURE DIRECTIONS

These installations form the first steps in creating hybrid biological and technological systems that can deepen our understanding of the biosphere through artistic means. To build upon this type of work, more accurate sensor systems that can work in the field need to be developed to increase resolution. I am also working on a system that converts such signals not only into sound but also into light.

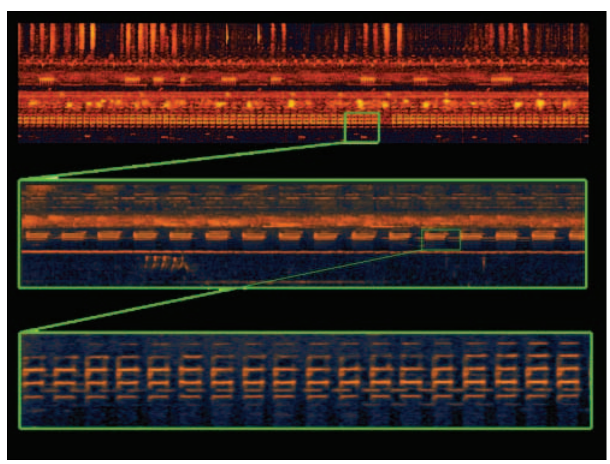


Fig. 8. The top spectrogram shows a typical rainforest dawn, with different sounds exhibiting a large degree of separation as if occupying the different frequency bands of a radio. Zooming in and isolating different sounds and then processing their pitch and duration provided virtually infinitesimal sound materials to form the basis of composition. (© Augustine Leudar) Listen to the audio recording at <www.augustineleudar.com/Offline%20Website/page13.html>.

References and Notes

1 G. Highpine, “Unraveling the Mystery of the Origin of Ayahuasca,” 2009. [Online]. <www.neip.info/novo/wp-content/uploads/2015/04/highpine_origin-of-ayahuasca_neip_2012.pdf> (accessed 17 February 2016).

2 F. Baluška et al., “The ‘Root-Brain’ Hypothesis of Charles and Francis Darwin: Revival After More Than 125 Years,” *Plant Signal Behaviour* **4** (2009) pp. 14–20.

3 J. Burdon-Sanderson, “Note on the Electrical Phenomena Which Accompany Stimulation of the Leaf of Dioneamuscipula,” *Proceedings of the Royal Society of London* **21** (1873) pp. 495–496.

4 A.W. Galston and C.L. Slayman, “The Not-So-Secret Life of Plants,” *American Scientist* **67** (1979) pp. 337–344.

5 A. Leudar, “Integrating Plant Electrophysiology and Art,” *CEIARTE* **19**, No. 1 no. 02/2016, <www.ceiarteuntref.edu.ar/leudar> (accessed 2014).

6 S. Olsson and B.S. Hansson, “Action Potential-Like Activity Found in Fungal Mycelia Is Sensitive to Stimulation,” *Naturwissenschaften* **82**, No. 1, 30–31 (1995).

7 Y. Song et al., “Interplant Communication of Tomato Plants through Underground Common Mycorrhizal Networks,” *PLoS One* **5**, No. 10 (2010).

8 M. Gagliano, S. Mancuso and D. Robert, “Towards Understanding Plant Bioacoustics,” *Trends in Plant Science* **17**, No. 6, 323–325 (2012).

9 F. Baluška and S. Mancuso, “Plant Neurobiology: From Stimulus Perception to Adaptive Behavior of Plants,” *Plant Signaling & Behavior* **4**, No. 6, 475–476 (2009).

10 M. Gagliano, “Experience Teaches Plants to Learn Faster and Forget Slower in Environments Where It Matters,” *Oecologia* **175**, No. 1, 63–72 (2014).

11 F. Baluška, “Swarm Intelligence in Plant Roots,” *Trends in Ecology & Evolution* **25**, No. 12, 682–683 (2010).

12 A. Alpi, “Plant Neurobiology: No Brain, No Gain?,” *Trends in Plant Science* **12**, No. 4, 135–136 (2007).

13 A. Ananthaswamy, “Root Intelligence: Plants Can Think, Feel and Learn,” *New Scientist* (2014). [Online]. <www.newscientist.com/article/mg22429980-400-root-intelligence-plants-can-think-feel-and-learn/> (accessed 17 February 2016).

14 Jatun Sacha Foundation, <www.jatunsacha.org/> (accessed 2015).

15 Parque Etno-Botánico Omaere, <www.omaere.wordpress.com/english/> (accessed 2015).

16 Damanahur, “The Singing Plants of Damanahur,” 2011. [Online]. <www.youtube.com/watch?v=aZaokNmQ4eY> (accessed February 2016).

17 M. Masaoka, “Brainwaves & Plants,” 2009. [Online]. <www.youtube.com/watch?v=PD1Uf5BnK78&feature=youtube_gdata_player> (accessed February 2016).

18 C. Canaday, *Common Birds of Amazonian Ecuador: A Guide for the Wide-Eyed Ecotourist* (Ediciones Libri Mundi E. Grosse-Luemern, 1997).

19 Olsson [6].

20 F. Baluška, “Root Apices as Plant Command Centres: The Unique ‘Brain-Like’ Status of the Root Apex Transition Zone,” *Biologia (Bratisl.)* **59**, No. 13, 1–13 (2004).

21 S. Simard, “Do Trees Communicate?” (2012). [Online]. <www.youtube.com/watch?v=iSGPNm3bFmQ&feature=youtube_gdata_player (accessed 17 February 2016).

22 A. Leudar, “An Artist’s Guide to Plant Electrophysiology,” *Plastir Journal of Science and Art* **3**, No. 34 (2013).

23 A. Leudar, “An Alternative Approach To 3D Audio Recording and Reproduction,” *Divergence Press* **3**, No. 6, 1–9 (2014).

24 M. Wei and Y.-y. Zhang, “Playback Technique in Ornithological Research: A Review,” *Sichuan Journal of Zoology* **052**, No. 3 (2010).

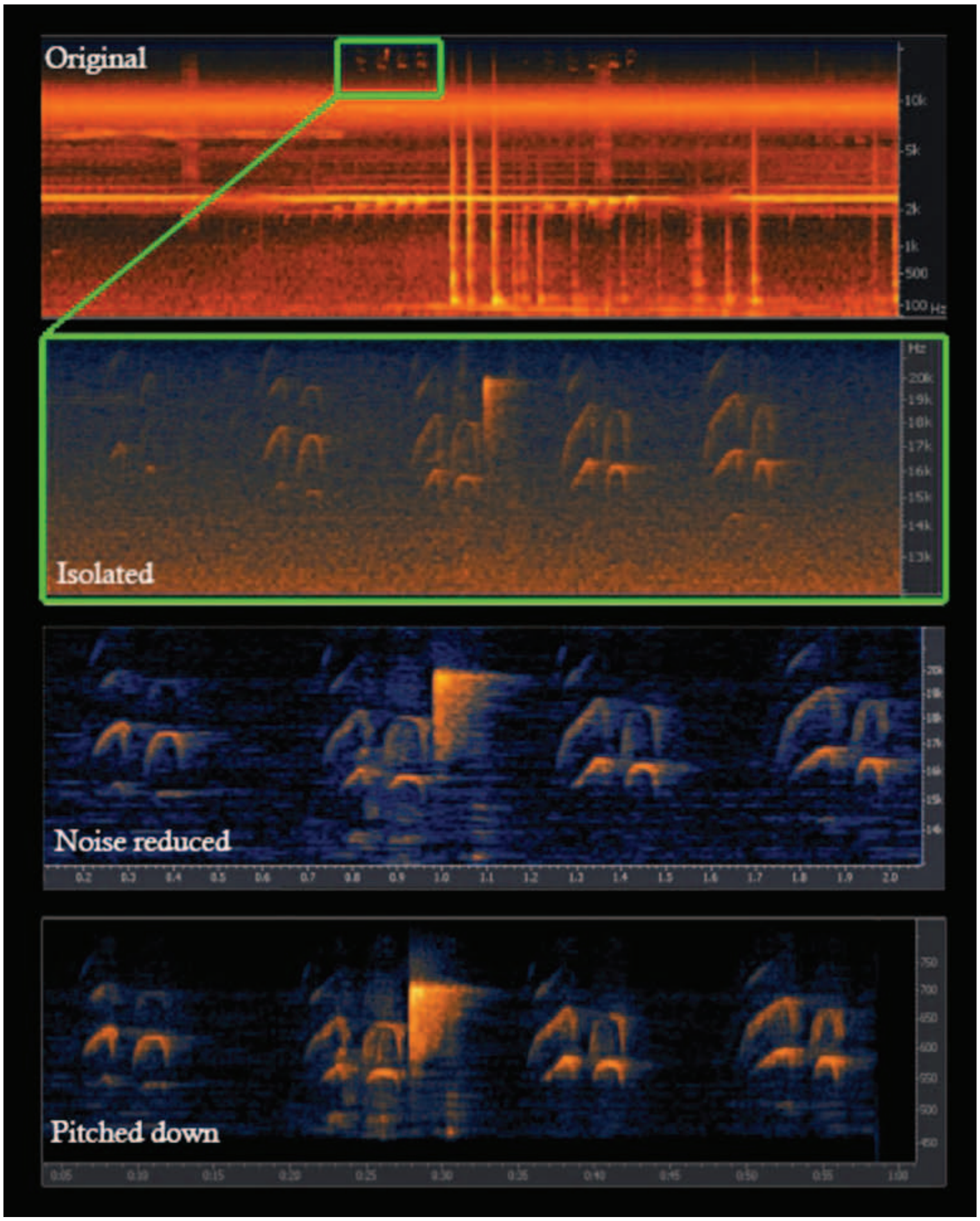
25 <www.linv.org/> (accessed 2015).

26 Q. Lirong, “Influence of Sound Wave Stimulation on the Growth of Strawberry in Sunlight,” *Computer and Computing Technologies in Agriculture III* **3**, No. 3, 449–454 (2010); T. Hou et al., “Application of Acoustic Frequency Technology to Protected Vegetable Production,” *Transactions of the Chinese Society of Agricultural Engineering* **25**, No. 2, 156–159 (2009).

Manuscript received 29 November 2015.

AUGUSTINE LEUDAR *is a sound artist who specializes in 3D audio. He has recently branched out into many other installation mediums and theater. He has a PhD in plant electrophysiology and 3D sonic art.*

COLOR PLATE D: ***SURROUNDED*: A SERIES OF SOUND INSTALLATIONS THAT COMBINE PLANT ELECTROPHYSIOLOGY AND 3D SONIC ART**



The image labeled "original" shows the full spectrogram of the forest and all sounds in it. The sounds selected in the green box and "isolated" show a sound above the hearing of most adult humans (16,000hz). This would certainly have been inaudible in the forest masked by so many other sounds and many people cannot hear it even when isolated. "Noise reduced" shows the noise reduction process. "Pitched down" simply plays it lower and slower. Sound: "pitched down" in the supplemental files at <mitpressjournals.org/toc/leon/51/5>. (© Augustine Leudar) (See article in this issue by Augustine Leudar.)