Listening with the Trees:

The Subterranean Bioacoustics of Old Growth Forest Groves in the Hoh River Valley

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A B S T R A C T

This research is an acoustic exploration into the Olympic Rainforests of the Pacific Northwest, and one of the healthiest ecosystems of the world, the Hoh River Valley. The focus of the inquiry is the subterranean soundscape, and the primary subjects are Old Growth Sitka Spruce trees. Acoustic emissions originating from tree root systems were gathered and analyzed.

Plants are communal and intelligent. Their physiology generates sound which could carry meaningful information in a diverse and living rhizosphere. It is possible that plants use sonic tools to express, receive, and communicate with other plants and other-than-plants. This preliminary research opens further questions and intends to explore the layers of aliveness, deep intelligence, and the communal nature of trees.

1. Plants: Animate and Aware

Plants compose 99.7% of our planet's biomass and hold a vital role in the regulation of Gaia, our living planet. Classically, plants are viewed as inert and only a hierarchical step higher than rocks and minerals (Cohen, 2004). Though the truth of the (plant) matter is becoming clear. Plants are intelligent, sentient beings able to form complex relational webs of community with altruistic exchanges of nutrients and information. They form the foundation of our living planet through the recycling of oxygen, the upcycling of water, and carbon fixation. We condescendingly call these acts ecosystem services, though, without the 'services,' there would be no one alive to serve.

The study of plant intelligence and sentience were, until recently, considered blasphemous by conventional science standards and have remained largely unexplored. The narrow anthropocentric definitions of these terms have limited our ability to step fully into and study the vegetal realm. It is unwise to assume that all intelligence and expressions of aware aliveness can be analytically compared to our own (Marder, 2017). Plants are not a "lesser-us" (Meyers, 2014). Their way of life is inherently 'other' than ours, and best viewed from the perspective of the plant itself. Here, a review of relevant scientific findings is offered to illustrate the animate and aware nature of plants.

1.1 Intelligence

Plants are contextual creatures. No two in the wild are precisely the same though plants that live closer together are more similar. A cedar tree that lives in the wet Pacific Northwest behaves and grows differently than the cedar living in the high, dry mountains of the Sierra Nevada. Plants respond to their environmental context appropriately and to their benefit.

Classically, intelligence is measured as the ability to solve problems (Davis et al., 2011). In this research, however, the definition of intelligence is expanded to include the depth and complexity of organism-environment relations (Marder, 2016: 34). We are not able to isolate and separate the plant from their environment if we wish to gain a true understanding of their intelligence. The intelligence of a plant is an expression of the intelligence of the whole organism-environmental system. An asphalt lot and the root-ball-cut, machine-planted trees lining the parking spaces are of lower relational intelligence than trees in a forest surrounded by ferns, mosses, herbivores, and predators.

If we must individualize and ask, what is the level of intelligence of that particular tree? Then we would have to observe the interconnectivity of the tree with the environment and their ability to respond appropriately as the living context changes.

Plant intelligence is the complex array of interactions and exchanges with local biota and geota, which allow increased fitness and propagation over ecological time. We might better understand plant intelligence as akin to a property belonging to the entire grove or ecosystem. Like the plant body, plant intelligence is modular and decentralized. Each partial whole (individual) contributes to the whole (ecosystem), and the intelligence of the system clarifies with each additional player, input, and interaction.

Organisms are expressions of their environment,
and the environment is an extension of the organism.

1.2 Sentience

Sentience is the ability to sense one's self in relation to the environment (Calvo et al., 2017). Plants have no discernable sense organs as most animals do, though they are undoubtedly aware. Their environmental context shifts – there are floods and droughts, big trees fall, and the microclimate changes – and they respond. Plants are not automatons; they respond to a changing world with complex and highly organized behaviors.

Typically, plants, and particularly trees, are seen as dormant and inanimate, only moved by a passing breeze or rolling thunderstorm. We watch their seeds fall and disperse out of their control. Where the seed lands is where the plant will grow and die. Plants fulfill a lifecycle whose length depends not only on environmental factors and herbivory, but also on the plant's ability to sense and appropriately respond to their environment. Through an inability to uproot and move, plants hold deep and innate connections with their environment. The lines between self and other are blurred in the vegetal world. Nothing natural exists in isolation and between the root hairs that much is clear. Plant sentience opens an expansive line of questioning on the nature of proprioception, or how one detects oneself in space, as well what is self as opposed to non-self.

The path to plant intelligence and sentience is sensuous, how plants experience their world. They have many senses, more than our classical five! (Mancuso and Viola, 2015: 46) With plant sensing, there is also a response, a behavior.

1.3 Tropism, an Innate Behavior

Any proud parent of a houseplant will observe their phyto-friend growing towards a natural source of light. Asymmetry increases in the plant's form as growth reaches for more chlorophyllic contact to the sunlight, the plant's source of sustenance. This simple tropism, a growing-towards directed by an external stimulus, shows "phenotypic plasticity" (Stearns, 1989) in which the plant's genotypic expression or behavior responds to environmental conditions. Plant behavior is ultimately physiological (Karban, 2008) and is characterized by a response to environmental or biological stimuli. The speed of this response is relative to the plant's perception of time and has potential reversibility of action (Silvertown and Gordon, 1989). If the houseplant was turned around, so the growing side was now shaded, the plant may forego its structural investment and begin to grow in the sunlit direction. Tropisms are morphological expressions of plant sensing and most likely related to an ancient biological behavior present in all life forms, attraction and aversion. In animals, this is experienced as movement, towards food and away from danger. Growth is how a plant moves and is directed by their abilities to sense and make sense of the world around.

1.4 Plants Hear

It's long been folklore that plants which are sung to or spoken positively about will grow better and produce more vibrant fruits (Tompkins and Bird, 2018), however in more recent years scientists are discovering plant's abilities to sense and respond to their acoustic environments (Gagiliano, 2012). Most organisms use physical vibrations and acoustics to communicate and orient themselves in relation to their environment. Terrestrial mammals have ears to capture acoustic vibrations and convert them into mechanical and electrical energy from which environmental information is interpreted (Brownwell, 1997). However, hearing does not depend on having ears. Insects such as mosquitoes and fruit flies have developed a specialized morphology to pick up airborne vibrations. Their antennae are shaped such that they oscillate with traveling acoustic vibrations at harmonically related wavelengths, allowing the insects to tune into specific frequencies (Callahan, 2001). Snakes perceive sound by using their jawbone as coupling element to pick up substrate vibrations and then transduce the waves into environmental information (Young, 2003). Without ears, animals acoustically absorb information about their environment to increase fitness, and it is no stretch to gather that plants do as well.

Sound travels well and far in dense media such as soil and "given that substrate vibrations are present at all times and places," (Gagliano, 2012a) the ground-dwelling creatures exist in a world of sound. We may surmise that fossorial creatures and indeed plants rooted in the soil would benefit by their perception of substrate vibrations (Gagliano, 2012a). A widened awareness of the local environment will increase organism fitness by allowing a more informed ability to act in response. Plants are known to respond to eco-sonic stimuli, such as the Primrose sweetening its nectar after hearing the sound of a pollinator's buzzing wings (Veits, 2018), or chili pepper seedlings sensing their neighbors as kin or competitor and responding accordingly with strategically increased root growth when all known forms of communication are restricted (Gagliano, 2013). Often in cities, tree root balls must be caged lest they break into belowground pipes for its water source. This hydrotropic behavior has typically been attributed to the sensing of groundwater gradients. However, a 2014 study reduced the water-seeking behavior of pea plants to sound alone (Gagliano, 2017). When a water gradient was not present, the peas grew towards the sound of water and displayed their abilities to rely on multiple senses to extract environmental information and make informed decisions. Mechanoreception, the sensing of mechanical vibration, influences behavior. Plants respond to specific sound waves by altering germination, growth rates, and tropism behavior (Klein and Edsall 1965; Weinberger and Burton 1981). While the mechanoreceptor mechanisms within the plant are yet to be found, it is increasingly evident that plants not only hear, they listen.

1.5 Plants Sing? Sonic Expression

> "I could distinctly hear the varying tones of individual trees – spruce, and fir, and pine, and leafless oak – an even the infinitely gentle rustle of the withered grasses at my feet. Each was expressing itself in its own way – singing its own song, and making its own peculiar gestures – manifesting a richness of variety to be found in no other forest I have yet seen."
>
> *– John Muir, The Mountains of California*
> *(Muir, 1917: 279)*

Plants generate sounds. As for the aforementioned breeze blowing through the trees, we could imagine the rustle of pine needles and leaves as a voice. Conifers rustle differently than maples do: each species of tree and plant has their own unique sound based on morphological expression. This is not dissimilar to the differences in humans' tones of voice, which are generated by the physiological resonance frequency of their vocal cords (Hanna, 2019).

But these passing sounds only scratch the surface of plant bioacoustics. Plants are also known to generate acoustic emissions in the ultrasonic (Zweifel, 2008), audible and infrasonic ranges (Gagliano, 2012). Plant acoustic emissions are thought to be a byproduct of physiological vascular processes (Jackson and Grace, 1996; Gagliano, 2012). Acoustic emissions from trees have classically been attributed to rupturing cell walls due to air bubbles in the xylem system though there is now evidence that plants generate acoustic emissions independently of cavitation-disruptions (Gagliano, 2012a).

In comparison to chemical signals, sound is energetically cheap and travels far distances, while also accurately transferring spatial information (Gagliano, 2012). We could easily imagine that plants use sound to their benefit. It is possible that plant bioacoustic emissions could be intentionally generated as a tool to explore the soil, for proprioception, and to communicate (Gagliano, 2012).

The edge of plant sensing and expression is where my research begins. The time is ripe for more studies of plant bioacoustics that we may widen our vegetal perspectives and explore the yet-unheard.

1.6 Plants, They are Alive

Classically, plants are viewed as inert, deaf, dumb, and blind, or merely a mechanical extension of the classically dead material environment. This is simply untrue. Plants see without eyes, smell without noses, hear without ears, and speak without tongues. They hold a diverse and complex existence that we are only beginning to understand. As other-than-plants, we humans live in primordial dependence to the ones who link Sun and Earth (Marder, 2017). Their way of life is environmentally aware, communal, and ecologically interconnected. Plants host an embodied cognition, in which their physiology is inseparable from their psychology just as plant individuals are inseparable from their living environment.

2. The Study

2.1. Orientation

Ecology is etymologically rooted in *oikos-logia*, and roughly translates from Latin to the Science, Word, Theory, or Practice of Home. I include myself, all other-than-human, and all other-than-material beings in this study of natural relations and Home. I acknowledge that as we step into the forest, we enter a living being. Acknowledgment and the study of 'other-than,' served as a means of ecological participation with the wider and grander intelligence than my own.

I am here to listen. I am here to learn

I did not set out to prove a pre-formulated hypothesis nor take implicit assumptions in this work. I allowed the data to incite implicative questions for further research.

The data and field research of this dissertation guided the formulation of my hypothesis, which intends to allow a holistic multiplicity of understandings to form as opposed to a specific and highly contextual true/false claim post research.

My hypothesis was also informed by standing scientific findings and evolved by direct observations. This project was research-driven, exploratory, and inquiry-based. Theory served as a frame from which to understand the hands-on experience of field research. I understand that the knowledge of science is grown from the edges and formed by climbing the shoulders of giants to reach an inch higher.

2.2 Hypotheses

- Trees originate and receive physical vibrations. These vibrations are emitted and received selectively for relevance to organism behaviors and benefit.
- Conifer morphology is linked to mechanoreception and is relevant to the propagation and transmission of acoustic energy.
- Conifer trees emit a subterranean biosonic field. The field is likely created by the sudden regrouping of peristaltic micro-bubbles in the xylem system whose coherent excitation incites a resonance in roots, root systems and trees in close proximity.

2.3 Experiment

The field research period lasted approximately two months. In 3-4 day stints, I spent extended time in the rainforest, listening. I brought with me a broadband hydrophone, used primarily to record whale song, and a soil probe. I dug narrow holes near the base of Old Growth trees to find major roots and placed the hydrophone in good root contact. The techniques used to locate roots and make a proper connection developed with practice. Approximately ten hours of root recordings were taken.

I attempted one experiment: a playback technique typically used in animal behavioral studies. Classically, an animal's sounds are played-back to the creature in order to observe any response. This experiment helps us begin to understand another organism's languaging. I tried this with the trees.

After obtaining significant data that showed a repeatable sound, I drove a 10-minute recording through a piezo-electric contact microphone* onto an exposed root. The acoustic emissions of the observed tree 10-minutes before the 'playback' and 10-minutes after were analyzed and compared.

No significant differences were found. The experiment would be better attempted with a larger speaker and longer time period. Also, the acoustic emissions are not the only way a tree could respond to the 'played-back' sound. In future experiments, airborne volatiles and galvanic responses† should be observed for response. This experiment would also be best repeated with seedlings to observe a potential phonotropism.

This was a preliminary study. An exploration of the question: Do tree roots originate physical vibration? During fieldwork, I discovered a sound that seems to originate in the tree's root system. The detected sound was also recorded within proximity to the root systems of Sitka Spruce and Western Hemlock trees, which led to the 'subterranean biosonic field' hypothesis. I present my methodology and findings below.

3. Methodology

3.1 Equipment

The equipment used consists of an Aquarian Audio H2-A Hydrophone, two J-Frez insulated contact microphones, a Zoom 120° XY microphone, an H-6 Handy Zoom audio recorder, a medical-grade stethoscope, a 3/4" diameter soil probe sampler, and the data analysis software Izotope RX7 Standard.

3.2 Site Selection

Ten research sites were selected on the South Fork of the Hoh River in Olympic National Park. This area was chosen for its advanced and highly interconnected ecology, the pristine condition of the forests thanks to the protection of the U.S. Parks Service, and the lack of noise pollution and anthropogenic disturbance. Twelve test sites have been selected in the river valley and riparian zone. Each site hosts a grove of Old Growth conifer trees, which was defined as three or more trees within 10 meters and more than 300 years old. The land of each site is relatively flat with moss, clover, or fern ground cover and nurse logs. The soil's composition differs slightly in each site and ranges from silt to loamy to clay dominant varieties, which are noted in the ancillary data. As well, the sites range from being within earshot of the river as a white noise stimulus to being out of average human audible range.

Three sites outside Olympic National Park and within the South Fork of the Hoh River valley were also selected. Two of these sites are classified as Second Growth, being once logged in the last 200 years and in the process of succession to the previous state of Primary Forest. And one of the sites was in a Department of Natural Resources clear-cut. Typically, a few trees are left standing to be denoted as 'selective logging' and to give Birds of Prey a roost from which to eat any ground creatures who may eat the newly planted timber crop. The surviving trees were the study subjects.

Research sites in the forest were also found based on feeling. Each place of study held a quality of natural organization and incited a visceral sensation in me of ease and wonder. The researcher allowed the land, fungi, flora, and fauna to guide them to the recoding sites. Elk create trails through the understory that led to meadows and groves, and often, a corvid would call out as they wandered close to what became a research site. Every time the researcher entered the forest, they verbally explained why they had come and asked for help. These natural practices are often unspoken in scientific work, though, this was part of the method and offered great insight and inspiration into the development of this study.

3.3 Setup

At each site, a medical grade stethoscope was used to listen at the base of the selected tree's trunks and find the best placement for data acquisition. A contact microphone was placed on the selected spot and connected it to the Zoom H-6 Recorder. A soil probe was then used to dig a narrow hole and find a major root about 2 meters away from the trunk. The hydrophone, which also connects to the H-6 recorder, is placed in the hole with good contact to the root. To confirm root contact, the tree's trunk was knocked and made sure a clear sound was heard through the hydrophone-connected headphones. As well, 120° XY microphones were used to record the ambient sonic environment of the site. All recordings were taken simultaneously at 96KHz/24bit and onto the same high-quality SD card. The recordings were 20 to 30-minute long and taken at various times during the day, roughly 10 am, 2 pm, and 6 pm. While recording, the researcher walked 10 meters away from the site, remained still and silent, did their best to bear the flies and mosquitoes. All ancillary data and events such as jet flyovers, wind gusts, or the presence of animals were also recorded.

Ancillary data includes weather, temperature, relative humidity, air pressure, and approximate wind speed, which were noted at regular intervals. Phenological data of species, approximate age, trunk diameter at breast height, qualitative health, and % of leaf coverage was also recorded. Soil data was taken with a quantitative 0-5 scale to record the relative wetness, structure, and elasticity, while the qualitative smell of the soil was noted.

After some weeks of recording, the researcher returned to do a playback experiment with five trees. Using the same setup as above, a soil probe was used to dig a narrow hole to a primary root and the hydrophone placed in solid contact. As a baseline, the acoustic emissions of the root were recorded for 10 minutes. Then a contact microphone was attached, which can be used as a dynamic speaker, to an exposed root and the recording of a different tree's acoustic emissions was played for 10 minutes. After the recording stopped, the tree was acoustically observed for 10 more minutes to observe any changes in acoustic emissions.

3.4 Analysis

This data was analyzed using a Fast Fourier Transform (FFT) on Izotope RX7. The software created sonogram and performed a spectral analysis, which located peak frequencies, noted relative intensity and visualized the dominate frequency bands. Special attention was paid to the lower frequencies (<300 Hz) as these will travel well in the soil, and previous studies (Gagliano et al., 2017) have pointed to root response to lower frequency ranges.

Randomly selected five-second intervals were analyzed from the recordings taken at each site. Peak frequency and relative intensity were noted at each time step (about 0.133 seconds). These were then graphed as box-and-feather plots through Excel to visually compare. Average peak frequency and relative intensity over the entire 20-minute recording was also noted using Izotope Rx7.

4. Data and Analysis

4.1 Detection: The Deep Tree Warble

This research was a preliminary acoustic exploration into the subterranean world of the Olympic Rainforest. As the previous sections have contextualized, the time is ripe for further study of plant bioacoustics. Through hundreds of hours of fieldwork, and dozens of hours spent recording, a sound was detected. This low-frequency sonic event was repeatedly found emanating from major roots and the trunks of Sitka Spruce and Western Hemlock trees along the South Fork of the Hoh River Valley. The sound was also recorded off-root in the soil within relative proximity to a spruce or hemlock tree. In qualitative expression, I have named the sound a "*deep tree warble*." Examples of the recordings are available in *digital form here*[‡]. I encourage the use of headphones or a subwoofer to properly experience the *deep tree warble*. Listeners have expressed psycho-acoustic affects ranging from grounding, meditative, and love-inducing sensations to an uneasiness and distaste. Sounds of the subterranean sphere are vastly different than our day-to-day sonic human experience.

"In trying to discern these [plant] voices, we ought to be careful not to overwrite them with the sounds of the familiar, let alone pleasing, to us."

– Monica Gagliano, Grafts
(Marder, 2016: 101)

4.2 Falsification

Once the *deep tree warble* was reliably and repeatedly detected, all possible external sources were actively explored and methodically tested out.

The detected sound is not a product of equipment noise, as it is neither stable nor uniform. As well, the equipment was left to record while isolated for ten minutes in a felt, wooden, and metal insulated box. The recording showed no presence of this sound.

The presence and intensity of the detected sound is also not linked to river or stream proximity. Methodically, soil recordings at depths of 2" and 12" were taken at gradually increasing distances away from the Hoh River. There was no correlation found between presence of the sound and distance to the river. This sound was also found some miles away from any source of running water on the living roots of a Sitka Spruce in a Department of National Resources clear-cut.

The detected sound was also not found with more intensity at greater depths. In the same spot, the sound was found at 2" and 12" though not 24" or deeper. This removes the possibility of a groundwater source for the *warble*.

The sound was also not detected in the ambient background noise recorded simultaneously on the XY microphone. So, there is little probability that this sound is background noise from the ambient environment. There was, however, an observed correlation between the presence of the *warble* and proximity to conifer tree root systems.

The detected low-frequency *warble* is likely related to the tree's vascular system. I suspect that it is a sonic byproduct of the hydro-pneumatic bubble system in the water-transporting xylem tissue.

4.3 Data

How to visualize sound? An immaterial event which exists in time and moves through space. Fortunately, with the availability of microphones to capture and sound analysis software to digitalize, we are able to represent the sonic events as a means to quantify and compare.

Graph 1a is a box-and-feather graph of every peak frequency found within randomly selected five second intervals in eleven of the test sites. The vertical axis is measured in hertz. The graph represents the range and median peak frequencies at eleven of the observed sites.

Each tree holds its own unique range and variation within 20-90 Hz. In *CC Seven Alone* and *Spruce Flat*, the variation was large, as the sound oscillated in peak frequencies between the 1st and 2nd harmonic. The detected frequencies are similar in range to the

‡ https://archive.org/details/subterraneanbioacoustics

observed acoustic emissions of corn roots in the study done by Gagliano, Mancuso, and Robert (Gagliano et al., 2012a).

"That plants produce sound waves has been known for some time. Specifically, plants emit sound waves at the lower end of the audio range within 10–240 Hz…"

– Monica Gagliano, Green Symphonies (Gagliano, 2012)

Graph 1b is a box-and-feather graph showing the variation in relative sound intensity at the same randomly selected five second intervals. The vertical axis is measured in dB, which were changed from negative decibel units into relative positives by adding 96 to every value.

Note that there is variation within and between sites. Though they are all comparable. The loudest three sites, *Spruce Nursery*, *SG Stump Creek*, and *CC Seven Alone* are the youngest three stands of trees. Every tree produces a similar, yet-unique version of this sound. Much like the leaves of any Oak tree, they are all alike, though no two are exactly the same.

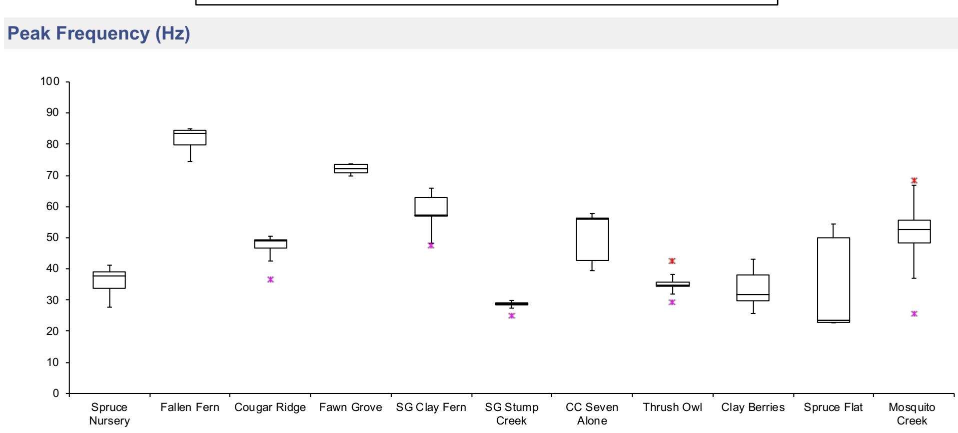
See Graphs 3a-d for a spectral analysis of 20 minutes of recorded data for four of the sites. This graph takes the average of every timestep and combines them to form a graph of frequency vs. relative intensity.

The horizontal axis is frequency measured in hertz and vertical axis is the relative sound intensity measured in decibels. Please note that the vertical units are measured in negative decibels. The spike at 20 and 30 kHz is most likely signal noise from the equipment. Note that the signal is strongest at the lower end of the frequency range and peaks between 20 and 200 Hz.

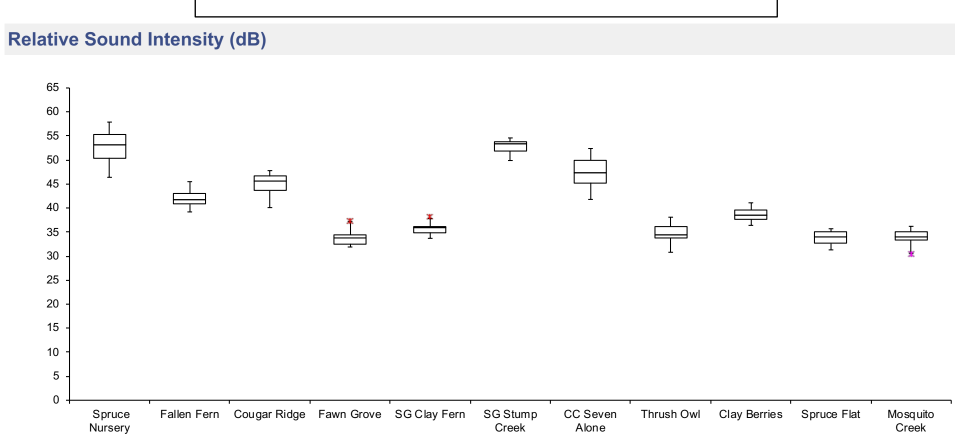
Note that Graph 3d is a recording taken off-root. This was taken 12" into the ground within 3 meters of two Sitka Spruce trees. The signature is comparable to the recordings taken on the root systems. Recordings taken at the same depth more than 7 meters away from a spruce or hemlock showed no signs of this low-frequency sound.

For one final way to visualize the observations, Graphs 2a and 2b are examples of FFT created sonograms. The blue line in the middle is a sound wave and shows the relative intensities over time. The orange markings are the sonogram whose height denotes frequency, depth of color shows relative intensity, and horizontal spacing is with respect to time.

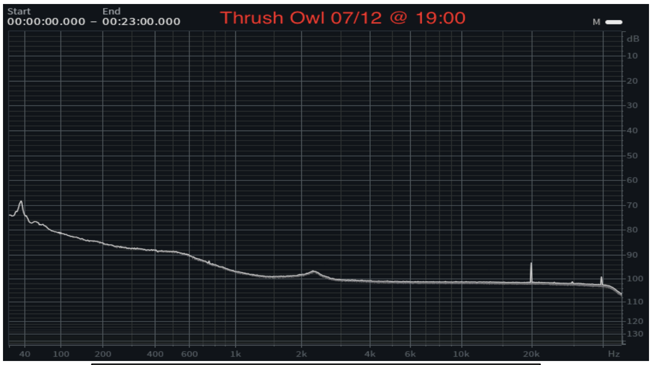
Graph 1a: Peak Frequencies measured in hertz



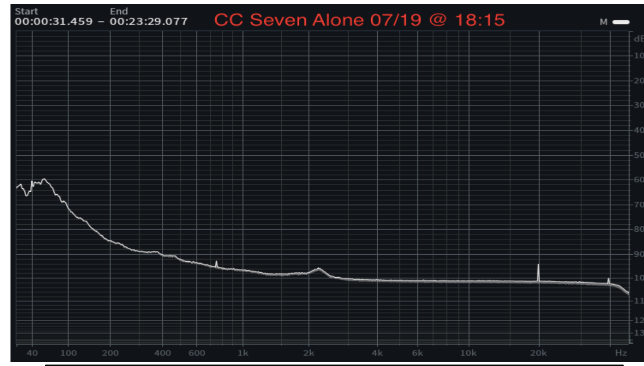
Graph 1b: Relative Sound Intensity measured in decibels



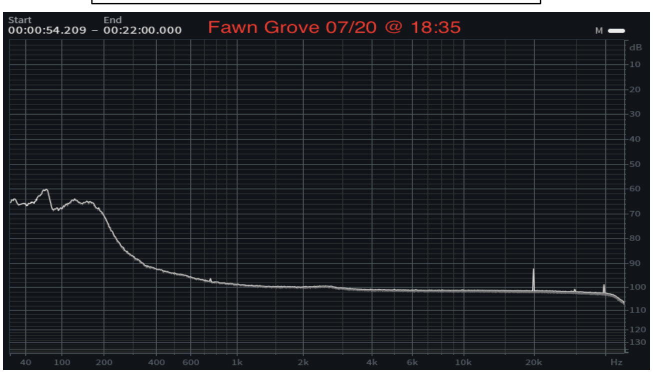
Graph 3a: Spectral Analysis of Thrush Owl



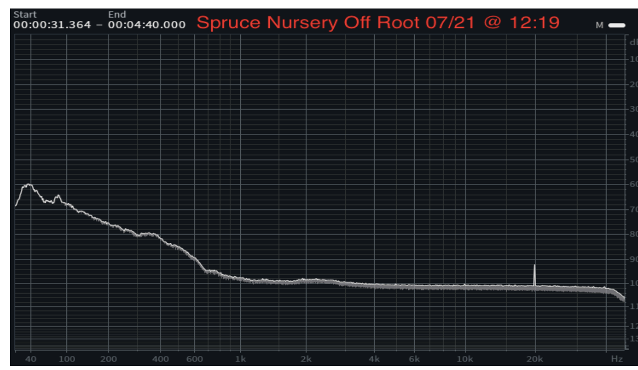
Graph 3c: Spectral Analysis of Seven Alone



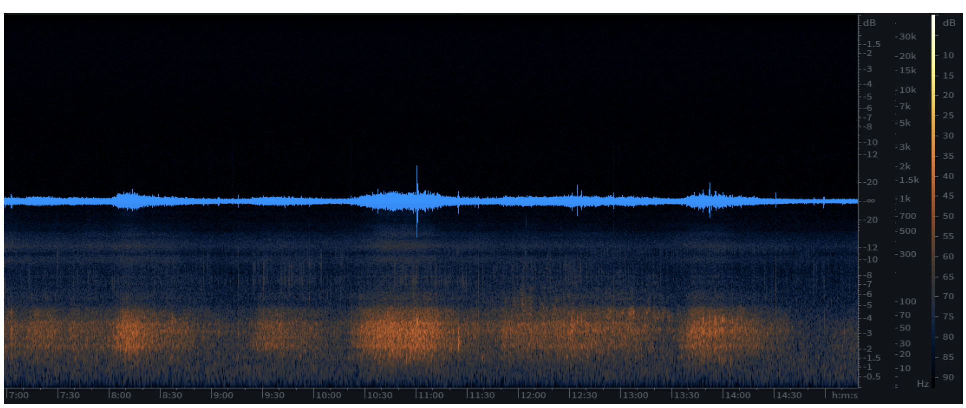
Graph 3b: Spectral Analysis of Fawn Grove



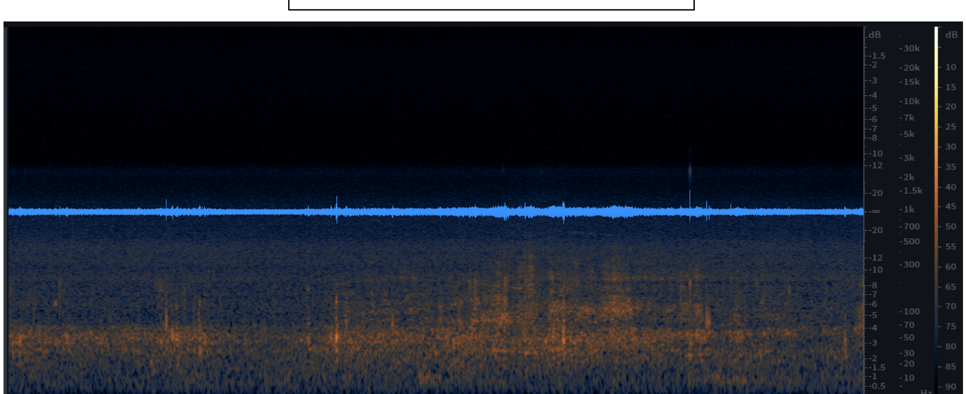
Graph 3d: Spectral Analysis of Spruce Nursery (Off Root)



Graph 2a: Sonogram of Clay Berries



Graph 2b: Sonogram of Cougar Ridge



5. Discussion and Speculation

Nature does not make machines; Nature makes tools. A machine does one thing, while tools do many things. As a modular and decentralized organism, trees behave in a morphological multiplicity: every part is used in numerous ways. It would be no stretch to say that their physiological processes operate in the same way.

"We anticipate that plant acoustic radiation is not simply an incidental mechanical by-product attributable to cavitation alone."

– Towards Understanding Plant Bioacoustics (Gagliano et al., 2012a)

As mentioned earlier, sound carries information over long distances and with high accuracy. Plant bioacoustic emissions could very well be used as a tool for the tree's benefit. We know that plants possess mechanoreception, and, that their roots respond to sound. Is it so far-fetched to believe that they hear their neighbors and also, themselves?

5.1 Source

Based on standing scientific work and gathered data, the detected sound likely originates from vascular physiology and morphology.
In the water transportation hypothesis proposed by Laschimke et al., the sudden regrouping of microbubbles adhering to the xylem walls, which help to pump water up the tree's trunk, also create observable acoustic emissions. Cells nearby are affected by the mechanical vibrations of their neighbors, which build into a collective mode (Gagliano, 2012). This process of coherent excitation could amplify acoustic emissions into an observable range. As well, Sitka Spruce is a tonewood, the timber of choice for luthiers' guitars. With stiff and flexible qualities, spruce is known around the world to produce beautiful sounds. I propose that the collective mode, created by the movement of microbubbles in the xylem system, resonate the spruce's roots and root system to generate a *subterranean biosonic field.*

5.2 Signature

The recorded data shows acoustic variations between each tree. There are similarities in frequency and relative intensity. However, they each hold an individuality. The similar but not identical quality of these sounds leads us to the direct possibility that trees possess an *acoustic signature***.** More analysis and research must be done to confirm this postulation, though it is not irrational to imagine that every tree would have a unique sound based on their particular morphology. Trees of the same species and in closer environmental conditions grow similar root system patterns (Pagés, 2014). As sound relates to space and structure, root systems of analogous organization, molecular composition, and metabolic processes (all aspects of genetic and phenotypic affinities), will likely generate similar acoustic emissions. With this in mind, similarities in genotype and phenotype could be expressed as similarities in acoustic emissions.

5.3 Are you me? A Speculation

Roots are exploratory and exist in a dark subterranean world. By branching and growing, they encounter other roots and must determine how to behave. Is this self, or non-self? Is this encountered-other, kin, or a competitor?

Preliminary data shows that the *deep tree warble* radiates off primary root structure and could be used as a means of proprioception. Root swarm behavior is a complex and coordinated activity that expresses an intelligence greater than the sum of each root tip, and its method is still unexplained. How are roots aware of each other's presence and movement without touching? I speculate that the self-similar acoustic presence of roots informs coordinated root swarm behavior.

Plants actively sense and respond to the presence of their neighbors in cooperation or competition, depending on their affinity (Mancuso and Viola, 2015: 94). Root-produced acoustic fields would allow plants to recognize their neighbors (Gagliano et al., 2012b) and behave in ways that benefit themselves and their kin. Based on the self-similarity or coherence of acoustic presence, roots could actively identify who they are encountering without having to touch physically. As well, it is possible that phenological and physiological information could be contained in the acoustic emission and decoded by listeners to determine who it is they hear and even how they are.

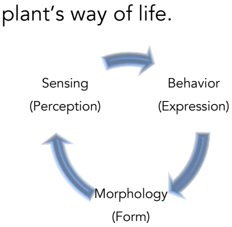
"Clearly, roots represent a complex underground communication system for plants and much information about their surroundings and neighbours is transmitted via root interactions."

– Out of Sight but Not out of Mind (Gagliano et al., 2012c)

5.4 Morphology and Perception

The structures of our ears modulate incoming sound waves, and the structures of our vocal cords allow us to speak and sing in particular ways. As trees are modular and have no discernable organs, we could imagine that their entire being acts as an organ of perception and expression. If a primrose's petal is removed, the flower displays inhibited abilities to sense and respond to the sounds of a pollinator's buzzing wings (Veits, 2018). Disruption to natural morphology affects sensory abilities and impairs the primrose's response, an expression of sweetening nectar.

Plants sense the living environment and behave in response; they express phenotypic plasticity. Plant behavior influences their morphology, and as seen in primrose, morphology affects the plant's ability to sense. This loop is a hermeneutic circle, in which sensory experience, expression, and morphology are linked and interdependent in a plant's way of life.



Over generations, behaviors shift gene expression through epigenetics and influence the adaptation and evolution to place (Thellier et al., 2018). A tree on a windy high-altitude plateau phenologically responds by growing short and stoutly. The tree's offspring also grow in response to the environment with wind-resistant bark and branches. Developed responses become stored in the tree's natural expression as they adapt themselves to the local conditions over ecological time.

I imagine that lifetimes of trees, which develop in a community, could tune to the living environment together. As understood from Gaia Theory, life's communal activity modulates the environment. So, in a sense, the trees could not only *tune to* the environment; they could also *tune* the environment.

5.5 Communities and Communication

I am walking us to the possibility that developed communities of trees share a self-similarity. In epigenetically-influenced physiology and morphologically-represented behaviors, which both have acoustic expressions, trees in natural communities may share biosonic channels of communication that are environmentally influenced over long time scales. If these *deep tree* warbles are acoustically significant to each tree, and a sort of speech, then the differences across soil compositions, wetness, and other geota features, could be observed as dialects particular to specific groves or ecosystems.

"If such mechanical vibrations or sound waves can extend over large distances within the organism and also outside the organism, then the possibility arises that plants may actually use sound to communicate with other plants or organisms."

– Monica Gagliano, Green Symphonies
(Gagliano, 2012)

At the low-frequency range found in the tree's roots (20-90 Hz), the sound waves could travel for miles. Spruce, as a tonewood, conducts sound 15 times faster than in air (Woods, 1997). One wavelength of a 20 Hz sound wave traveling through a spruce tree will be approximately 250 meters long. The rainforest's soil composition contains layers of clay which propagate sound at about ten times the speed in air (Lide, 2005) and the same 20 Hz wavelength will be approximately 174 meters long. Similar to whales calling from afar at certain depths in the ocean, channels of subterranean bioacoustic communication are a distinct possibility that we must explore further.

The potential of an individual tree's sound being detected at great distances by fellow trees or other organisms is slight, due to attenuation factors and various interfering sounds. However, it is possible that by *coherent excitation*, the acoustic emissions from one root system will excite a neighboring root system into entrainment and coherence. If this is true, then we may imagine there is some 'song' of the forest, which is both sung by the trees and sings the trees.

I suspect that a seedling sprouting into the biosonic field of its mother or fellow kin could physiologically entrain to their processes and patterns of behavior. When infants are in 'skin-to-skin' contact with their mothers, they receive physiological benefits through heart rhythm entrainment (Feldman et al., 2011).

Trees are social beings; they thrive in interspecies communities, in which continuous interactions, exchanges, and communications naturally up-cycle the communities into more complex configurations and organized states of being. It is not unreasonable to think that sound and the *deep tree warble* is a communicative part in the forest community, working in tandem with the chemical conversations we already know to be taking place.

5.6 Holophonics

This sound, the *deep tree warble*, could be an expression of the forest itself, the symbiopoietic being that emerges from the interrelations of biota and geota. The subterranean sound could be one layer in the grand dynamic song that is the Hoh Rainforest, an arboreal ensemble in the symbiophony.

5.7 Conclusions

In this preliminary study, I have concluded three points and opened the door for a proliferation of meanings to be made through philosophical inquiry and speculative imagination.

Conifer trees originate low-frequency physical vibrations that can be detected acoustically. The acoustic emissions are also detectable within proximity to the root system and are expressed as a subterranean biosonic field. Every tree emits a slightly different sound.

With regard to these conclusions and previously stated standing studies on bioacoustics and plant intelligence, three implications are reasonable to suspect:

The variations in acoustic emissions could be linked to the tree's morphology and physiology. Root acoustic emissions could have evolutionarily significant adaptive functions and be expressive of the tree's responsiveness to the environment. Through mechanoreception, trees could receive acoustic emissions from neighboring trees and respond accordingly.

Future studies must be done if we are to explore the real potential of root bioacoustic communication.

5.8 Future Studies

Clearly, and as I imagined from the beginning, this preliminary study into the subterranean bioacoustics of Old Growth trees in the Olympic Rainforest has opened more questions than it has answered. I strongly encourage all who are interested in recreating my work and exploring this topic further to pick up any of these questions in future studies. Below I have outlined a series of questions that sprouted from this exploratory inquiry.

- *Does each tree have an acoustic signature?*
- *How do acoustic emissions change diurnally and seasonally? Do acoustic emissions change in varying environmental conditions? How do environmental stressors, such as strong winds, drought, earthquakes, and pests, affect acoustic emissions?*
- *Is there a connection between tree acoustic emissions and morphology? Are there significant mathematical relations between the spacing of tree branch nodules and the frequencies of acoustic emissions?*
- *Are there observable connections between acoustic emissions and other physiological expressions, such as chemical and electrical signals? Do trees express a behavior in response to other trees' acoustic emissions?*
- *Do seedlings display a phonotropism when exposed to the acoustic emissions of a mature tree? How do other organisms that benefit from root activity, such as mycorrhizal fungi, respond to the tree's acoustic emissions?*
- Do the acoustic emissions from trees synchronize? Are groves of trees resonating or in a state of entrainment?
- How do humans physiologically or psychologically respond to tree acoustic emissions? We are affected by their volatile chemicals, are we also affected by their sound?

6. Acknowledgements

I offer sincere thanks to my teacher and supervisor Dr. Stephan Harding, for his encouragement, support, and deep friendship. Through his teachings, I have realized Gaia and feel the earth more alive beneath my feet. I also offer great thanks to my advisor, mentor, and friend, Gordon Hempton, who has given me home and taught me how to listen. I humbly acknowledge Jason Hirsch as my friend and editor, and for his help in developing the voice of the Holistic Scientist.

I am thankful for Olympic National Park and the U.S. Parks Service for granting me a research permit and supporting my work.

I acknowledge and offer myself fully to the South Fork of the Hoh River, the mighty Sitka Spruce, Western Hemlock, Red Alder, Big Leaf Maple, Roosevelt Elk, Black Bear, Cougar, Ravens, Jays, Bald Eagles, and all fellow flora, fauna, and fungi who I encountered during my fieldwork. Thank you for guiding my research and supporting me in ways beyond words. Forever, I am here to listen; I am here to learn.

I acknowledge all my relations.

REFERENCES

1. Brownell, W.E., 1997. How The Ear Works – Nature's Solutions for Listening. Volta Rev 99, 9–28.
2. Callahan, P.S., 2001. Tuning in to Nature: Infrared Radiation And the Insect Communication System. Acres USA.
3. Calvo, P., Sahi, V. and Trewavas, A. (2017). Are plants sentient?. Plant, Cell & Environment, 40(11), pp.2858-2869.
4. Cohen, S.M., 2004. Aristotle on the Soul [WWW Document]. URL https://faculty.washington.edu/smcohen/320/psyche.htm (accessed 8.11.19).
5. Davis, K., Christodoulou, J., Seider, S., Gardner, H., 2011. The Theory of Multiple Intelligences. pp. 485–503.
6. Feldman, R., Magori-Cohen, R., Galili, G., Singer, M., Louzoun, Y., 2011. Mother and infant coordinate heart rhythms through episodes of interaction synchrony. Infant Behavior and Development 34, 569–577. https://doi.org/10.1016/j.infbeh.2011.06.008
7. Gagliano, M. (2012). Green symphonies: a call for studies on acoustic communication in plants. Behavioral Ecology, 24(4), pp.789-796.
8. Gagliano, M. and Renton, M. (2013). Love thy neighbour: facilitation through an alternative signalling modality in plants. BMC Ecology, 13(1), p.19.
9. Gagliano, M., Grimonprez, M., Depczynski, M. and Renton, M. (2017). Tuned in: plant roots use sound to locate water. Oecologia, 184(1), pp.151-160.
10. Gagliano, M., Grimonprez, M., Depczynski, M. and Renton, M. (2017). Tuned in: plant roots use sound to locate water. Oecologia, 184(1), pp.151-160.
11. Gagliano, M., Mancuso, S. and Robert, D. (2012a). Towards understanding plant bioacoustics. Trends in Plant Science, 17(6), pp.323-325.
12. Gagliano, M., Renton, M., Duvdevani, N., Timmins, M., Mancuso, S., (2012c). Out of Sight but Not out of Mind: Alternative Means of Communication in Plants. PLOS ONE 7, e37382. https://doi.org/10.1371/journal.pone.0037382
13. Hanna, N. (2019). Why the human voice is so versatile. [online] Phys.org. Available at: https://phys.org/news/2017-01-human-voice-versatile.html [Accessed 9 Aug. 2019].
14. Jackson, G. and Grace, J. (1996). Field measurements of xylem cavitation: are acoustic emissions useful?. Journal of Experimental Botany, 47(11), pp.1643-1650.
15. Karban, R. (2008). Plant behaviour and communication. Ecology Letters, 11(7), pp.727-739.
16. Klein, R. and Edsall, P. (1965). On the Reported Effects of Sound on the Growth of Plants. BioScience, 15(2), pp.125-126.
17. Lide, D.R., Baysinger, G., Chemistry, S., Berger, L.I., Goldberg, R.N., Kehiaian, H.V., 2005. CRC Handbook of Chemistry and Physics 2661.
18. Mancuso, S. and Viola, A. (2016). Brilliant green. [Place of publication not identified]: Island Press, p.54.
19. Marder, M. (2016). Grafts. Minneapolis: University of Minnesota Press, p.34.
20. Marder, M. (2017). To Hear Plants Speak. In: M. Gagliano, J. Ryan and P. Vieira, ed., The Language of Plants. Minneapolis: University of Minnesota Press, pp.103-125.
21. Muir, J., 1917. The Writings of John Muir: The Mountains of California. Houghton Mifflin.
22. Myers, N., 2014. Conversations on Plant Sensing: Notes from the field.
23. Pagès, L., 2014. Branching patterns of root systems: quantitative analysis of the diversity among dicotyledonous species. Ann Bot 114, 591–598. https://doi.org/10.1093/aob/mcu145
24. Stearns, S. (1989). The Evolutionary Significance of Phenotypic Plasticity. BioScience, 39(7), pp.436-445.
25. Thellier, M., Lüttge, U., Norris, V., Ripoll, C., 2018. Memory and Learning in Plants, Signaling and Communication in Plants. Springer International Publishing.
26. Tompkins, P., Bird, C., 2018. The Secret Life of Plants: A Fascinating Account of the Physical, Emotional, and Spiritual Relations Between Plants and Man. HarperCollins.
27. Veits, M., et al., 2018. Flowers respond to pollinator sound within minutes by increasing nectar sugar concentration. bioRxiv 507319. https://doi.org/10.1101/507319
28. Woods, C., 1997. Wood Testing [WWW Document]. URL http://www.scavm.com/Woods.htm (accessed 8.16.19).
29. Zweifel, R. and Zeugin, F. (2008). Ultrasonic acoustic emissions in drought-stressed trees - more than signals from cavitation?. New Phytologist, 179(4),