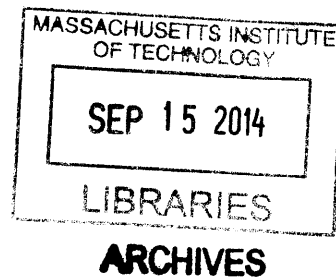


Taking Nature's Pulse

by

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Bachelor of Art, Creative Writing
Columbia College Chicago, 2011



Submitted to the Program in Comparative Media Studies/Writing in Partial Fulfillment of
the Requirements for the Degree of

Master in Science Writing

at the

Massachusetts Institute of Technology

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August 19, 2014

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ABSTRACT

People have taken delight in nature throughout human history, but more recently the work of the natural historian has become more like that of the scientist. Using methods and tools of science, today's naturalists can record nature with precision—and through this, learn more about it.

Ecologists now pay heed to the often-forgotten sense of hearing. The Tropical Ecology Lab at University of Puerto Rico, San Piedras, blurs the lines between natural history and science. An array of remote microphones collects sounds from the forests and wetlands, and researchers use computers to analyze the soundscapes themselves.

Thesis Supervisor: Thomas Levenson
Title: Professor, Comparative Media Studies/Writing

Taking Nature's Pulse



En Puerto Rico

Upon my arrival to Puerto Rico, I wandered around the airport looking for the bus stop. Evening had fallen, warm and humid. I waited for the bus, anxious I had missed it, watching other lines pull in front of me and carry on to their destinations. I'd turn my head at the shudder of an engine, hoping for the right one. I thought about how I could be anywhere, how strange it was that I'd crossed the ocean in a matter of hours and slept through most of it.

For an airport, it was rather quiet. A few people were walking around, shops were closing down, and I could hear one sound that assured me I was in Puerto Rico: the cry of a lone coquí—the island's emblematic frog. The sound presumably came from the only plant in sight: a potted palm.

I didn't see a single frog during my stay in Puerto Rico, but oh, did I hear them. Coquí at the airport, coquí in the rainforest, coquí in the flowering bushes down the street from the hotel, coquí in the swamplands, coquí in the back alleys of Old San Juan, coquí in the online sound database at University of Puerto Rico's Tropical Ecology Lab.

Oddly enough, most of the sounds in this database are unheard, just as they would have been without the microphones that recorded them. With an intake of 144 short recordings per site per day, Mitch Aide's lab has gathered some 370,000 minutes of sound from El Yunque National Forest alone.

For it is in El Yunque that you may find not a researcher, but instead a device hooked up to a small solar panel. In fact, there is an entire team of sensors periodically deployed around the island. That is to say, the forest has ears.

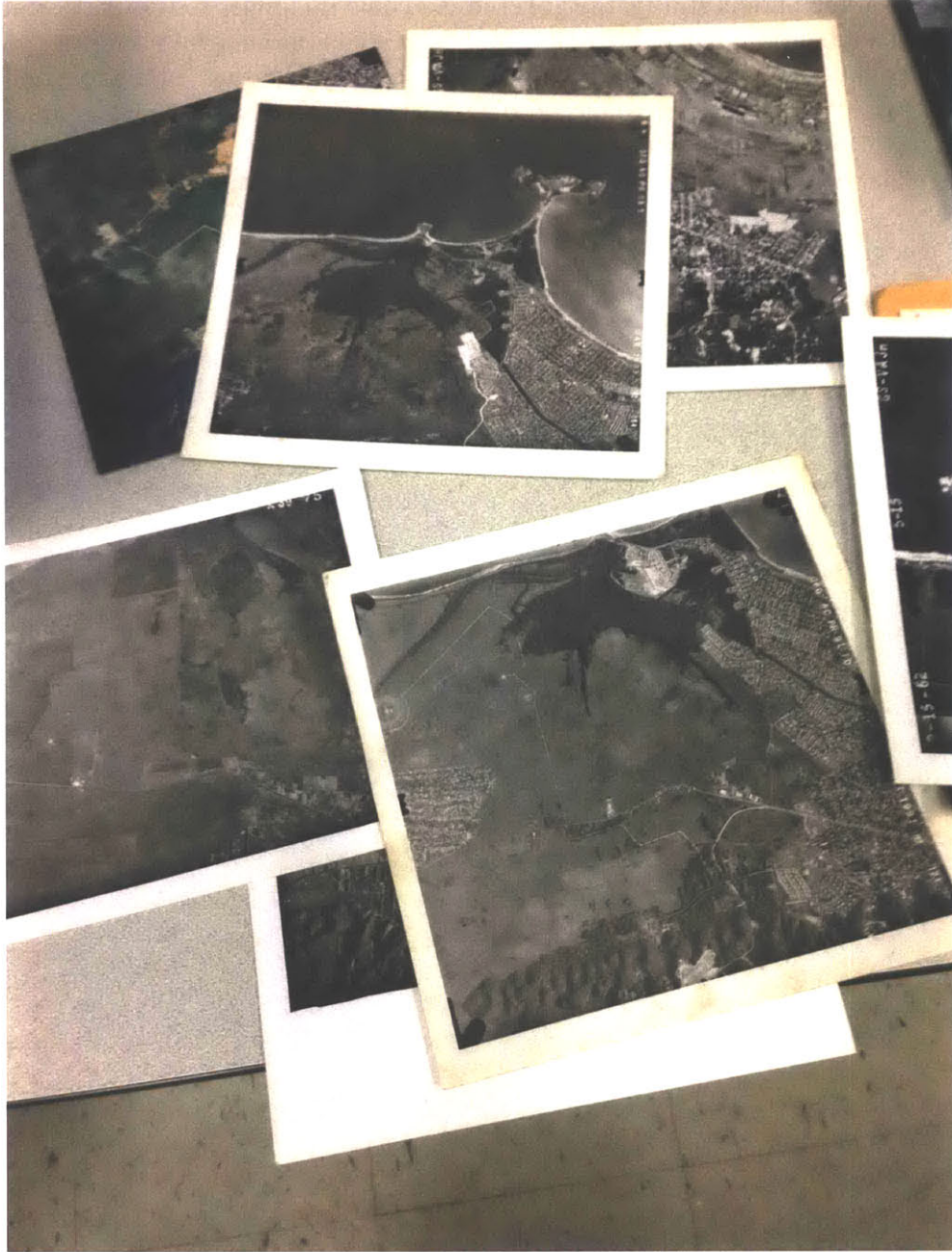
For the past seven years, Mitch's lab has gathered one minute out of every ten minutes of sound from various sites. Each remote recording station gathers the soundscape, then sends its data back to the server, where they can be accessed by anyone connected to the network. From there, the sound joins an archive where it can be filtered, tagged, or downloaded for further analysis.

At first, the data were analyzed manually by student researchers. Dull repetitive tasks are a common rite of passage for the undergraduate biologist. Mitch recalls coming into the lab one day, and finding the students distracted—absently categorizing frog calls while browsing the internet.

Among these students was Luis Villanueva-Rivera, now a doctoral fellow at Purdue's Department of Forestry and Natural Resources. Mitch chided him for neglecting the research, though he knew the jobs involved were hard to pay attention to.

The problem simmered in the back of his mind until a conversation with one of his colleagues, Carlos Corrada-Bravo. Over food (and perhaps margaritas, says Mitch) at a nearby tacqueria, the two came up with a simple solution: machine learning. Where a repetitive task may be unbearable to undergraduates, it is just the thing for a computer. And why not? Speech recognition technology, though imperfect, has come a long way, and even a sorting of similar sounds could speed up data analysis tremendously.

Now the student researchers are tasked with different things: set up recording equipment, make and run models, experiment with different types of data analysis, make transects with a fleet of recording devices, and maintain hardware.



Sound Decay

On my first visit to Mitch Aide's office in Rio Piedras, I watched him pull a folder from the shelf behind his desk. It was sunny outside, but Mitch wore a green fleece pullover in his office. The air conditioner hummed in the background.

He emptied out a pile of square aerial photos. These were photos of Puerto Rican landscape. They were taken at different scales, in different years. Some were black and white, some brownish, greenish, or a dark, wide blue swath of ocean. He thumbed through the photos, inspecting them. He then placed them on top of each other, and muttered in lament—he used to keep them in order but they've since fallen to disarray.

He acquired this photo collection from an old archive as it was shutting down.

After years of the photos sitting, the government could no longer justify the cost it took to keep their storage room amenable to its contents: air conditioning and filtering, proper humidity control. They sold off what photos they could and discarded the remainder.

These photos cover irregular intervals back to 1937. The land is partitioned for sugar cane crops, an important export of Puerto Rico. Mitch doesn't have earlier photos (understandably, considering the technology needed), but he knows the history of the land.

The images in Mitch's stacked photos met each other in the line of a road in Sabana Seca. The top photo still shows a US military bunker, and three well-worn circles: monolithic radio antennae used to listen in on Cuba. They eventually converted it into an NIH medical research facility. Researchers from University of Puerto Rico set up shop, and the monkeys moved in. The forest in the upper right of the photo is mostly dark green, but a distinct margin of lighter trees lines its edges. Mitch pointed to it. Regrowth.

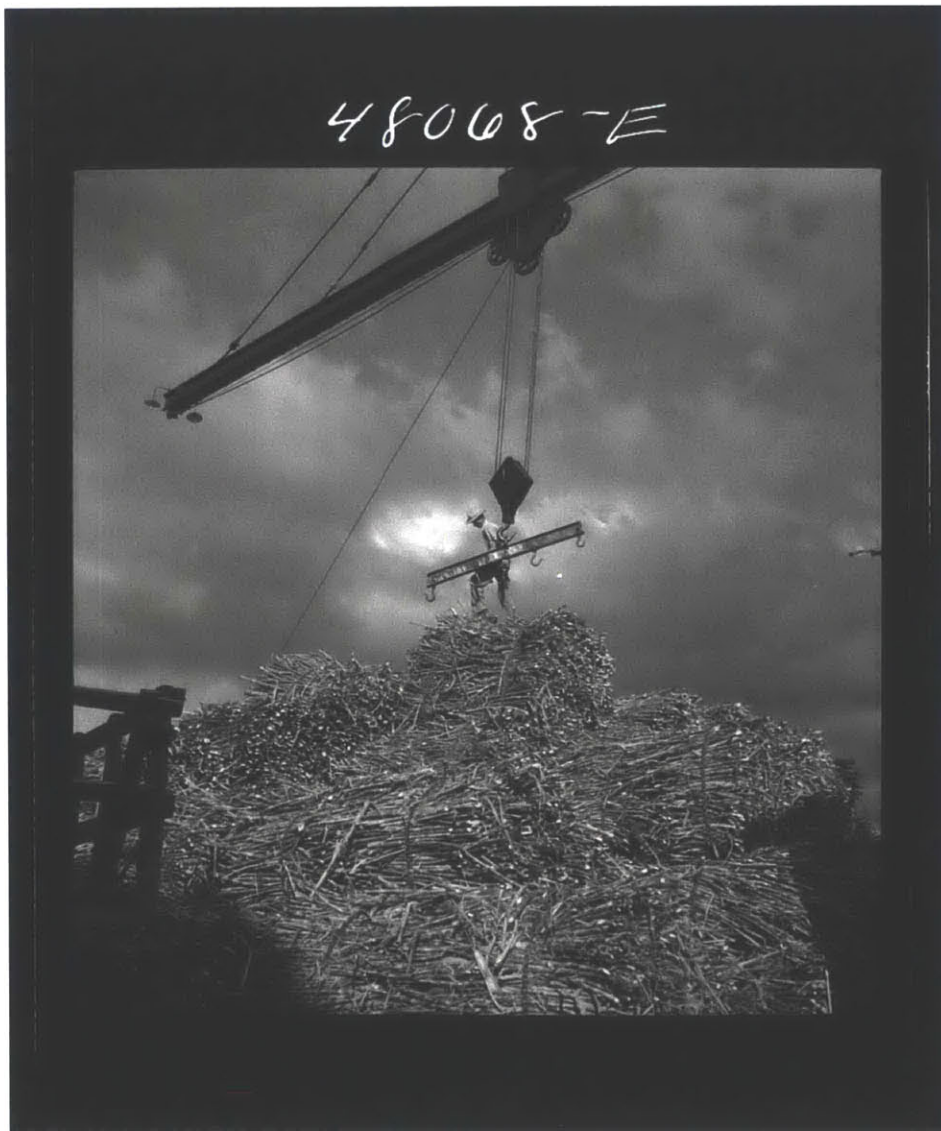


photo: Library of Congress, Prints & Photographs Division, FSA/OWI Collection, LC-DIG-fsa-8c29364.

Before the sugar cane, Sabana Seca was very lush and green. It was populated with springy vegetation that absorbed the water. Agriculture in the early 1900s and throughout the 20th century prompted the loss of about 90% of Puerto Rico's forests. Even after farmers stopped growing sugar cane in the area, the land did not return to its former state. The plants that soaked up the moisture were no longer there, and the place turned into a huge swamp.

Enter, the coquí. A new species of coquí frog was recently discovered in the swamps of Sabana Seca. Like the other coquí, well-known throughout Puerto Rico, the frog's name comes from its characteristic (and nearly incessant) nocturnal call. The call is two syllables: a high-pitched "co" and an even higher-pitched "KEE."

The coquí's characteristic call, familiar to anyone who's been on the island of Puerto Rico, is not represented in photographic archives. The images of Sabana Seca lie on the desk, silent. The photographs show trees, water, the implications of life, but no animal life can be identified. There is no way of retelling the conversation had by the species that lived there. One might spy the visual change in the landscape, but eavesdropping is out of the question. There is no lipreading here.

With a collection of sounds, we could hear the changes in the soundscape accompany those in the landscape. Capture the buzzing of insects in the mangrove forests, the creaking of sugar cane, the bootsteps of troops, the coming and going of birds. We could have a record of the inhabitants and sounds of the area—or at least of the chatty ones. This is what Mitch wants to do.

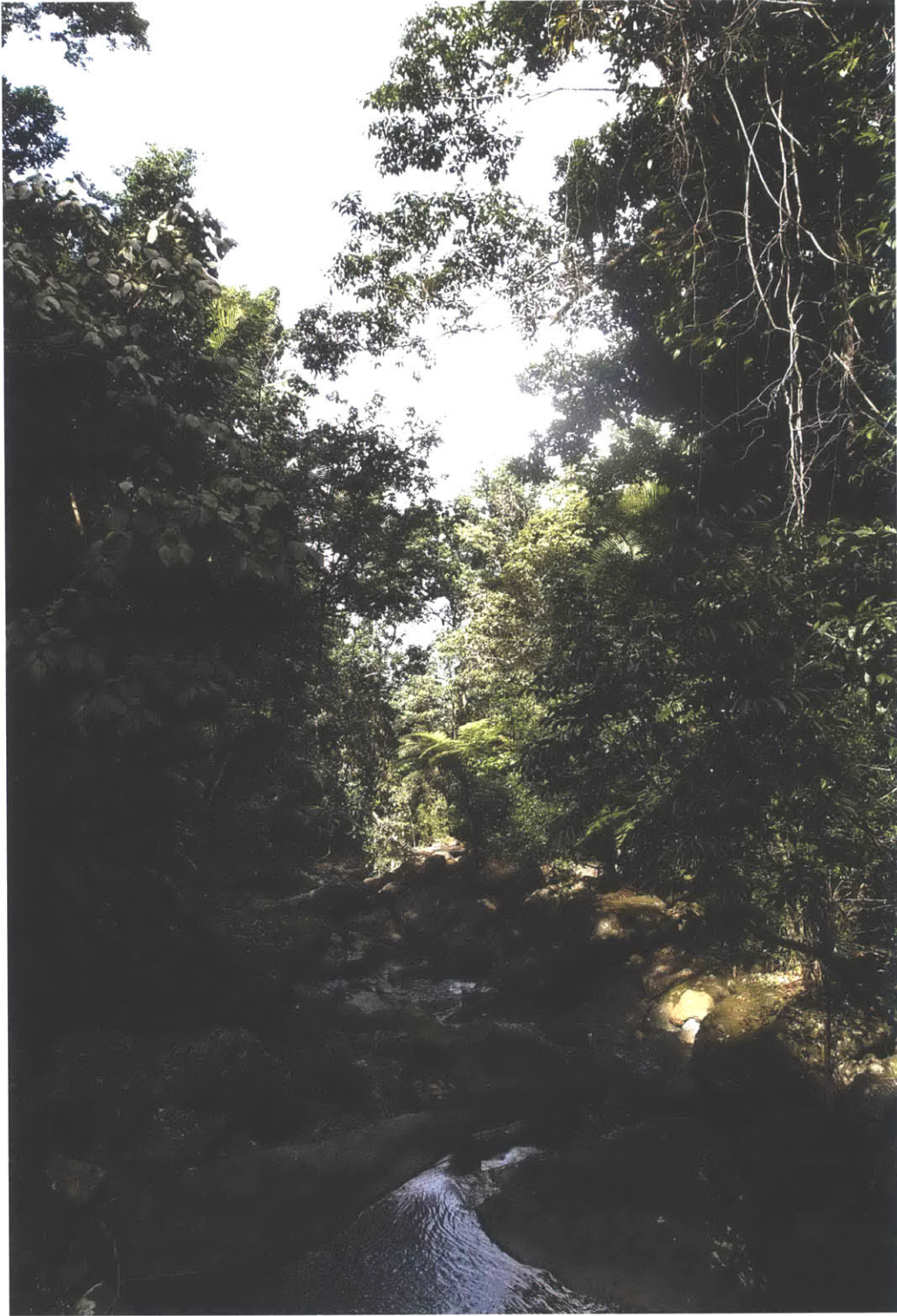
With the presence of the new coquí and the connections to the existing research station, Sabana Seca seemed an adequate place for an additional permanent recording station

The first station came in 2006, when Mitch's lab set up a microphone at El Verde research station in El Yunque, about 40 miles from Sabana Seca. El Verde had a long history of housing scientific research. Radiation experiments in the 1960s established an infrastructure for research and drew biologists to the area.

I accompanied one of the students to El Yunque to do some hardware maintenance. We drove out in the lab truck, and the day was hot. We traveled from Rio Piedras, where the lab is based, through the suburbs, and went from the loud rumble of heavy traffic to the quieter, winding forest roads. Over the 30 miles we drove, the landscape changed from colorful squat houses and businesses to bamboo, vines, and deciduous trees. The air felt cooler, and rain misted down from the skies.



First we entered the station to set up the repaired hardware. The research assistant, Pedro, visits each station about once a month for maintenance. The problem this time was an unreliable ethernet cable. As he worked amidst the wires, I looked around the station. There were specimens preserved in jars, collections of soil samples, old lab equipment all boxed up in the server room, unhearing relics bearing witness to new science.



We donned our boots and headed into the rainforest. The mud squished under our feet, spider webs caught our faces, and every now and then we'd pass other researchers' paraphernalia—though we destroyed a few spider webs, we took care not to interfere with debris-catching nets set up by station researchers.

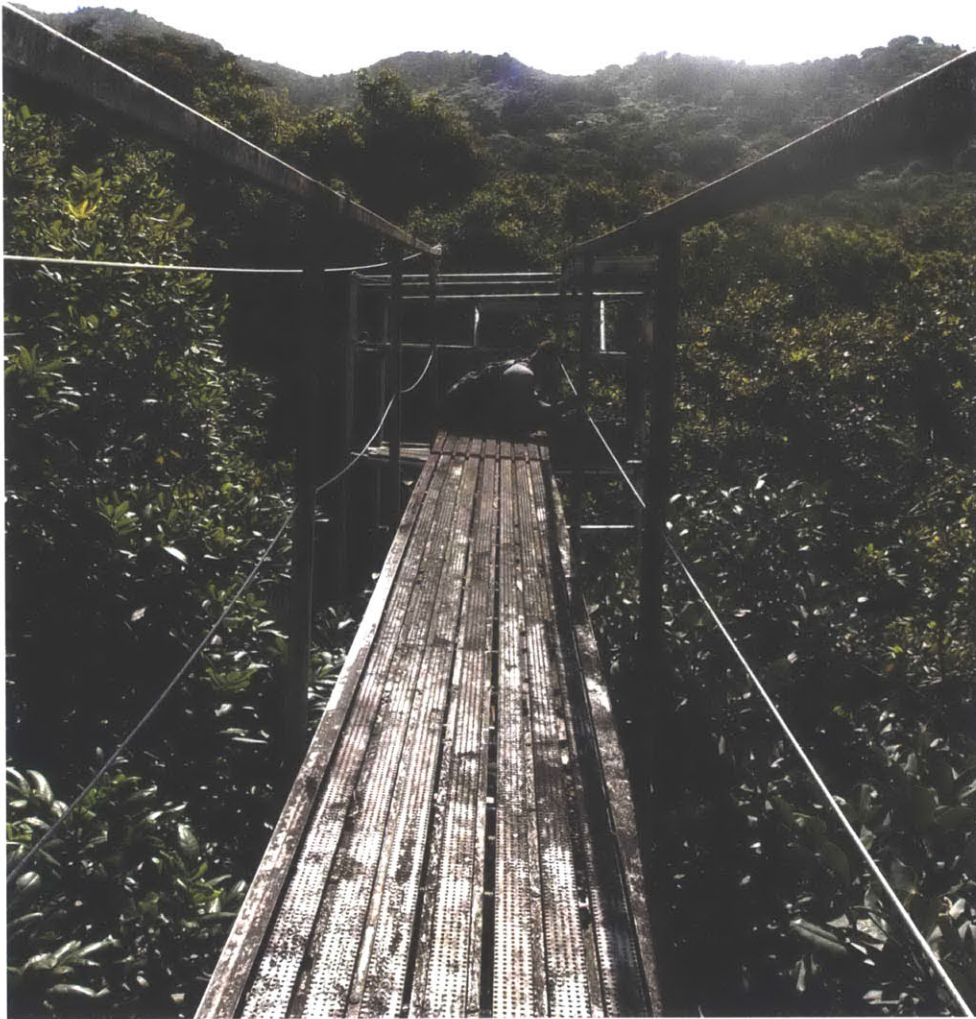
After several twists and turns, slippery rocks, streams bridged and trees fallen, we arrived at our destination. The birding scaffold, covered in pollen and debris, towered up to the forest canopy.



So we climbed. And climbed.

And climbed.





I could not see the ground from the top of the tower. The recording equipment sat in a small weatherproof box. It was fairly inconspicuous, and the tower is occasioned by birdwatchers for whom it was originally erected.

Above the forest canopy, it felt very quiet. I could see the city far away, but I could not hear its roar. For a short time, I was immersed in nature with only a visual clue of the city. It was not long enough for me to attune myself to the sounds of the forest—

and I left before night fell. I can only infer that the frogs slept quietly through the day.

Scientists and naturalists have often aspired to observe nature in depth and length. Jane Goodall was one of three women selected by Louis Leakey to study primates. Leakey specifically chose women partly because he felt that their research subjects would be less affected by the presence of women than that of men.

Goodall certainly brought huge advances to her field, but there was a tradeoff in being so close to her subjects. Amongst the many challenges of collecting data in person, there lies yet another, problem: the human presence of the researcher may interfere with nature itself. A microphone does not have such a tendency to interfere.

Using technology to spy on nature offers benefits beyond subtlety. It extends the reach of the senses, and picks up a sense that we often forget.

If the human body is a tool of science, it is a limited one. Our eyes are privy to only a small spectrum of colors—350-790 nanometers in wavelength. We receive light with three cones, from which the information combines in our heads as a unified color. Our touch perception is limited to nothing much smaller than 10 microns (for scale, a human hair is 40-50 microns, a fiber of fine wool is 10, and bacteria are typically 1-1.5 microns). Our chemical sensors—tongue and nose, vary from one person to another. For many, it takes only mere molecules of a scent in a room for them to smell it. For some, the slightest dash of salt can transform a gallon of soup, while others carry hot sauce everywhere because it's virtually all they can taste.

Sound is vibration moving through a medium, such as the air. Something vibrates, and pushes the air around it. Waves expand outward like ripples in a pond. The waves hit a tiny tympanic membrane in our ear, and hairs of the same harmonic mode as the sound quiver sympathetically within the cochlea. The hairs, connected to nerves, send electrical signals to our brains, where the sounds combine and gets interpreted. We can hear the waves of pressure in the air. Our ears are limited to 20-20,000 hertz—a low cat's purr to the whining of an electronic.

Within that range of sound alone lies a wealth of information. But even when we do sense something, it gets filtered through our perceptions. In the quietest places, there are at least 20dB of background noise to which we pay no heed. Had we no filter of perception, the sound might overwhelm us.

The same could be said of light. The images we see are a result of light's journey from a source to anything that reflects it—even the moisture and dust in the air. Like sound, we measure its wavelengths, and interpret them as colors like we interpret sounds as pitch. Yet somehow, between the two physical phenomena, we often ignore sound's usefulness in science.

Until recently, the task of recording nature's sounds has mainly been that of the artist or the hobbyist. One such sound-obsessed artist took it even further, and saw a need to record the silence.

John Cage's deafening silence

On Earth, silence is a rare thing. The natural world is full of vibrations. Plants and animals pulse with life, the restless sea rolls between air and rock, and even some technologies exist solely for the purpose of making vibrations. There are a few places on

land whose murmurs fall below 20dB, but these places are carefully engineered to eliminate sounds. An anechoic chamber could at first glance be mistaken for the set of a 1970s sci-fi movie. Any walkways are covered with a mesh to prevent the sound of footsteps, much of the structure is made of plastic or wood, and the walls, ceiling, and floor are covered in radiation-absorbing material: big foam wedges. (Perhaps you've seen them in recording studios or sound proofed music practice rooms.) Often in the center, there is some pedestal for placing a device to be tested. As if it is a shrine to radio frequency signal devices.

John Cage visited Harvard's anechoic chamber in 1951. The chamber has since been decommissioned (to my disappointment). Chambers like these are often co-owned by an academic institution and a military one—they are used to test military equipment that uses radio frequencies.

It was after I got to Boston that I went into the anechoic chamber at Harvard University...in that silent room, I heard two sounds: one high and one low.

Afterward, I asked the engineer why, if the room was so silent, I had heard two sounds. He said 'describe them.' I did. He said 'the high one was your nervous system in operation, the low one was your blood in circulation.

(Cage)

But perhaps one of the most jarring reports from those who have been in such a chamber describe returning to the cacophony of the world outside. Inside the chamber, one can hear the pulsing of her own blood, her bellowing lungs, and perhaps even the high ring of the nervous system.

Upon exiting, the ambient noise of the room must be deafening. A choir of electronics running hot and high-pitched, the noise of people around you, your footsteps, and the echo and reverb of it all—ghostly sound waves haunting the room after the attack of the sound itself. An echo is a distinct repetition, often heard in larger reflective spaces, where reverb is the chaotic bouncing—the wet washing machine sound of a choir in a cathedral.

The ears adjust to the silence, and suddenly you are able to hear the noise that constantly happens around you. It is like exiting a dark cave and stepping into the bright sun—the sensation can overwhelm. Fortunately, we can also have a small amount of control over our perceptions.

When I listen to the symphony, perhaps I want to focus on the woodwinds. I can't separate them out completely, but I can pay more attention to them than other instruments. I can ignore the sounds of my own body: heartbeats, breath. Sounds are coming at me from all directions, yet most of them don't even register.

After his visit to the anechoic chamber, Cage gained attention for *4'33''*, a piece containing various lengths of performed or recorded silence presented as music. A popular interpretation of Cage's *4'33''* is that silence may be listened to as intently as a musical masterpiece. The lights dim for the performance, the audience murmurs to quiet attentiveness and the musicians lay their warm-ups and last-minute run-throughs to rest. The conductor steps onto the podium, opens the music, and the orchestra sits up.

He picks up his baton and holds it steadily in front of him for 33 seconds, after which the lowering of the baton allows people to squirm again and cough. If needed, the

musicians turn a page of music to view the next movement, of which the only notation reads "TACET." All the regular rules of a night at the symphony are followed, and the audience applauds at the end of the last movement.

Conductor Lawrence Foster described the experience as deafening.

The idea of a large symphony orchestra sitting in front of you in absolute concentration and silence, perhaps up to 100 people each in his own world, probably. Thinking whatever he's thinking about those four minutes and thirty-three seconds that he's there. God knows how many thoughts are going on, or what kind of energy is being released at that moment. (Foster)

And *God knows how many* frogs there are, or birds, or bugs that escape our notice. And how their behaviors change over time. When I was studying percussion, a visiting musician shared a story of her interaction with Cage. He had come over to her house for dinner, and while waiting for the food to be ready, spent his time in the back yard listening to the plants. She said he told her that you have to want to die for a sound.

I've spent my own time in botanical conservatories, rustling vines and petting the prickly cactuses. Though I can't say I'd die for the sound, I certainly hold it dear.

Even sitting alone in isolation is never entirely silent. There is the sound of one's own heartbeat, breathing, the tensing of muscles or simply the air moving around the room. Then there is sound beyond our abilities to detect it.

The Invention of the Stethoscope

The human heartbeat, one interruption of silence, is an intimate thing. It is reserved for people's selves, their lovers, and their doctors. In the case of the doctor, the listener need not even touch the person whose heart they hear. The stethoscope is now so commonly used, and yet its invention was merely brought on by an awkward interaction between doctor and patient, not by some interest in hearing the body more clearly.

In 1816, I was consulted by a young woman labouring under general symptoms of diseased heart and in whose case percussion and the application of the hand were of little avail on account of the great degree of fatness. The other method just mentioned being rendered inadmissible by the age and sex of the patient, I happened to recollect a simple and well-known fact in acoustics, and fancied, at the same time, that it might be turned to some use on the present occasion. The fact I allude to is the augmented impression of sound when conveyed through certain solid bodies-as when we hear the scratch of a pin at one end of a piece of wood, on applying your ear to the other.

Immediately, on this suggestion, I rolled a quire of paper into a sort of cylinder and applied one end of it to the region of the heart and the other to my ear, and was not a little surprised and pleased, to find that I could thereby perceive the action of the heart in a manner much more clear and distinct than I had ever been able to do by the

immediate application of the ear... The result has been, that I have been enabled to discover a set of new signs of diseases of the chest, for the most part certain, simple, and prominent, and calculated, perhaps, to render the diagnosis of the diseases of the lungs, heart and pleura, as decided and circumstantial, as the indications furnished to the surgeons by the introduction of the finger or sound, in the complaints wherein these are used. (Simmons)

When one goes to the doctor, the taking of their pulse is part of a routine examination. The doctor herself will listen to the pulse and lungs of the patient, and she will use simple machines to test blood pressure.

Whale.fm: Synthesized Synesthesia

A heartbeat is a human constant, and there are a few basic pieces of information one can gain from a heartbeat. There are murmurs, muffles, and inconsistencies, but most often we pay attention its tempo.

Outside the human body, sounds are more difficult to interpret. A whale's upcall can scrape the lowest part of human hearing, then shoot up beyond the highest. The strange clicks, squeals, and booms are unintelligible to us. At the same time, observation of whale songs can tell us where whales are, and if they're communicating. The trick is telling whale from whale.

The first few calls I tried to classify on whale.fm were difficult. The site is a citizen science project, in which humans are put to work matching up whale calls to the proper whale. Most often, I could not distinguish the difference by ear, but I could see the difference in the sonograms.

Each sonogram shows frequency (or pitch) over time, and in this way the calls are quite distinct. Amidst the acoustic smog underwater, the clicking, the wavering moan, and the swooping upcalls of whales can be picked out. The technology of a sonogram provides, in this way, a sort of synesthesia. The visual representation of sound does not ordinarily happen by means of our own mind's interpretations, but through the assistance of technology. It is like translating the language of sound into vision. Our forgotten sense yields to what is arguably our most-used one. Since we did not form this acute ability to recognize sound in our evolution, the ability to see sound was not necessary for survival. With the future waiting ahead of us, it may be entirely crucial.

Our senses pick up what we need, but attend very little to things beyond that. Technology extends those senses, and interprets physical phenomena into something we can make more sense of. Something more comprehensible. There's an AI from one of the labs at MIT that amplifies the changes in videos. You can see the pulse of a newborn, the wiggle of an eye, the movements that are otherwise filtered.

The concept is quite similar to the tech that is now famous for its use in music: auto tune. Developed by Andy Hildebrand, auto tune was not always a tool for enhancing vocals. In his work for Exxon, Hildebrand built technologies to analyze sound for oil exploration. His program could detect sound and enhance the important parts so they could be analyzed more easily.

So we see, hear, and touch things, but perhaps we don't perceive them even after that. Our mind is tremendously good at discarding unnecessary information.

In a similar way, Cornell's Right Whale listening network uses machines to process the sounds they collect from New England's coast. A network of hydrophones sit at buoys near the shipping lane to listen for the call of the North Atlantic Right Whale, an endangered whale that migrates from the coast of Nova Scotia, through New England and Cape Cod, and down to Florida every year.

It would be impractical for analysts to listen for whales 24/7, but the technology helps out with that. A specialist teaches the machine what to listen for: what frequencies, how long, what the sound is shaped like... and any sound that fits the bill gets sent back for analysis. This leaves a handful of calls for the specialist to listen to.

Even if the scientist overcomes all the obstacles of the body's limitations, she must then make adequate recordings. We've come a long way from sketching and jotting down logs, but much research is performed toward a particular hypothesis, the data collected is useful to that hypothesis, and any researcher seeking to review or survey a set of studies is given the great challenge of trying to control for different methods, unit measurements, data collected for this experiment or that and then rendered remnants.

Nature's Record

Nature keeps its own history in the manner by which it is organized. Elements decay at a certain rate, light travels at a certain speed to strike photographs billions of years to follow, the content and chemistry of a given layer of rocks has its own story to tell about the time when that ground was laid bare to the sky. Even cities sometimes build ruins upon ruins, landfills leave layers of telltale waste, and reused paper can get cluttered by the leftover markings of a palimpsest.

I wonder if the first people to chisel records into stone did so with the idea that natural history preserved its own records of life and death in stone. It seems apt that graves are often marked by stone.

Maya Lin, most known for her design of the Vietnam Memorial in Washington, DC, saw it appropriate to memorialize nature in a different way. In the entry to Cornell's Lab of Ornithology sits a large wooden ring that sings soundscapes.

Before all these high-tech installations, people could only really hear nature by going into nature. We used our senses to gather nature—and we recorded what we could see with the technologies we had: language and drawings. A person held the memory of an experience in his mind, then passed that experience on by telling others about it, or showing it to them. Later, people used drawings and paintings to record stories, then written language to keep track of business interactions. Later still, we learned to capture the reflection of light off an object with photography and videography, we learned to analyze things according to their chemical content, to read histories recorded in the decay of stone. And, of course, we learned to record sound by allowing vibrations to impress upon a medium, and after that we learned to convert them into electrical signals that could be replicated and manipulated.

I might point out that in Darwin's ornithological notes, taken longhand in a series of notebooks (some of which were unfortunately lost), are practically useless if one is looking for a description of sound. To his credit, he recorded a great many species of birds, and could not have possibly even heard all their calls.

[The partridges] utter *whilst on the ground*, a whistle,

which is much shriller than in the other species; when on the wing fly to a considerable distance: meat, when cooked, snow-white. I have seen this bird at B. Blanca. Northern Patagonia. (Darwin)

But consider the difference between that, and the true sounds of the partridge, as archived by a birder.

Then consider the difference between the recordist's archive of a bird call and the record of an entire soundscape.

But what, really, is the sound we're listening for? If we can't trust our perceptions, can we trust the other capacities of our senses? In all the things we have chosen to measure, we often forget the one that whispers, cries, shouts into our ears, or hisses high above our range of hearing, or rumbles beneath our feet.

Sound artist David Dunn seeks out such elusive sounds to learn more about the goings-on of nature. Specifically, he has recorded insect sounds from water and trees. He has focused on pinions infested with pine beetles, and employed the various clicks, scrapes, and squeaks of the pine beetle in his soundscape compositions, "The Sound of Light in Trees."

But Dunn is not a scientist by trade. A composer, he watched the forest around him slowly grey and die over the years as the seasons intensified. He wondered what he'd hear if he listened to the inside of a tree.

"It's an absolute cacophony," says Dunn, of a peak-season listening to a tree. He drives metal rods into the xylem of the tree and uses them to pick up recordings of the sound. Most of what he hears is the beetles' scrapings from within the pinions.

And with enough of this listening, he's found that the beetles are surviving longer into the year—before all too long they could overwinter and demolish the forest even more rapidly.

A beetle infestation is a breathtaking sight once it's too late to do anything. The tiny creatures bore through trees, eating them from the inside out. In Colorado, pine beetle infestations ravage the forests. Trees lose their structural integrity, forests faint or fall to blazes.

But an ongoing record of the sounds within a tree might offer valuable information. Infested trees could potentially be identified sooner, and removed before the beetles spread further.

And that aside, the survival of the beetles through the year adds yet another case to what we can expect from climate change.

While an artist does science, elsewhere a scientist does art. Tamara Heartsill is a USDA Forest Service scientist who studies riparian biology in Puerto Rico. When I met her, she greeted me with a smile and a kiss on the cheek. She studied biology with Mitch before pursuing her Ph.D. in Salt Lake City.

While I was visiting, Tamara was working with an artist to create a soundscape installation for the MAC, San Juan's museum of contemporary art, as part of the Wilderness Institute. She and Mitch met in his office, and scoured the ARBIMON database for unique calls. Tamara was looking to put together an auditory trail of the sounds one might hear walking from the beach to the peak of el Toro—the highest point

in El Yunque rainforest.

While collaborating with a sound artist, Tamara had an experience that impressed upon her. The artist lowered a waterproof microphone into the water, and Tamara thought she heard something interesting, “for the second that it was underwater I thought I heard [something]... ‘shrimp make noise?’”

Of course, from above the water, one would not often consider the many sounds of the deep. A naturalist simply cannot build a small cabin *a la* Thoreau underwater to spend a year immersing herself in nature. But for those who study underwater life using technology, as Tamara did, a different sonic dimension opens up to them.

“It’s still a very foreign feeling, like you’re in another world.” says Tamara, recounting the experience of scuba diving. We may not hear them from our regular habitat, but the ocean has its own daily chatter. The creaking of barnacles, wide-range songs of whales, the rush of currents.

When going to get her Ph.D. in Utah, Tamara had an experience that is perhaps the mirror image of the underwater microphone. She had seen photos of Sawtooth, UT. It was a beautiful national forest that sat upon old mountains with a prairie laid out in front of it. But while Tamara was visiting this picture perfect scene, she heard the huge knock of oil drills (or fracking, she wasn’t sure). An interruption to the soundscape, a sound that might be a giant burn on a photograph. “The image is pristine—but the noise—that’s just wrong,” she said.

We humans are filling the world with all sorts of noise. Through the window of my hotel in Rio Piedras, I could hear the sounds of the city. Loud people, music, cars, rain, wind. The street on which I stayed was particularly loud, with Thursday nights peaking out the noise before students headed home for the weekend. Of course, this was no ordinary weekend, it was the weekend of *Fiesta de la calle San Sebastian*, or *SanSe*, or, *the biggest party in all of Puerto Rico*. Every January, people from all around the island flock to Old San Juan for the event, and the sound of it is impressive.

The street was packed with people, occasionally with singing and dancing, but mostly with drinking and yelling and the booming of speakers. In a city where the coqui are heard everywhere, the song of the night had changed. In the midst of the anthrophony, the frogs had to find somewhere to do their own partying. In the quiet crack of an alley, next to a stand selling freshly pressed sugar cane juice, the coqui sang on.

Most Puerto Ricans don’t consider the coquí noise. When I spoke to Jose Alicea Pou at Puerto Rico’s center for noise control, he said, “to be a noise, someone had to be annoyed by it.” He dealt with noise complaints, among other things. “In the tropics, there’s a tight relationship of interior & exterior acoustic space.” He explains that for much of the year, people keep their windows open.

This was a delight to see on a walk through the city—the windows of buildings were practically doors, but with wooden or iron bars in front of them. They were open, and through them you could see people going about their days. Indoor and outdoor sounds blended. In the center of the Old San Juan sat a large hotel, but the hallways were exposed to the outdoors. Courtyard walls wrapped around a large tree, and bats could be seen swooping between branches above dinner guests.

Still, there is always an exception to the norm. Jose once received a noise complaint about the coquí from a resident of a rural area. “The countryside is not that

quiet either,” he says. He adds that this may be why people feel that they can be loud. “You moved into the home of the coquí!” he told her.

The woman who complained about the coquí was bothered by its noise—the calls in some way interrupted her daily activities. This is not too far from what is seen between the frogs themselves. One thing Aide’s study noted was the acoustic niche between creatures. Of course creatures do not often nest in each others’ burrows, but in addition to time and space, the coquí and other calling creatures also inhabit time and pitch. Delighted about this fact, Mitch pulled up a sonogram from one of the El Verde samples to show me.

Of the many things the coquí need to survive and reproduce, a major one is the ability to hear each other. They call for mates. They’re not the kind to hang out in a crowded bar or hook up at a rock concert. Coquí like to have their own conversations. They don’t like being interrupted.

To find out when the frogs are calling, a biologist who knows the species’ calls makes models of it.

“The models are based on the maximum and minimum frequencies, bandwidth, duration and silence between notes (or ROIs) in the calls.” (Ospina) The models are then validated by random recordings from the ARBIMON collection.

With the help of computers, biologists could work with the large amounts of data brought in by ARBIMON, and pay attention to “a finer time scale (e.g., daily, hourly). Due to the high variability in amphibian populations, this kind of high resolution data can help us better determine the population trends.” (Ospina)

What they found was that the frogs tended to give each other sonic space.

Each of the four *Eleutherodactylus* species emits sounds in a different range of frequencies (Fig. 1A).

Eleutherodactylus coquí produces two notes (“CO” and “QUI”; Townsend et al. 1984, Stewart and Rand 1991, Rivero 1998): The “CO” occurs between 1.5 and 1.7 kHz, and the “QUI” from 1.9 to 4.0 kHz. At a slightly higher frequency range (3.3–4.2 kHz, Ovaska and Caldbeck 1997), a long note (0.1 to 0.4 s) similar to a whistle is emitted by *E. cochranæ*, rarely followed by one or more clicks. The other two species, *E. brittoni* and *E. juanariveroi* are more similar in their call structure (i.e., repeated “chips”), but differ in their frequency ranges (*E. brittoni*: 4.5–6.0 kHz and *E. juanariveroi*: 6.0–9.0 kHz, Drewry and Rand 1983, Rios-Lo’pez and Thomas 2007). The acoustical characteristics of each species determined the parameters used to create and train the species-specific identification models. (Ospina)

Some changed their pitch to accommodate for other species, while others frogs changed their timing. They occupied what is known as an “acoustic niche” as well as a niche in the landscape. But the frogs don’t like to move around. “*E. coquí* has been found that they are very sedentary, moving in average 4.5 m per night.” (Ospina)

In a city like San Juan—or like LA or Beijing or any place where many humans

have build complex developments—humans dominate the soundscape, leaving little airtime for animals to inhabit an acoustic niche.

A frog that slips away unnoticed.

The coqui is a national symbol of Puerto Rico, people know them well—they're adorable. And all of those things are useful emotionally, but there's more to it than that. The calls of the coqui are fading, but their habitats are degrading as well. These frogs, known across the island, could be early warnings for climate change.

And where one frog has appeared with the shifting of a habitat, many have disappeared. Over 40% of amphibian species are suffering population decline, (Ospina) and overall, “amphibians are becoming extinct 200 times faster than the background rate.” (MacCallum)

This is a proverbial canary in the coal mine--frogs respond dramatically to changes in the ecosystem, and different species vary in what they respond to. (Hayes)

But we don't just want to look at one species—frogs vary greatly, which is why diverse soundscapes are important. One species will call less in rainfall, another will change places due to temperature.

The Tropical Ecology Lab has listened to several different species of coqui to find out how they react to their environment. Even within this small selection, they found different reactions from species to species.

The four *Eleutherodactylus* species responded differently to temperature and precipitation (Table 4); two showed a significant relationship only with temperature (*E. coquí* and *E. cochranæ*) while the other two significantly responded to both temperature and precipitation (*E. brittoni* and *E. juanariveroi*). (Ospina)

What is seen on this smaller scale connects to records of the coqui population as it compares to the weather. Even in five years of lower-than-usual rainfall in Puerto Rico, *E. coqui* felt a 60% decline in population densities. (Woolbright)

So it seems that rainy day ruins the mood for these little frogs. The cause of this is not yet known—perhaps the lack of rain makes for less-than-ideal nesting grounds, or the weather is dangerous for the adult frogs, or all that pitter-patter is simply too loud to call over, or perhaps there's some combination of factors known only to the frogs.

Whatever the cause, we now know that rainfall makes the coquí call less, and it can be inferred that this contributes to the population decrease. What sounds beautiful to the human observer is a sound crucial to the survival of these tiny frogs.

Later, Mitch told me that one of his students had just analyzed some of the data from ARBIMON to find that over the past few years, the coquí calls in the monitored region of el Yunque had decreased by 40%. Compare this to the data that over the past 25 years there had been a one degree rise in temperature at the El Yunque station (four times as fast as average predictions of global warming, notes Aide), and the correlation may tell us something.

“It's not nice,” said Mitch, “but it's good for the proposal.” He was worried about the future of ARBIMON, and its ability to stay financially viable.

But with the project's progress so far, it has certainly made an impact on ecology.

Tamara Heartsill brought Puerto Rico's soundscapes to the MAC, and Luis Villanueva-Rivera continued studying soundscapes at Purdue. There, Bryan Pijanowski and his lab approach soundscape ecology in several different ways. They seek patterns, set up recording stations in national parks, take 15 minute samples or even month-long ones for analysis.

The science of soundscape ecology is still new, and people are exploring variations on technique and different ways to use computer models. What was a method for natural historians is now becoming more like the rest of science. Listening is becoming more formal, more standardized.

As science defines itself, technology enhances both the sorts of things we can detect and the sorts of things we can record. Our feeble eyes once caught only some of the universe's light, and when we expanded our tools to detect beyond the visible spectrum, astronomy exploded.

We are learning to put the stethoscope to nature, to take its pulse and listen to sounds we didn't even know existed.

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