Appendix.

Patagonian Soundscapes: An acoustic survey of subantarctic Chile and generative soundscape composition

By Garrison Gerard

> *As the wind gently lifts the bow of the canelo tree, and the glacier on the mountain slowly drips through the moraine to the bay, a guanaco watches from high up in the mountain. I stand there for quite a while, staring back at the creature; my eyes drift to the gulley below as rafts of ice spin listlessly in wandering currents which seem to disappear as soon as I follow them. The guanaco suddenly jumps below the ridgeline. Behind me a truck honks its horn as it carries cement along the newly constructed road.*

Yendegaia National Park (YNP) in Chile is changing. Like all natural spaces, the cycle of the seasons alters the landscape surrounding Yendegaia Bay each year, but the pace of change is accelerating. To meet increasing tourist demand, the Chilean government is building a road to connect this remote region on the southern end of the world to the rest of society. As you drive along the still uncompleted road, every few hundred yards a sign demarcates an archeological site: a compromise to maintain some of the indigenous Yaghan locations that the new park road must cut through. Downed trees line the sides of the road, and dynamite traces mark the rock that workers cut through to level the path forward.

With the imminent impact of a new road to YNP in the background, I set out to examine the acoustic interactions of the ecosystems of the park through listening and systematic field recording. The field recordings served a dual purpose as both the foundation for a music composition and as a soundscape ecology survey – both disciplines informed by the work of the other. In this paper, I first examine the ecological results of the surveys, followed by a discussion of my generative soundscape composition tool which uses the field recordings as a foundation for musical composition.

Soundscape ecology is an emerging field that leverages insights from multiple other disciplines such as landscape ecology to investigate the acoustic dimension of ecosystems. Pijanowski et. al (2011) see soundscape ecology as "emphasizing the ecological characteristics of sounds and their spatial-temporal patterns as they emerge from landscapes" (ibid., p. 203). Given this focus, my main goal was to understand the differences between YNP and other areas of Patagonia, particularly those separated from the park by the Beagle Channel. Two main hypotheses informed my approach to recording and data analysis, the Acoustic-Niche Hypothesis (ANH) of Bernie Krause which argues that animal vocalizations occupy a particular section of the available frequency spectrum (Krause 1993, p. 3-6) and the Acoustic Adaption Hypothesis (AAH) which posits that animals adjust their vocalizations to take advantage of the acoustic properties of their environment (Farina 2013, p. 45-54).

Acoustic Surveys

The central location for these acoustic surveys is YNP. I recorded for more than 12 hours at three field stations within the park. I also recorded at two other locations within Patagonia, Omora Ethnobotanical Park and Guerrico, to document any differences between YNP and nearby locations. The recordings reveal a delicate set of ecosystems that are already being impacted by anthropogenic noise.

The principal analysis tool that I employed through field recording was to track the temporal audibility (TA) of categories of sounds. I modeled my approach on the American National Park Service's Acoustic Monitoring Plan (Betchkal 2011, p. 7-8). By listening to five seconds out of every five minutes of audio and cataloging the types of sound present, I can identify trends across the day and between different locations. This approach does not capture every sound – some animals may only pass once a day or an aircraft might pass between five second listening windows – but over a sufficient timescale, this method reveals the average presence of a given sound source. To complement TA, I used other techniques such as amplitude tracking and event counts which reveal details about the ecosystem not apparent from TA.

Yendegaia National Park, Chile

Yendegaia National Park is situated on the north shore of the Beagle Channel west of Ushuaia, Argentina. It serves as a continuous protected ecological corridor between the remote Alberto di Agostini National Park in Chile and Tierra Del Fuego in Argentina. The park contains forests, flatlands, mountains, and glaciers, and is home to a variety of unique subantarctic species. While the Chilean government is constructing the road to increase access to the park, currently the only way to access the bay is by ferry or chartered boat along with special permission from the Carabineros de Chile. Subsequently, the park is still relatively untouched by human activity, allowing me to capture an aural snapshot of the area before the road leading to the park is completed.

My goal in Yendegaia was to record a wide variety of ecosystems; to facilitate this, I monitored three sites within the park. The first extended recording was made in the riparian forest that divides the Beagle Channel from the mountains deeper in the park. The recording device was mounted on a tree within a grove of Lenga (nothofagus pumilio) and Canelo (drimys winteri) trees. In addition to the first recording station, I set up two separate stations further into the park—one at a bend in the park road at the end of the bay, and a second on a mountain further north.

At the first field station, there is a high level of sonic activity from avian, wind, and anthropogenic sources (see figure 1). Because of its relative proximity to the Beagle Channel, wind is a near constant presence in this area. The ever-present winds, combined with the evergreen costal forest creates a high ambient noise level, meaning that animals must expend higher levels of energy in order to communicate. Compounding the high noise level, distant construction activity is heard as often as bird calls in the area. There is occasional ground activity from both birds and mammals, and the occasional call of animals such as the culpeo fox manages to cut through the noise.

Contrasting the congested frequency spectrum of the first field station, the second field station was relatively silent. This field station was situated further north into the park where the bay ends and the long glacial river begins winding toward the glaciers on Monte Darwin. The recorder was placed approximately 500 feet from the newly constructed road along a bend; this allowed for accurate tracking of automobile passings. Almost every sound source is considerably lower

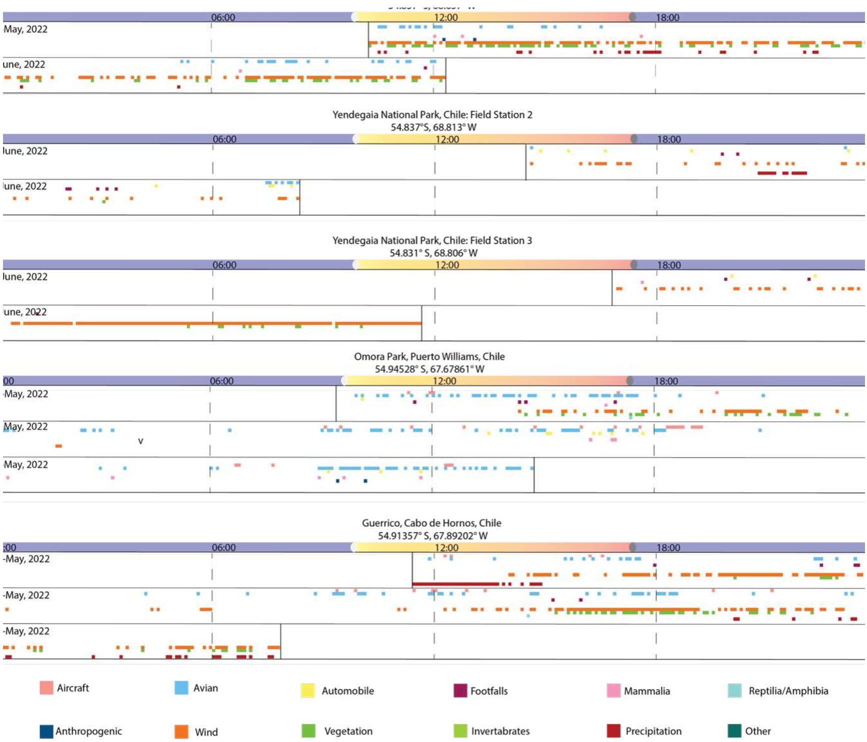

Figure 1: Temporal Audibility, YNP Field Stations 1-3, Omora Park, and Guerrico. Gerard, 2022.

in frequency compared to the first station with wind activity dropping below 20% audible compared to closer to 70% at the first station (see figure 2). Automobile and ground activity however were much higher. On average, an automobile passed by the station every 90 minutes. Notably, this area experienced relatively low avian activity.

The third field station was located further into the park, approximately half of a mile up into the mountains on the same side of the bay as field station 2. Because of the greater elevation, wind noise was almost as prevalent here as at the first field station closer to the channel. Sonic activity was the lowest in almost every other category here, with only occasional automobile noise reaching the station. The only animal activity recorded here were wild horses moving across the ridge line – avian activity was noticeably absent in this area.

All stations in Yendegaia exhibited a flat decibel base decibel level with varying rates of noise spikes. At the first field station, there is a higher base level of sound: the proximity to the Beagle Channel and resulting wind noise account for this higher level (see figure 3). At the second field station, there was a relatively low baseline decibel level of 38 decibels, however occasional bursts of wind created outliers.

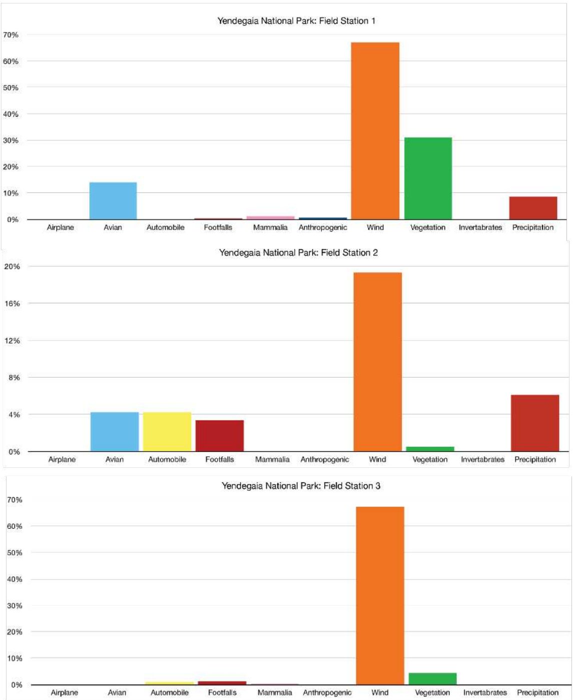

Figure 2: Percent Time Audible for YNP Field Stations 1-3. Gerard, 2022.

Combined, these three field stations paint a picture of an isolated ecosystem that relies heavily on efficient acoustic transmission. Wind noise is very common and tends to dominate the frequency spectrum, but this masking effect may be useful for animals such as the fox to use in its hunting. Already, auto mobile noise from the road is clearly audible in multiple regions of the park, this before the road is open to the public.

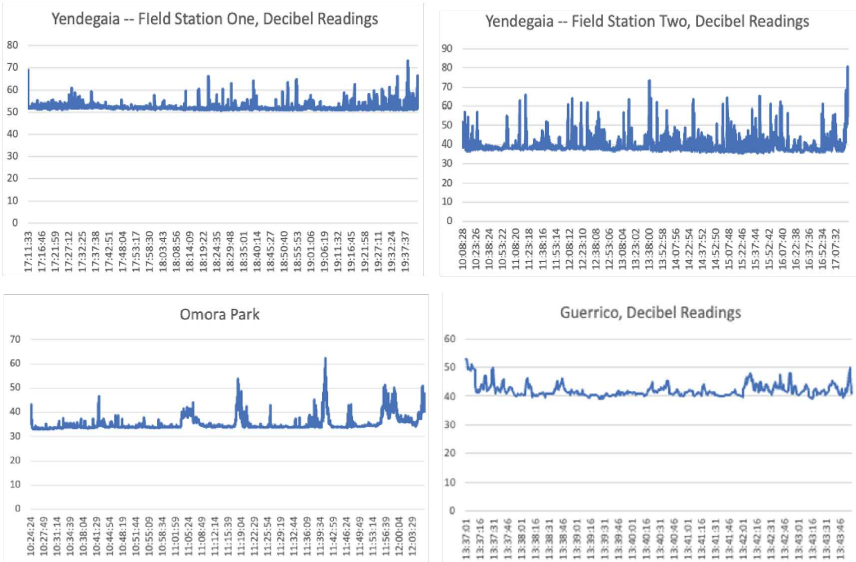

Figure 3: Decibel Levels Recorded in Yendegaia, Omora, and Guerrico. Gerard, 2022.

Isle Navarino

Across the Beagle Channel from YNP is the Isle Navarino. On the island is Omora Ethnobotanical Park, a protected area 2 miles outside of Puerto Williams. As the southernmost city in the world, Puerto Williams and the surrounding area provide a home to a unique combination of ecosystems. Much of the park is made up of woodlands, bogs, and riparian forests; the river from laguna Róbalo cuts through the park, and the surrounding wetlands are home to multiple species, including the invasive American beaver (Schüttler, et al. 2019, p. 1093-1105).

The most striking aspect of the Omora soundscape is its silence. This is particularly evident at night when there is almost no biologic acoustic activity except for the occasional bird call or mammalian sound. Due to the low acoustic activity, acoustic signals can transmit meaning at a very high signal to noise ratio. But this also means that Omora is susceptible to noise pollution and other masking effects. For instance, the few aircraft that fly to Puerto Williams dominate the soundscape when they pass overhead. Daylight can clearly be seen to closely correlate with animal activity (see figure 1). Each morning avian activity begins immediately before sunrise and continues throughout the day until slightly following sundown. What few ground mammals are present on the island are more active during the day.

The decibel readings from Omora were considerably lower than in Yendegaia: Omora had one of the lowest average decibel readings of any ecosystem in this survey, with a floor hovering around 33 dB (see figure 3). Tracking the decibel levels over time is a blunt instrument, but nevertheless one that indicates a certain level of activity; it is important to keep in mind acoustic activity that functions outside of these measurement devices and the range of human hearing such as ultrasounds, hydro sounds, and sounds sources with an incredibly small range.

I also recorded for three days at the end of Guerrico Valley situated approximately twelve miles to the West of Omora Park. The recording location was close to the Beagle Channel, but far enough removed in elevation that water noise was not present. The area was heavily wooded with numerous downed trees. There are some ranches on the island that allow their livestock to roam free, so cows would occasionally move through the forest. Many levels of activity matched Omora Park, however the proximity to the Beagle Channel had a significant impact on weather conditions. Bird activity is present, but mostly concentrated in the dawn and twilight choruses (see figure 1). Aircraft activity mirrors Omora park – essentially every flight heading to and from Puerto Williams will also fly within an audible distance of the Guerrico Canyon area. However, the proximity of the Beagle Channel introduces different weather conditions. Wind is a near constant presence with breezes from the channel often rushing through the forest. The plentiful downed trees combined with old trees still standing create fascinating sounds of interlocking creaks and groans. These sounds often overlap with bird noises and share a similar frequency range, making identification of some bird sounds difficult during high wind periods.

The base sound level at Guerrico is relatively low, but greater than other locations on Navarino island. Between the more prevalent wind from the channel, increased animal activity, and noise from the Beagle Channel the average base decibel level is around 40 dB (see figure 3). This is greater than the base level at Omora by 7 dB, more than an objective doubling of sound level.

Generative Soundscape Composition Tool

In addition to the ecological component, my work in Patagonia has a creative facet as well. Based on my observations and the data from the acoustic surveys, I designed a system to generate soundscape compositions based both on audio features determined through real-time analysis and on physical connections such as similar weather patterns or geography that are defined manually in the program. The program is flexible and can include visuals, reactive lighting, live performers, electronic processing, and other elements. Here, I examine the design of the generative soundscape composition tool and one possible realization of the system: *Ecosystem [352]*.

Ecosystem [352] is a fixed media work that combines the field recordings from Patagonian Chile with field recordings from Iceland and the Chihuahuan Desert to create a multi-layered soundscape that moves between surreal and imagined spaces. *Ecosystem [352]* is one possible result of the generative system; it uses the field recordings and electronic processing engines alone and so does not contain the entire possibilities of the generative system. However, it illustrates the ecological and artistic concepts that underlie the system as a whole. This realization of a flexible system is inherently limited, but those limitations are appropriate to the project at hand: just as the acoustic surveys provide a snapshot of the acoustic state of these changing ecosystems, so does this single eight-minute fixed media piece provide a static version of a flexible, changing system. Where appropriate, timestamps are included that indicate the minute and second referenced from *Ecosystem [352]*.

The aesthetic goal of the system and *Ecosystem [352]* is not to reproduce the actual recorded soundscapes, but to create a system that is built on the interrelationships of these spaces and produces a composition that represents my personal experience of these ecosystems. The layers of abstraction between the real spaces and the final work – the microphones, post-processing, electronic effects, re-organization – are all part of the conception of the piece. Following from this, some "imperfections" are retained in the work. There are moments where passing traffic or microphone handling noise are audible in the work (00:10-01:25)[1]. These apparent imperfections could have been removed, but they are integral to the purpose of the piece.

The field recordings in Patagonian Chile used in the piece include the acoustic survey recordings from Omora Ethnobotanical Park, Guerrico, and Yendegaia National Park. The concepts explored in the acoustic surveys informed my approach to these sounds, namely that as these areas are in the far south, they are especially susceptible to climate change, with small changes having a magnified impact. The recordings were made during the winter, so an already bare soundscape was even more sparse, but individual bird sounds and distinct wind patterns carry easily through the space. The second recording region was Iceland. Here I recorded in a variety of ecosystems ranging from isolated fjords to otherworldly steam vents. The constant activity serves as a foil to the relative calm from the Patagonian recordings. The third major area was from the Chihuahuan Desert. Here insect choirs provide a dull background to the occasional rushing water. In addition to the natural sounds of each area, anthropogenic sounds feature prominently. Passing airplanes, traffic, and construction sounds join the sounds of nature in unpredictable and surprising ways.

Ecosystem [352] uses the visual coding environment Max to combine the field recordings from each location. The field recordings are organized into nodes, each node represents a specific location from the three main recording areas. There are more than 30 locations represented in the piece; each location node contains at least one long recording (ten minutes or greater), and up to four shorter recordings. The system moves from location to location based on connections between recording sites such as geographic proximity. When a location is triggered, the long recording is played from a random point in the recording. The motion from space to space is driven by an algorithm that combines analysis of the current recording playback with a set of probabilities to trigger a new location. Since *Ecosystem [352]* is shorter than ten minutes, it uses a small portion of the available sounds in creating its soundscape.

Organizing Principles

There are four principles that I explore in this work; the first is the role of personal perception. In other words, what is the difference between ecosystems as they exist and ecosystems as one perceives them? The sounds used in the piece were all recorded by me, meaning that my orientation, motion, and experience inherently impact the sound of the piece, but the role of personal perception is especially apparent in the electronic processing: the ways that I manipulate or transform the recordings are based on the connections I drew while in these spaces. As Barry Truax and the World Soundscape Project argued, a soundscape composition originates from an experience of a place, and this piece explores my experience in these places (Truax 2008, p. 104).

A second fundamental tension explored in *Ecosystem [352]* is that between real, imagined, and surreal locations. As I use the terms, real locations are those that exist somewhere in the world and are being presented through performance in a new light (00:21-01:35). An imagined space combines real sounds in an arrangement that might or might not be possible in the real world but is not based on an actual location (02:05-02:40) And a surreal space uses processing or synthesis to create sounds not normally found in the world without the use of electronics (03:50-04:10). The piece moves fluidly between these and attempts to blur the line of what sounds are "real" and what sound combinations move into the realm of the surreal.

The third principle of the work is that of heterarchical organization, which is most important when considering the form of the work. Instead of composing a linear composition that progresses from a beginning to an ending point, I developed systems that relate and influence each other in myriad ways to create a piece that can unfold in a variety of realizations. Heterarchical organization is a system where there is no clear hierarchy and each element has varied and unpredictable relationships with other elements in the system. This organizing principal mirrors the physical ecosystems recorded for the project where climate, weather, animals, and other sonic phenomena interact in multivariate and unpredictable ways.

The final topic I explore in the work is that of meditative listening. This perspective originates in my experience of time in nature and therefore is in some ways an outgrowth of the first topic explored in this work, personal perception. Natural spaces have a profound effect on my sense of time and personal wellbeing. The guiding principle of form was to create a system that did not overwhelm the audience, but rather mirrored the reflective nature of a forest grove or the bank of a stream. This influenced the development of the algorithms that determine density in the work, as well as informing the underlying aesthetic of the piece. Electronic processing and moments of high density are used sparingly, the basic state of the work is sparse and reflective.

Formal Design: Organization and Movement Between Locations

Mirroring the real-world source of the sounds in the piece, the organization of the piece is necessarily rooted in geography and characteristics of the real places. The electronics trace a path through the locations, creating a new soundscape by overlapping sounds that would not necessarily coexist normally. The electronics start by randomly selecting one location to begin playing sounds. After the initial location, the electronics progress by "moving" from one location to another based on triggers from an analysis engine. All sounds are analyzed by multiple tools which are looking for changes in amplitude, centroid frequency, frequency spread, roughness, and spectral slope. When enough changes have been detected, a trigger is sent for the electronics to move to a new location. If the analysis engine surpasses a high threshold of triggers, it will begin sending triggers to stop playing existing locations, beginning from the oldest location nodes still sounding. A location either ends when it has been triggered to stop or the long recording ends.

Because of the variability in initial conditions and selection of sounds, no two realizations will be the same—the system will move through the locations at a different pace and different order with each execution. Each location has a set of probabilities for how likely it is to move to another location based on geography and other connections. The highest probability is to move to a location that is close geographically to the current location. Secondarily, the system identifies similarities between two places such as similar climate, topology, or animal populations and uses these to trigger the next location node. A location that is currently playing cannot be triggered again until it has either played to the end or been turned off by the system. The combined results of these tendencies mean that the engine initially prefers to stay within a geographic region, but as more location nodes are triggered within a region it increasingly prefers to move to another geographic region along a secondary connection (green line). Further, there are some regions that are relatively isolated in their connections, meaning that they are less likely to be triggered than a region with numerous connections.

The algorithm that drives the location selection is fundamentally the decider of form for the piece, therefore, tuning the tendencies and tolerances of the system to trigger or remove location nodes and electronic processing is central to the composition of the work. The system works by counting the number of outliers in the various data analysis streams over a given period; by comparing those amounts to a desired activity level, it decides whether a new location node should be triggered or if one should be deactivated. The desired activity level normally begins at a low level, gradually increases, then is reset when a new location is triggered; however, if certain sound trends are detected, the system will modify the rate and direction of change in the desired activity level. For example, if a signal that imitates white noise (such as a stream) dominates the frequency space for more than two minutes, the system increases the desired activity level three times faster than normal until white noise is no longer dominant.

Electronic Processing

The Max patch incorporates electronic processing onto the field recording materials from the location nodes. When the analysis engine detects a period of stasis on a single sound source for a sufficient period, it adds one of three sets of processes to the most recent location node that has been triggered. The electronic processing includes comb filtering, delay networks, granulation, and reverb.

The electronic processing on the field recordings is designed to aurally separate the processed material from the other field recordings. A set of comb filters and delay lines add a distinctly processed sound to a recording that also emphasizes certain pitches in the recording—the emphasized pitches are selected at random when the comb filter is triggered (02:50, 06:37). Reverb is used on all of the sounds as a whole, but reverb with a much longer delay time and wider space is used on individual location nodes to single out that sound as separate and in a different space than the other sounds (07:12). Finally, granulation creates a similar effect to the comb filtering of distinguishing that location as processed and distinct from the other sounds (07:34). Overall, the use of electronic processing is purposely subtle and infrequent.

Spatialization

The generative soundscape system can render a piece for any number of speakers ranging from a stereo set-up to an ambisonic dome, or even a sound installation of speakers spread throughout a concert venue. *Ecosystem [352]* is designed to be listened to by individuals with headphones. While it is in stereo, there is still a sense of spatialization through the use of binaural processing.

Each location node is pre-assigned a point in three-dimensional space, as well as a vertical and horizontal span, resulting in sounds that are either focused in one location, or spread over a large portion of the sound stage. The basic positions of sounds within the field of listening are based on their physical location in real space. Each sound has three starting positions, a local position, a regional position, and a global position. The local position draws on the local geography of an area and is the most focused of the three options. In a local position, the real-world geography of the region is imagined to encompass the entire sound stage—the sound then is placed within that area according to its physical position (see figure 5). Height is also considered in the spatialization of sounds with a high elevation increasing the height of the sound in the spatialization. Regional locations are one level removed and view the entire sound stage as a wider region: two examples in the piece are Iceland and the state of Texas which both function as the boundaries for their respective region. And finally, there is a global position where all sounds are placed according to their position on a globe. The analysis engine triggers a

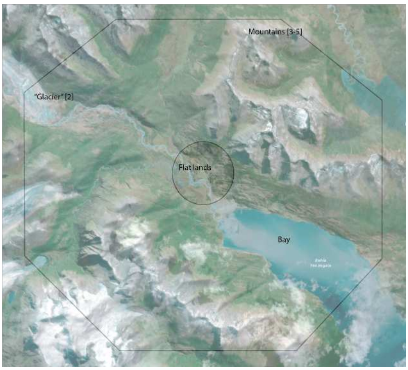

Figure 5: Local Arrangement of Sound Sources in Yendegaia Local Scene, *Ecosystem [352]*. Gerard, 2022.

change between local, regional, and global when it detects that no sound has dominated the soundscape for three minutes and an adequate number of high amplitude events have recently occurred.

Starting from any home position (local, regional, or global), sounds can travel to a new location based on multiple other factors. First, when some locations are triggered, they "pull" nearby sounds with them to a new location; for instance, when the sounds of the birds in the Westfjords in Iceland are triggered, all sounds from the Westfjords move independent of other existing sounds.

The spatialization of the work blurs the lines between real and imagined spaces. While the sounds are initially spatialized based upon their real-world geography, sonic interactions gain an outsized impact on the spatialization as the piece progresses, so that the performance of the piece is, in many ways, the creation of a new, unnatural space.

A Note on Noise

Noise holds a central position in discussions of both acoustic ecology and soundscape composition. Noise can often be characterized as negative and something to be removed – both from soundscapes and from electronic recordings. R. Murray Schafer wrote extensively on noise and on methods to reduce it or remove it entirely (Schafer 1977, p. 181-204). I hold that noise is not inherently bad, and further that it is crucial to the study of ecosystems. This then introduced a problematic dynamic in the use of field recordings: all recordings have some level of noise, especially recordings of outdoor locations. The background hiss of wind, the hum of electrical motors, or a constant rumble of distant traffic were all present to varying degrees in the unedited field recordings. And while these sounds are part of the soundscape, when the locations were combined in this project the level of noise overwhelmed any other signal. This necessitated the use of noise removal tools; I used the tools to extract background noise to a separate file that is then mixed back in at a lower level. In this way, I can control the degree of noisy elements of each ecosystem within the piece. This balance allowed the noise to retain its role in the sonic environment, while not covering all other sounds.

Conclusion

The fundamental project of this work is to examine the potential for overlap between soundscape ecology and music composition. The acoustic surveys I carried out in Patagonia were fundamentally informed by a perspective of listening and musical thought: I would not have selected the same locations or approached the area in the same way without first reflecting on the areas from a perspective of soundscape composition. The influence of ecology on the compositional process is perhaps more obvious, *Ecosystem [352]* is clearly tied to the real locations in multiple ways such as in the organization of sounds and my approach to the underlying material.

While far from exhaustive, these acoustic surveys provide a window into the acoustic state of Chilean Patagonia. It reveals ecosystems that rely on alternating silence and predictable white noise obscuring sound transmission. It will be necessary to continue to track the acoustic activity in Yendegaia and the surrounding area over time, particularly as the road connecting the park to the highway network is completed. The composition of this work focused on creating a flexible system that could unwind in myriad ways and create multiple results in live or recorded performance. As such, it is in some ways difficult to create a work such as *Ecosystem [352]* which uses such a small portion of the material available. While this realization of the work is inherently fixed and therefore lacks the flexible and reactive nature of the system in live performance, it is just as valid of a performance of the work. It is like a picture of a moving stream, capturing one possible soundscape and preserving it.

> *With my eyes closed, I feel the dappled sunlight pressing against my face. The cushion of leaves beneath my head crinkles and cracks with every small movement. The trees above cross the sky and meet in deciduous arches, building a cathedral by the river. But instead of echoes, the woods seem to absorb every sound into their bodies. The slow rush of the river is subsumed in the dappled silence.*

Notes

[1] A recording of the *Ecosystem [352]* is available under https://soundcloud.com/garrisong/ecosystem-352 (last access, Jan. 15, 2024).

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