The Rhizosphere

Subterranean Listening

by

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ABSTRACT

For about a decade, I have thought of composing as a form of sonic gardening. The processes are very similar in that I cultivate ecosystems of interrelated parts, whether in sound or in the soil. My interests in creating sonic ecosystems and in learning more about environmental issues motivated me to research soil health and the rhizosphere, the microbiome around a plant's root system. For my dissertation project I have composed a piece titled *The Rhizosphere* inspired by the processes and behaviors found in the rhizosphere for percussion sextet of about 8 minutes in duration. This piece was commissioned by the Arizona Contemporary Music Ensemble, with a performance date of April 21, 2022.

In this document, I discuss issues relating to soil and sustainability, provide a survey of relevant sound art, and describe processes and features of the rhizosphere. I share how I mapped different aspects of the rhizosphere to various sonic parameters and processes in my composition. I then consider *The Rhizosphere* as it relates to other pieces in my portfolio, specifically works inspired by nature or environmental issues. During my doctoral studies I have been inspired by and sought to depict plants (*Dandelion*) and desert (*Desertification* and *Desert Rain God*), among others.

ACKNOWLEDGMENTS

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TABLE OF CONTENTS

Page

CHAPTER

LIST OF FIGURES

Figure Page

CHAPTER 1

INTRODUCTION

The purpose of this document is to present a sonic interpretation of the rhizosphere, the ecosystem in the soil surrounding plant roots. Soil is one of the more neglected aspects of nature, and nature-inspired artists should include soil in a holistic hearing of the environment. One of the goals of this project is to help raise awareness about the importance of soil health and to use sound to explore and interpret this complex underground ecosystem.

I am not a soil scientist, and my perspective on this subject is limited by what can only be a shallow understanding of the rhizosphere. My interest in this topic stems from about a decade of gardening experience, growing food, composting, and building and maintaining healthy soil. Part of why I committed to writing a piece centered on the rhizosphere is the simple fact that I wanted to learn more about it. The main goal of this project was to better understand the ecosystem below the ground, to share that information, to try to listen to this site (by making subterranean recordings), and to create a musical representation of the rhizosphere's multi-layered processes. I have explored my concern with environmental issues and interest in nature through several of my works which I discuss in greater detail in the chapter on my portfolio.

CHAPTER 2

BACKGROUND AND CONTEXT

There are many unsustainable practices that damage healthy soil. Many of these problems are discussed in the documentary *Kiss the Ground*, including the postwar rise in chemical fertilizers, insecticides, and fungicides on farms which led to today's current overreliance on these inputs, the unsustainability of monocrops, and harmful livestock practices. Ray Archuleta, a Conservation Agronomist at the National Resources Conservation Service (NRCS), argues that our dependence on chemical inputs hides the true degradation of the soil, and points out that the number of inputs required to grow the same amount of food is increasing year after year. As much as a third of the world's topsoil has been destroyed since just the 1970s because of industrial agriculture. Additionally, for each person in the United States there are about three pounds of chemicals added to the soil annually.[1]

Climate change, desertification, and unpredictable weather patterns are not the only reasons we should be concerned about maintaining healthy soil. Regenerative agriculture has great potential to offset our carbon footprint. As discussed in the documentary *Fantastic Fungi*, plants can store as much as 70 percent of their carbon intake below ground.[2] Scientists have also noted that:

> Globally, the input of C to the soil has been estimated to be as great as 60×10^{15} g yr^{-1}, approximately one order of magnitude larger than the global annual rate of fossil fuel burning and other anthropogenic emissions, which is 6×10^{15} g yr^{-1}. Thus, small changes in the equilibrium between inputs and decomposition could

[1] *Kiss the Ground*, directed by Tickell, Josh, and Rebecca Harrell Tickell (2020; Ojai, California: Big Picture Ranch).
[2] *Fantastic Fungi*, directed by Louie Schwartzberg (2019; Los Angeles, California: Moving Art).

> have a significant impact on atmospheric CO_2 concentrations, which may either exacerbate or reduce the consequence of burning of fossil fuels.[3]

The ability for plants to sequester carbon is an overlooked but important opportunity for us to try to prevent some of the worst effects of climate change.

Survey of the Literature and Relevant Works

After studying acoustic ecology and different listening and recording practices, I have concluded that how the artist presents their work is essential to unpacking its meaning and impact. I will discuss different approaches which attend to soil and the ground / land more generally, and consider subterranean recording practices, commercial and non-commercial sonification, and sound art and installations which feature recordings of soil microorganisms. I recognize that this is a very complex environment and I am addressing only what I have been able to learn about the relationships and behaviors found in the rhizosphere. I also discuss recent and ongoing research by soil acousticians and artists such as Jez Riley French, Karine Bonneval, Matthias Rillig, Marisol A. Quintanilla, and Marcus Maeder, among others. There are many artists that address these topics, and a catalog of these works is available in the Appendix.

Philip Blackburn is a composer by training, with a PhD from the University of Iowa in music composition, and self-described "environmental sound artist."[4] His subterranean sound installation, *Sewer Pipe Organ* (2011), featured sound art created for speakers suspended down into the sewer network, carved into limestone underneath a

[3] Weixin Cheng and Alexander Gershenson, "Carbon Fluxes in the Rhizosphere," in *The Rhizosphere: An Ecological Perspective* edited by Zoe G. Cardon and Julie Lynn Whitbeck (Amsterdam: Elsevier Academic Press, 2007), 31.
[4] Philip Blackburn, "Bio," Philip Blackburn, http://www.philipblackburn.com/bio.

public park, in St. Paul, Minnesota.[5] He commented that most park visitors rarely notice the sewer covers and openings, overlooking this vital piece of infrastructure that lays beneath their feet. This piece is not directly about soil health, but its goal is to encourage listeners to become more aware of the ground and water system below them.[6] Furthermore, by drawing attention to local drainage systems, park visitors would be reminded that water runoff and wastewater drain to the watershed and return to our water supply eventually.

John Bullitt, a former geophysicist, has been working with seismographic data and mapping it to sound for almost two decades.[7] His *Deep Earth Dome* (2006-2008) was a sound installation that situated listeners in the center of eight speakers playing back seismographic data sped up to the audible range. The purpose of this piece is to pose the question, "if you could stand inside the Earth, what would you hear?"[8] This installation encourages the listener to imagine what the subterranean world might sound like. Although not connected directly to soil health, *Deep Earth Dome* centers the listener's attention on the ground, reminding them that the ground is always shifting and transferring seismic vibrations, however small and imperceptible (to us, unaided) they might be. Bullitt's ongoing *Earthsound Project* is a "near-real-time" online streaming platform that allows website visitors to access seismographic sonifications from multiple

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[5] Philip Blackburn, "Sewer Pipe Organ," in *Environmental Sound Artists: In Their Own Words* eds. Frederick Bianchi and V. J. Manzo (Oxford: Oxford University Press, Incorporated, 2016), 12-15.
[6] Philip Blackburn, "Philip Blackburn's Sewer Pipe Organ," YouTube video, https://www.youtube.com/watch?v=5o7WHeo9fVU&ab_channel=PhilipBlackburn.
[7] Frederick Bianchi and V. J. Manzo, eds., *Environmental Sound Artists: In Their Own Words* (Oxford: Oxford University Press, Incorporated, 2016), 34.
[8] John Bullitt, "Deep Earth Dome: A Seismic Sound Installation," JT Bullitt, https://www.jtbullitt.com/earthsound/deep-earth-dome/index.html.

locations around the world. The nearest station to Arizona is in Hollister, California, and plays back recorded data at 1800 times the true speed.[9]

Jez Riley French is a composer, sound artist, and field recordist based in the United Kingdom.[10] He has developed a practice of recording and working with subterranean sound using "specially adapted geophones" that allow him to record infrasound down to frequencies of 10 Hz.[11] He's created several series of works under the names *Geophonics*, *Ink Botanic*, and *Soil Horizons* that explore recordings taken from soil, and created sound art, installations, and field recordings.

Karine Bonneval is a French artist who has spent several years asking the question: "can we listen to the soil, what sounds could the soil make?"[12] Her installation *La terre*, created in collaboration with ceramic artist Charlotte Poulsen and bioacoustician Fanny Rybak, consisted of large sculptures which looked reminiscent of mushrooms that contained playback devices featuring audio collected from a personal compost pile. In her description of the work, Bonneval makes the case for us to thoughtfully reconsider our connection to the land, reminding us that the soil is "not a simple and inert material, [rather] it is a world in itself, complex and thriving."[13]

Bonneval further developed this mode of listening by connecting with soil scientists Matthias Rillig and Johannes Lehmann at their plant ecology laboratory in Berlin. The result of her artist residency there led to her being included as co-author of a

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[9] John Bullitt, "Hollister, CA, USA (Seismic)," The Earthsound Project, https://www.earthsound.earth/content/Stream.html?id=sao.
[10] Jez Riley French, "About," jez riley french, https://jezrileyfrench.co.uk/about.php
[11] Jez Riley French, "Geophones," jez riley french, https://jezrileyfrench.co.uk/geophones.php.
[12] Karine Bonneval, "Listen to the Soil," Karine Bonneval, https://www.karinebonneval.com/eng/projets/ecouter-la-terre-10.
[13] Karine Bonneval, "The Soil," Karine Bonneval, https://www.karinebonneval.com/eng/projets/la-terre-9.

scientific research paper that investigated the function of sound vibrations created by fungi and microorganisms living in healthy soil.[14] Bonneval was also able to construct an installation, called *Écouter la terre*, similar to her previous work, *La terre*, where ceramic sculptures erected on a bed of soil held devices that played back recordings of soil. Perhaps one of the most important questions raised by this collaboration, yet to be answered, is on the potential for sound waves to damage living things at the microbial level:

> One may also wonder if the sounds we produce, especially in urban areas or near roadways or those emanating from heavy agricultural machinery, might adversely affect soil biota, much like what has been demonstrated to be the case in aquatic environments. Some sounds travel extremely well in soils, which is exploited in worm grunting, and could thus affect relatively large areas. Can acoustic pollution interfere with communication in the soil or could it mimic signals of danger?[15]

They go on to add that there are several challenges to be faced by researchers interested in researching soil acoustics. Factors such as water, temperature, and different levels of sound attenuation due to differing density and permeability of nonorganic soil matter mean that it will be difficult to isolate sonic characteristics of microorganisms and rhizomatic chemical or bacterial interactions. They caution that: "physical changes in soil produce acoustic emissions; also, other processes, like water flow, shrinking, and swelling may produce such emissions that would need to be disentangled from biological signals," meaning that researchers will need to consider how to hear only what they want to hear, if they're interested in listening to a specific sound.[16]

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[14] Matthias C. Rillig and Karine Bonneval, "The Artist Who Co-authored a Paper and Expanded My Professional Network," Nature, February 2020. https://www.nature.com/articles/d41586-020-00575-7.
[15] Matthias C. Rillig, Karine Bonneval, and Johannes Lehmann. "Sounds of Soil: A New World of Interactions under Our Feet?" *Soil Systems* no. 3: 45 (2019).
[16] *Ibid.*

Monica Gagliano has conducted research into plant bioacoustics and discovered that plants do respond to sonic stimuli. In different studies, she has observed that plant roots grew toward an underwater speaker playing a frequency of 200 Hz and that they responded to this frequency specifically, not to 100 Hz, 300Hz, and so on.[17] She has also recorded sounds emitted by plant roots growing in an isolated lab environment, and described these "acoustic emissions" as sounding like "clicks."[18] Gagliano's research suggests that plant roots can perceive, react to, and create sound.

Soil researchers have described the underground soundscape in multiple ways, as featuring "thrumming and chirring and scraping," with both plants and animals creating sounds audible with proper recording equipment: "Root-munching larvae emit short clicks as they break the fibers of their meal. Worms rustle as they crawl through tunnels; so do plant roots as they push past grains of soils."[19]

Marcus Maeder is an acoustic ecologist and sound artist based in Switzerland. Maeder has discovered that anthrophonic soundscapes such as traffic noises and "even airplanes" are audible in the subterranean soundscape.[20] It is important to remember that although human ears do not perceive many of the underground sounds without technological assistance from special microphones like geophones or from speeding up seismographic signals to the audible range, human-created sounds are still audible below ground.As part of his research, he has started a national database and citizen science

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[17] BBC Earth Unplugged, "What Does the Plant Say?" YouTube video, February 6, 2014, https://www.youtube.com/watch?v=m-lq4sTMCqg.
[18] Monica Gagliano, Stefano Mancuso, and Daniel Robert, "Towards Understanding Plant Bioacoustics," *Trends in Plant Science* 17, no. 6 (2012): 324–325, https://doi.org/10.1016/j.tplants.2012.03.002.
[19] Ute Eberle, "Life in the Soil Was Thought to Be Silent. What If It Isn't?" *Knowable Magazine*, 2022, https://knowablemagazine.org/article/living-world/2022/life-soil-was-thought-be-silent-what-if-it-isnt.
[20] *Ibid.*

project of soil recordings, *Sounding Soil*.

CHAPTER 3

THE RHIZOSPHERE

The rhizosphere is a complex and biodiverse ecosystem, described by soil scientists as:

> the crossroads of the soil habitat, a hub of biological, chemical, and physical activity surrounding the living infrastructure of plant roots. Complex fine-scale gradients of substrate availability, water potential, and redox state distinguish this habitat from bulk soil and constrain the distribution and the activity of the tremendously diverse rhizosphere biota. Populations of archaea, bacteria, protists, fungi, and animals live here along with plant roots, the activities of each influencing those of the others across spatial and temporal scallions spanning orders of magnitude.[21]

I find these interactive systems and processes to be very compelling and well-suited for adaptation into sonic environments. The authors go on to add that: "the rhizosphere is thus spatially and temporally patchy environment with rapid (commonly diurnal) fluctuations between potentially extreme conditions, including cycles of water stress and anaerobiosis, that microbes must respond to in order to survive and thrive."[22] Extremes, cyclicity, and dynamic fluctuation are consistently investigated in my compositional practice, and I would like to build on these themes to address the interconnectedness of rhizospheric elements. The rhizosphere features many overlapping temporalities, such as life cycles of microbacteria (living in a generally "fast cycle"), fungi (living in a "slow cycle"), root growth and decay, animals such as mites, nematodes, worms, and non-living nutrient cycles (of water, carbon, and minerals). These components of this ecosystem are

[21] Zoe G. Cardon and Julie Lynn Whitbeck, eds., *The Rhizosphere: An Ecological Perspective* (Amsterdam: Elsevier Academic Press, 2007), xv.
[22] Ibid., 15.

all related, and often merge together in space and function, which I try to convey through shaping superimposed sonic densities of constantly shifting processes.

Healthy soil is characterized by a "highly heterogeneous environment" with multiple types of minerals, nutrients, soil particles, and a very biodiverse collection of living organisms.[23] The rhizosphere itself is a site of great biological activity due to the interactions between the plant roots and soil microorganisms.[24] The rhizosphere is different from "bulk soil" – it is a dynamic environment with multiple interacting cycles, organisms, and processes. Roots are an important component of the rhizosphere; root growth and its mechanical impedance, the porous nature of the roots themselves, and the diurnal fluctuation of root respiration are a few examples of root behavior.[25] It is worth noting that there is an important relationship between roots and branching; roots propagate by repeatedly branching at the large and small scale (including tiny root hairs). Bernston describes this more clearly:

> Plants are by their very nature modular. The form of an entire root system is the result of the repeated iteration of a structural unit – the *module.* Because of the iterative nature of this modular growth, root systems contain within them nested similarity […] fractals, branching structure at macro and micro levels. Clouds and branching root systems share complex fractal geometry.[26]

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[23] Uffe N. Nielsen, Diana H. Wall, and Johan Six, "Soil Biodiversity and the Environment," *Annual Review of Environment and Resources* 40, no. 1 (2015): 68, https://doi-org.ezproxy1.lib.asu.edu/10.1146/annurev-environ-102014-021257.

[24] *Ibid.*

[25] Hans Lambers, Ingeborg Scheurwater, Owen K. Atkin, "Respiratory Patterns in Roots in Relation to Their Functioning" in *Plant Roots: The Hidden Half* eds. Yoav Waisel, Amram Eshel, Uzi Kafkafi (New York: Marcel Dekker, Inc., 1996), 339.

[26] Glenn M. Berntson, "Fractal Geometry, Scaling and the Description of Plant Root Architecture" in *Plant Roots: The Hidden Half* eds. Yoav Waisel, Amram Eshel, Uzi Kafkafi (New York: Marcel Dekker, Inc., 1996), 259-271.

As illustrated by Eshel and Waisel, plants are able to grow different types of roots depending on highly specific conditions, demonstrating a wide variety of plasticity. Within a single plant, different types of roots serve different functions, such as anchorage, water absorption, nutrient uptake, and shedding dead root cells.

> The ability of plants to produce different types of roots is an aspect of the plasticity of the plant which has an important adaptive characteristic….Very few of the numerous roots that constitute one root system are exposed to uniform conditions…Moreover, the roots themselves increase the environmental variability by depleting certain zones in the soil of minerals and water, by secreting organic compounds, and by changing the pH of their immediate rhizosphere," and also by the sloughing off of older root tissue"[27]

These plant exudates help build more stable soil aggregates, "groups or clumps of soil particles joined together by organic matter, clay, and fungal hyphae."[28] Soil aggregation is a good indicator of soil health because soil aggregates maintain "protected organic matter" and prevent "erosion and soil degradation."[29] Conventional farming practices interrupt the sharing of these "organic compounds" and resultant stronger aggregates by tilling the soil - a practice that is meant to prevent weeds and unwanted insects as well as quickly loosen the soil to prepare for mass-seeding. No-till practices, such as lasagna gardening and permaculture, allow roots to fulfill their natural role in maintaining structurally sound soil. Roots are not only affected by their environment, but they affect the environment of which they are a part. Soil acousticians have observed a correlation between tilled vs. non-tilled land and the amount of sound heard in subterranean

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[27] Amram Eshel and Yoav Waisel, "Multiform and Multifunction of Various Constituents of One Root System" in *Plant Roots: The Hidden Half* eds. Yoav Waisel, Amram Eshel, Uzi Kafkafi (New York: Marcel Dekker, Inc., 1996) 175.
[28] Marisol A. Quintanilla-Tornel, "Soil Acoustics," in *Ecoacoustics* eds. Almo Farina and Stuart H Gage (Chichester, UK: John Wiley & Sons, Ltd, 2017) 227.
[29] *Ibid.,* 227-228.

recordings, with conventionally-farmed sites producing much less sound compared to untilled meadows.[30] This connection between the presence of sound and more sustainable agricultural practices inspired me to connect two of my main interests, composing and gardening, for my dissertation piece.

[30] Ute Eberle, "Life in the Soil Was Thought to Be Silent. What If It Isn't?" *Knowable Magazine*, 2022, https://knowablemagazine.org/article/living-world/2022/life-soil-was-thought-be-silent-what-if-it-isnt.

CHAPTER 4

DISSERTATION COMPOSITION: THE RHIZOSPHERE, FOR PERCUSSION SEXTET

Goals and Challenges

My original intent for this piece was to create a sonic multiplicity of processes and behaviors in order to reflect the dynamic environment found at plant roots. The rhizosphere and its many interdependencies serve as a microcosm of the interconnectedness of all things. When conceptualizing this piece, I began by thinking in terms of exploring multiple densities and temporalities. I wanted to create multiple simultaneous temporal layers because the rhizosphere features many different overlapping time scales. There are not only different life cycles for flora, fauna, bacteria, and fungi, but different timelines for water and nutrient cycles as well. These elements are explored, superimposed, and interwoven in distinct but also related ways, making it difficult to parse analytically. However, the following descriptions are able to explain some general and specific sonic interpretations of the rhizosphere.

Several listening frameworks and approaches to shaping sound that I have studied during my time at ASU that have influenced me and in writing this piece. These include strategies from acoustic ecology, influence from principles of electroacoustic music, and different ways of treating sonic density and thinking about time. The temporal aspects of the composition were considered with the goal of representing different facets of the rhizosphere and its overlapping cycles. In his chapter titled "The Perception of Musical Time," in *The Time of Music: New Meanings, New Temporalities, New Listening Strategies*, composer and theorist Jonathan Kramer reminds us of the importance of

remembering the "holistic experience" of listening. In my piece, I was faced with many decisions regarding which elements of the rhizosphere should be represented by which musical material. As Kramer states, "In real music there are no isolated events, no independent parameters, no single processes,"[31] which reinforces the challenge composers face when trying to create a coherent sonic ecosystem out of multiple parameters without sounding like each parameter was considered in isolation. When musical parameters follow a one-to-one mapping process, they can sound blocky, as if they were conceived at different, unrelated times. As will be discussed further on in this document, I tried to use multiple time scales, multiple types of processes to convey the interconnected aspects of the rhizosphere. Kramer discusses multiple types of temporalities as falling on a spectrum between linear, both nondirected and goal-directed, and nonlinear time, examples of which are moment time (via Stockhausen) and vertical time.

Inspired by the work of soil scientists and artists that work directly with recorded soil audio, such as French, Rillig, and Bonneval, I set out to capture my own recordings of subterranean sound at several locations: Arizona State University Tempe Campus, different sites near where I live including a compost pile, near a lemon tree, and sandy, rocky soil, as well as the Arizona Worm Farm in Phoenix, Arizona. I borrowed and used the following pieces of equipment: a Lom Geofón, studio headphones, and a Sony PCM-D10 Portable Audio Recorder.[32] After resolving some technical issues, I discovered that the earth I could access did not sound like the "thrumming, humming" meadow described

[31] Jonathan D. Kramer, *The Time of Music: New Meanings, New Temporalities, New Listening Strategies* (New York: Schirmer Books, 1988), 322.
[32] Thank you to Gabriel Bolaños and Wang Ziyu for letting me borrow their equipment.

by Marcus Maeder. Only later did I learn that the Geofón has a limited frequency bandwidth of 10 Hz to 1000 Hz. I found an electrical hum in a flower patch outside of the music building. I recorded and tested the Geofón under a lemon tree, in sandy/rocky soil, in my small patch of garlic, and in my compost pile both before and after watering and turning it. I had hoped to use field recordings in this project, and had looked forward to hearing some of these subterranean soundscapes for myself, but did not hear the sounds for which I was searching – the recordings were very quiet.

When I did not find much sound from the soils which I see during my daily life, I asked and was granted permission to visit and collect recordings at the Arizona Worm Farm,[33] which breeds and sells red wiggler worms.[34] I was given access to a structure (which looked to be a repurposed shipping container) where they breed worms in large plastic tubs. I was very interested in hearing what sounds these small animals might make. On this day, I had been able to borrow two more types of microphones, in addition to bringing the Geofón: a contact mic and a mikroUcho Pro mic. I also used the Geofón's 50mm extender attachment again, and the suction cup attachment as well. Although this disturbed the worms from their normal activities, I dug through the damp soil and tested out the sounds after activating them in this way, and even tried putting worms directly onto the suction cup and extender attachments.

I was frustrated by my inability to access and perceive this sonic environment as I had imagined it from reading and listening to the aforementioned artists, acoustic

[33] Thanks to Zach and Sam for their help at the farm, as well as to Wang Ziyu for generously letting me use her car.

[34] The Arizona Worm Farm is a locally owned business that promotes "waste reduction techniques, carbon capture in soil, and regenerative agriculture." See https://arizonawormfarm.com/about-us for more information.

ecologists, and soil scientists. I was able to hear things belonging to the normal range of human hearing (outdoor voices, equipment, machinery, wind in plants, airplanes) but I did not want to dwell on them. I wanted to focus on sounds produced in the soil. These recordings did not prove to contain what I thought I was looking for, and from this experience I was reminded of the tension between my expectations, the needs of the piece, and the variety of the sonic ecology of soilscapes.

Originally, I had planned to include optional electronics, but ultimately decided to absorb influences from electroacoustic composition instead. I also collected samples of some percussion instruments, such as bowed tam-tam, superball on timpani, different strike locations on drums, and examined these samples in SPEAR, a free spectral analysis software known by its acronym which stands for Sinusoidal Partial Editing Analysis and Resynthesis, developed by Michael Klingbeil.[35] These recordings were not used in terms of computer-assisted composition. I did not use their spectral analysis to determine specific frequencies, but this process has informed the timbral and pitch aspect of my piece and will be discussed further on in this document.

Rhizosphere Features and Musical Interpretations

Healthy soil, as discussed earlier, is a very heterogeneous environment. This biodiversity and wide variety of minerals and other non-living components of the soil is represented by the wide variety of percussion instruments used, as well as the variety of techniques used to play them. On a more holistic scale, the piece expands from a single pitch, F, to all 12 chromatic pitches and pitch materials that do not fit into the 12-tone

[35] Michael Klingbeil, "SPEAR," SPEAR Homepage, https://www.klingbeil.com/spear/.

division of the octave, such as sounds from instruments with “indefinite pitch,” that are essentially sounds with more inharmonic rather than harmonic partials. The piece opens with this limited pitch material to represent bulk soil before a seed is planted and roots begin to transform their surroundings, but it also represents other things. The use of rapid rhythms and mallet shafts to create a sharp attack and quick decay are my interpretation of soil aggregates and their tiny particles. The clicking timbre and rhythmic fluctuations (via tuplets), shown in Figure 1, also represent the “clicking” timbres and irregular rhythms described and heard in recordings of soil and Gagliano’s description of sounds emitted by plant roots.

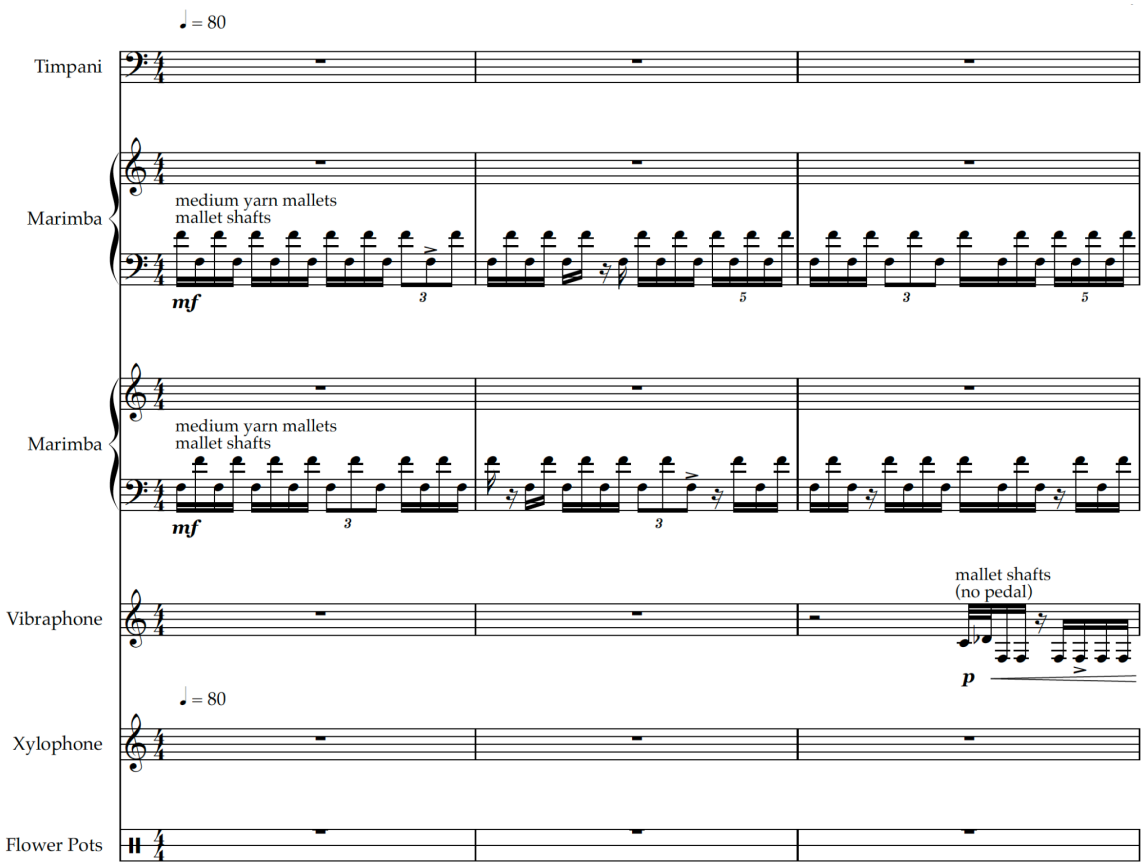


Figure 1. A “Clicking” Soundscape

This multi-use of the clicking soundscape is one example of my interpretation of the interdependency found in the rhizosphere.

Interconnectedness

Certain musical materials represent multiple things. Glissandi, for example, doesn't just represent water, but also connection and interdependency. Measures 24 – 63 feature glissandi of different contours, registers, playing techniques, and instrument types, shown in Figure 2.

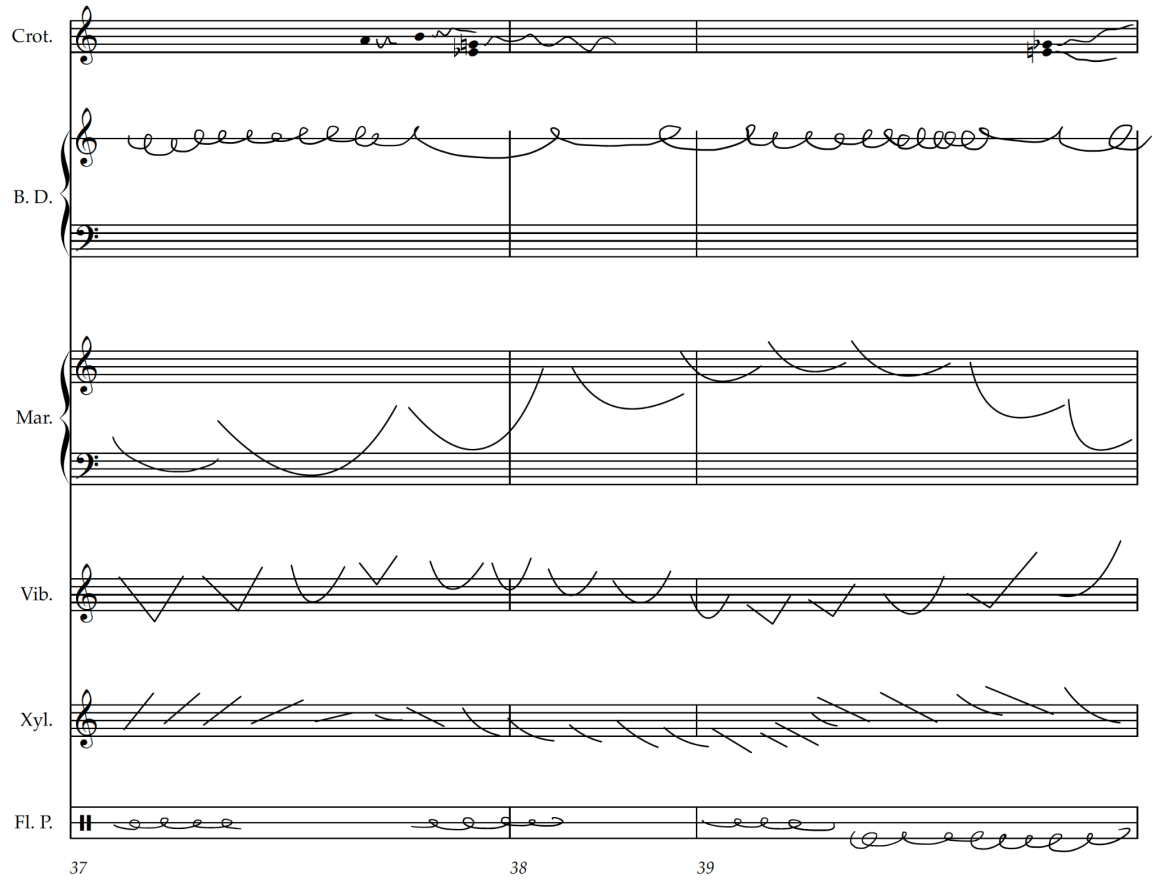


Figure 2. Different Types of Glissando Gestures

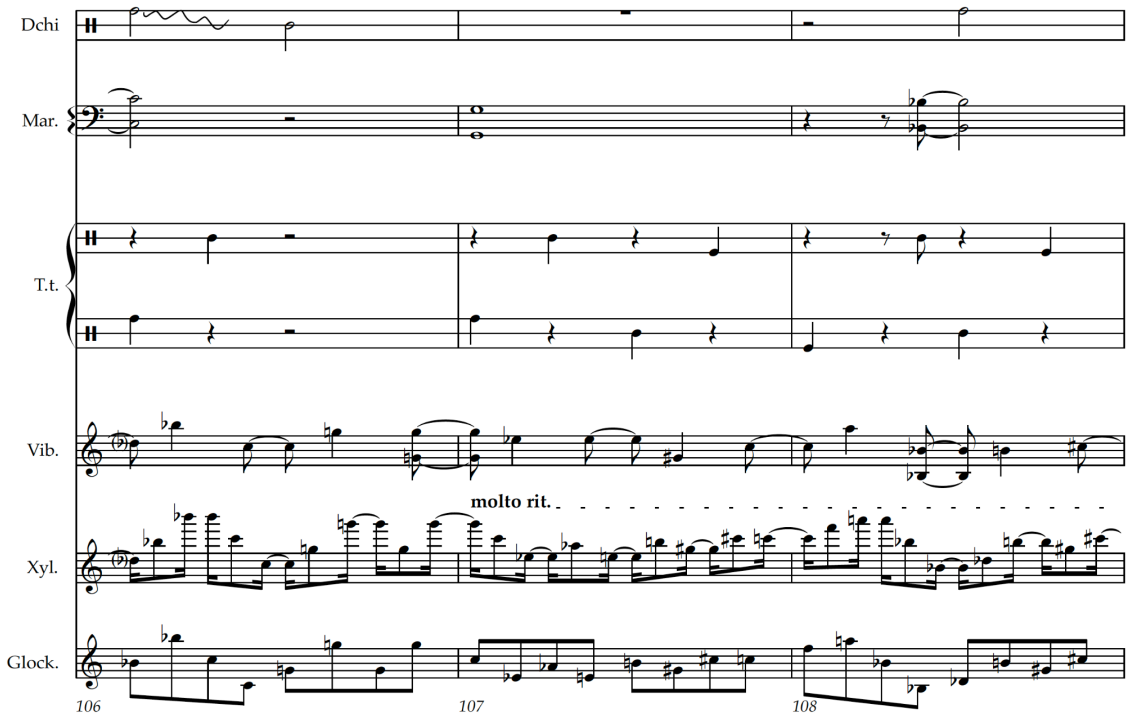


Figure 3. Interlocking Cycles

The rhizosphere has been described "as a grouping of sub-webs not only operating in concert, but also possessing quasi-independent tendencies."[36] Figure 3 depicts my interpretation of this description of interrelated but distinct patterns as interlocking cycles between all six players.

Roots

With regard to pitch specifically, the source material of the piece stems from what I consider "root branching." The root branching motive stems from triads offset by a half step, using different chordal voices as pivots, and sites of splitting off into a new "root." This pattern is demonstrated by the vibraphone in Figure 4, where its line moves from Gb major to C major, then Ab major to A major.

[36] John C. Moor, Kevin McCann, and Peter C. de Ruiter, "Soil Rhizosphere Food Webs, Their Stability, and Implications for Soil Processes in Ecosystems," in *The Rhizosphere: An Ecological Perspective* edited by Zoe G. Cardon and Julie Lynn Whitbeck (Amsterdam: Elsevier Academic Press, 2007) 119.

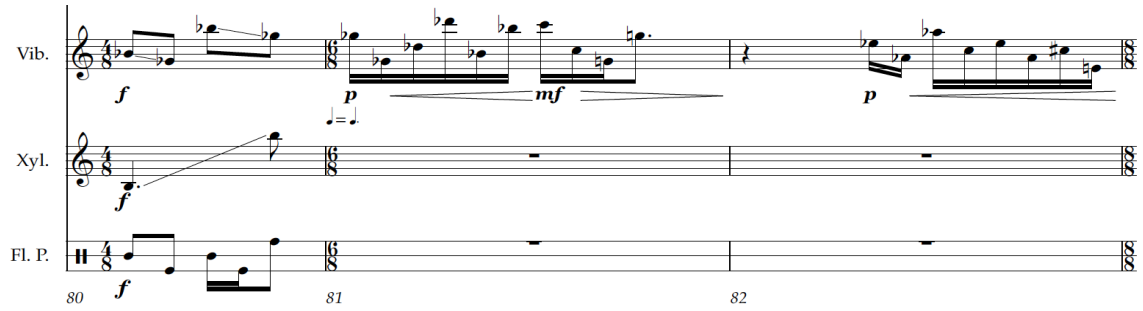


Figure 4. Vibraphone Root Branching

Motives branch from unisons to large leaps. These roots develop in different (pitch) directions, and grow to different lengths over the course of the piece. There is not a true hierarchy of pitch in the linear or goal-directed sense, and while writing the piece I conceived of pitch more as "roots" to be stretched into different directions as a form of intuitive or analog interpolation. For this reason, the pitch material does not strictly follow the previously mentioned triadic offsets. I consider this practice to fall under the category of "stretchy-lattice" music, an approach to pitch that isn't trying to break away from the lattice, as described by Trevor Wishart,[37] but does try to push and pull at it, an example of which is shown in Figure 5.

[37] Trevor Wishart, *On Sonic Art* ed. Simon Emmerson (New York: Routledge, 1996): 23-30.

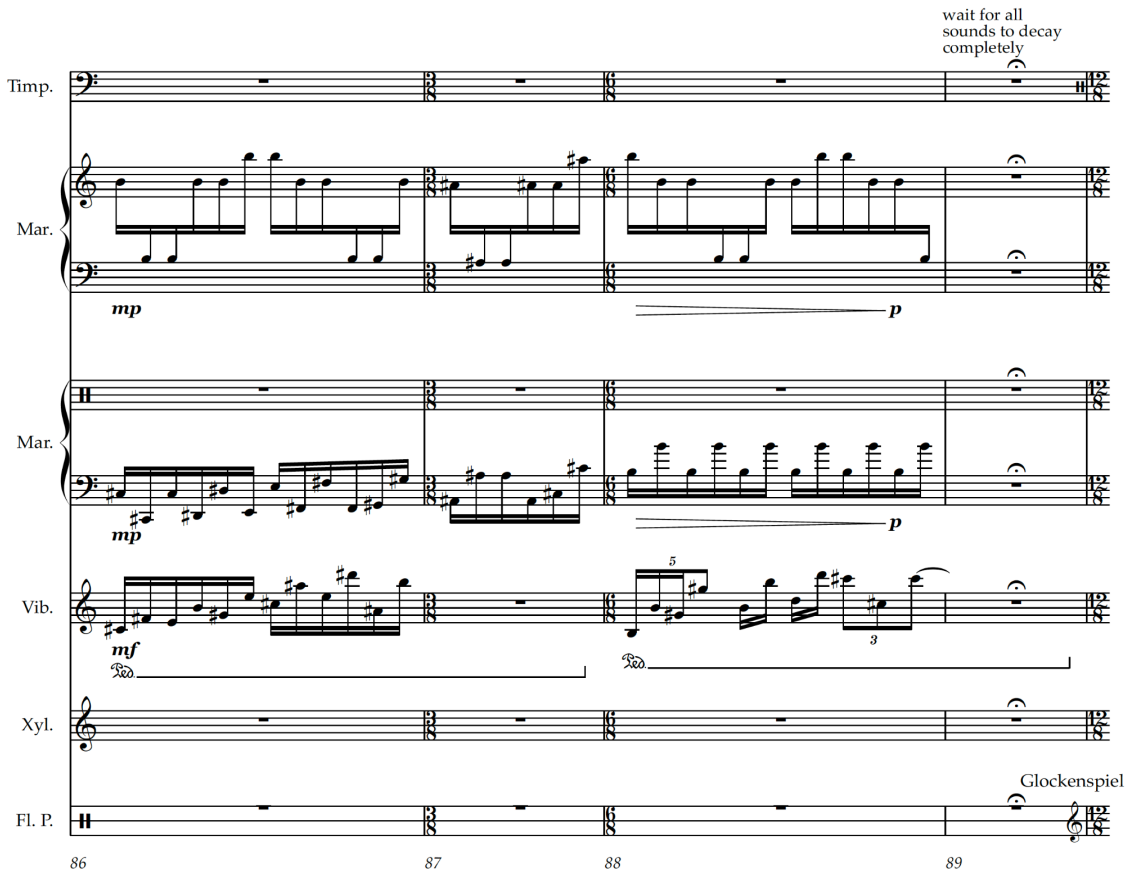


Figure 5. Vibraphone with Stretched Root Branching Motives

I use the term “stretchy-lattice” very loosely, because in Wishart’s concept of the lattice, he is referring to the practice of limiting pitch material to tempered scales, and only certain sounds feature non-tempered pitch, such as the superball rolls and timpani glissandi. I call the practice of offsetting triads “stretchy-lattice” because it was my version of creating a type of analog interpolation between various chords.

Root Exudates and Rhizodeposits

Plant roots produce and secrete several types of carbon compounds, including dead root cells, chemicals with varying pH, residues, and carbon dioxide. [38] These organic materials affect the surrounding soil:

> The quality of the carbon, as a substrate and as a chemically active input to the soil environment, is a critical determinant of the composition of the community that results from the root interaction with the extant soil community. In addition to simply acting as a resource, root exudates can influence biotic interactions by attracting beneficial and pathogenic organisms.[39]

As mentioned above, I also analyzed samples taken from percussion instruments to observe their spectra. I noticed that the timpani had a lot of dense, clustery partials present in the second octave above its most prominent partial. There were some lower, "out of tune" partials that suggested the fundamentals of the harmonic series – in other words, the most prominent partial seemed to be the second partial, giving an effect as if the successive partials were transposed an octave down, resulting in the dense, somewhat noisy timbre of the timpani. This blurry timbre of the timpani is reflected in moments such as mm. 62-79, part of which is shown in Figure 6, where there are clusters of

[38] Weixin Cheng and Alexander Gershenson, "Carbon Fluxes in the Rhizosphere," in *The Rhizosphere: An Ecological Perspective* edited by Zoe G. Cardon and Julie Lynn Whitbeck (Amsterdam: Elsevier Academic Press, 2007), 32-35.
[39] Zoe G. Cardon and Julie Lynn Whitbeck, eds., *The Rhizosphere: An Ecological Perspective* (Amsterdam: Elsevier Academic Press, 2007), 15.

seconds and thirds above a B-flat fundamental.

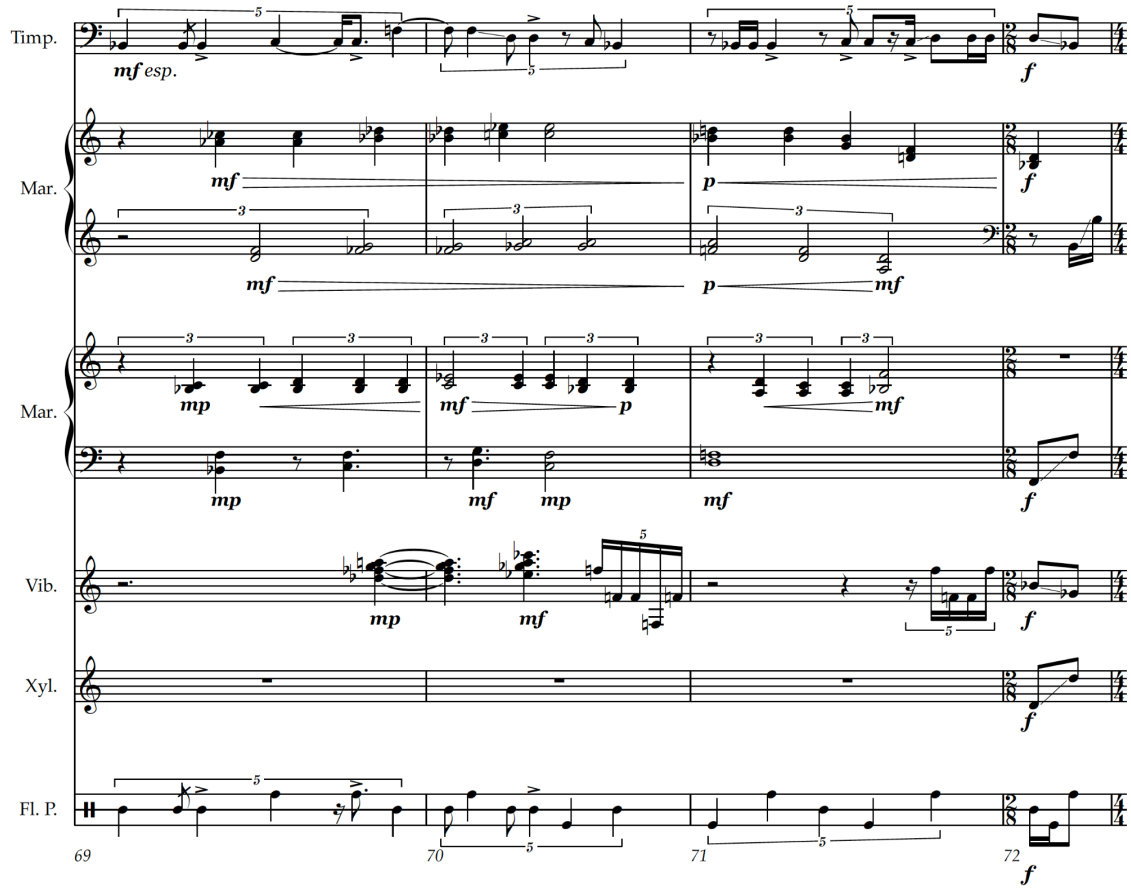


Figure 6. Shaping Density Through Pitch and Rhythm

In other words, the pitch material in this section is mainly focused on compressing and expanding pitch.

Fungi

Fungi, as mentioned earlier characterized as featuring a "slow cycle," and a mycorrhizal network are explored via macro-rhythm, metric modulations and tempo relationships, and also longer sustained durations. I consider the metric modulations to represent a zoomed-out view of fungi. I think of this like a small grain of an idea expanded out to form the larger macrostructure of the piece, representing the fungal network that connects plants

through mycorrhiza. Also, on a smaller scale, fungi are represented by longer, sustained sounds drawn out of the tam-tam and bass drum.

Bacteria

Characterized as living in a "fast cycle," bacteria are represented by tuplets and shifting meters, smaller-scale durational patterns. These smaller, passing rhythmic dissonances represent the shorter time scale of bacteria.

Fauna

Nematodes, mites, and larger animals such as worms and grubs (explored via gestures) are depicted via one-off events, imagining moments where a worm may be crawling by or a grub may be communicating with another grub (described by Mankin). These are non-developed gestures, existing in "moment time," one-off events that represent a movement or action taken by fauna.

Water

There are two depictions of water cycles in the piece. In my ear, water is represented by Player 1 in the sections with crotales or dobachi placed on top of the timpani. These metallic, shiny timbres evoke water to me, and are reinforced by timpani pedal glissandi. The first water event, mm. 34 – 63 (of which an excerpt is shown in Figure 7) represents a gardener watering plants, with sprinkled water gradually seeping down, slowing as it gets deeper. The second water event, mm. 90 – 109, represents a heavy rain, where a larger volume of water suddenly appears.

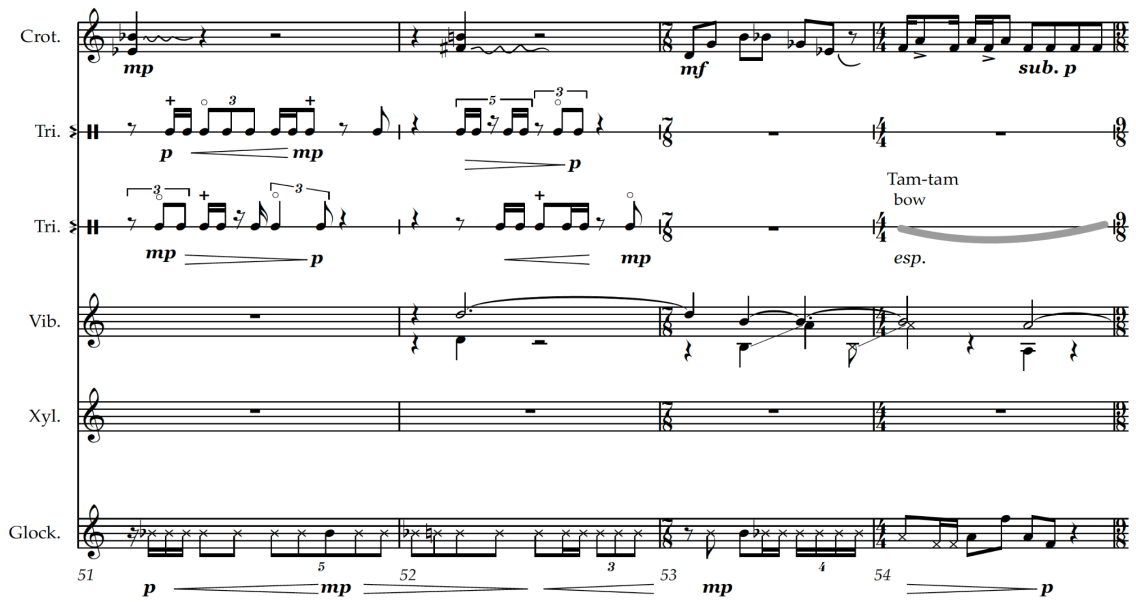


Figure 7. Metals and Glissandi

Carbon

The rhizosphere is a carbon sink, meaning that it is able to store carbon in the ground, taking it out of the atmosphere and accumulating carbon compounds in the soil. Carbon sequestration is represented by increasing timbral and motivic variety and greater cumulative density at the end of the piece.

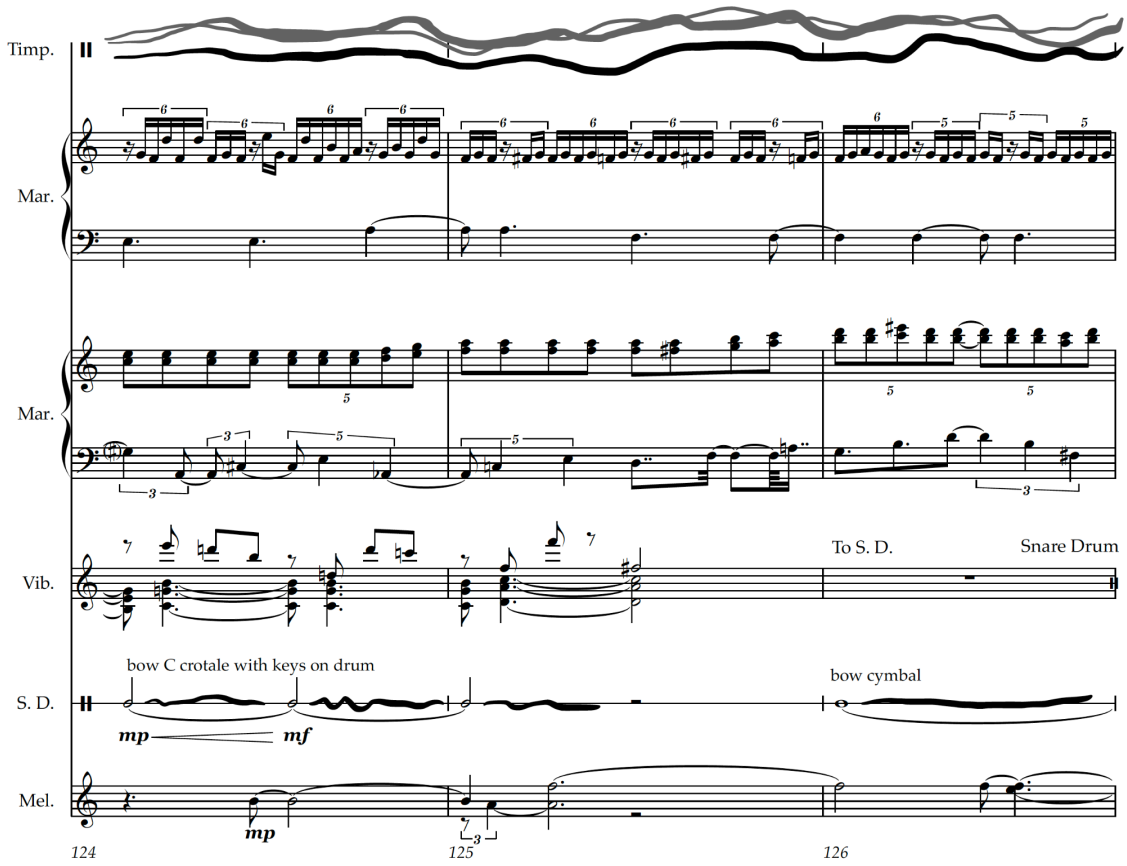


Figure 8. Dense Texture to Represent a Thriving Rhizosphere

Figure 8 represents a rhizosphere with lots of vibrant interaction, evoking a healthy ecosystem around a well-established plant and its roots, and features multiple types of musical activity. There are multiple kinds of sustained, “noisy” timbres which represent multiple threads of mycelia growing: superball mallet and fingers rubbing on the surface of two timpani, bowed cymbals, and bowed crotales on snare drums prepared with keys. In my mind, these noisier timbres also represent more active environments because their spectra are less “ordered” and their partials are less predictable. These instruments as well as the pitched instruments feature different rhythmic patterns to reflect the biodiversity of the rhizosphere.

Player 2 performs the marimba line that maintains the pulse from the previous section (see Figure 9 for the metric modulation), and sextuplets to represent the faster life cycle of bacteria. Player 3 distorts time in a stretchy 2/4 metric grouping, Player 4 provides contrast with a more regular 2/4 grouping before abandoning the pulse to alternate threads of noise, Player 5 explores only longer durations of noise, and Player 6 has a delayed entrance until m. 124 with a lyrical melodica line that condenses into sinking clusters.

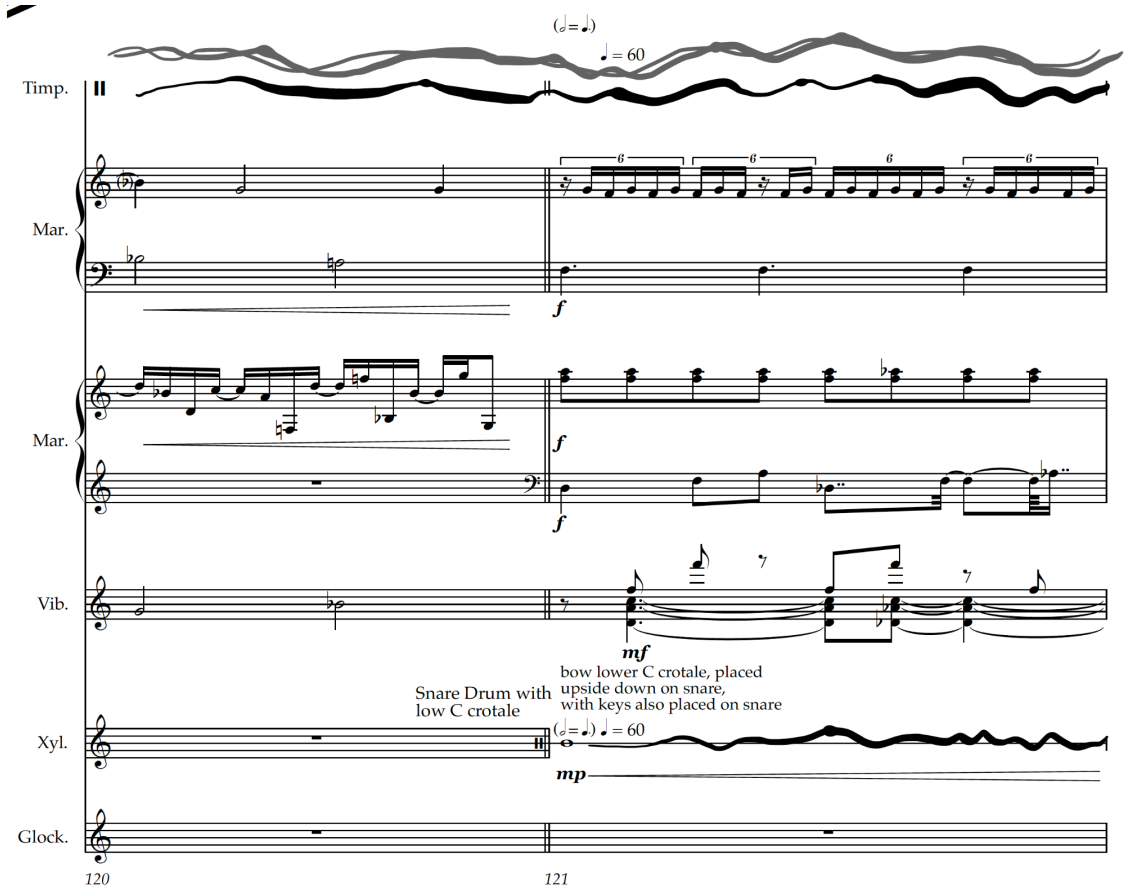


Figure 9. Half Note to Dotted Quarter Metric Modulation

This section also features a tonal reference to represent the underground aural perspective, imagining a slightly distorted version of a ii-V-I-vi progression. This harmonic allusion is presented in the marimba part for player 3, where the rhythm and chord progression are both slightly stretched as time passes, as shown in Figure 10. The thickened texture in the ending section, mm. 121-138, also represents the gardener's goal of training plant roots to grow deeper, where they can access water more efficiently.

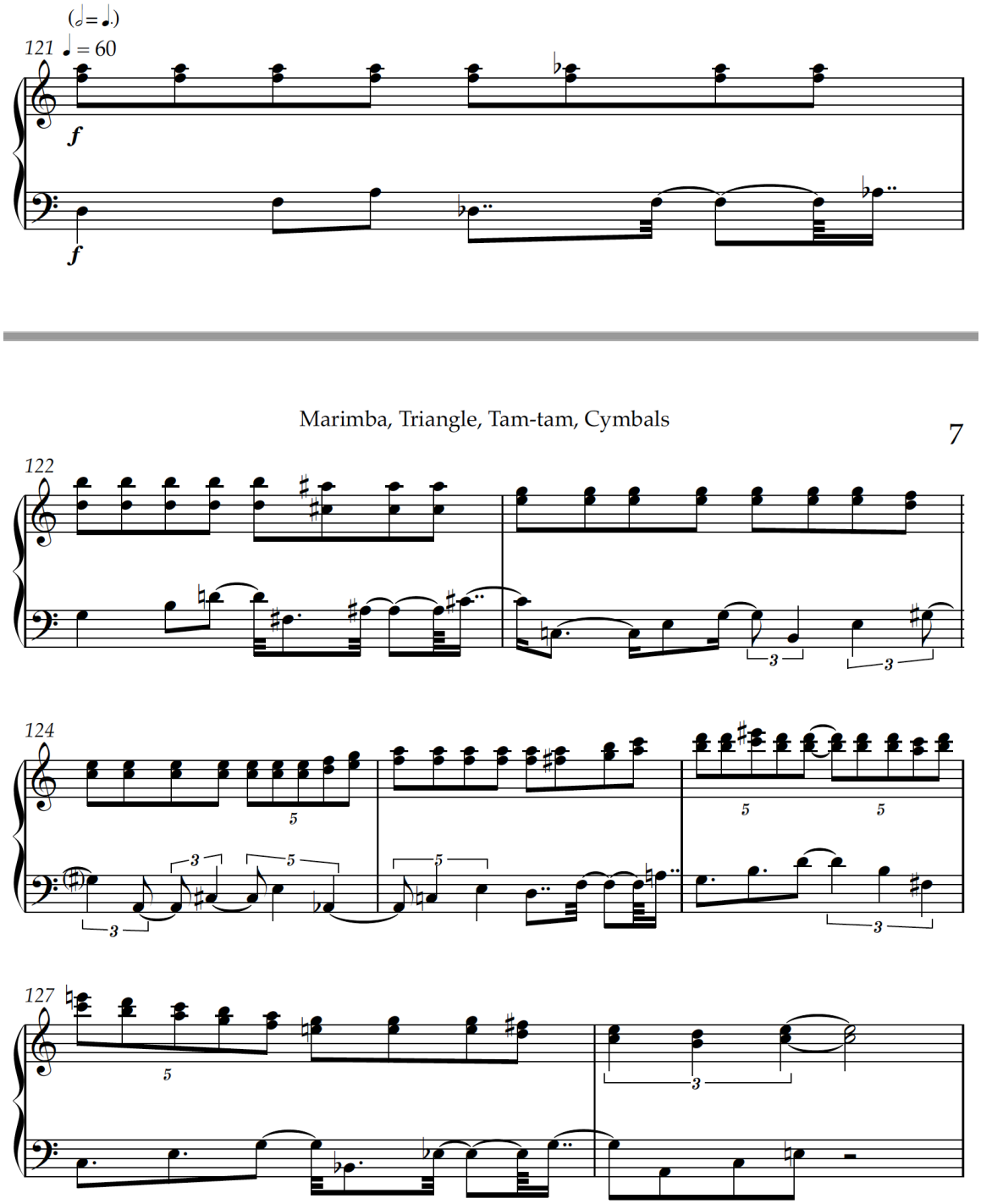


Figure 10. A Timestretched and Pitchshifted Tonal Reference

Formal Analysis

This piece is difficult to divide into large sections because there are multiple processes superimposed and interwoven in many ways at different times. However, there are some general ways the piece can be divided. The opening presents the soil line, a seed shooting out new roots, from mm. 1 – 25, with mallet shafts, each onset representing a tiny soil particle. Note that the previous statements intentionally present overlapping measure numbers to reflect the blurred structural edges. This structural blur is also representative of the ambiguity found in the rhizosphere at the small scale - it can be difficult to distinguish boundaries between chemical, bacterial, fungal, animal, and root regions.

CHAPTER 5

PORTFOLIO OF WORKS

This chapter discusses works written during my time at ASU that explicitly address aspects of nature in their conceptual design.

***Cloudlands*, for solo carillon (2022)**

Cloudlands was commissioned by the Mayo Clinic for their annual "Music for Mayo" Carillon Music Series. The timing of this commission was marked by several personal and societal challenges, most notably the Covid-19 pandemic. The piece was inspired by the process of loss and acceptance, but also by the particularly environmental nature of the carillon. This instrument cannot be played without sounding in a large outdoor radius, and cannot be isolated from outdoor sounds such as traffic, birds, passersby, for example. In other words, it is always part of an acoustic ecology that is larger and less sonically secluded than the typical recital hall. For these reasons, I focused on exploring spectral density, beginning with the highest register of the instrument before gradually descending and collecting into longer gestures. Figure 11 shows the high, more sparse opening of the piece, a beginning may blend with the outdoor environment, and

that people within hearing distance of the carillon may not perceive to be music at first.

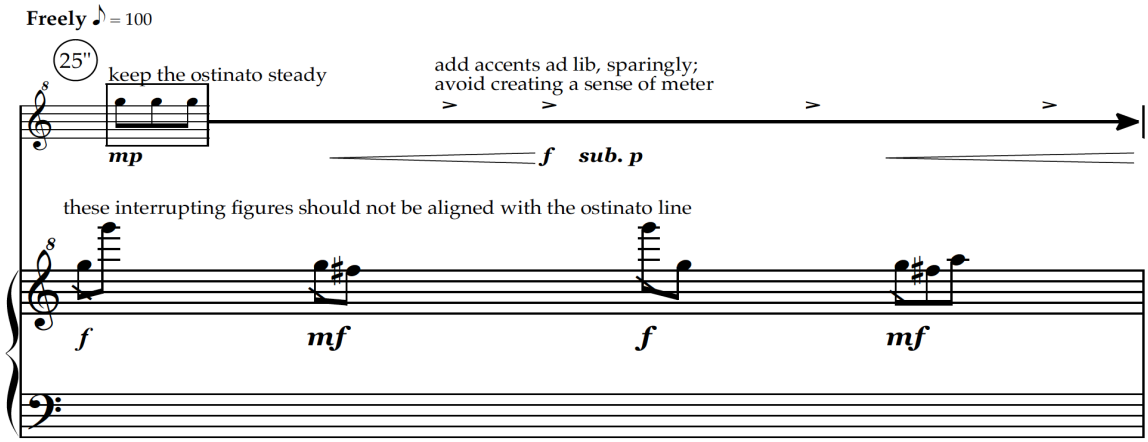


Figure 11. The Opening of *Cloudlands*

As the title suggests, the piece imagines a landscape of clouds forming and blending. The music works to reconcile the differences between a persistent ostinato and freer, wave-like gestures. Similar to *The Rhizosphere*, *Cloudlands* explores contrasting temporalities but in a solo-performer context. Competing materials drift against each other, merge, and condense before ultimately dissipating peacefully. Figure 12 shows an example of this kind of sonic collision.

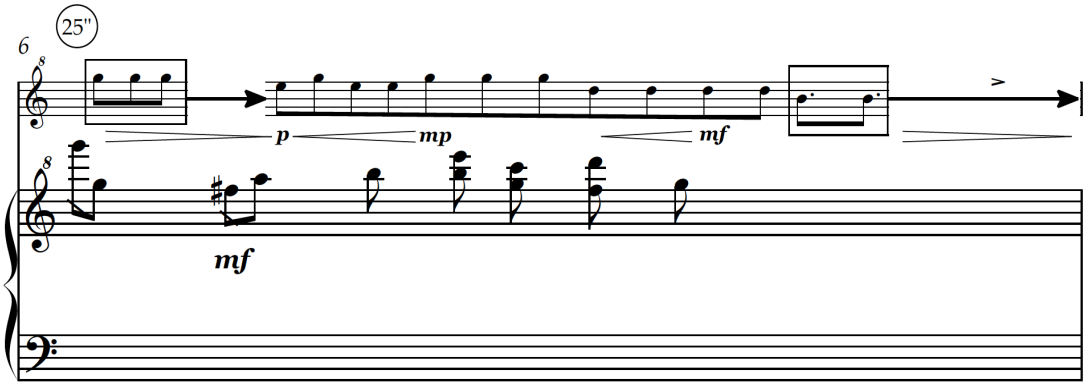


Figure 12. Collision Between the Expanded Ostinato Line and Freer Rhythms

Since there is no way to dampen the bells, the sustains and decays of each bell can overlap in interesting ways. As the register of the pitch material descends, the pitch material condenses into a simple chord progression: G^{maj7}, B^{maj7}, E^{maj7}, and C^{maj7}. The use of major 7th chords was intended to honor the commissioning party's favorite harmony, the major 7th chord, while also exploring the indistinct endings of each bell strike and the way these harmonies can overlap.

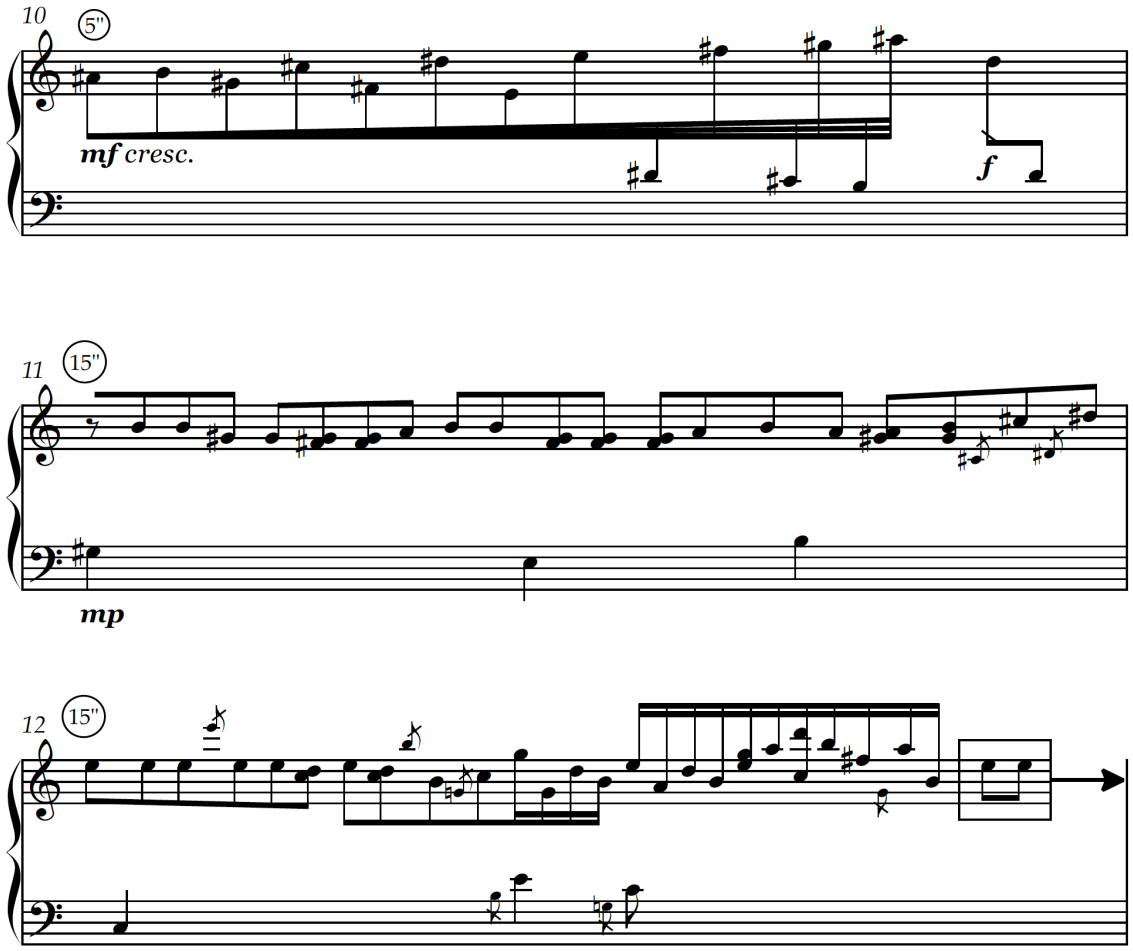


Figure 13. Moving from B^{maj7} to E^{maj7} and to C^{maj7}

Figure 13 demonstrates these shifting harmonic centers. This amorphous harmonic language represents clouds of bells which collide and blur into each other. This piece is

not explicitly environmental, but featured cloudlike sonic imagery from the beginning of its conception.

***a river runs through me*, for wind ensemble (2022)**

During the 2021-2022 academic year, I had the opportunity to serve as the Composer-In-Residence with Arizona State University's Wind Ensemble. The piece I wrote for the group, *a river runs through me*, depicts the San Marcos River, a spring-fed river I lived near for several years. I tried to depict my many overlapping experiences of the river, different aspects of it that flow through my memory. Some of these ideas include: sunlight glinting on water, rice grass, rippling textures, a rush of multiple currents, letting things pass you by, and peaceful moments of stillness and suspension around river bends.

I represented light reflecting and refracting on the water with metallic percussion instruments, assigning a shining image with what I consider to be an aural counterpart. Figure 14 shows the instrumentation I chose, crotales, vibraphone, glockenspiel, and triangle, to evoke this glinting idea.

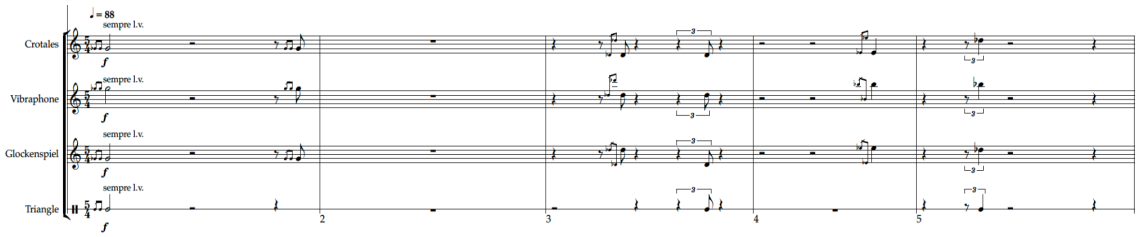


Figure 14. Sunlight Glinting on Water

The rice grass grows from the bottom of the riverbed in long, thin, bright green blades that can live entirely submerged but also grow above the water line when left undisturbed. During colder seasons and when the river was closed due to the pandemic,

the rice grass grew especially long and took over. This motive represents floating above the grass or otherwise observing it from the riverbank, and depicts the undulating yet securely rooted movement of the leaves. The grass is very special in that it only grows in the first mile and a half of the river, at the headwaters, which is where I visited the river the most.[40] I used staggered attacks that weave throughout the instrumentation to depict the underwater movement of the grass. Figure 15 demonstrates this motive where it is first introduced in the upper woodwinds and brass, at m. 31.

[40] Harold E. Beaty, "Texas Wild Rice," Texas State Historical Association, 1995, https://www.tshaonline.org/handbook/entries/texas-wild-rice.

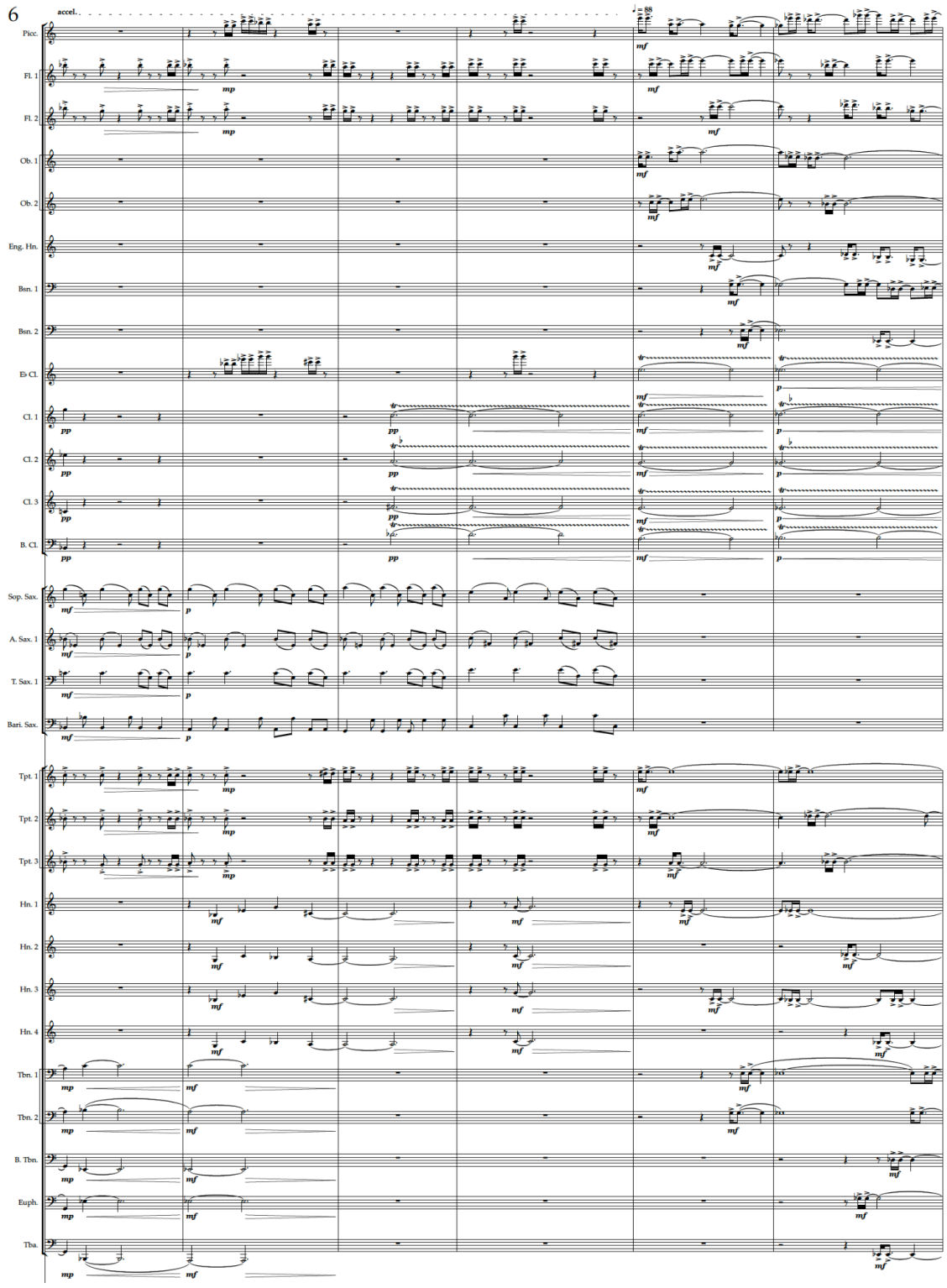


Figure 15. Wild Rice Grass Motive

The rippling surface textures, resulting from multiple flowing currents, is represented by varied, small gestures in the woodwinds. These motives range from trills, rapid sixteenth-note tuplets, eighth notes, and feathered-beam patterns. Figure 16 shows this material in the clarinets and saxophones in a moment when their rippled movements serve as a transparent surface texture above the rice grass motive previously discussed.

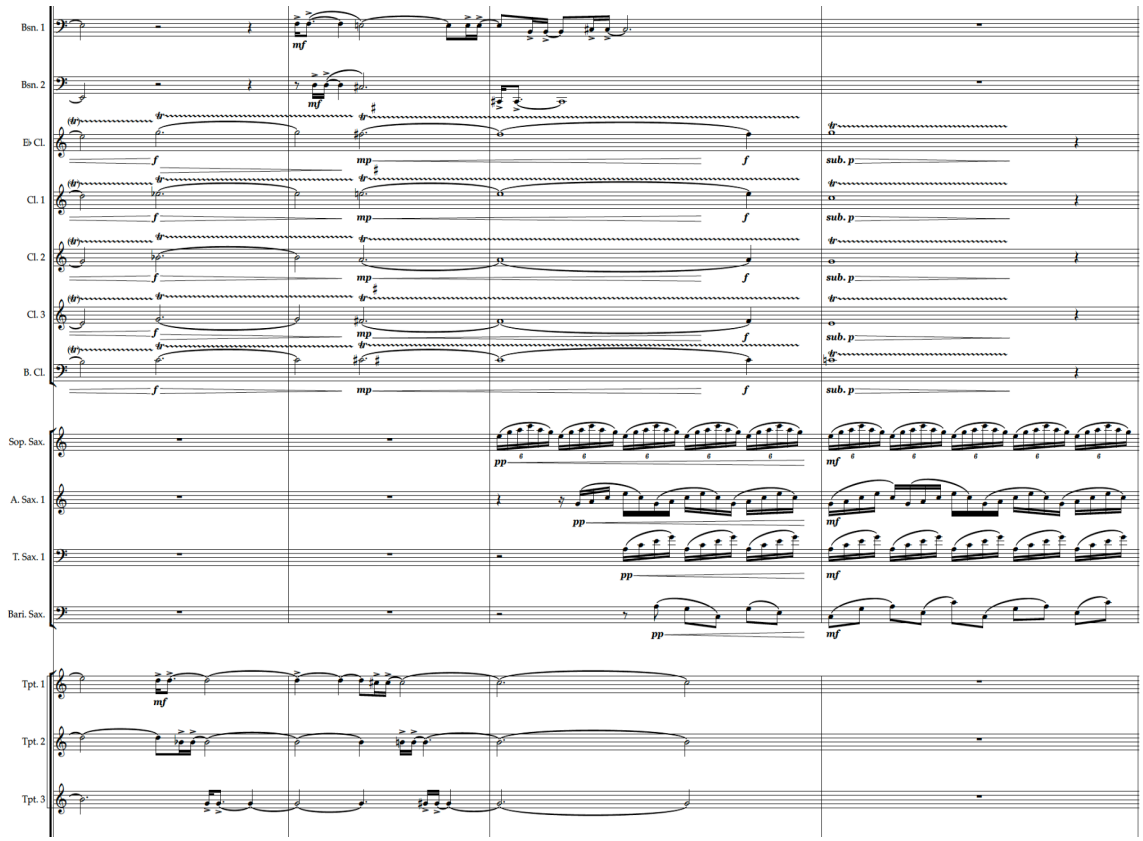


Figure 16. Rippling Surface Texture

This piece is not explicitly environmental or ecological in an activist sense. I was not seeking to draw attention to the environmental issues related to the river. I took this opportunity to reflect on my many experiences of the river, and to explore how I could relate these memories to ideas in sound. However, the San Marcos River is home to at

least two endangered species. The wild rice grass and a blind salamander face issues with runoff pollution, and in 2020-2021 the state of Texas granted Kinder Morgan eminent domain to build a pipeline through the Edwards Aquifer recharge zone. There are activist groups and stewards of the river such as the Save Our Springs Alliance.

***Dandelion*, for violin and electronics (2022)**

This piece was inspired by dandelions, resilient enough to grow even in the Valley of the Sun, and depicts their jagged shape and delicate nature. Commonly thought of as an unwanted weed, the whole plant is actually edible and cultivated by some gardeners because they're very nutritious. The leaves have a multitude of vitamins and minerals, and the roots are said to be useful for detoxifying the liver. The trajectory of the piece maps the life cycle of a dandelion, from single seed to thousands of seeds. The opening and closing materials recreate the sound of an aeolian harp synced with a breath across the f holes of the violin, as if blowing to scatter the seeds of a dandelion. This breath gesture is shown in Figure 17.

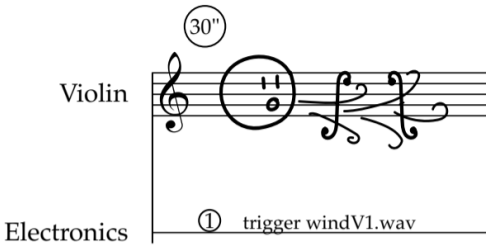


Figure 17. Breath Gesture

The name for dandelion in Spanish is *diente de león*, which draws more attention to the jagged shape of the leaves. In the past I've grown a variety of dandelion with extra bitter leaves, and I have noticed dandelions thriving in the desert at my home and outside of the

Arizona State University Music Building. I decided to depict these familiar leaves by taking a jagged approach to timbre, left hand pressure, rates of tremolo, and bowing styles. Figure 18 demonstrates quick changes of bow location, from sul tasto to sul ponticello; bowing techniques, from a longer bow stroke, to individual bow strokes and arpeggiando as well as circular and vertical bowing; and left hand pressure which explores the spectrum between ordinary and natural-harmonic amounts of pressure.

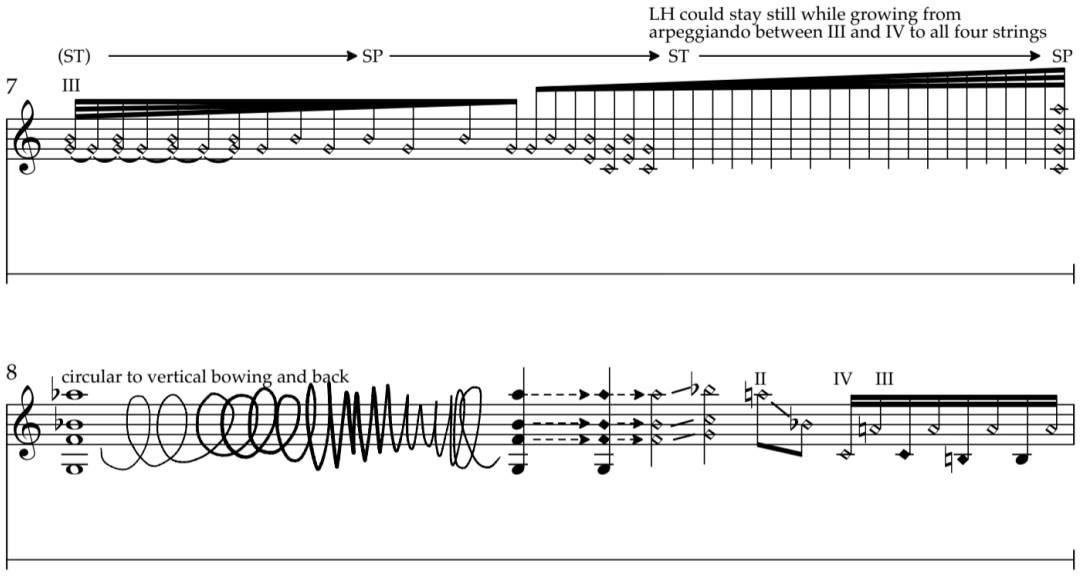


Figure 18. Rapid Fluctuations in Timbre, Bow Technique, Left Hand Pressure

The piece uses Max/MSP as an extension of the solo violin performer, complemented by fixed media created from violin samples recorded with my collaborator, violinist Julian Nguyen. Figure 19 features a picture of the Max patch.

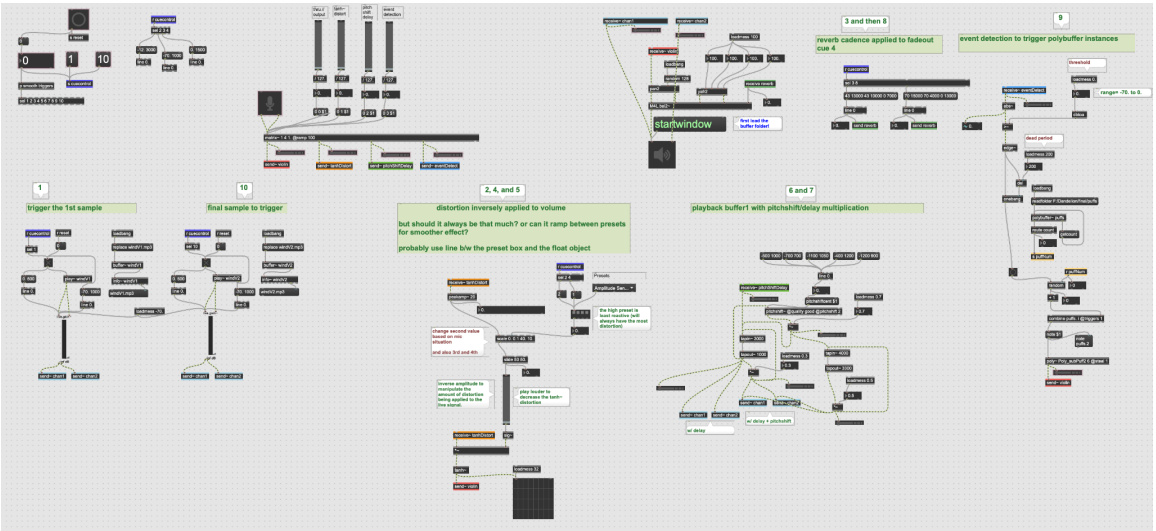


Figure 19. The Max Patch

Sometimes live processing or pre-processed media are triggered by cues, sometimes by event detection. This piece is also not explicitly environmental, but as an invitation to consider the dandelion it raises awareness of this wild plant.

***Desert Rain God*, for string quartet (2020)**

This piece was originally written to be paired with an artwork, *Desert Rain God* by Louisa McElwain, and was inspired by the painting's subject and use of texture and color. The monsoon's shifting winds disrupt the rain shadow over the desert, bringing summer storms with fluctuating air pressure and sudden downpours. The piece was originally notated with shifting meters, and the overall metric trajectory of the piece moves from competing, small-scale asymmetrical patterns into more unified asymmetrical meters. Figure 20 illustrates the way I conceived of the metric framework for the middle of the piece, and the way I explored contrasting temporalities in this work. In m.36 there are 3 different temporal layers, one in the cello, one in the viola and second violin, and one in the first violin. In m. 38, the violins switch roles and the second violin

briefly takes the rhythmically dissonant melody before returning it to the first violin in m. 39. Eventually, the piece was re-notated in 4/4 to make it easier for the performers to read. Figure 21 shows the version of the score given to the performers, replacing the shifting meters with grid time.

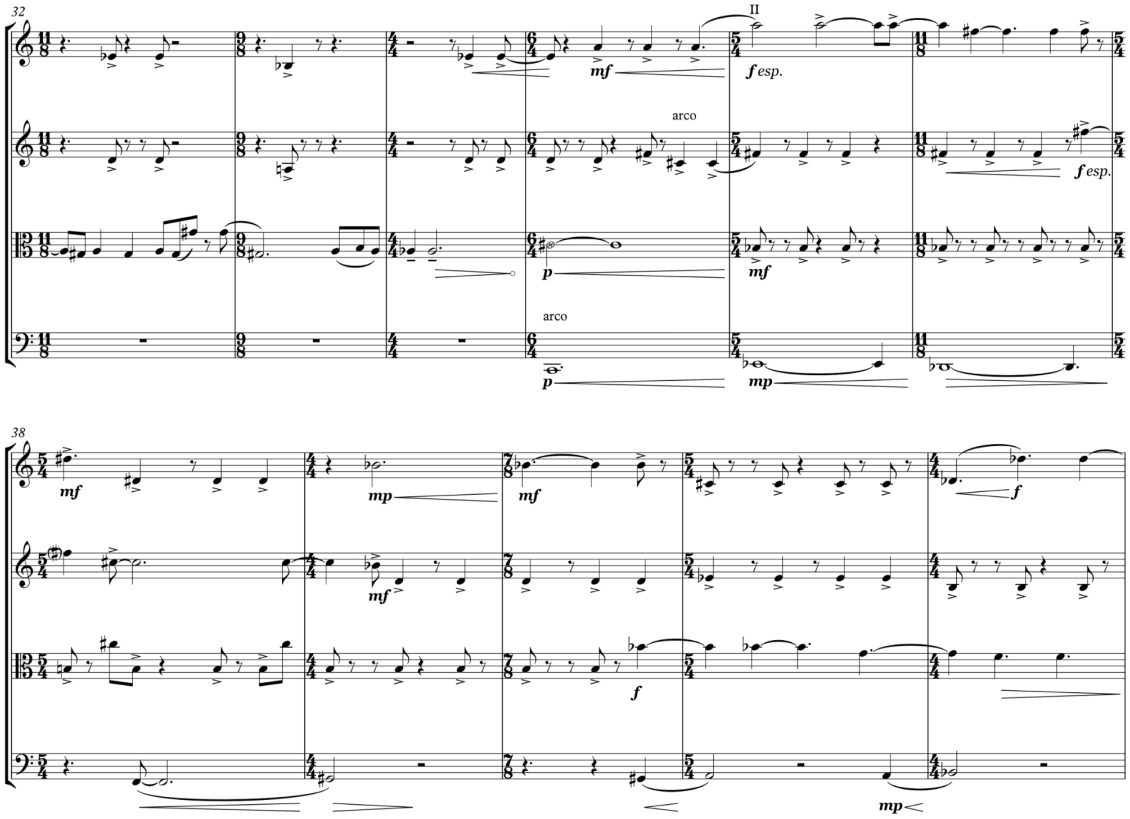


Figure 20. Shifting Meters

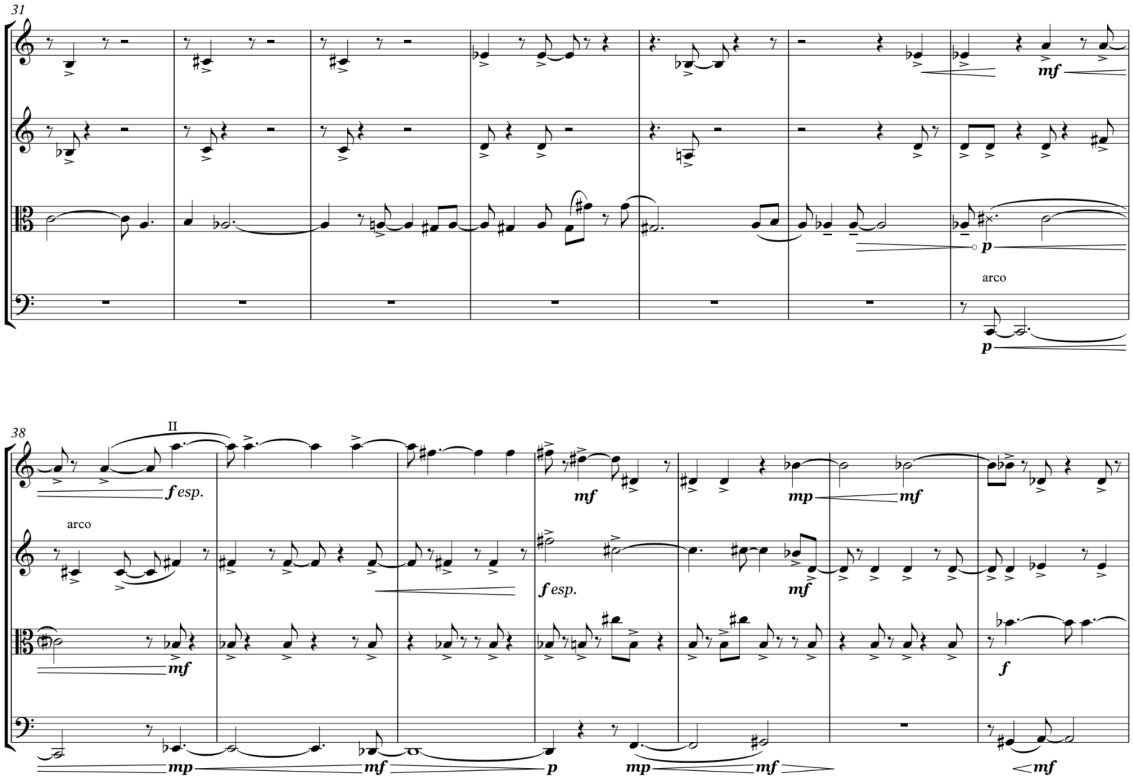


Figure 21. A Version of the Score That Maintains a 4/4 Metric Framework

The harmonic cyclicity contrasts with the emergence of synchronized meter to portray conflicting temporalities, representative of the monsoon's chaotic wind patterns. Texture, timbre, and orchestration have been carefully notated, as demonstrated in Figure 22, to evoke the depth and relief of the almost sculptural effect of McElwain's oil painting technique. (She painted using a trowel).

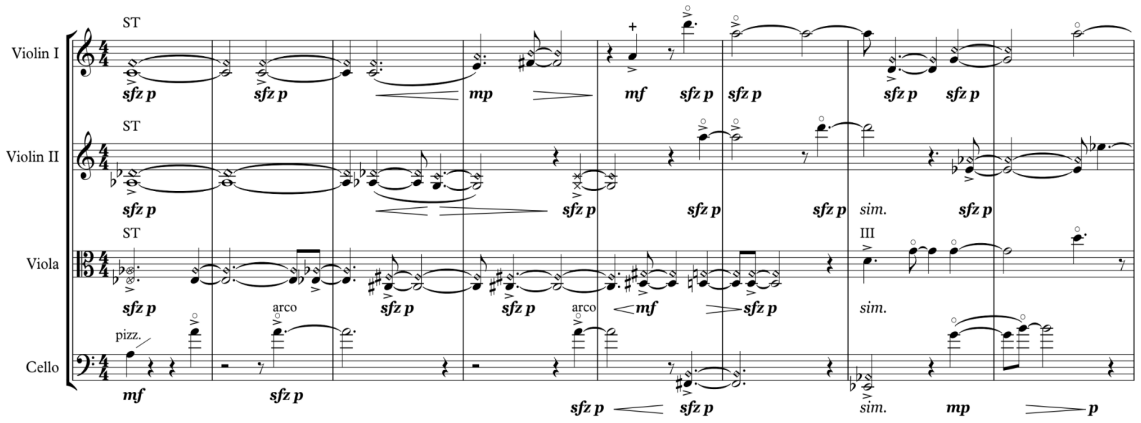


Figure 22. Timbral and Textural Variety in the Opening of *Desert Rain God*

***Desertification*, for string quartet (2019)**

Desertification is an ecological process which results in the growth of the desert at the expense of healthy soil, and is intertwined with poor land management and climate change. *Desertification* evokes the arid soundscape of the desert with all its dust and sand. Figure 23 exemplifies the hazy, brushy, and constantly shifting timbral world of this piece. The "v"-shaped noteheads call for vertical bowing to achieve a drier sound. Much of the piece calls for a more prescriptive rather than descriptive approach, and explores a more indeterminate and transient sense of pitch.

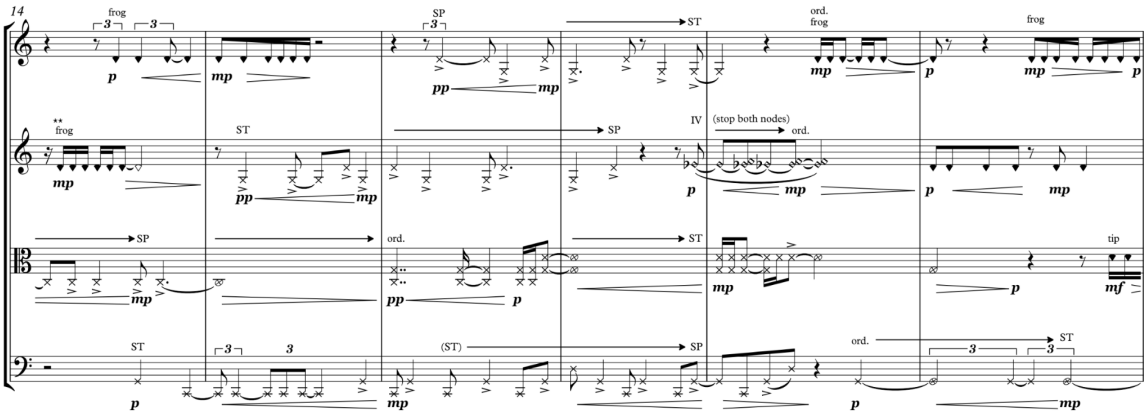


Figure 23. Drier String Timbres

In contrast to these lighter textures, the piece builds up to a heavier climax in m. 106, as provided in Figure 24.

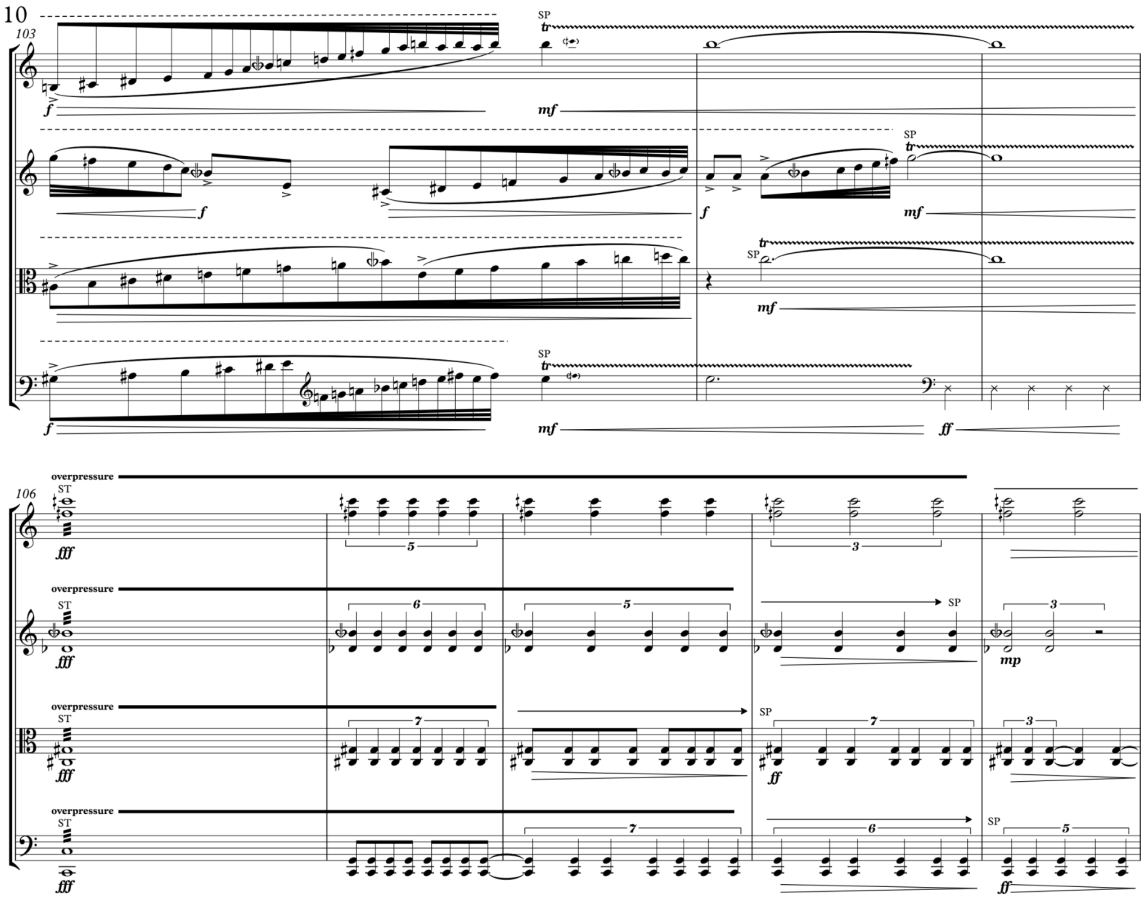


Figure 24. The Climax of the Piece

I learned more about desertification after moving to Arizona in August of 2019. I was very affected by experiencing the urban heat island effect, learning about water issues and dried rivers, and witnessing and being a part of unsustainable practices. This piece is the most explicitly environmentally engaged piece I have composed.

CHAPTER 6

CONCLUSION

This project serves to research a specific and important aspect of nature, the rhizosphere, and interpret its behaviors and processes through writing music. One of the goals in focusing on this topic and related works that address soil, land, and subterranean spaces is to draw attention to soil, sometimes called the living skin of the Earth. More broadly, I sought to connect my interests in sustainable agricultural practices with my academic studies in cultivating sonic ecosystems. The dissertation composition, *The Rhizosphere*, takes a biological "hotspot" and tries to recreate this vibrant environment in a percussion sextet context.

In the context of my portfolio, *The Rhizosphere* represents a continued interest in exploring aspects of nature through my compositional practice. Several of the pieces I wrote while at ASU draw attention to outdoor environments, such as *Cloudlands,* which imagines cloudlike sonorities surrounding the out-of-doors listener, *a river runs through me*, which explores my memories of the San Marcos River, *Dandelion,* which depicts a wildflower, *Desert Rain God,* which interprets a monsoon storm, and *Desertification*, which was my response to learning more about the ecological process. With regard to soil, soil health, and the rhizosphere specifically, most of the artistic precedents I discovered featured subterranean recording or data sonification rather than acoustic composition. Going forward, I would like to continue studying the rhizosphere and issues related to sustainability, which may or may not influence my work.

REFERENCES

Akiyama, Mitchell. “Nothing Connects Us but Imagined Sound.” In *Sound, Media, Ecology*, edited by Milena Droumeva, and Randolph Jordan. Cham, Switzerland: Palgrave Macmillan, 2019.

Ahn, Sabina Hyoju. “Sonomatter.” Sabina Hyoju Ahn. http://sabinaahn.com/index.php/project/sonomatter/.

BBC Earth Unplugged. “What Does the Plant Say?” YouTube video. February 6, 2014. https://www.youtube.com/watch?v=m-lq4sTMCqg.

Beaty, Harold E. “Texas Wild Rice.” Texas State Historical Association, 1995. https://www.tshaonline.org/handbook/entries/texas-wild-rice.

Berntson, Glenn M. “Fractal Geometry, Scaling and the Description of Plant Root Architecture.” In *Plant Roots: The Hidden Half*, edited by Yoav Waisel, Amram Eshel, Uzi Kafkafi, 259-271. New York: Marcel Dekker, Inc., 1996.

Bianchi, Frederick, and Manzo, V. J., eds. *Environmental Sound Artists: In Their Own Words*. Oxford: Oxford University Press, Incorporated, 2016.

Blackburn, Philip. “Bio.” Philip Blackburn, http://www.philipblackburn.com/bio.

Blackburn, Philip. “Philip Blackburn’s Sewer Pipe Organ.” YouTube video, https://www.youtube.com/watch?v=5o7WHeo9fVU&ab_channel=PhilipBlackburn.

Blackburn, Philip. “Sewer Pipe Organ.” In *Environmental Sound Artists: In Their Own Words* edited by Frederick Bianchi and V. J. Manzo, 9-17. Oxford: Oxford University Press, Incorporated, 2016.

Bonneval, Karine. “Listen to the Soil,” Karine Bonneval, https://www.karinebonneval.com/eng/projets/ecouter-la-terre-10.

Bonneval, Karine. “The Soil,” Karine Bonneval, https://www.karinebonneval.com/eng/projets/la-terre-9.

Bullitt, John. “Deep Earth Dome: A Seismic Sound Installation.” JT Bullitt. https://www.jtbullitt.com/earthsound/deep-earth-dome/index.html.

Bullitt, John. “Hollister, CA, USA (Seismic).” The Earthsound Project. https://www.earthsound.earth/content/Stream.html?id=sao

Cardon, Zoe G., and Julie Lynn Whitbeck, eds. *The Rhizosphere: An Ecological*

Perspective. Amsterdam: Elsevier Academic Press, 2007.

Deluca, Erik. "Selling Nature to Save It: Approaching Self-critical Sonic Art," *Organized Sound* 23/1 (2018), 71-79.

Eberle, Ute. "Life in the Soil Was Thought to Be Silent. What if It Isn't?" *Knowable Magazine* (2022) https://knowablemagazine.org/article/living-world/2022/life-soil-was-thought-be-silent-what-if-it-isnt.

Eshel, Amram and Yoav Waisel. "Multiform and Multifunction of Various Constituents of One Root System." In *Plant Roots: The Hidden Half*, edited by Yoav Waisel, Amram Eshel, Uzi Kafkafi, 175-192. New York: Marcel Dekker, Inc., 1996.

French, Jez Riley. "About." jez riley french. https://jezrileyfrench.co.uk/about.php.

French, Jez Riley. "Geophones." jez riley french. https://jezrileyfrench.co.uk/geophones.php.

Gagliano, Monica, Stefano Mancuso, and Daniel Robert. "Towards Understanding Plant Bioacoustics." *Trends in Plant Science* 17, no. 6 (2012): 323–325.

Gibson, John. "sLowlife: Sonification of Plant Study Data." *Leonardo Music Journal* 16 (2006): 42–44.

Gilmurray, Jonathan. "Ecology and Environmentalism in Contemporary Sound Art." ProQuest Dissertations Publishing, 2018.

Helker, Lucas. "Listening to the Last Frontier: How Climate Change Has Affected the Music of John Luther Adams and Matthew Burtner". ProQuest Dissertations Publishing, 2020.

Inglis, Barbara. "Soil Song." YouTube video, https://www.youtube.com/watch?v=-HvlgWtq0bE&t=3s.

Klingbeil, Michael. "SPEAR." SPEAR Homepage. https://www.klingbeil.com/spear/.

Kramer, Jonathan D. *The Time of Music: New Meanings, New Temporalities, New Listening Strategies*. New York: Schirmer Books, 1988.

Hans Lambers, Ingeborg Scheurwater, Owen K. Atkin, "Respiratory Patterns in Roots in Relation to Their Functioning" In *Plant Roots: The Hidden Half*, edited by Yoav Waisel, Amram Eshel, Uzi Kafkafi, 323-362. New York: Marcel Dekker, Inc., 1996.

Licht, Alan. *Sound Art Revisited*. New York: Bloomsbury Academic & Professional, 2019.

Mankin, RW, Hubbard, JL and Flanders, KL. “Acoustic Indicators for Mapping Infestation Probabilities of Soil Invertebrates.” *Journal of Economic Entomology*, 100 (2007): 790–800.

Nate and Hila. “COMPOST feat. DiorNoel - A Portrait of the NYC Composting Community.” Nate & Hila. https://www.nateandhila.com/.

Nielsen, Uffe N, Diana H Wall, and Johan Six. “Soil Biodiversity and the Environment.” *Annual Review of Environment and Resources* 40, no. 1 (2015): 63–90. https://doi-org.ezproxy1.lib.asu.edu/10.1146/annurev-environ-102014-021257.

Rillig, Matthias C., Karine Bonneval. “The Artist Who Co-authored a Paper and Expanded My Professional Network.” *Nature*, February 2020. https://www.nature.com/articles/d41586-020-00575-7.

Rillig, Matthias C., Karine Bonneval, and Johannes Lehmann. "Sounds of Soil: A New World of Interactions under Our Feet?" *Soil Systems* 3, no. 3: 45 (2019).

Quintanilla-Tornel, Marisol A. “Soil Acoustics.” In *Ecoacoustics* edited by Almo Farina, and Stuart H. Gage, 225-233. Chichester, UK: John Wiley & Sons, Ltd, 2017.

Paine, Garth. “Reeds: A Responsive Environmental Sound Installation.” *Organised Sound: An International Journal of Music Technology* 8, no. 2 (2003): 139–149.

Schwartzberg, Louie, dir. *Fantastic Fungi*. 2019; Los Angeles, California: Moving Art.

“Technology.” Music of the Plants. https://www.musicoftheplants.com/technology-2/

Tickell, Josh, and Rebecca Harrell Tickell, dirs. *Kiss the Ground*. 2020; Ojai, California: Big Picture Ranch.

Wishart, Trevor. *On Sonic Art*, edited by Simon Emmerson. New York: Routledge, 1996.

Westerkamp, Hildegard. “The Local and Global Language of Environmental Sound,” in *Sonic Geography Imagined and Remembered*. Toronto: Penumbra (2002): pp 130-140.

Xenakis, Iannis, and Roberta Brown. “Concerning Time.” *Perspectives of New Music* 27, no. 1 (1989): 84–92.

APPENDIX A

RELEVANT ARTWORKS: SOUND ART AND MUSIC RELATED TO SOIL, SUBTERRANEAN SPACE

Artist(s)	Title	Date	More information
Adams, John Luther	*The Place Where You Go to Listen*	2006	Installation and sonification of seismographic data (among other data such as light and electromagnetic data)
Aitken, Doug	*Sonic Pavilion*	2009	Installation, microphones suspended down 202 meters amplified in an enclosed gallery space with multichannel speakers
Arne, Devin	*Unheard Voices*	2021	Networked microcontroller installation, sonification of garden sensor data including soil moisture
Ahn, Sabina Hyoju	*Sonomatter*	2016	Sonification of bioelectrical data from microorganisms living in mud
Blackburn, Philip	*Sewer Pipe Organ*	2003	Sound installation in a public park's sewer system
Bonneval, Karine, Fanny Rybak, and Charlotte Poulsen	*La terre*	2018	Installation featuring soil and ceramic sculptures containing audio playback devices with recordings of a compost pile
Bonneval, Karine, Fanny Rybak, Matthias Rillig and Johannes Lehmann	*Écouter la terre*	2016-2019	Installation featuring soil, ceramics, and audio recordings of different soils
Bullitt, John	*Deep Earth Dome*	2006-2008	8-channel sound installation, sped-up seismographic data
Bullitt, John	*Earthsound Project*	2015-present	Live streaming of sonified seismographic data, with global measurement stations
Curran, Alvin	*Floor Plan/Notes from Underground*	1991	Sound installation of below-ground speakers, this work is a memorial for the Holocaust

EcoSono	*Sandprints*	2009	Underground microphones, dancers, computer
Hole, Francis, NCRS	*Soil Songs*	1980s	Educational songs and new lyrics to older melodies by a soil scientist
Inglis, Barbara	"Soil Song"	2014	New lyrics written by a 3rd grade science teacher to the tune of "Royals" by Lorde
Feisst, Sabine and Garth Paine	Listen^{n} Project	2014-present	Acoustic ecology and citizen science project, documenting and exploring new ways of listening to the land. Features a public archive of field recordings
French, Jez Riley	*Geophonics* (the name of his practice, he has several pieces created under this term)	2014-2018	Adapted contact mics and recorders to record subterranean sound
French, Jez Riley	*Ink Botanic*	2020-2021	Installation and multichannel sound art series exploring "transpiration, root systems, cavitation, vibrations in soil horizons and situated connections between species"
French, Jez Riley	*Soil Horizons*	2022	Multichannel installation. Focus on soil structures and resonance
Gibson, John	*sLowlife*	2005	Installation and 8-channel audio mix created for exhibit about plant biology. Focus on imperceptibly slow plant growth
Guerra, Joana	*Chão Vermelho (Red Floor)*	2021	An album by a cellist, composer, and vocalist about desertification in central Portugal

Maeder, Marcus	*Sounding Soil*	2017-present	Ongoing soil acoustics research project, installation, sound map (archive of mapped recordings), citizen science project
Music of the Plants	[n/a]	1976-present	A company which sells commercial sonification devices
Nate, Hila, and DiorNoel	"Compost"	2021	Ecorap and music video about how to compost and the NYC composting community
Neuhaus, Max	*Times Square*	1977-1992; 2002-present	Subterranean sound installation
Nauman, Bruce	*Untitled Piece*	1969	(Installation plan, never realized) Microphones suspended in a mile-deep, subterranean hole, amplified into a gallery room
Paine, Garth, Visar Berisha, Helen Rowe, Kyle Hoefer, Aishwarya Pratap Singh, Srinivas Puranam, Sabine Feisst, and Sharon J. Hall	EcoSonics	2017	"Psychoacoustic Environmental Monitoring Toolkit" – an interdisciplinary project measuring the effects of changing acoustics on different ecosystems
Paine, Garth	*Listening Lands*	2017	An album of environmentally inspired work (featuring field recording). See "Forest," "Becoming Desert," "Conversations Prelude," and "Present in the Landscape" in particular
Sound Matters	*Soil Composer*	2018	Sonification of soil moisture, nutrients, temperature, and microbial activity

Tagaq, Tanya	“Fracking”	2014	A song that imagines the earth’s perception of fracking
Young, Neil and the Promise of the Real	“Monsanto Years”	2015	A track on an album of the same name, this song’s lyrics criticize industrial agriculture and Monsanto, the large agribusiness, specifically

APPENDIX B

SCORE TO THE RHIZOSPHERE, FOR PERCUSSION SEXTET

The Rhizosphere

for percussion sextet

Laura Brackney

2022

The Rhizosphere

Instrumentation

Player 1
Timpani
Dobachi (3)
Crotales (lower octave, chromatic from D to B)
Superball mallet

Player 2
Triangle
Marimba
Bass Drum
Superball mallet
Medium size stone

Player 3
Triangle
Marimba
Sizzle Cymbal
Tam-tam
Superball mallet
Bass bow

Player 4
Triangle
Vibraphone
Snare Drum with lower D-flat crotale
Cymbal
Bass bow

Player 5
Xylophone
Cymbal
Snare Drum with lower C crotale
Bass bow

Player 6
Glockenspiel
Melodica
Flower Pots of 3 sizes (small, medium, large), preferably terracotta
Two medium sized stones (which you can hold in your hand)
A couple of handfuls of small stones (not so small that they would fall through the hole at the base of the flower pots)

Program Notes

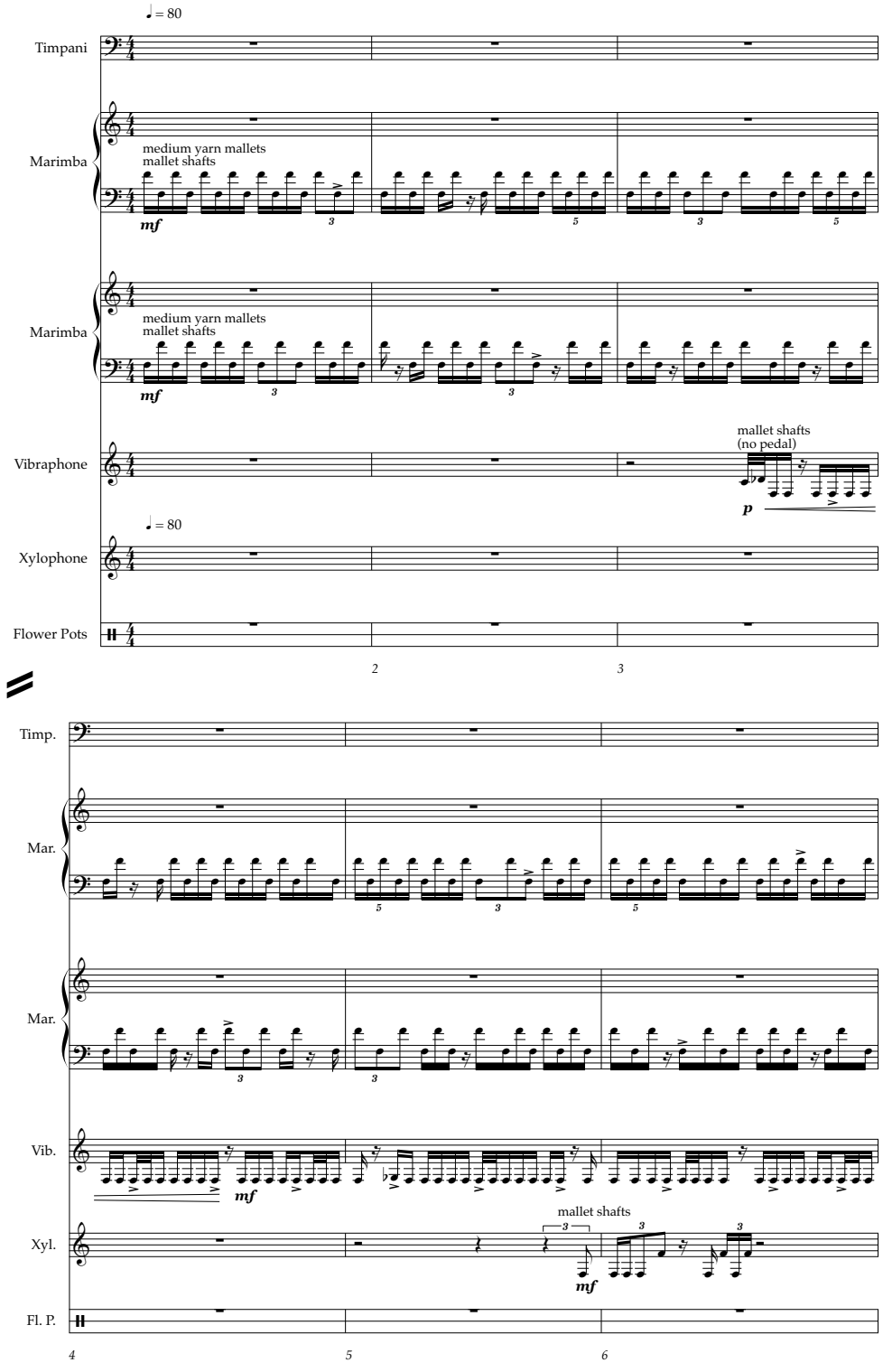
The Rhizosphere was commissioned by the Arizona Contemporary Music Ensemble, under the direction of Simone Mancuso. The piece was inspired by the rhizosphere, the complex and biodiverse ecosystem found in the soil around plant roots. The percussion sextet explores the dynamic flux, temporal multiplicity, and interrelationships of this underground microbiome.

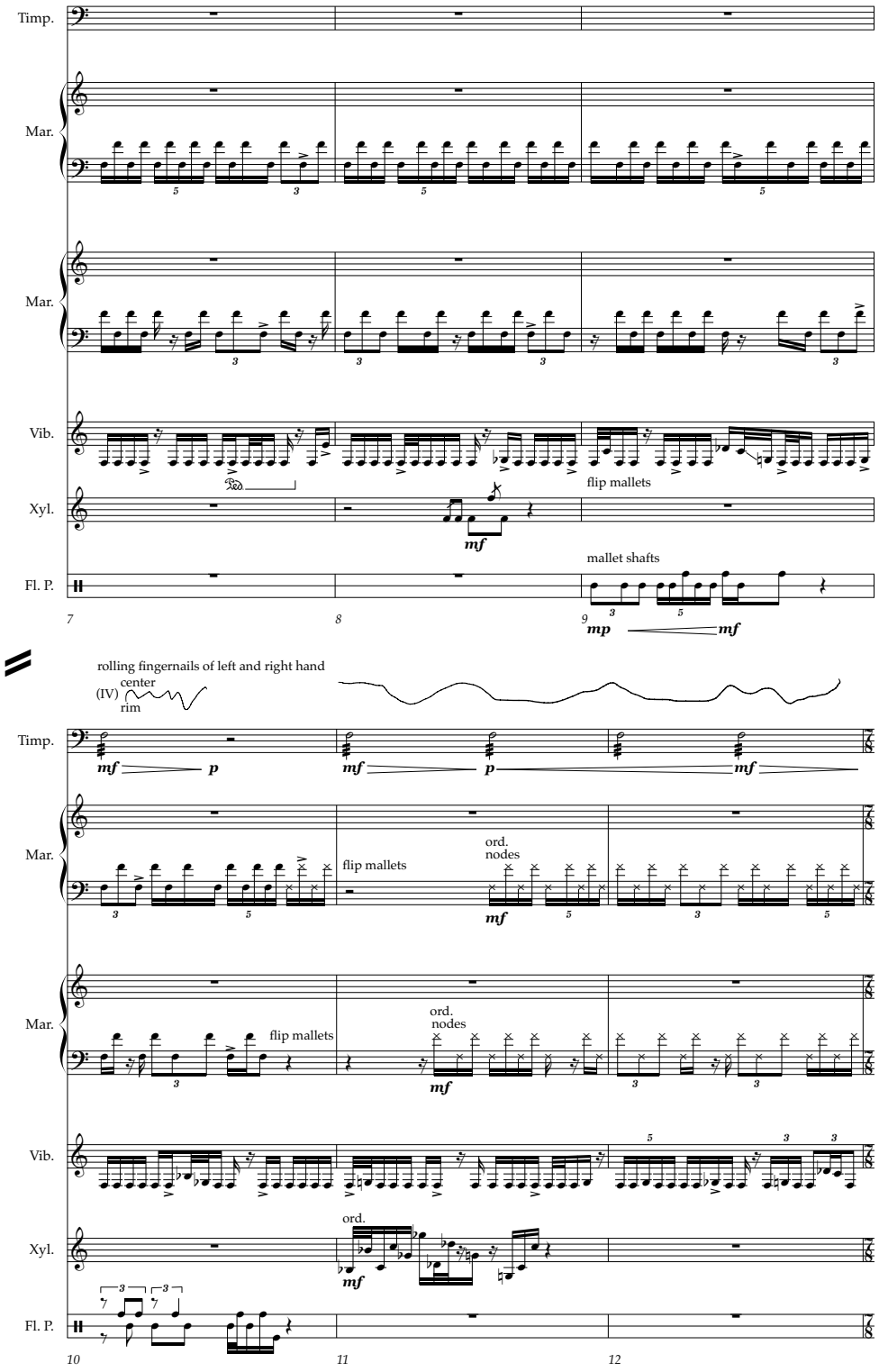
Duration: 8'

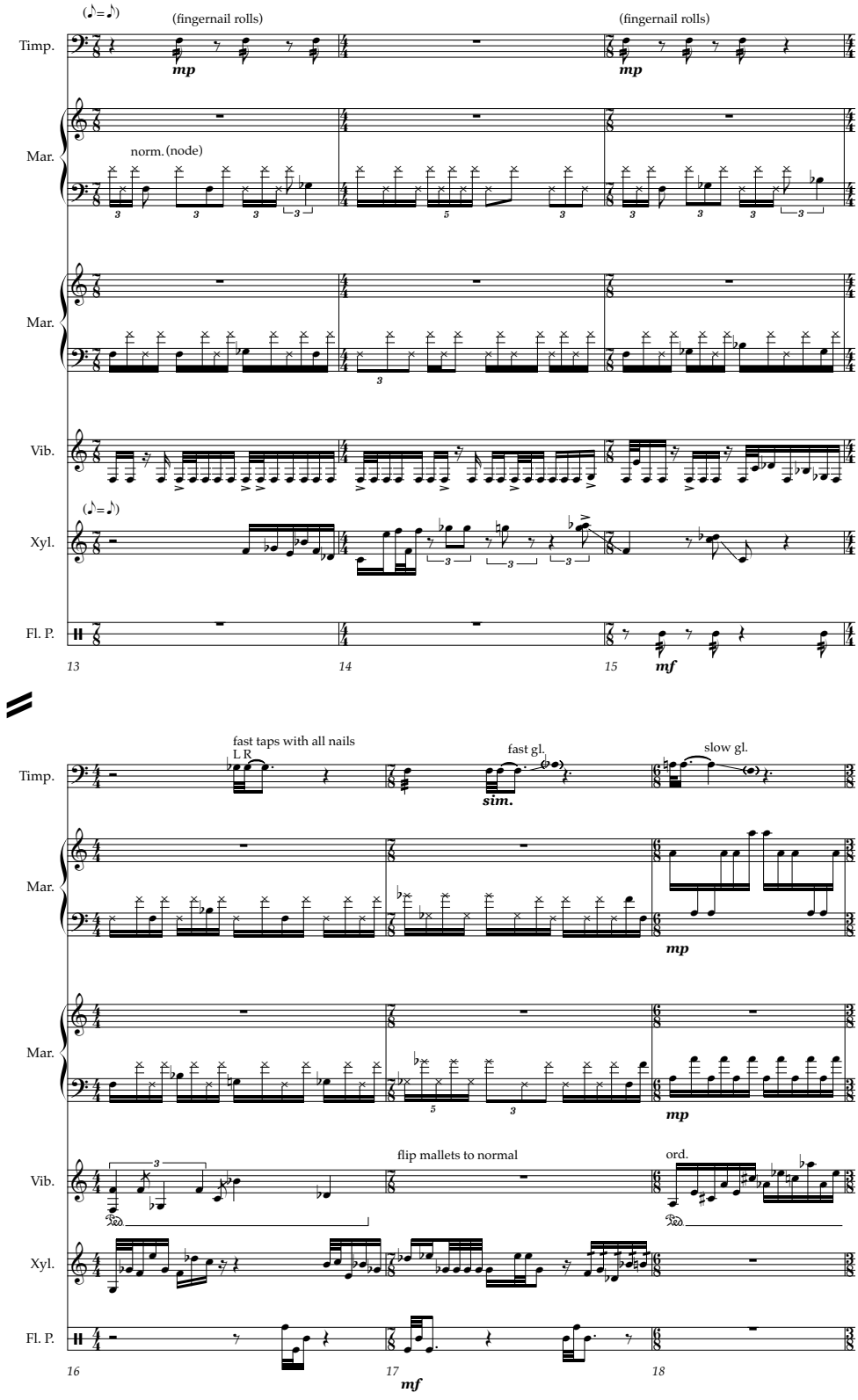
The Rhizosphere

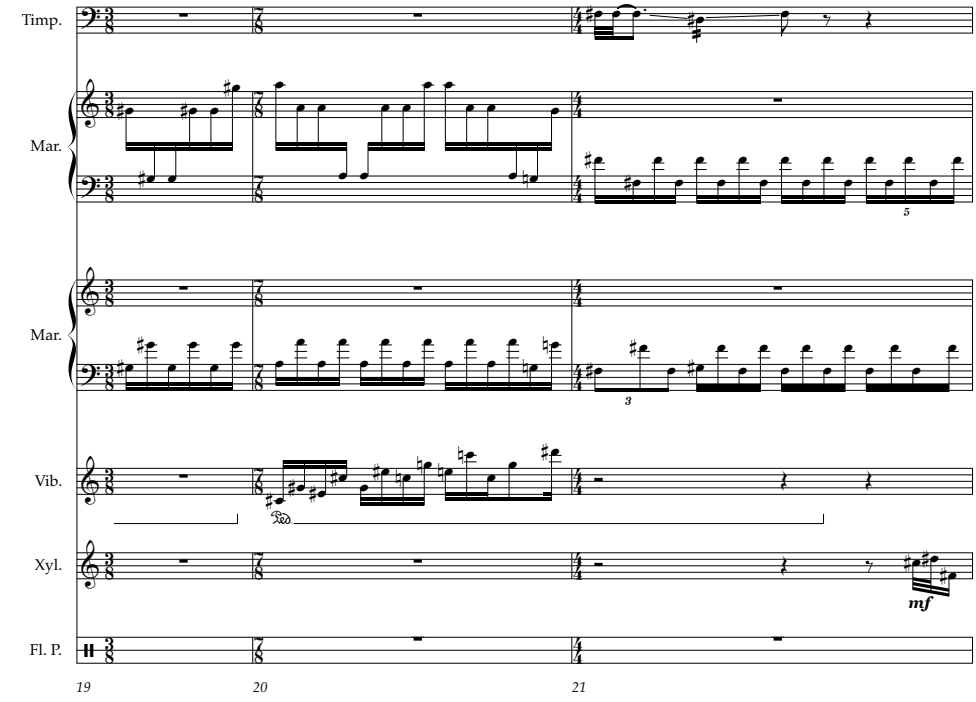
Dedicated to Simone Mancuso and the
Arizona Contemporary Music Ensemble

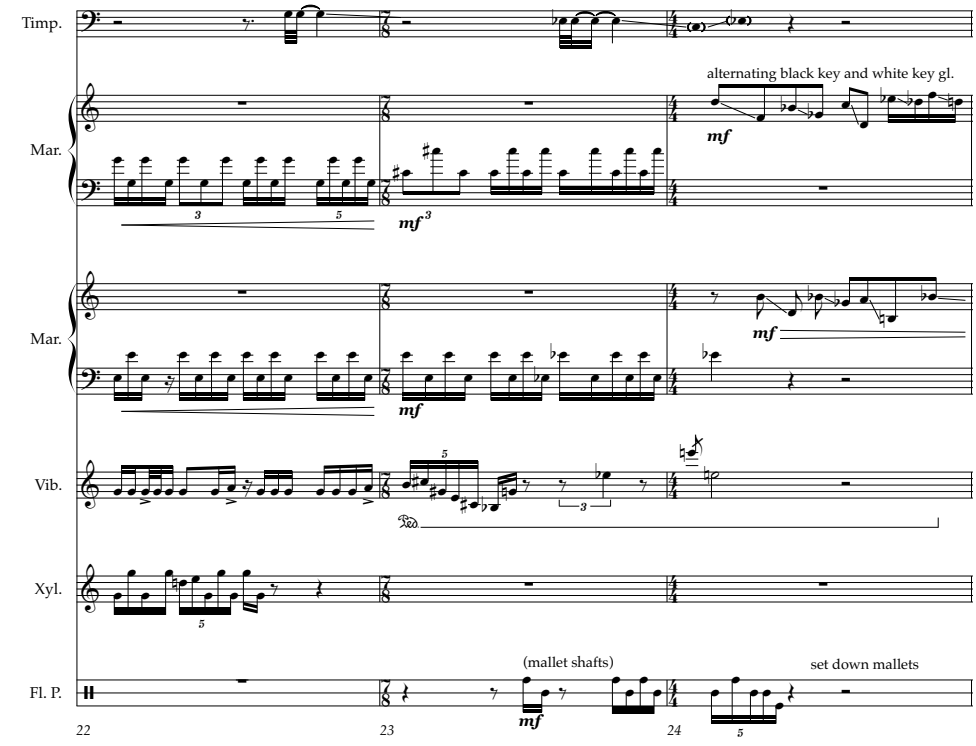
Laura Brackney

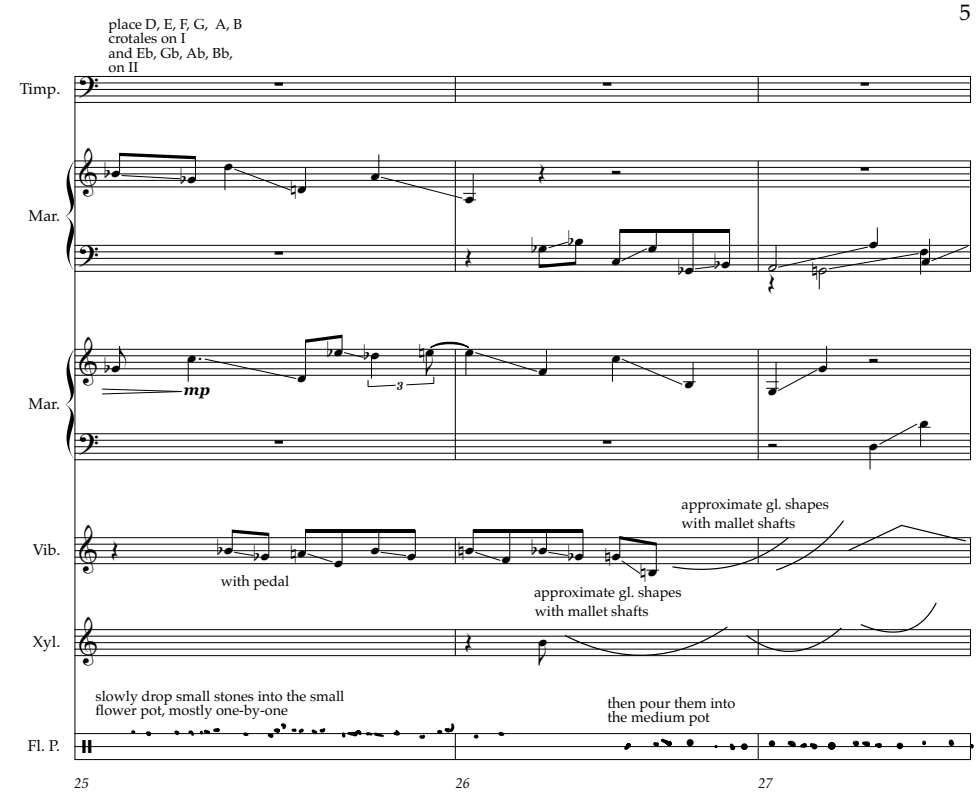


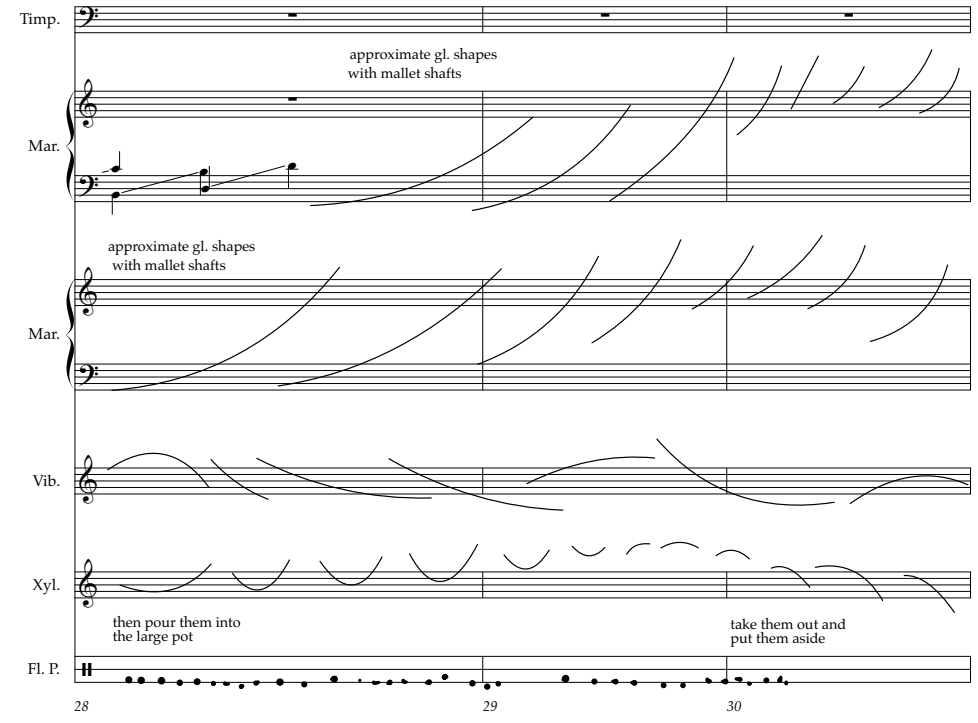

Timp.
Mar.
Mar.
Vib.
Xyl.
Fl. P.
flip mallets
mf
mallet shafts
mp
mf
7
8
9
rolling fingernails of left and right hand
(IV)
center
rim
Timp.
mf
p
mf
p
mf
Mar.
flip mallets
ord.
nodes
mf
Mar.
flip mallets
ord.
nodes
mf
Vib.
Xyl.
ord.
mf
Fl. P.
10
11
12


(♪=♪)
(fingernail rolls)
(fingernail rolls)
Timp.
mp
mp
Mar.
norm. (node)
Mar.
Vib.
(♪=♪)
Xyl.
Fl. P.
13
14
15
mf
fast taps with all nails
L R
fast gl.
sim.
slow gl.
Timp.
Mar.
mp
Mar.
mp
flip mallets to normal
ord.
Vib.
Xyl.
Fl. P.
16
17
18
mf

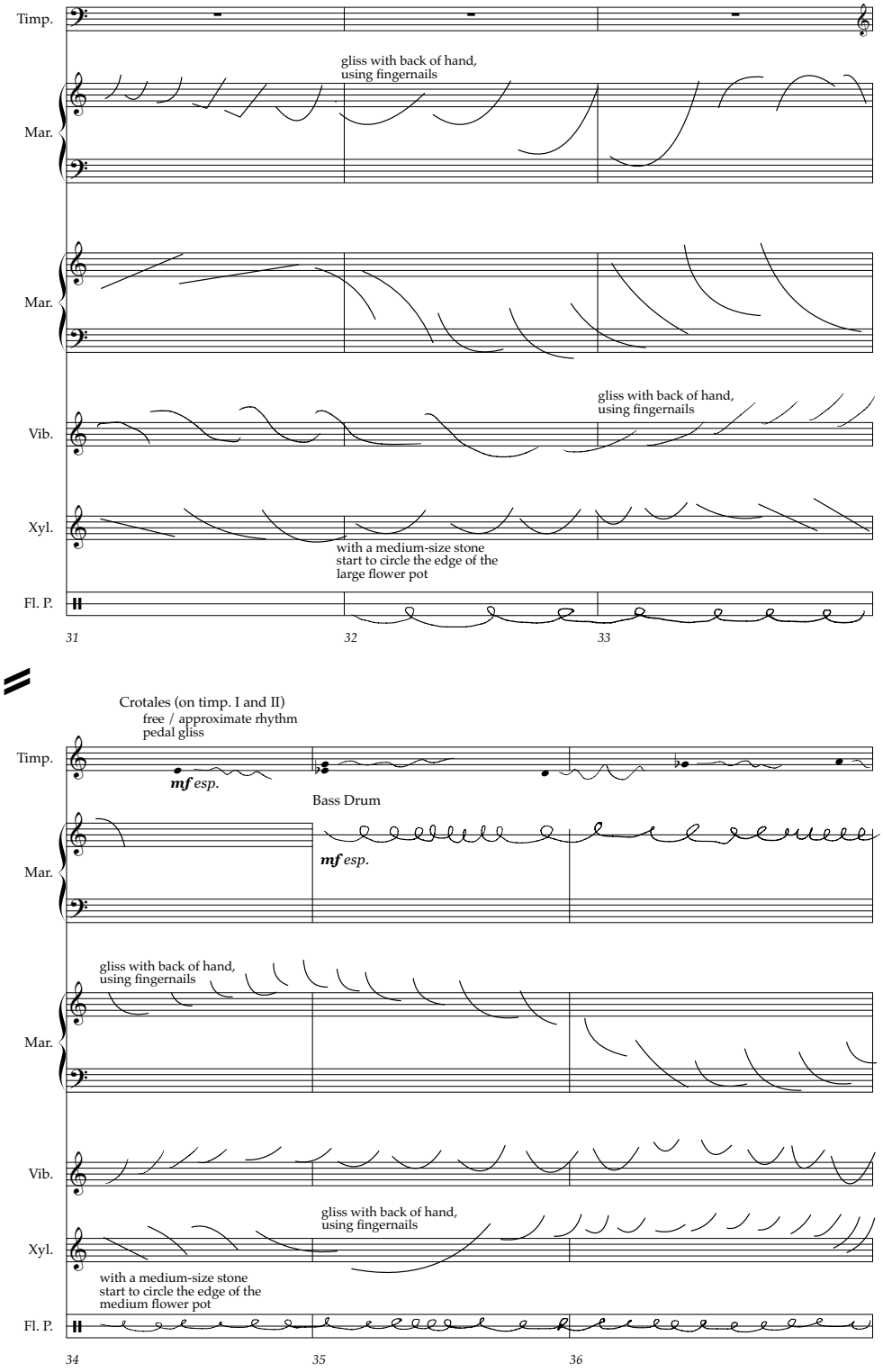

Timp.
Mar.
Mar.
Vib.
Xyl.
Fl. P.
mf
19
20
21

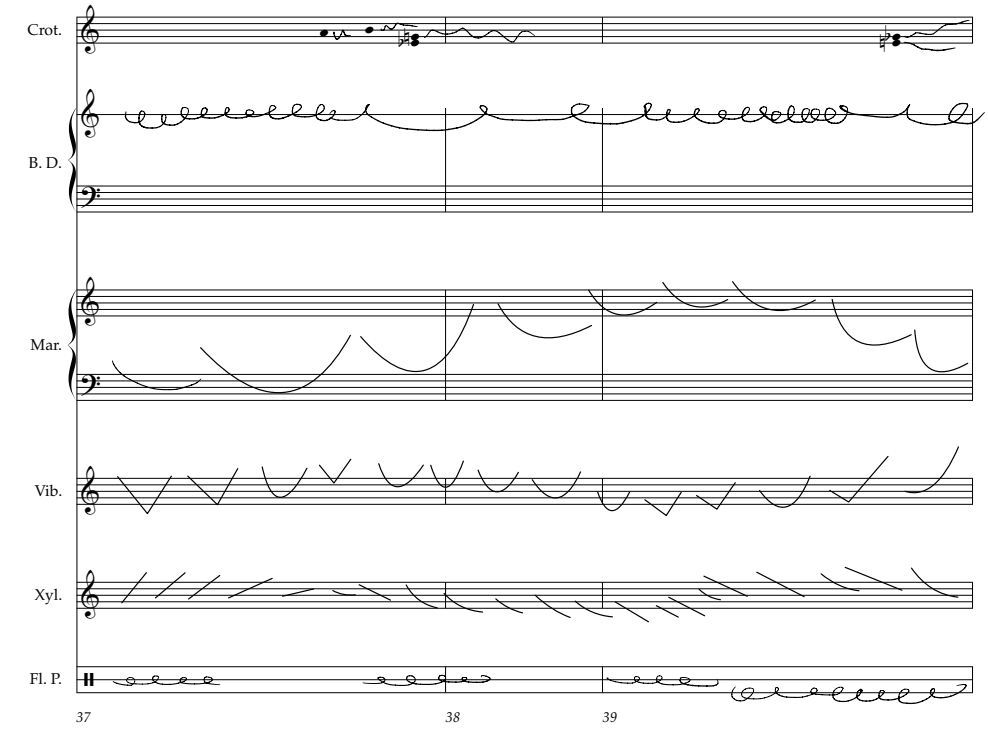

Timp.
alternating black key and white key gl.
Mar.
mf
mf
Mar.
mf
mf
Vib.
Xyl.
(mallet shafts)
set down mallets
Fl. P.
mf
22
23
24

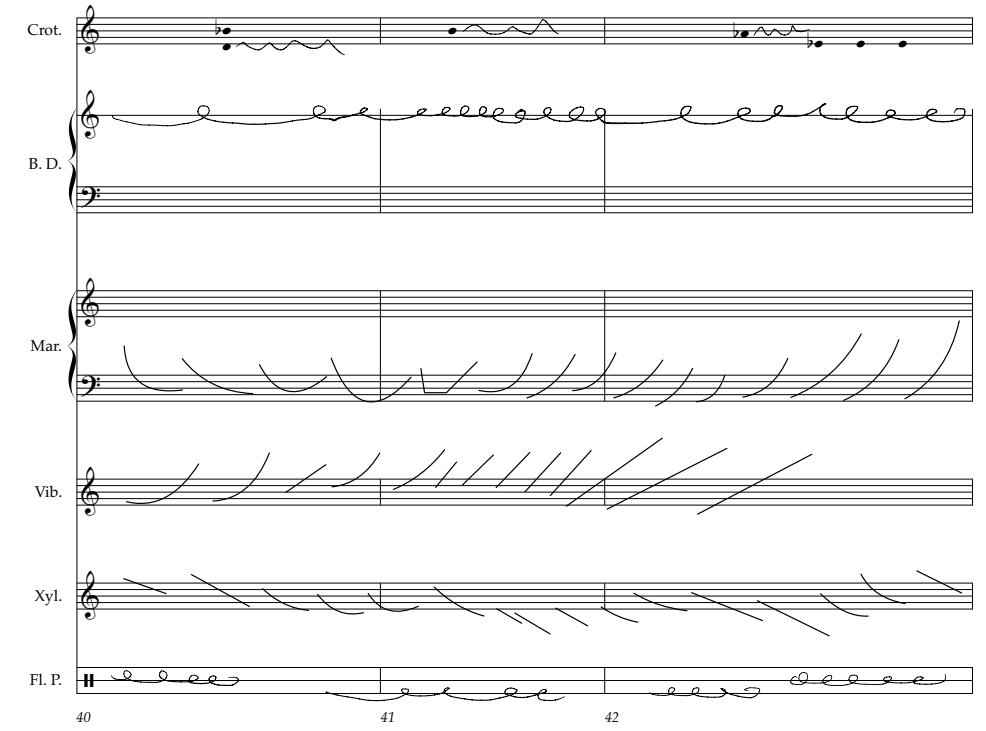

place D, E, F, G, A, B
crotales on I
and Eb, Gb, Ab, Bb,
on II
Timp.
Mar.
Mar.
mp
3
Vib.
approximate gl. shapes
with mallet shafts
with pedal
approximate gl. shapes
with mallet shafts
Xyl.
slowly drop small stones into the small
flower pot, mostly one-by-one
then pour them into
the medium pot
Fl. P.
25
26
27


Timp.
approximate gl. shapes
with mallet shafts
Mar.
approximate gl. shapes
with mallet shafts
Mar.
Vib.
Xyl.
then pour them into
the large pot
take them out and
put them aside
Fl. P.
28
29
30

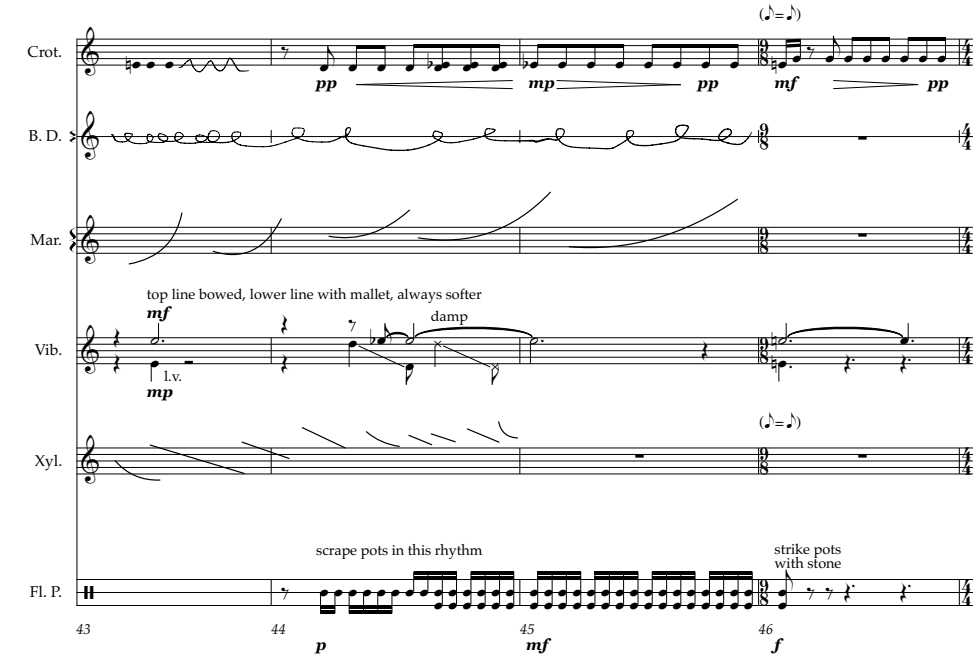
6

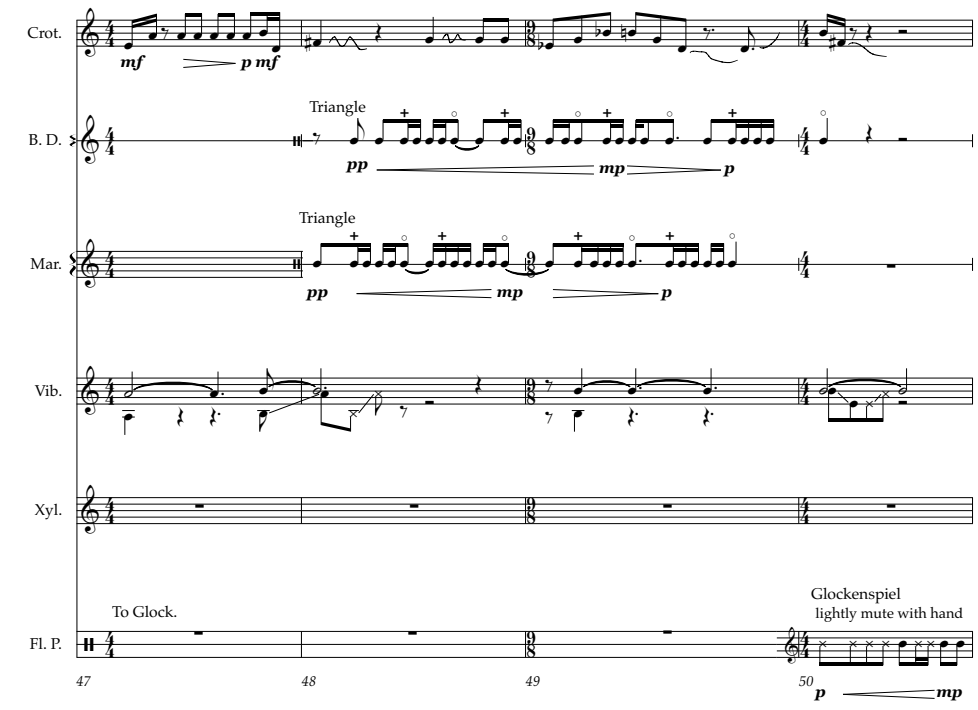

Timp.
gliss with back of hand,
using fingernails
Mar.
Mar.
gliss with back of hand,
using fingernails
Vib.
Xyl.
with a medium-size stone
start to circle the edge of the
large flower pot
Fl. P.
31
32
33
Crotales (on timp. I and II)
free / approximate rhythm
pedal gliss
Timp.
mf esp.
Bass Drum
Mar.
mf esp.
gliss with back of hand,
using fingernails
Mar.
Vib.
gliss with back of hand,
using fingernails
Xyl.
with a medium-size stone
start to circle the edge of the
medium flower pot
Fl. P.
34
35
36

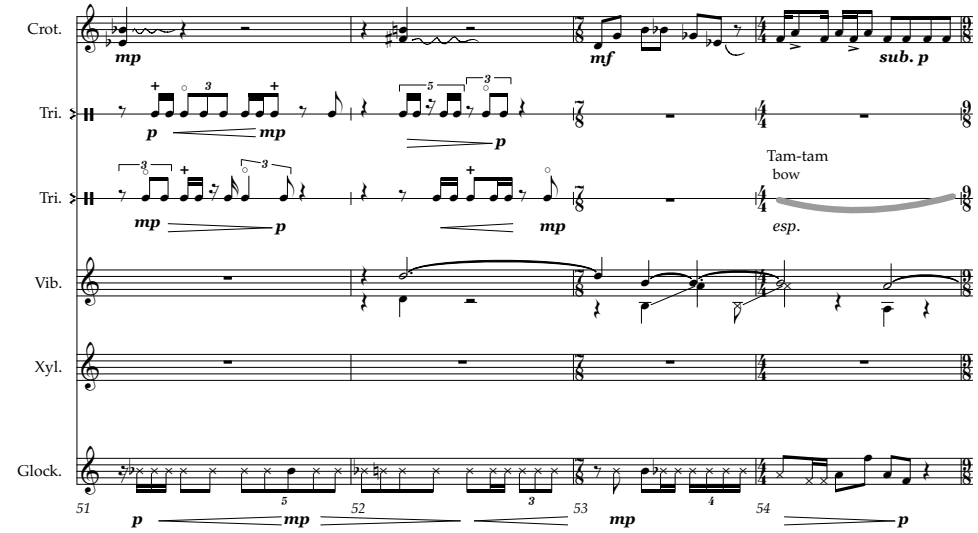

Crot.
B. D.
Mar.
Vib.
Xyl.
Fl. P.
37
38
39

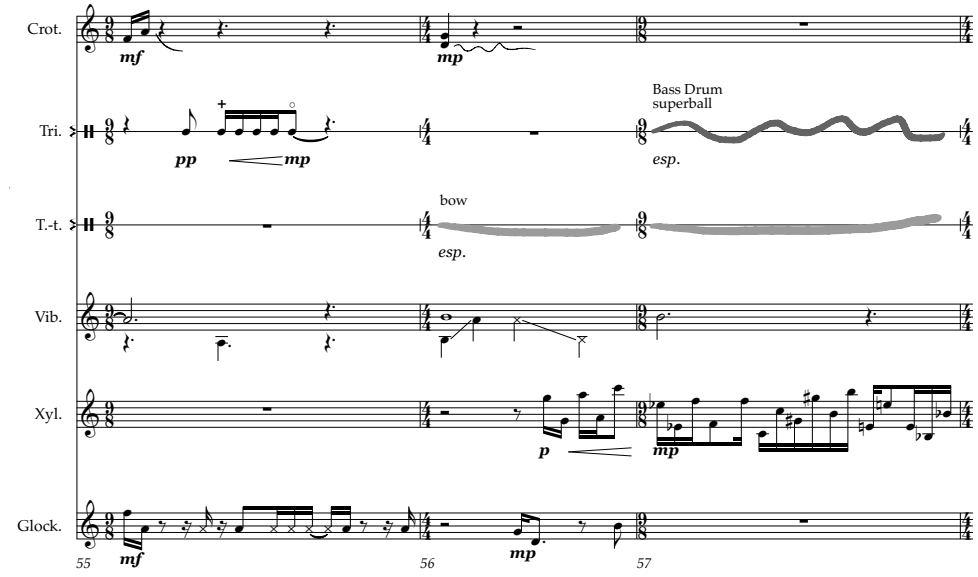

Crot.
B. D.
Mar.
Vib.
Xyl.
Fl. P.
40
41
42

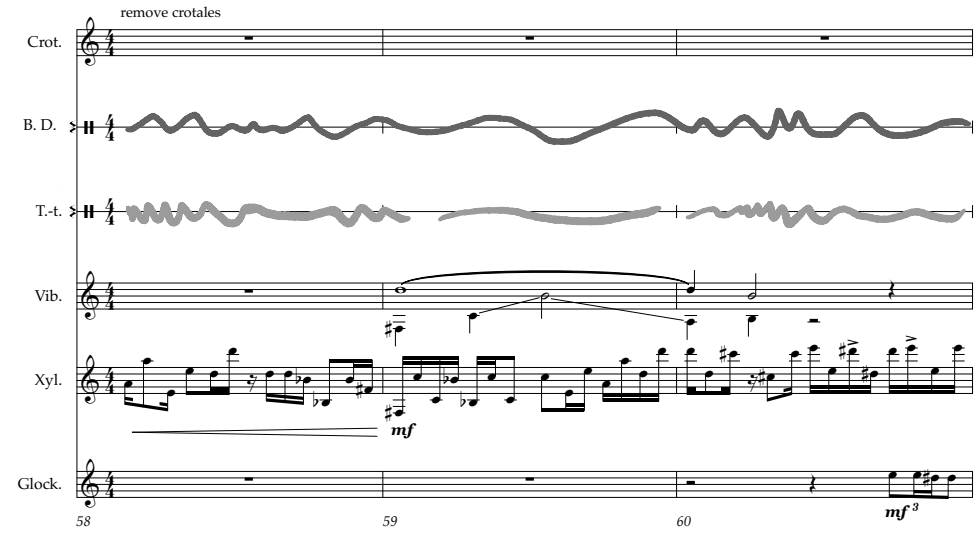
8

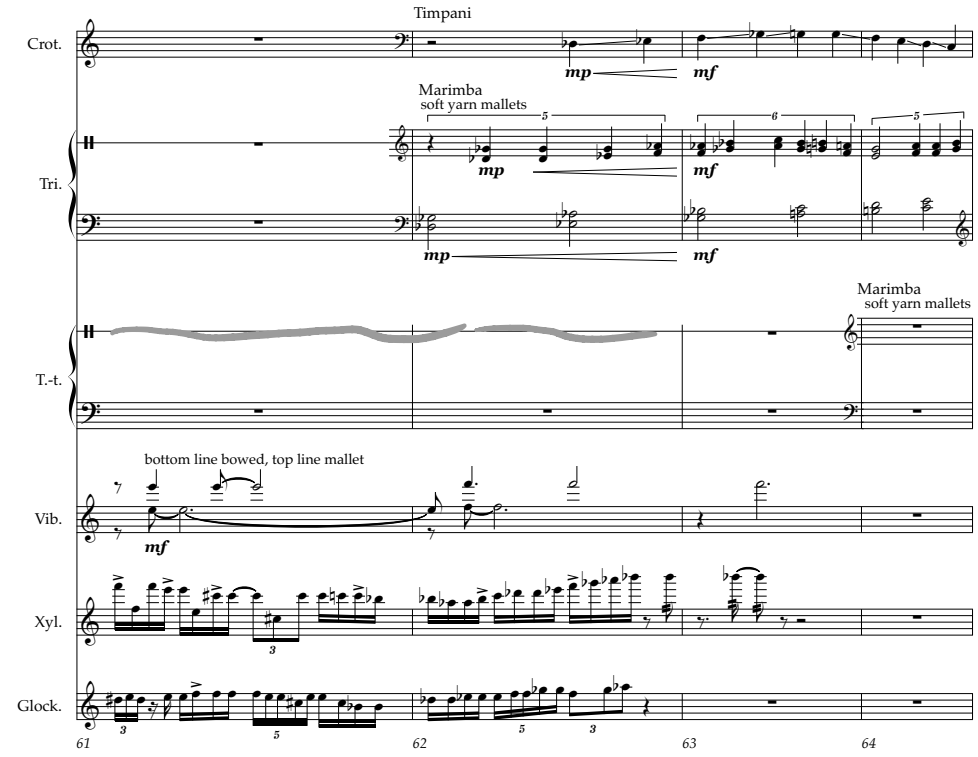

Crot.
B. D.
Mar.
Vib.
Xyl.
Fl. P.
top line bowed, lower line with mallet, always softer
damp
l.v.
scrape pots in this rhythm
strike pots with stone
43
44
45
46

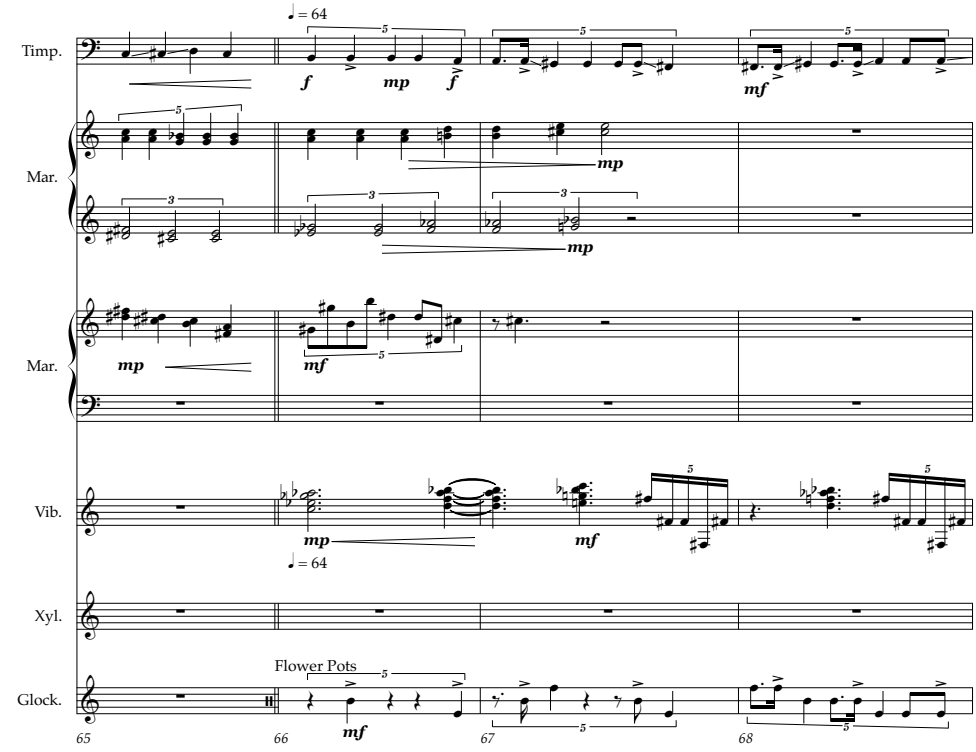

Crot.
B. D.
Mar.
Vib.
Xyl.
Fl. P.
Triangle
Triangle
To Glock.
Glockenspiel
lightly mute with hand
47
48
49
50

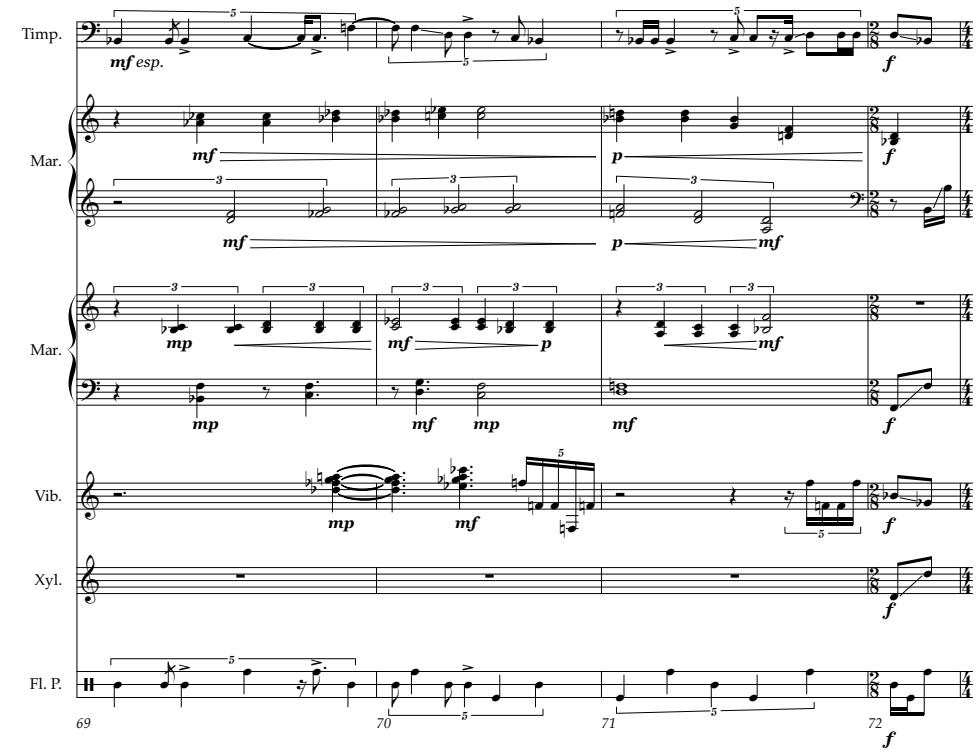

Crot.
Tri.
Tri.
Vib.
Xyl.
Glock.
Tam-tam
bow
esp.
51
52
53
54

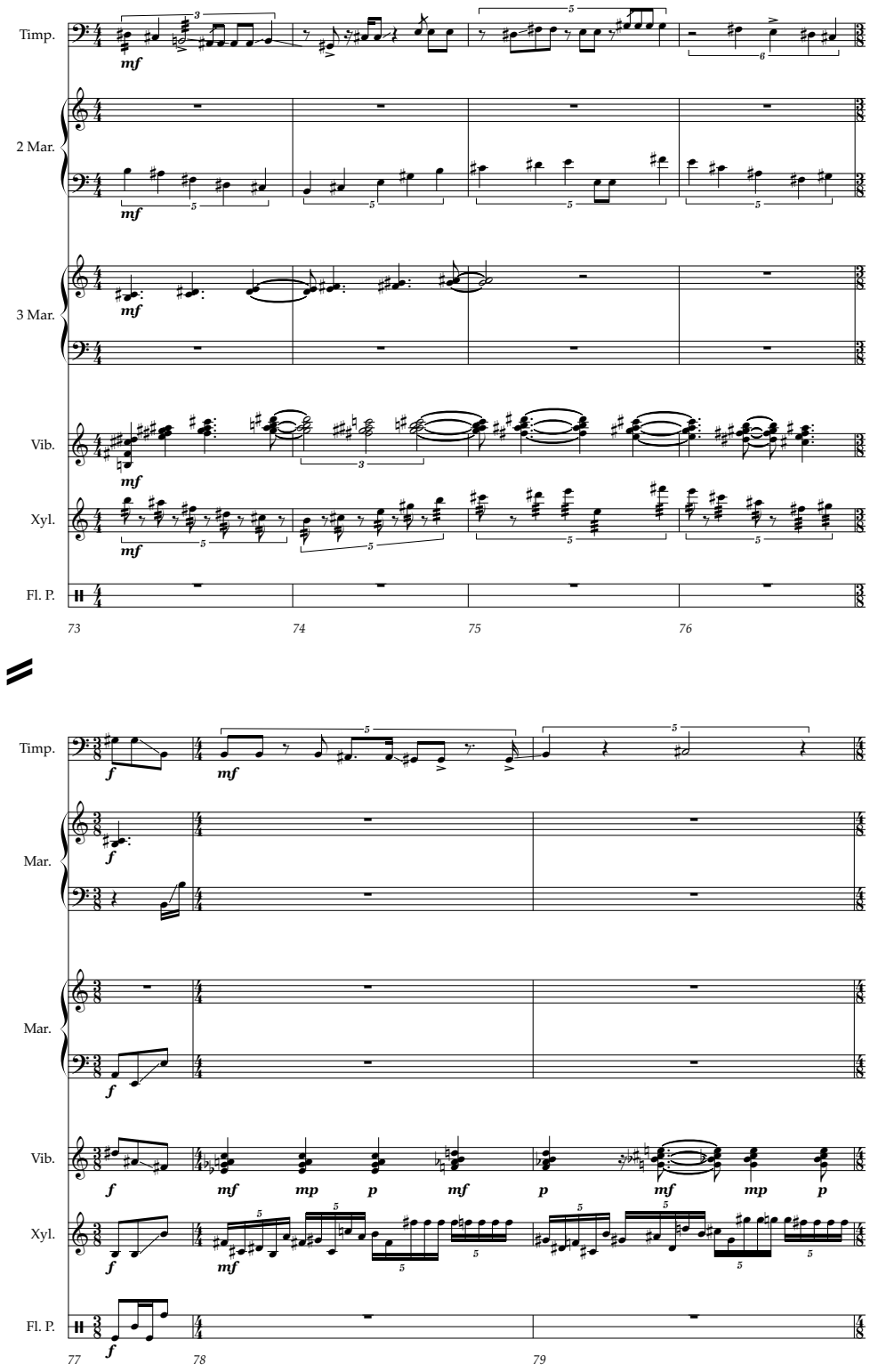

Crot.
Tri.
T.-t.
Vib.
Xyl.
Glock.
Bass Drum
superball
esp.
bow
esp.
55
56
57

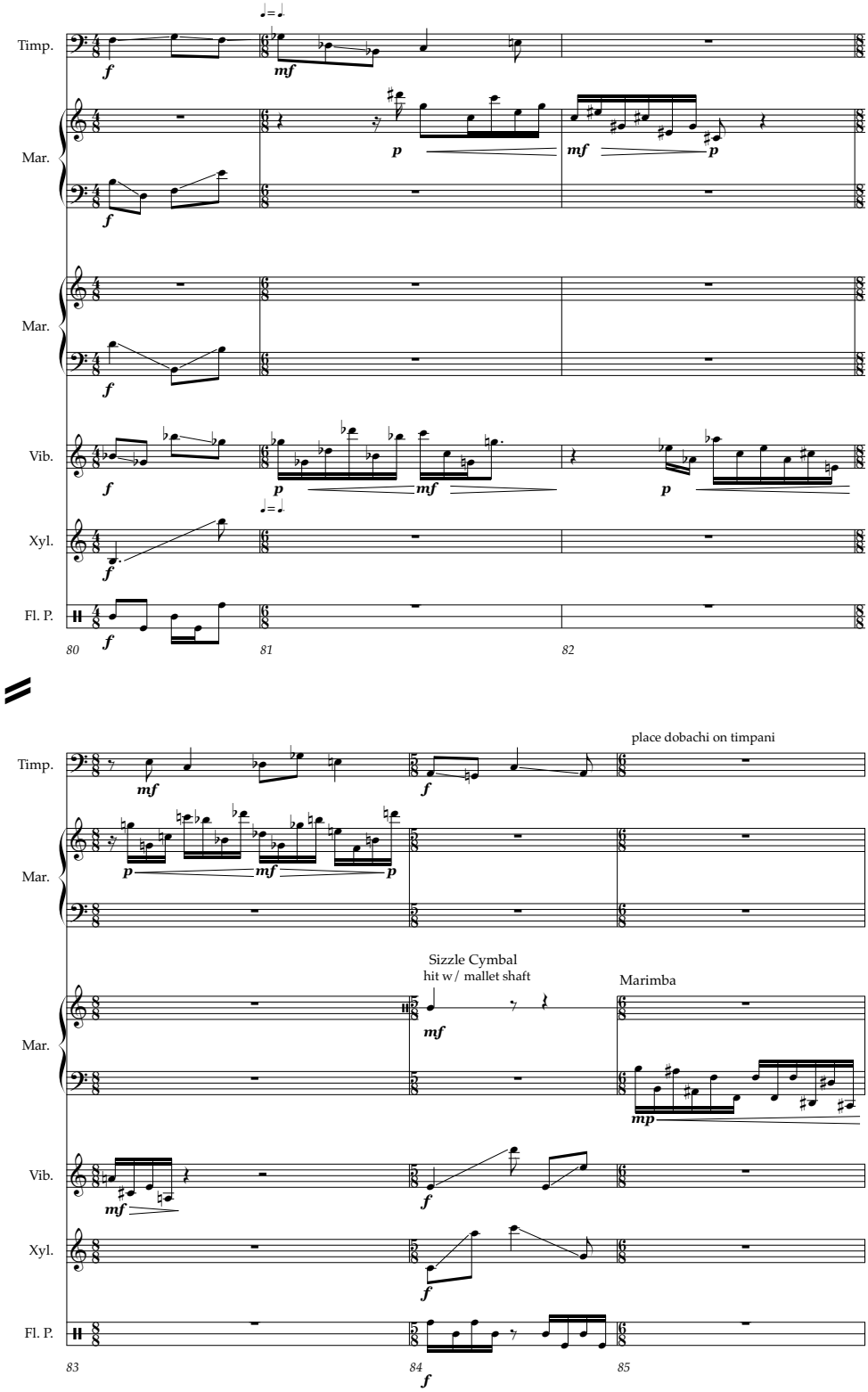

remove crotales
Crot.
B. D.
T.-t.
Vib.
Xyl.
Glock.
mf
mf 3
58
59
60

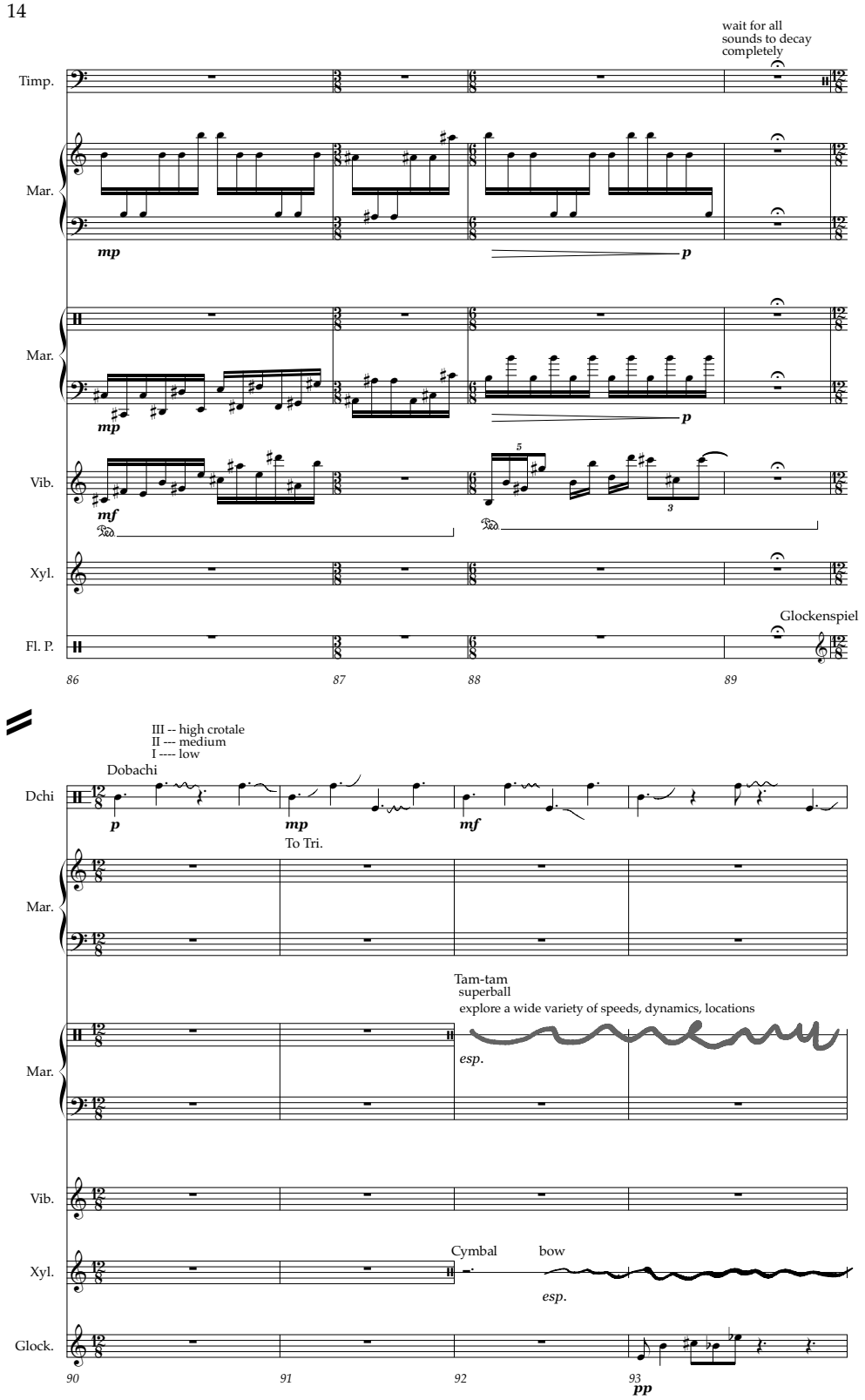

Timpani
Crot.
mp
mf
Marimba
soft yarn mallets
Tri.
Marimba
soft yarn mallets
T.-t.
bottom line bowed, top line mallet
Vib.
Xyl.
Glock.
61
62
63
64

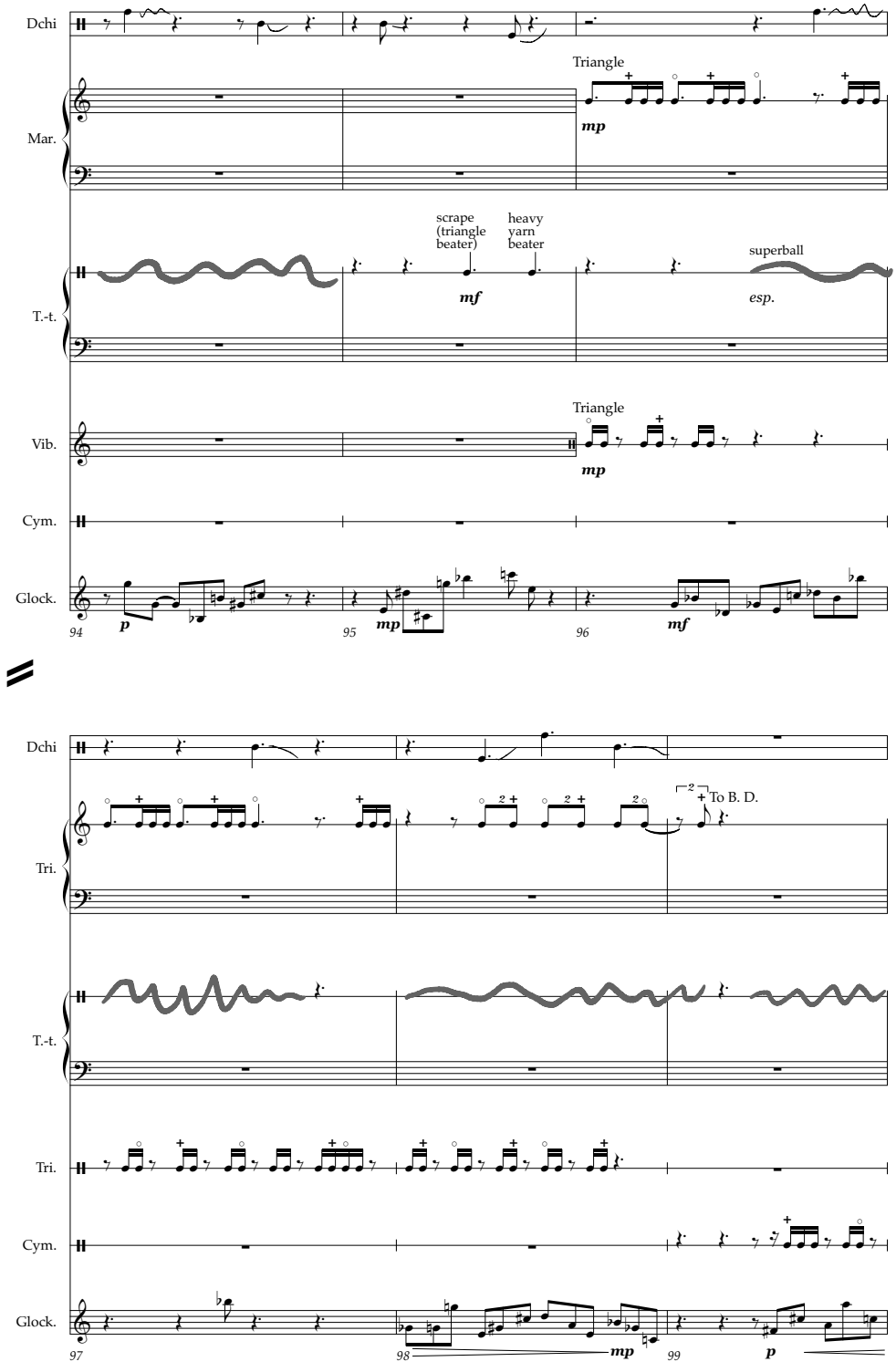

Timp.
Mar.
Mar.
Vib.
Xyl.
Glock.
Flower Pots
65
66
67
68

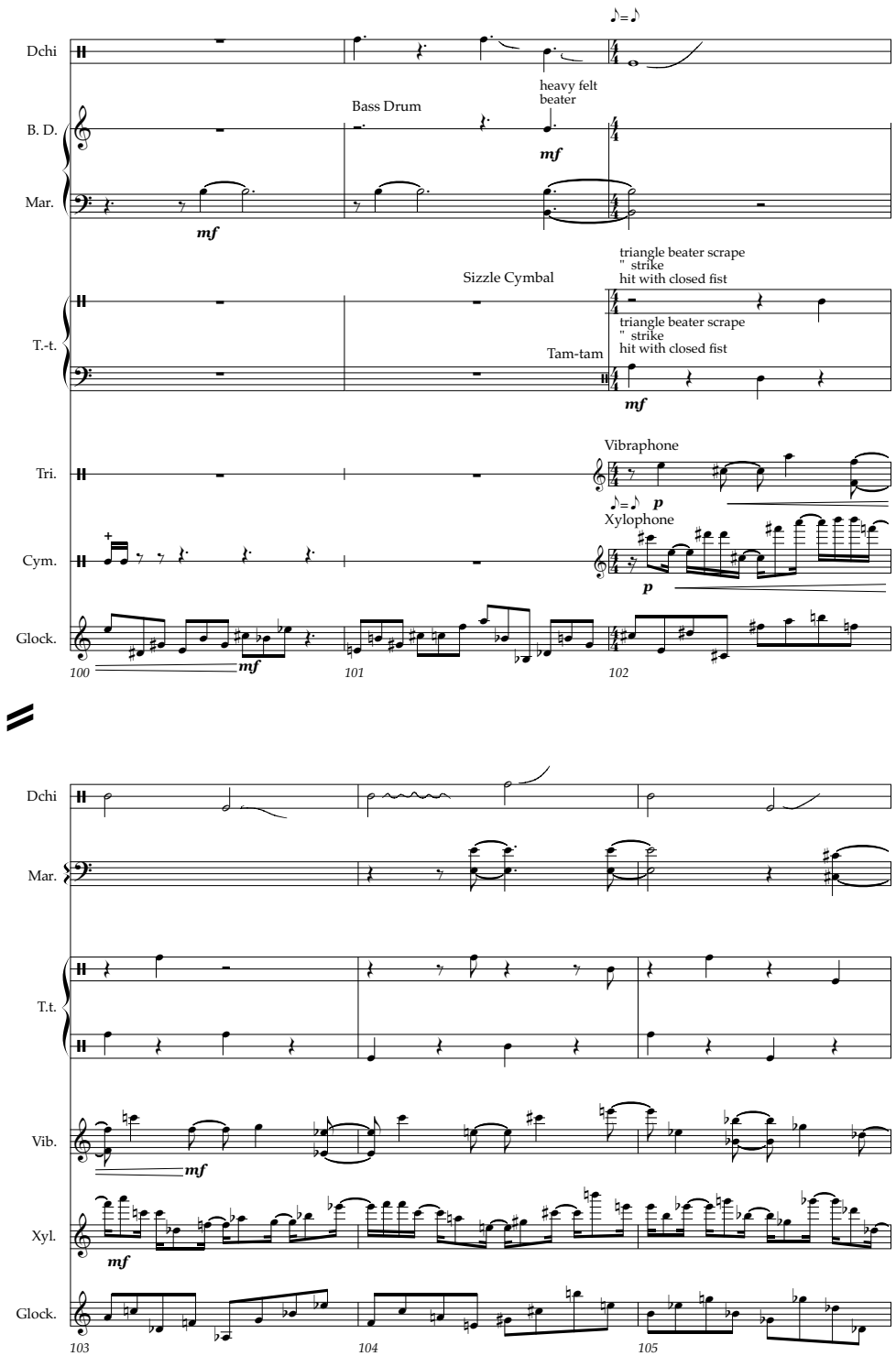

Timp.
Mar.
Mar.
Vib.
Xyl.
Fl. P.
69
70
71
72

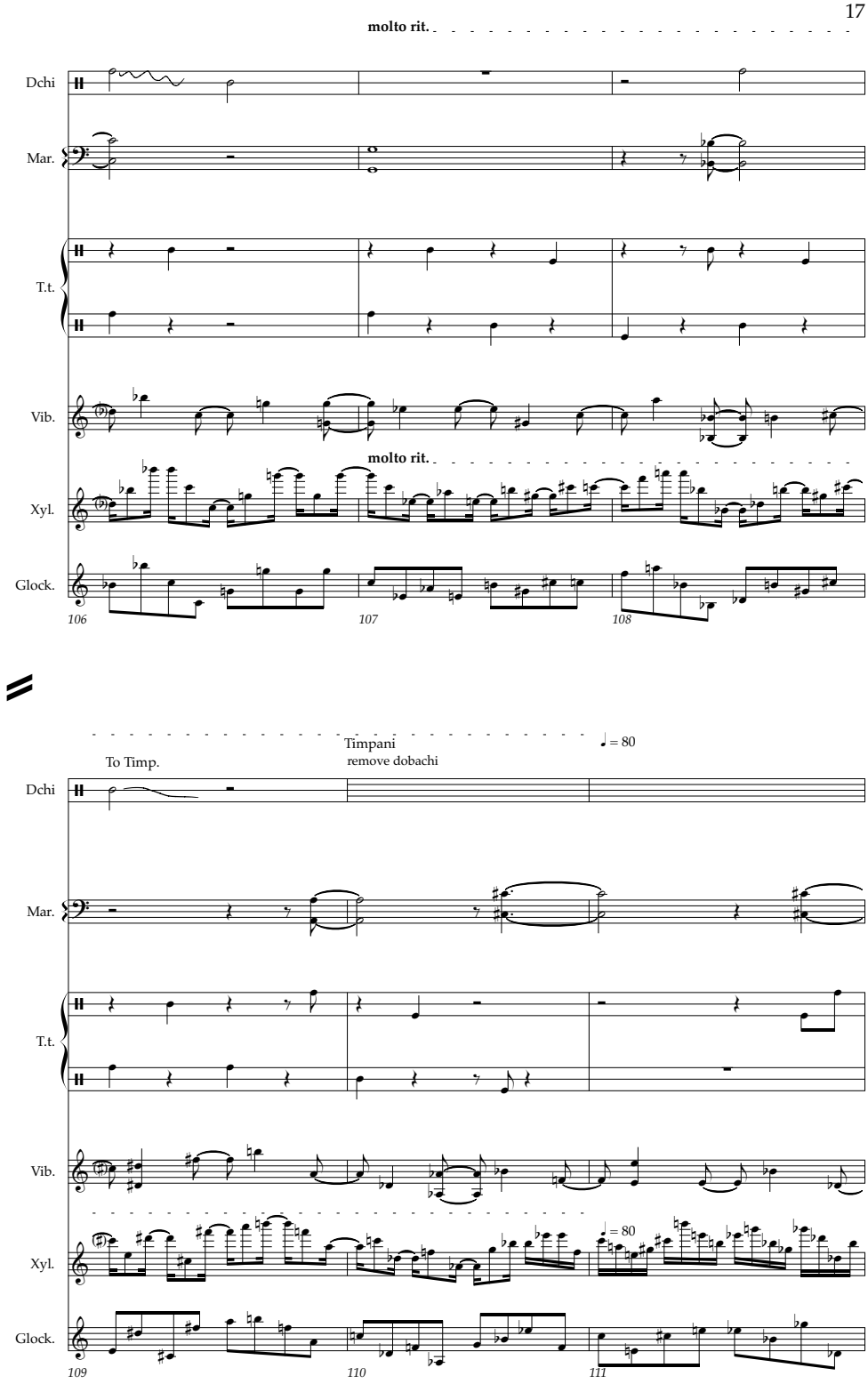

Timp.
2 Mar.
3 Mar.
Vib.
Xyl.
Fl. P.
Mar.
Mar.
73
74
75
76
77
78
79


Timp.
Mar.
Mar.
Vib.
Xyl.
Fl. P.
80
81
82
place dobachi on timpani
Sizzle Cymbal
hit w/ mallet shaft
Marimba
83
84
85

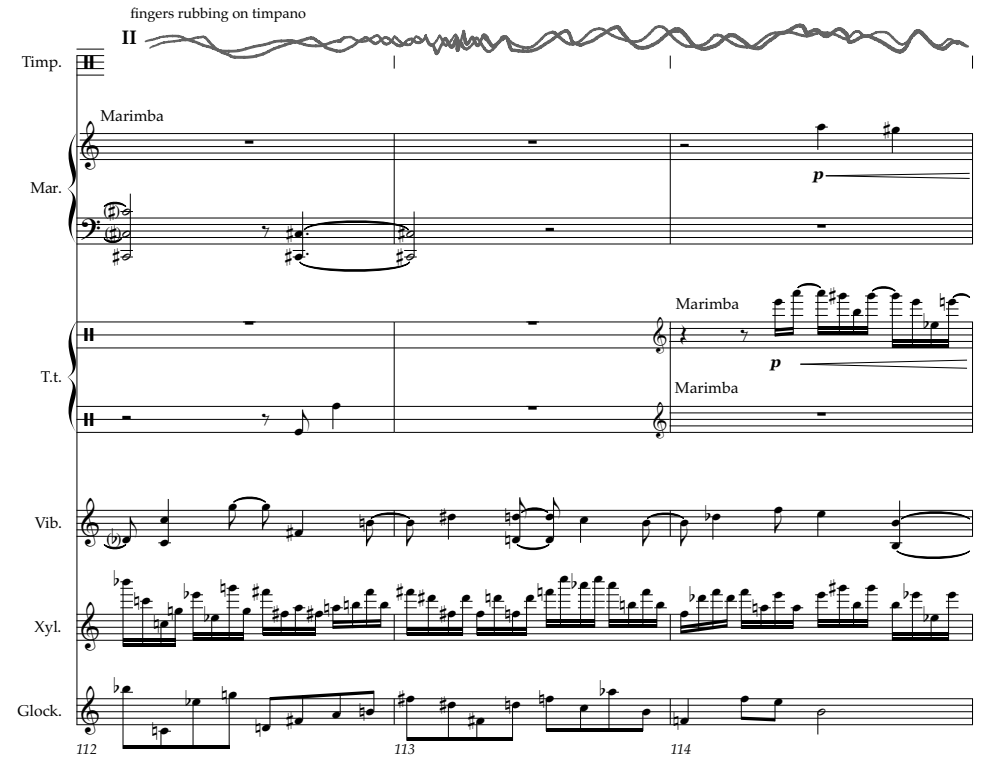

wait for all
sounds to decay
completely
Timp.
Mar.
mp
p
Mar.
mp
p
Vib.
mf
5
3
Xyl.
Fl. P.
Glockenspiel
86
87
88
89
III -- high crotale
II --- medium
I ---- low
Dobachi
Dchi
p
mp
mf
To Tri.
Mar.
Tam-tam
superball
explore a wide variety of speeds, dynamics, locations
Mar.
esp.
Vib.
Xyl.
Cymbal
bow
esp.
Glock.
90
91
92
93
pp

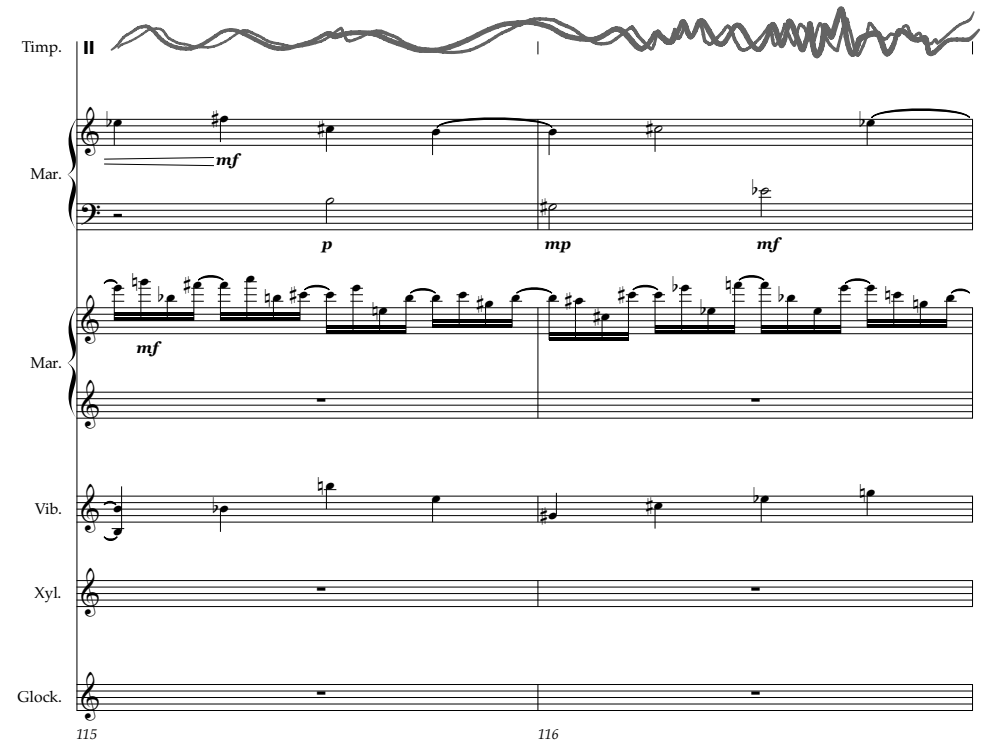

Dchi
Mar.
Triangle
mp
T.-t.
scrape
(triangle
beater)
heavy
yarn
beater
mf
superball
esp.
Vib.
Triangle
mp
Cym.
Glock.
p
mp
mf
94
95
96
Dchi
Tri.
2
To B. D.
T.-t.
Tri.
Cym.
Glock.
mp
p
97
98
99

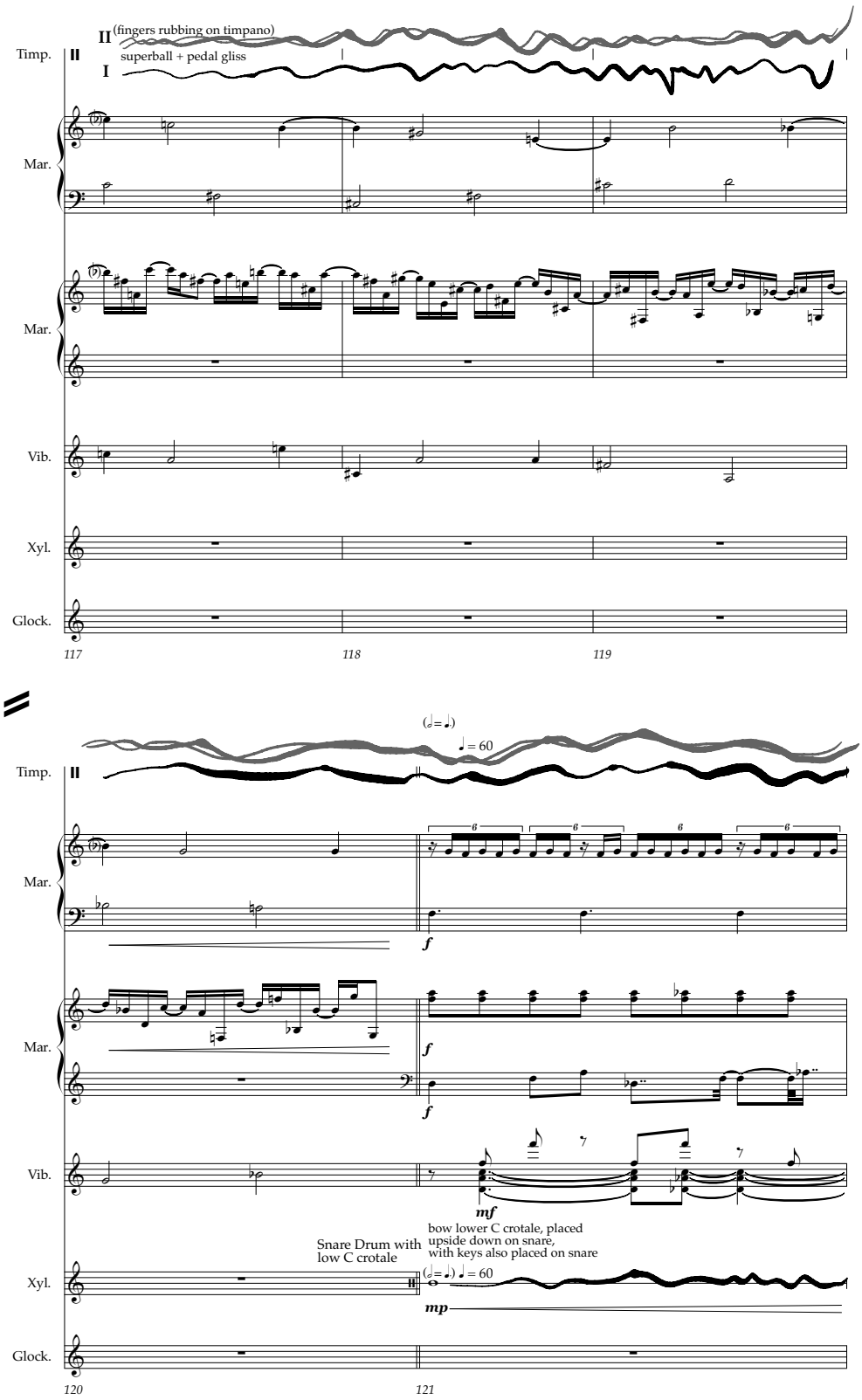

Dchi
B. D.
Mar.
T.-t.
Tri.
Cym.
Glock.
Bass Drum
heavy felt beater
Sizzle Cymbal
triangle beater scrape
" strike
hit with closed fist
Tam-tam
Vibraphone
Xylophone
mf
p
100
101
102
Dchi
Mar.
T.t.
Vib.
Xyl.
Glock.
103
104
105

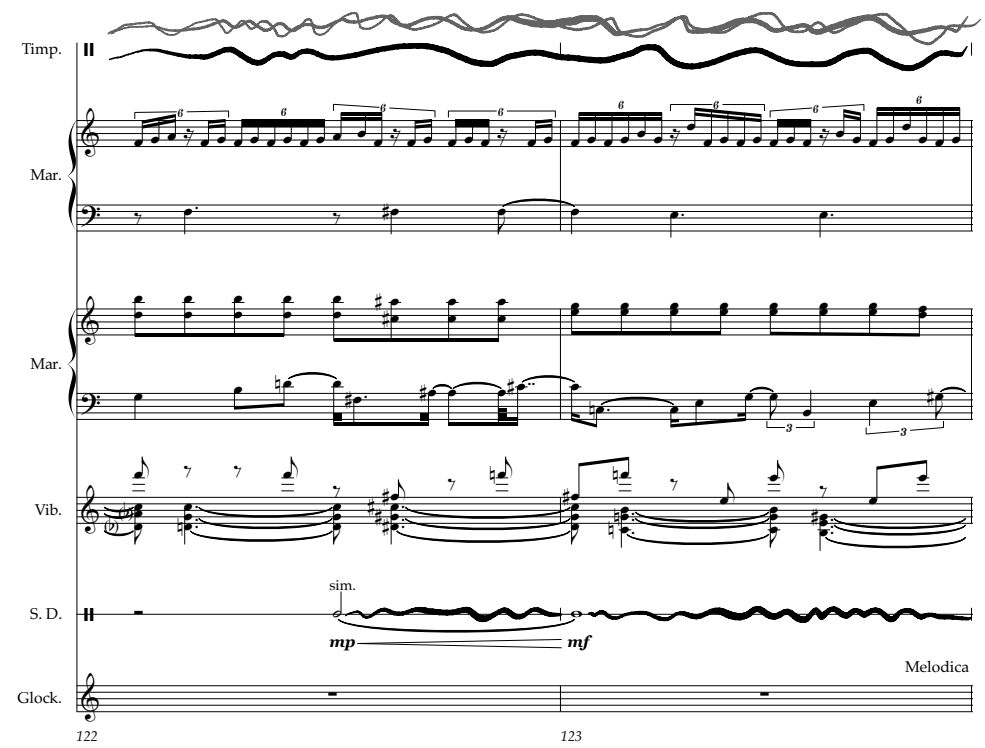

molto rit.
Dchi
Mar.
T.t.
Vib.
molto rit.
Xyl.
Glock.
106
107
108
To Timp.
Timpani
remove dobachi
♩ = 80
Dchi
Mar.
T.t.
Vib.
Xyl.
♩ = 80
Glock.
109
110
111

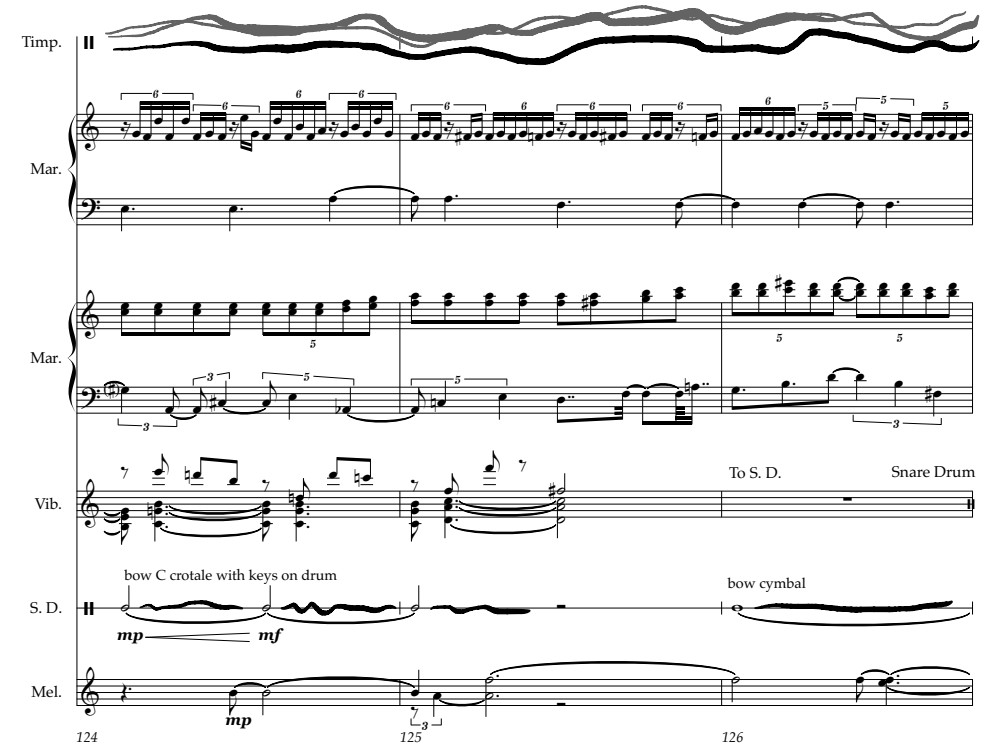
18

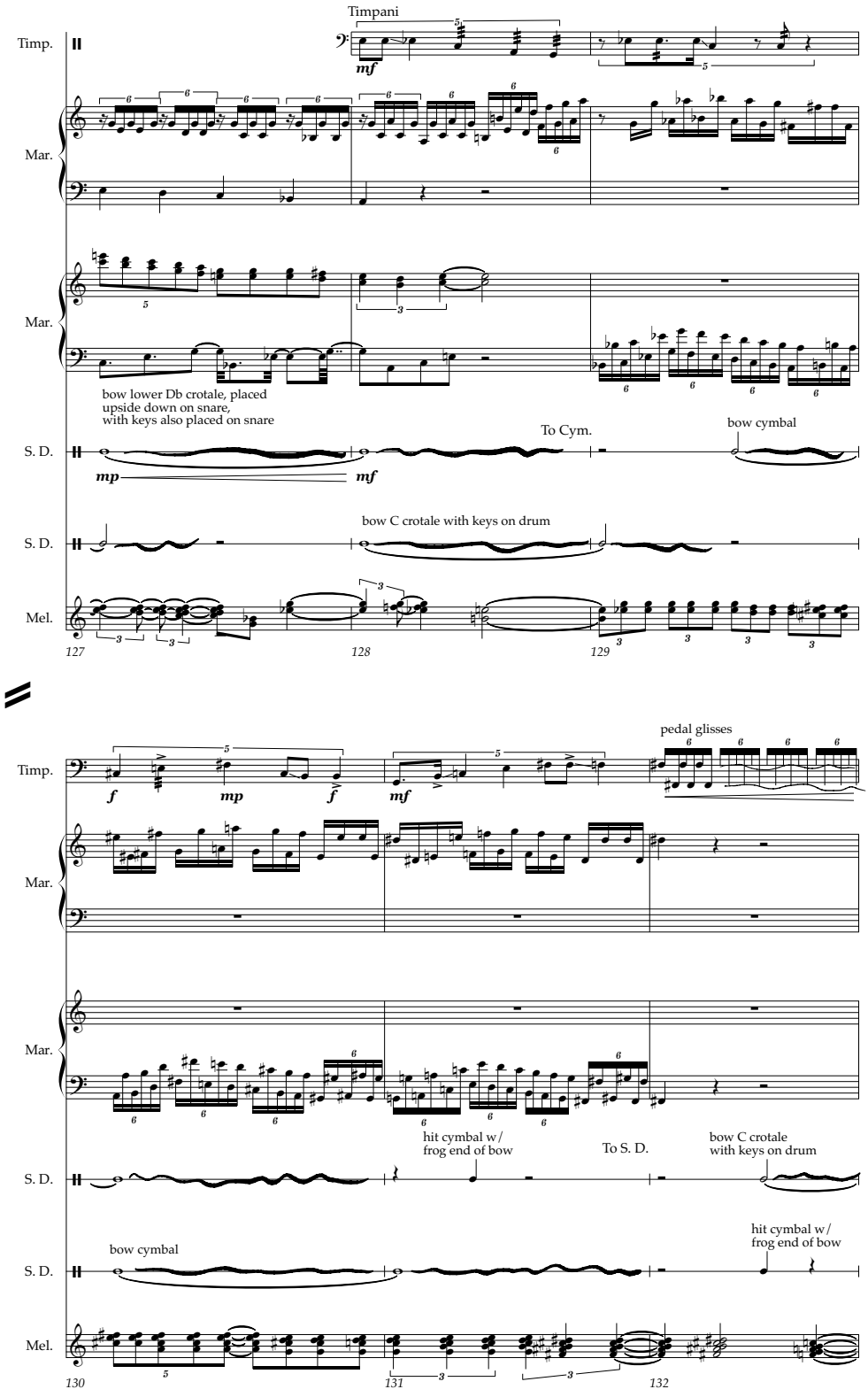

fingers rubbing on timpano
II
Timp.
Marimba
Mar.
p
Marimba
T.t.
p
Marimba
Vib.
Xyl.
Glock.
112
113
114

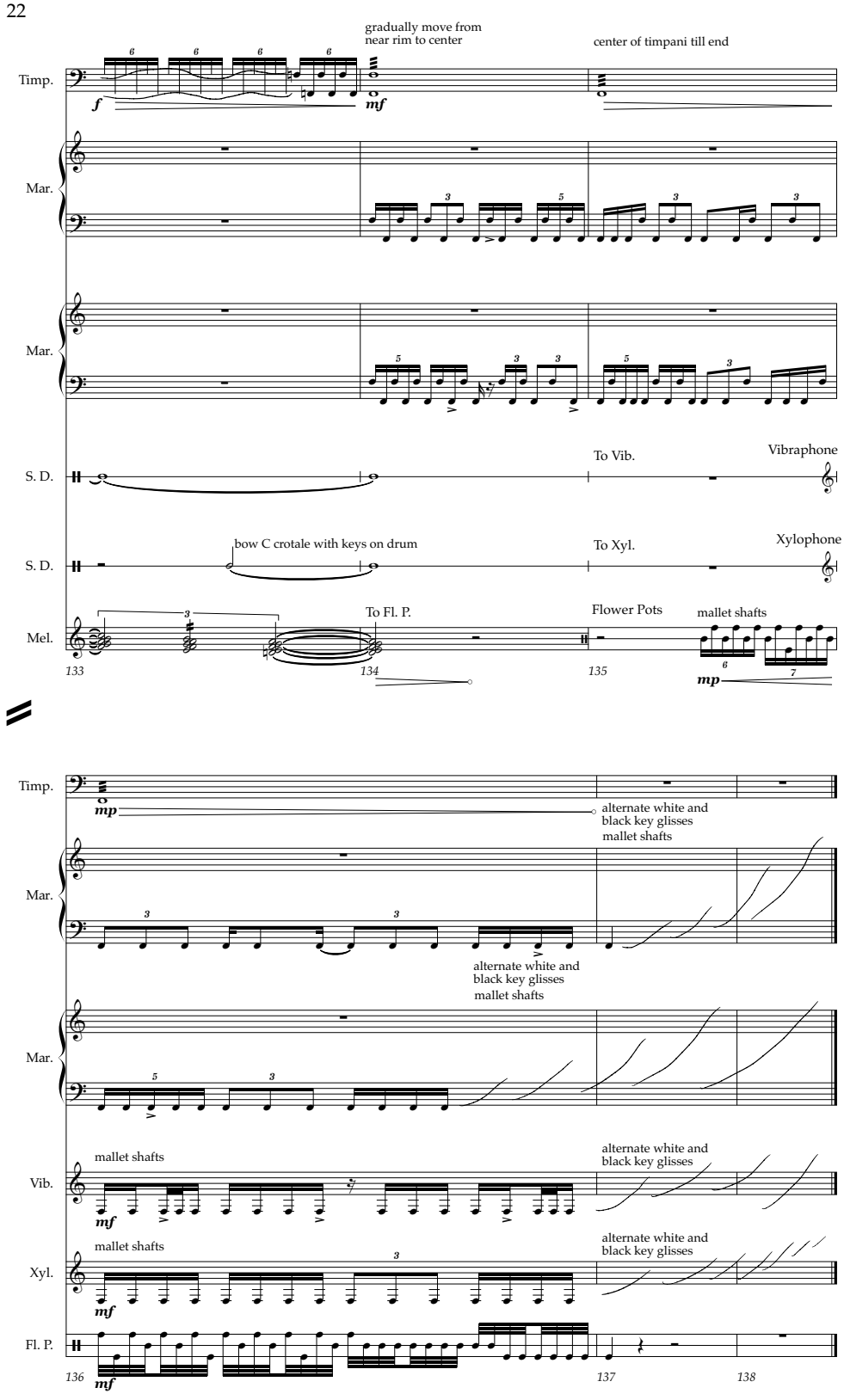

Timp.
Mar.
mf
p
mp
mf
Mar.
mf
Vib.
Xyl.
Glock.
115
116


II (fingers rubbing on timpano)
I superball + pedal gliss
Timp.
Mar.
Mar.
Vib.
Xyl.
Glock.
117
118
119
(𝅗𝅥 = 𝅘𝅥)
𝅘𝅥 = 60
Timp.
Mar.
Mar.
Vib.
Xyl.
Glock.
f
f
f
mf
mp
bow lower C crotale, placed upside down on snare, with keys also placed on snare
Snare Drum with low C crotale
(𝅗𝅥 = 𝅘𝅥) 𝅘𝅥 = 60
120
121


Timp.
Mar.
Mar.
Vib.
S. D.
sim.
mp
mf
Melodica
Glock.
122
123


Timp.
Mar.
Mar.
Vib.
To S. D.
Snare Drum
S. D.
bow C crotale with keys on drum
mp
mf
bow cymbal
Mel.
mp
124
125
126


Timpani
Timp.
mf
Mar.
Mar.
bow lower Db crotale, placed
upside down on snare,
with keys also placed on snare
To Cym.
bow cymbal
S. D.
mp
mf
bow C crotale with keys on drum
S. D.
Mel.
127
128
129
pedal glisses
Timp.
f
mp
f
mf
Mar.
Mar.
hit cymbal w/
frog end of bow
To S. D.
bow C crotale
with keys on drum
S. D.
bow cymbal
hit cymbal w/
frog end of bow
S. D.
Mel.
130
131
132


gradually move from
near rim to center
center of timpani till end
Timp.
Mar.
Mar.
S. D.
To Vib.
Vibraphone
S. D.
bow C crotale with keys on drum
To Xyl.
Xylophone
Mel.
To Fl. P.
Flower Pots
mallet shafts
133
134
135
Timp.
alternate white and
black key glisses
mallet shafts
Mar.
alternate white and
black key glisses
mallet shafts
Mar.
Vib.
mallet shafts
alternate white and
black key glisses
Xyl.
mallet shafts
alternate white and
black key glisses
Fl. P.
136
137
138