

EXTENDED ABSTRACT:**MUSIC OF MIGRATION AND PHENOLOGY: LISTENING TO COUNTERPOINTS OF MUSK OX AND CARIBOU MIGRATIONS, AND CYCLES OF PLANT GROWTH***Mark Ballora*

School of Music/School of Theatre
 The Pennsylvania State University
 Music Building I, University Park, PA 16802-1901 USA
ballora@psu.edu

1. INTRODUCTION

This extended abstract describes a sonification that was commissioned by a biologist/animal ecologist. The sonification was created with the software synthesis program SuperCollider [1]. The motivation for creating it was to pursue additional levels of engagement and immersion by supplementing the effects of visual plots, as well as to create an informative rendering of a multivariate dataset. The goal is for audiences, in particular students and laypeople, to readily understand (and hopefully find compelling) the phenomena being described. The approach is parameter-based, creating “sonic scatter plots” [2] in the same manner as work described in earlier publications [3], [4].

The work described here is a current experimental project that takes a sonic approach to describing the interactions of plant phenology and animal migrations in Greenland. This area is seen as a predictor of how climate change may affect areas farther south. There is concern about the synchronicity of annual caribou migrations with the appearance of plant food sources, as warmer temperatures may cause plants to bloom earlier and in advance of the caribou arrival at their calving grounds; depleted food availability at calving time can lead to lower populations of caribou.

Parts of this sonification will be applied to a multi-year professional development workshop for middle and high school science teachers. It is hoped that sonifications of plant observations made by teachers and students will enhance student engagement, and possibly lead to greater degrees of understanding of phenology patterns.

2. THE POLAR CENTER AT PENN STATE

The Polar Center at Penn State is an outreach program of the University’s Eberly College of Science. The Center’s mission is to foster understanding, awareness and appreciation of the polar regions through a variety of outreach, education, and research activities. Fine arts as well as the sciences are often employed to communicate the rare beauty as well as the scientific and cultural value of these regions. Its annual Polar Day Symposium, held each spring, features presentations by scientists, writers, and photographers. Since 2014, the event has included sonification presentations of various polar-related phenomena [5], [6].



This work is licensed under Creative Commons Attribution – Non Commercial 4.0 International License. The full terms of the License are available at <http://creativecommons.org/licenses/by-nc/4.0/>

The work described here was created for Polar Day 2016. The sonifications illustrate the interplay of migrations of Greenland caribou, musk ox populations, and the availability of the plant species that are their food sources.

3. DESCRIBING ANIMAL POPULATIONS AND PHENOLOGY**3.1. Background**

Penn State researchers travel to the Russell Glacier, located near Kangerlussuaq, Greenland, each year for approximately two months, from the end of April to the end of June (Julian Days 115-174). They record observations of caribou and musk ox populations, and the dates at which plants appear. Musk ox were placed in the area in the 1960s as a reserve population due to declining populations in other natural habitats. They inhabit the region year-round, and calve in early spring, while the area is still covered in snow. Caribou, which are indigenous to the area, spend the winter in the coastal area of Sisimut, and migrate 250 km inland to the Russell Glacier to calve in early June, when the landscape is green.

The caribou migrations have historically corresponded to the onset of grass and other plant species, which have higher nutrition than winter-growing lichens. Caribou are very conservative in their migration patterns, which date back thousands of years. It is unclear whether they have the ability to change their behaviors and leave their winter grounds earlier to adjust to changes in phenology [7], [8], [9], [10].

3.2. Description of the Dataset

The dataset includes observations taken in 1993, and in the years 2002-2015. Researchers stationed at Kangerlussuaq take daily counts of how many plant species have emerged. There are 9-14 plant species that are food sources for the musk ox and caribou, not all of which emerge each year. At the close of each annual observation period, the timing of the overall available food supply is expressed as a *mean proportion value*, whereby each daily measurement of the number of species that have leafed out is divided by the maximum number of observed species that are observed on Julian Day 174 of that year. This mean proportion normalizes the availability of food supplies to a value between 0 and 1, or from 0% to 100% of the available supplies in a given year. The variability from year to year lies with the first day that is a measurable value is observed, and with the slope of the

progression from 0 to 1, which indicates the rate at which food supplies become available.

Daily counts are also taken of the number of musk ox and caribou observed. For each day, there are three entry types: a value of the total number of each animal observed, a zero if no animal was observed, or a skip in the date sequence if no observations were taken on a given day. To standardize the scaling between food availability and number of animals sighted, the daily counts of musk ox and caribou are also normalized as a mean proportion in the same way that the food supply is expressed as a value between 0 and 1.

3.3. Goals of the Sonification

The goal of sonifying the dataset described above is to investigate whether patterns can be heard that indicate when the plants and animals first appear, as well as changes in their rate of increase.

4. SONIFICATION STRATEGIES

The sound design techniques that are used in this project draw on practices that have been utilized in earlier work, and are based in perceptual principles outlined in sources such as [3], [11], and [12].

4.1. Year and Date

A primary goal of the sonification is to make easily discernible the variations that occur from year to year in the appearance dates and population rates of plants and animals. The dataset consists of 900 total entries, which represent sixty Julian Days, from 115-174, for each year of data. The most basic layer of the sonification is an “auditory calendar,” which marks the dates with a percussive “tap” to represent each day. This type of sound is meant to be unobtrusive, and is discernible at low listening levels. As an undifferentiated stream of taps would be difficult to count and would quickly

become indistinct throbbing (I call this the “woodpecker effect”), regular intervals are demarcated with an accent. This is consistent with the suggestion in [12] that loudness changes may be effectively used as temporal markers. The scientist commissioning the work suggested demarcating each sequence of five days.

This “quintuple meter” is meant to allow listeners to easily hear a difference in arrival times of the plants and animals – at rapid playback rates, it becomes difficult to count the number of days that pass before the phenology activity begins, but it is fairly easy to count the number of accented beats.

Another type of temporal marker annotates the end of each year. A brief pause occurs, followed by a ringing percussion sound that is louder and lasts longer than the tapping sound that represents the days, and indicates the onset of a new year of data.

4.2. GUI

A GUI adds a visual reference (Figure 1). The current year and date are displayed in text boxes at the top of the display, and graphs of the plant, caribou and musk ox data are placed on top of each other. The chart portions illustrate the mean proportion values described earlier. The total numbers of caribou and musk ox observed each year are also printed in their areas of the graph.

A slider moves along the bottom of the display and between each of the graphs to aid the eye in quickly finding the current position in the dataset as it iterates. The GUI also allows adjustment of the time increment between dates and the volume balance between sound streams (described above and in the following section). The current position in the dataset may be adjusted by dragging any of the horizontal sliders.

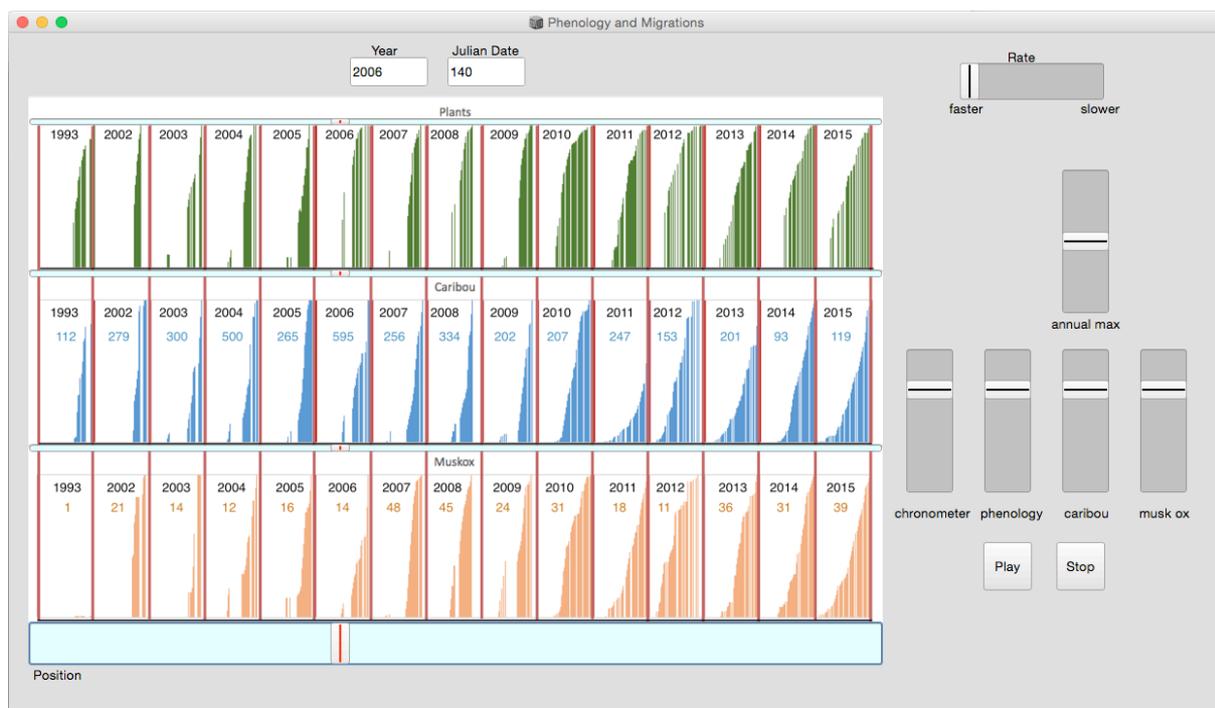


Figure 1: GUI allows control of playback start, pause, stop, volume balances, position within the dataset, and rate of iteration.

4.3. Phenology

The primary information being rendered is the phenology, i.e., the cyclic and seasonal activity of plant growth and animal migrations. Four types of phenology data are sonified: mean proportion values of plants, musk ox, and caribou, and the annual population totals for the caribou. As noted in [12], mapping numeric magnitude to pitch is one of the more intuitive and easily discernible mappings available to sonification designers. (In [3], it is suggested that pitch be considered a *primary auditory cue*, in that small pitch changes are apparent even to untrained listeners, which makes this a strong choice for representing data values.) With pitch as the means of expressing the data values, the values pertaining to plant growth and populations of caribou and muskox are assigned to different “instruments.”

Bearing in mind the caution raised in [12] that it is generally difficult to attend to three or more continually changing streams of auditory information, it seemed appropriate for this sonification to be flexible in how the streams are combined. The GUI, therefore, is meant to serve as a mixing panel, whereby users may adjust the relative balance of the instruments and the position within the dataset at will (as described in the previous section). This is meant to allow users to repeat and refocus as necessary, as one might do when reading and re-reading a passage or studying an image.

As the dataset is iterated, for each date a “note” is played on each of the four phenology-based instruments, plus there is a tap from the percussive chronometer. A QuickTime movie showing a sample run of the sonification may be downloaded from [13].

4.3.1. Pitch Derivation

The mapping of data values to pitch was done as described in [3], whereby a fundamental, f , is selected. The data values, d , multiplied by a scalar, r , are applied as a power of 2, which is multiplied by f , as shown in (1).

$$\text{pitch} = f \times 2^{(d \times r)} \quad (1)$$

With an r value of one, a data value (d) of 0 results in a pitch at f . A data value of 1 results in a pitch an octave higher than f , and a data value of -1 results in a pitch an octave lower than f . This is a “microtonal approach” to pitch mapping, since many data values are likely to result in pitches that fall “between the cracks” of the equal tempered pitches that are found on a concert piano. Since it is easy for untrained listeners to hear variations in pitch that are smaller than the equal tempered half step, this conversion approach has the potential of yielding more nuance in many cases than a coarser approach, such as assigning pitches to MIDI note numbers. The value of r acts as a scalar for the pitch range. The range can be reduced or expanded by changing the value of r to a value above or below 1.0.

For this project, the fundamental, f , was chosen to be 175 Hz. This was a subjective choice. It was a frequency that sounded neither too low nor too shrill to our ears. As outlined above, the observed animals and plants are represented by four “instruments”: plant mean proportion values, musk ox mean proportion values, caribou mean proportion values, and maximum number of observed caribou for each year. (The

mean proportion value was described in section 3.2.) The scalar value (r) is set to one. The result is that as the mean proportion values rise from 0 to 1 over the course of each year’s measurements, each “mean proportion instrument” rises an octave in pitch.

4.3.2. Timbral Characteristics

As described in [3], timbre is useful as a *secondary* (or *supporting*) *auditory cue*, meaning that it is generally not effective for delineating small changes in data values, but can be quite effective for differentiating different streams of information. As timbre is a multi-faceted property, it is recommended in [12] that envelope shape be considered along with harmonic content in creating timbral effects. In this project, the qualities (timbral and otherwise) that are meant to differentiate the instruments include overtone content, attack time, tremolo rate, and pan position. All of these were arrived at by ear, through trial and error, in an attempt to create sound types that were compatible yet also mutually exclusive.

4.3.3. Plant Mean Proportion Values Instrument

The “plant instrument” is a shimmering, percussive sound that is panned center. As the mean proportion values increase from 0 to 1, its changes are mapped to the following parameter ranges:

- The pitch goes from 175 Hz to 350 Hz, an octave higher;
- The relative volume goes from a level of 0.015 to 0.1;
- The tremolo rate goes from 4 Hz to 10 Hz;
- The attack time quickens, going from 0.1 to 0.01 seconds.

4.3.4. Musk Ox Mean Proportion Values Instrument

The “musk ox instrument” is a flute-like sound that is panned to the right. Similar to the plant instrument, as the mean proportion values increase from 0 to 1, its values are mapped to the following parameter ranges:

- The pitch goes from 175 Hz to 350 Hz, an octave higher;
- The relative volume goes from a level of 0.05 to 0.4;
- The tremolo rate goes from 2 Hz to 18 Hz;
- The attack time quickens, going from 0.5 to 0.3 seconds;
- The cutoff frequency of a lowpass filter in the instrument goes from 100 to 1500 Hz.

4.3.5. Caribou Mean Proportion Values Instrument

The “caribou instrument” is a brass-like sound that is panned to the left. As with the other two instruments, as the mean proportion values increase from 0 to 1, its values are mapped to the following parameter ranges:

- The pitch goes from 175 Hz to 350 Hz, an octave higher;
- The relative volume goes from a level of 0.03 to 0.2;
- The tremolo rate goes from 1 Hz to 15 Hz;
- The attack time quickens, going from 0.05 to 0.02 seconds.

4.3.6. Caribou Annual Maximum Instrument

The mean proportion values rendered by the three instruments described above give indicators of the arrival date and rate of growth, but do not contain any information about population fluctuations from year to year. That is, they are based on values that describe percentage of the maximum value. But when they are considered on their own, they can be misleading as there is nothing indicating what a given year's maximum value is. The population totals for caribou and musk ox are printed on the graph displayed in the GUI, as described in Section 4.2. Since the primary focus of this work is to track fluctuations in caribou populations from year to year, an additional auditory stream indicates the maximum numbers of animals observed each year.

A "caribou annual maximum" instrument is created in the form of a complex of five detuned sine waves, with a slight tremolo applied. These sound continuously throughout the playback time of each year, as a background drone. As the population values vary from their minimum of 93 (the value for the year 2013) and their maximum of 595 (the value for the year 2006), the pitch of the sine complex ranges from 175 to 350 Hz, and the tremolo rate is the year's population maximum value multiplied by 0.05, which produces tremolo rates in the range from 4.65 to 29.75 Hz.

Thus, the onset of each year is indicated by two changes: the sound of the bell-like percussive sound and a new annual maximum pitch, which gives an immediate indication of whether populations were greater or lesser than those of the previous year.

5. FURTHER WORK

The intention of this extended abstract is not to present this project as a particularly novel form of sonification, but rather to highlight its context. My suggestion is that this is another small step forward in an ongoing healthy evolution, wherein researchers in a variety of scientific fields are looking to sonification as a means of exploring and presenting data. It has been encouraging to see Penn State researchers become interested in exploring sound as a means of presenting their data, as well as the interest in museum exhibitors in presenting sonified renderings of natural science material as a way of introducing attendees to the dynamics of information being presented [6].

Taking the long view, we are particularly interested in introducing young audiences to science sonifications. By presenting science to a generation of students as something that is understood through listening as well as seeing, we feel that we could add an important dimension to science pedagogy, creating a more holistic and engaging experience than is possible with visual materials alone.

Plans are in place for elements of this sonification to be incorporated into a three-year summer training workshop for middle and high school science teachers [14] that is meant to promote study of phenology and engaged science. By having sonifications of plant growth data as a product of their work, our hope is that the students will have higher degrees of engagement and personal investment in the material. As a federally-funded teacher training program, every facet of it will be subject to assessments, which should give us concrete evidence of the efficacy of sonification in educational contexts.

Enhancement of museum exhibits and incorporation of sonifications into educational materials are the subjects of

other pending grant applications, which will hopefully be the subjects of future publications at ICAD and in other related journals.

6. ACKNOWLEDGMENTS

The data sonifications were commissioned by Eric Post, Professor of Biology at Penn State's Eberly College of Science, and Pernille Sporon Bøving, the Penn State Polar Center's Director for Programming and Engagement, for presentation at Penn State Polar Day 2016. This effort was partially supported by NSF grant PLR 1525636.

7. REFERENCES

- [1] <http://supercollider.sourceforge.net>
- [2] T. Hermann, A. Hunt, J. G. Neuhoff. (Eds.). *The Sonification Handbook*. Berlin: Logos Publishing House, 2011.
- [3] M. Ballora, "Sonification, Science and Popular Music: In search of the 'wow,'" *Organised Sound*, vol. 19, pp. 30-40, April 2014. doi:10.1017/S1355771813000381
- [4] M. Ballora, "Sonification Strategies for the film Rhythms of the Universe." Presented at the 20th International Conference of Auditory Display (ICAD 2014), June 22-25, New York, NY, USA.
- [5] M. Ballora, M. Kenney, "Changes in Antarctic Ice - 400,000 years to present." Presented at PSU Polar Day 2014. <http://www.polar.psu.edu/changes-in-antarctic-ice-400000-years-to-present/>
- [6] M. Ballora, "Two Examples of Sonification for Viewer Engagement: Hurricanes and Squirrel Hibernation Cycles." Presented at the 21st International Conference of Auditory Display (ICAD 2015), July 8-10, 2015, Graz, Austria.
- [7] E. Post, *Ecology of Climate Change: The Importance of Biotic Interactions*. Princeton, NJ: Princeton University Press Monographs in Population Biology, 2013.
- [8] J. T. Kerby, E. Post, "Advancing plant phenology and reduced herbivore production in a terrestrial system associated with sea ice decline," *Nature Communications*, vol. 4, article 3514, October 2013. doi:10.1038/ncomms3514.
- [9] E. Post, U. Bhatt, C. Bitz, J. Brodie, T. Fulton, M. Hebblewhite, J. T. Kerby, S. Kutz, I. Stirling, D. A. Walker, "Ecological consequences of sea ice decline," *Science*, vol. 341, issue 6145, pp. 519-524, August 2013.
- [10] E. Post, P. S. Bøving, C. Pedersen, M. A. MacArthur, "Synchrony between caribou calving and plant phenology in depredated and non-depredated populations," *Canadian Journal of Zoology*, vol. 81, no. 10, pp. 1709-1714, October 2003.
- [11] A. S. Bregman, *Auditory Scene Analysis*. Cambridge, MA: MIT Press, 1990.
- [12] J. H. Flowers, "Thirteen Years of Reflection on Auditory Graphing: Promises, Pitfalls, and Potential New Directions." Presented at the 11th International Conference of Auditory Display (ICAD 2005). July 6-9, 2005, Limerick, Ireland.
- [13] <http://www.polar.psu.edu/phenology-caribou-muskox-sonification/>
- [14] Arctic Plant Phenology Learning through Engaged Science (APPLES). bit.ly/arcticapples