Vatnajökulsþjóðgarður
2023-2024 Acoustic Survey

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Table of Contents

Executive Summary

The soundscapes of Vatnajökull National Park are diverse and provide a window into how Iceland's ecosystems are evolving and responding to human noise. This report focuses on two areas of the park: Skaftafell and Jökulsárlón. These areas were selected for their unique natural features and the high level of tourist traffic at each site. Field sites were chosen to contrast areas close to human-produced noise and spaces further removed from noise sources. The analysis from these recordings not only shows a sharp difference in noise level and type between these two classes of sites, but also reveals how biologic activity responds to noise pollution sources in these areas.

Analysis of the sound levels at each of these field stations reveals where noise pollution is highest and what is contributing to it. The field station with the highest levels of anthropogenic noise is Jökulsárlón; there boat noise is a near-constant presence. But there are also high levels of aircraft noise at Skaftafell—and while the overpassing aircraft are less frequent than the boats at Jökulsárlón, their sound level peaks are much higher. Passing aircraft regularly exceed 60 dB—a general rule for maintaining a quiet or natural soundscape is to limit air traffic noise to 40 dB or the median natural ambient noise level of the environment. By comparing the estimated natural ambient sound level with the measure median sound level, we can determine how much louder each site is than it would be without human-produced noise. This broad metric provides a good proxy for the amount of noise pollution at each site, and shows that the areas around Jökulsárlón are already expereincing considerable noise above the ambient sound level.

Field Station	**Decibels Over Natural Ambient**
Jökulsárlón East	5.9 dB
Jökulsárlón West	2.5 dB
Þröng	0 dB
Skaftafell High-Traffic Trail	0.6 dB
Skaftafell Low-Traffic Trail	0.1 dB
Svartifoss	0.3 dB

Beyond decibel levels, Jökulsárlón also exhibits a much shorter average noise-free interval than other locations within the park. The noise free interval measures the average length that a listener can expect to go without hearing loud noise (sound

exceeding 60 dbA), and in the area around Jökulsárlón this measure rarely exceeds one hour. Further, because the noise free sound interval is an average and includes the relatively quiet periods during the night, the functional noise free interval is much shorter for visitors during the day.

In addition to the broadband sound level, these recordings also reveal the frequency content of noise pollution sources. At Jökulsárlón for instance, motorized vehicle noise regularly stretches into the range of biologic communication (the so-called biophony band, 2000-8000 hz). Further study is warranted to determine the most important frequency band for migratory and native species and to determine what areas of the frequency band are most impactful on their vocalizations. But already it is clear that some problematic frequencies are having an impact on avian vocalizations.

The passive acoustic surveys show sharp differences in the acoustic composition of ecosystems when close to and far away from human noise. In both survey areas, avian activity increases dramatically away from anthropogenic noise. This is particularly true in Skaftafell where the effect is so pronounced that biologic activity is actually higher during midday than during the dawn and dusk choruses at more isolated recording sites. This correlates with a drop in biologic activity in areas close to human activity, suggesting that birds modulate their normal patterns to move and adjust around areas of high human activity. This would suggest that it is important to not only maintain areas with low human activity, but also that ensuring that protected areas do not become isolated within areas of high human activity is crucial. This is also demonstrated in the Jökulsárlón area where birds are detected very infrequently close to human activity than they are at more remote sites (see section “Comparisons Between Locations).

High sound levels impact biologic activity by causing stress and changing their environment, and sound levels exceeding natural ambient mean that visitors to the park will often experience human-produced sounds rather than the natural soundscape. This is compounded by the fact that these soundscapes have relatively low levels of activity generally. Iceland’s unique soundscapes are characterized by both very delicate sounds and high variability in natural sound cover (wind, rain, etc.). Understanding the current sound levels and composition of these soundscapes is crucial to understanding their transformation of time.

Overall Sound Level Summary

Field Station	L_{90}*	L_{nat}	L_{50}	L_{10}	Noise Free Interval**	Audible Motor Noise
Jökulsárlón East	43	52	57.9	82.9	1.2	29.8%
Jökulsárlón West	47.2	55.2	57.7	81.4	0.5	23%
Þröng	42	51.6	51.6	76	0.87	0.3%
Skaftafell High-Traffic Trail	41.8	44.9	45.5	62.9	2.05	7.5%
Skaftafell Low-Traffic Trail	36.4	37.7	37.8	61.6	2.5	7.8%
Svartifoss	37.4	40.4	40.7	65	1.75	5%

*L_x in decibels (A-weighted) **Noise free interval in approximate hours

L_x Sound Levels

The L_x metric represents the percent of time that sound levels exceed the stated level. So for instance, at the Jökulsárlón West field station 90% of the time sound levels are above 47.2 dBA; and at Þröng sound levels exceed 76 dBA 10% of the time.

L_{nat} is an approximation of the sound level without any human noise. This is calculated by averaging the amount of time that human noise is present, and using a formula to estimate the impact of that noise on sound levels. The greater the difference between L_{nat} and L_{50}, the greater the impact of human noise at that field station.

Noise Free Interval Measurements

The noise free Interval is measured by averaging the amount of time between a sustained peak of 60 dbA. This is useful for capturing how distributed noise events tend to be at each field station. For instance, at Jökulsárlón East the noise free interval is longer than at Jökulsárlón West because the the former is mainly driven by boat noise which is only present during limited hours and seasons, where the latter is driven primarily by traffic on Highway 1.

Method Overview

Beginning in October 2023, six AudioMoths have been deployed in Vatnajökull National Park, focusing on the Skaftafell and Jökulsárlón areas. These devices record 1 minute every 5 minutes, capturing the state of the ecosystem as well as sonic patterns over different weather and seasons. These recordings allow for analysis of noise levels and other statistics which provide a baseline figure to understand the acoustic impact on these natural soundscapes.

There are five principal analysis types included in this report:

1. Noise Level Analysis
    - Carried out using a broadband decibel measurement.
    - These metrics provide a high-level average of sound levels and are useful for understanding the broad impact of sound on the environment as well as an understanding of the listening experience for an average visitor.
    - Because they are averaged over long periods of time, they are not the most useful tool for determining sources of noise pollution and can be sensitive to common high-pressure sound events such as wind.
    - This report includes charts depicting changes in average sound levels over time for each site showing how loud each site is 10%, 50%, and 90% of the time measured.
2. Acoustic Index Measurements
    - An acoustic index provides a high-level overview comparing certain elements of a soundscape. These measurements can function as proxies for biologic diversity and are useful for understanding changes in an ecosystem over time.
    - The main acoustic index used in this report is the Normalized Difference Soundscape Index (NDSI; Boelman et al., 2007; Kasten et al., 2012).
    - NDSI is a ratio of biophony to anthrophony from 1. to -1. A higher number indicated more activity in the biologic sound band (2000-8000 hz) compared with the human noise sound band (500-2000 hz).
    - Other acoustic indices are included where appropriate such as the bioacoustic index.
3. Temporal Sound Audibility Analysis
    - Temporal Sound Audibility (TSA) tracks what kinds of sounds are present over a given time period. These are useful because they can capture both low- and high-intensity sonic events and are less sensitive to distortion due to weather.

- This metric is useful for examining specific ecosystems in greater depth. Because of the high level of hands-on analysis required for this analysis, they are limited to a short time period for each site.

4. Species Tracking
   - Using clustering and pattern matching algorithms, it is possible to identify bird and animal species present at each site.
   - These analyses show the number of species as well as bird counts over time.
5. Specific Sonic Event Analysis
   - At sites where there are particularly interesting or impactful sonic events, these can be measured and analyzed more closely to understand how they interact with other variables such as time of day, weather, season, and other acoustic events.

All recordings were calibrated using a decibel meter to confirm accurate sound levels. Acoustic indices were calculated in R using the soundecology package. Species were identified and tracked using the Arbimon platform. Long-term decibel averages and power spectrums were calculated using the PAMGuide platform. Analysis involving real-time listening was conducted using Sennheiser HD650 Headphones at a set output level of -0 dB.

Jökulsárlón and Surrounding Areas

Figure 1, AudioMoth Recording Locations Near Jökulsárlón

Field Station	Latitude	Longitude	Deployment Start	Deployment End
Jökulsárlón East	64.056	-16.175	17 Oct 2023	Ongoing
Þröng	64.134	-16.215	17 Oct 2023	Ongoing
Jökulsárlón West	64.043	-16.218	15 Dec 2023	26 Mar 2024

Field Station 1 – Jökulsárlón East

	L_{90}	L_{nat}	L_{50}	L_{10}	Noise Free Interval	Audible Motor (Aircraft/Boat)
Jökulsárlón East	43	52	57.9	82.9	1.2	29.8%

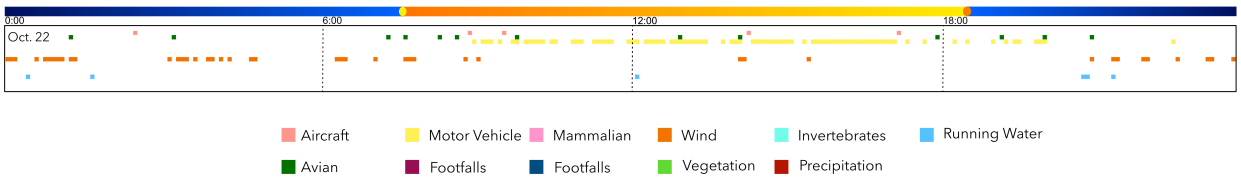

Figure 2, Temporal Sound Audibility, Jökulsárlón East Field Station

Located on the same side of lagoon as the main tourist parking area, this field station captures considerable tourist activity; particularly noticeable is the boat motor noise that is audible 20-35% of the time during the active season. Depending on the weather, motor noise is audible from a considerable distance, with many boat passings audible for 15 minutes or more. These motor events can also be very loud, sometimes exceeding 20 decibels above ambient sound levels (figure 7). Alongside the high level of motor noise, there are considerably fewer bird calls detected at this field station than at Solander's Eye field station (figure 37).

Of all the field stations, this location has the highest difference between the current ambient sound level and the estimated natural ambient sound level without human noise: a difference of almost 6 decibels (6 decibels correlates to a doubling of loudness). Considering that the majority of anthropogenic noise occurs during the day, this means that anthropogenic noise is regularly at least three times louder than the natural ambient level at Jökulsárlón.

This high variability is clearly apparent in the sound power distribution (figure 5). In the lower frequencies, many events rise high above the median in their loudness, and there is generally a high distribution of sound level. The highest level sounds can be attributed to wind noise, but boats and even motor noise from Highway 1 contribute significantly to the average noise statistics, especially considering that they are not present at all hours of the day.

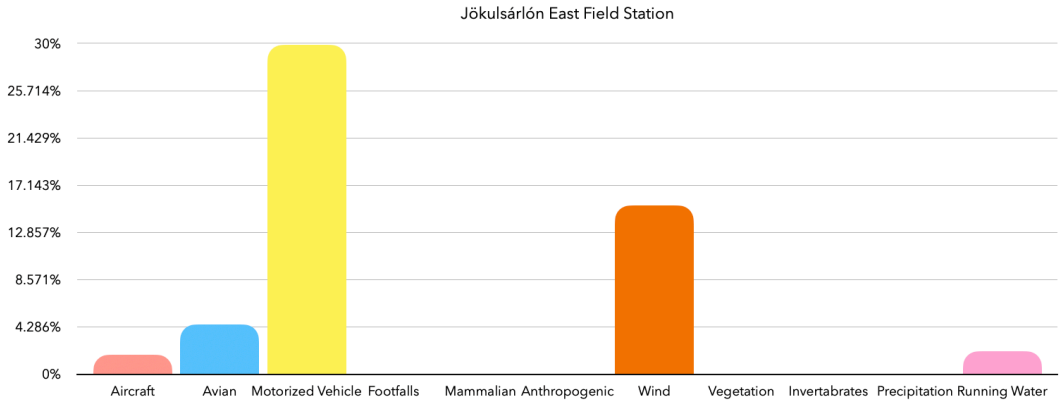

Figure 3, Proportion of Sound Types, Jökulsárlón

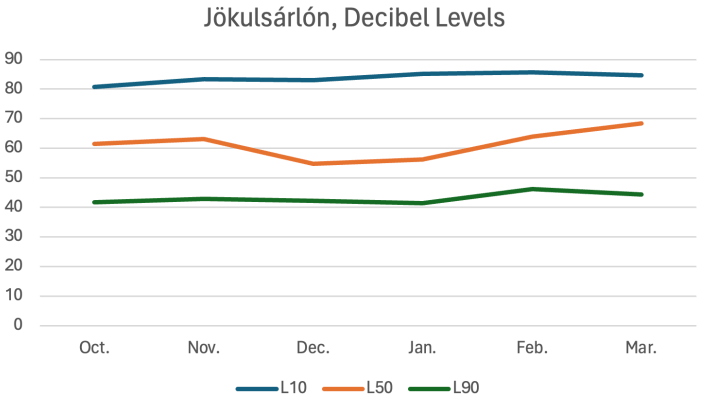

Figure 4, Decibel Levels Over Time, Jökulsárlón

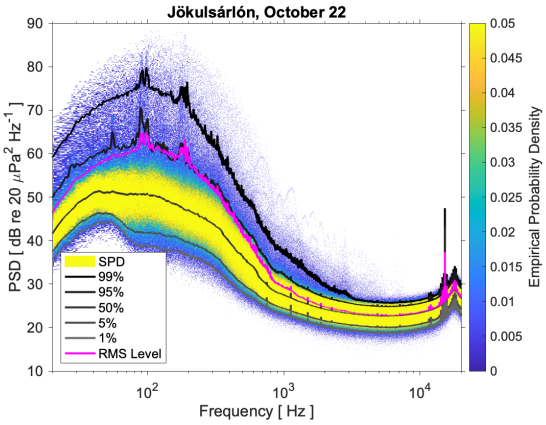

Figure 5, Power Spectrum, Jökulsárlón

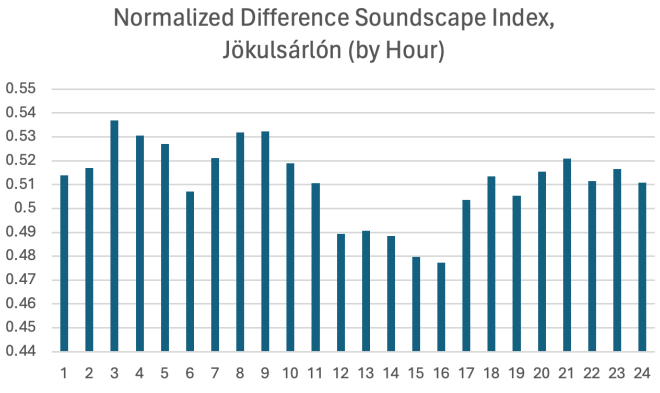

Figure 6, NDSI, Averaged per Hour

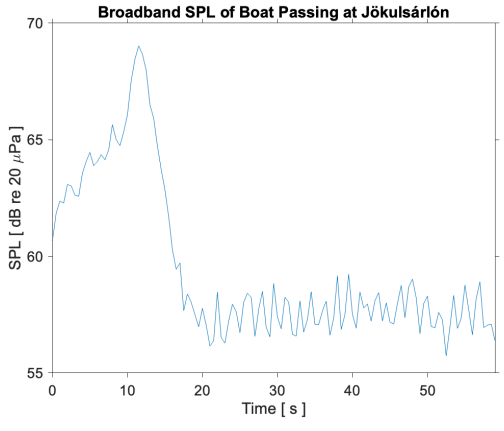

Figure 7, Sound Level of Passing Boat

Field Station 2 – Þröng

	L_{90}	L_{nat}	L_{50}	L_{10}	Noise Free Interval	Audible Motor (Aircraft/Boat)
Þröng	42	51.6	51.6	76	0.87	0.3%

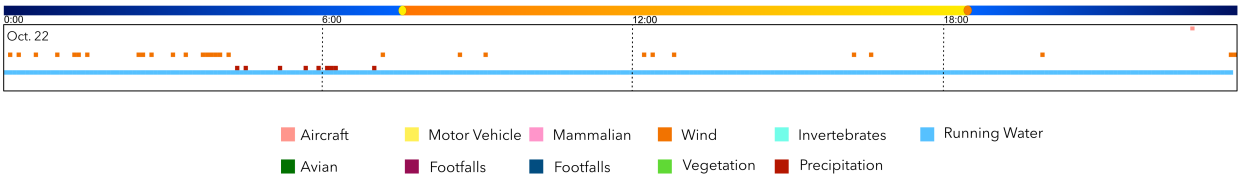

Figure 8, Temporal Sound Audibility, Þröng Field Station

The most remote of all the current deployments of AudioMoths in Vatnajökull National Park, this location has virtually no anthropogenic noise, except for the occasional overpassing plane. The river passing through the valley means that running water is always present in the recordings. Despite this, sound levels are consistently low, with the high decibel events being almost exclusively wind.

The valley the recorder sits within sets it back from the avian activity on the cliffside. Ambient water sound and wind noise mean that there is a relatively little biophony that reaches into the valley. This leads to a relatively stable NDSI, meaning that there is no consistent daily pattern to biologic or human-produced sound, and relatively little of both as well (figure 12).

This station was active before and after the car park used for tours was moved closer to the glacier (and thus closer to the recording station). While sound levels did trend louder from January to March (figure 10), no automobile noise is regularly audible on the recordings during tour times. The change in sound level is small enough to be attributable to weather variance rather than increased noise from tour vehicles.

The soundscape at Þröng serves to contrast the high anthrophony at Jökulsárlón and the high variance in biophony and species count at the Solander's Eye Field Station. Despite the highly unpredictable weather at an increased altitude, this recording site is consistently quieter than by Jökulsárlón (figure 36) and is a soundscape worth preserving.

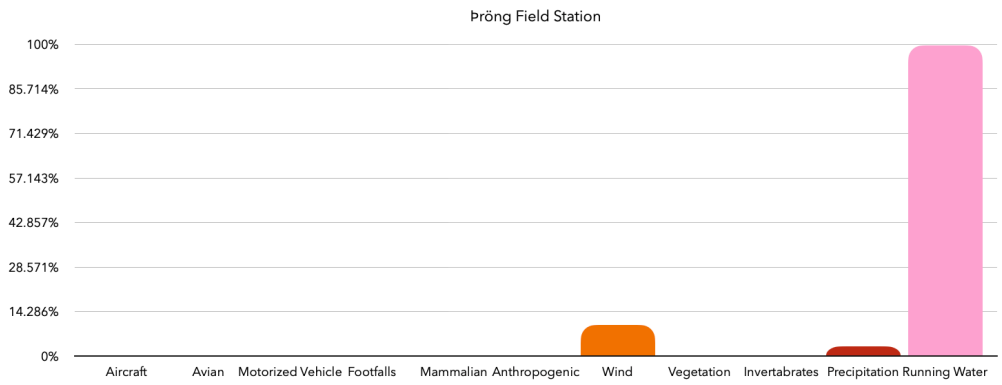

Figure 9, Distribution of Sound Types, Þröng

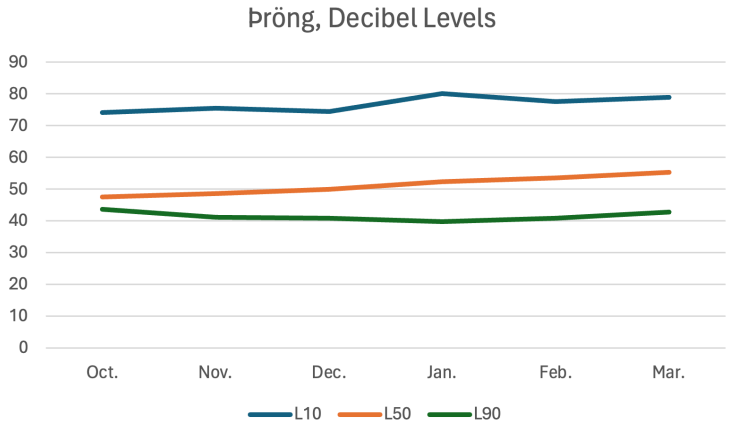

Figure 10, Decibel Levels Over Time, Þröng

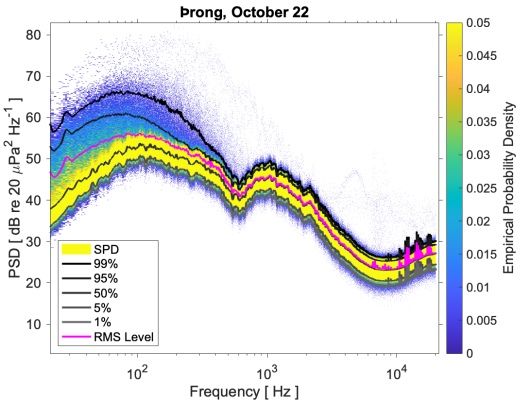

Figure 11, Power Spectrum, Þröng

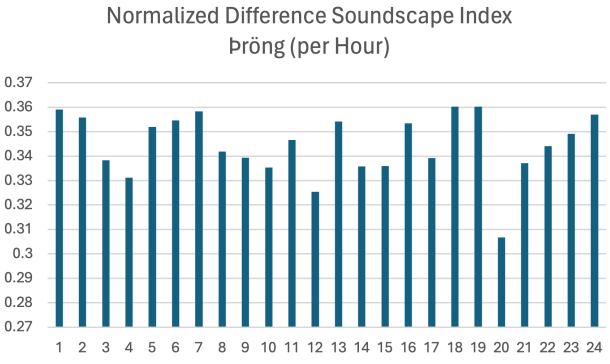

Figure 12, NDSI, Þröng (Averaged per Hour)

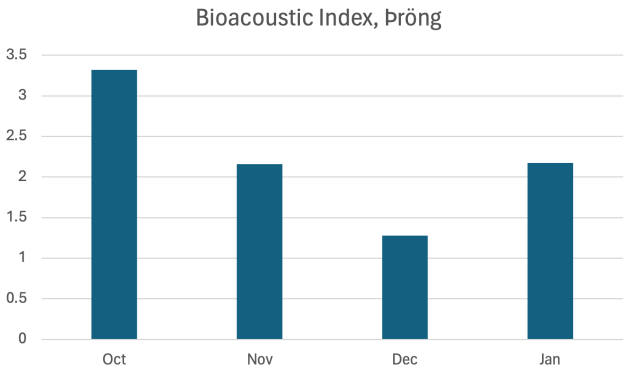

Figure 13, Bioacoustic Index, Þröng (Averaged per Month)

Field Station 3 – Jökulsárlón West

	L_{90}	L_{nat}	L_{50}	L_{10}	Noise Free Interval	Audible Motor Noise
Jökulsárlón West	47.2	55.2	57.7	81.4	0.5	23%

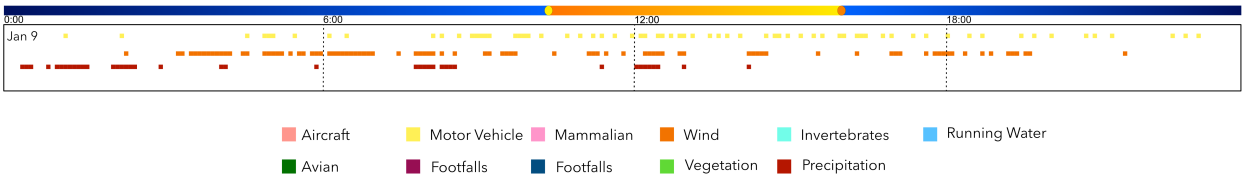

Figure 14, Temporal Sound Audibility, Jökulsárlón West Field Station

This field station is positioned close to Highway 1 on the West side of Jökulsárlón. It is far enough from the shore of the lagoon that it mainly picks up terrestrial activity, as opposed to boat and aquatic sounds that are clearly recorded closer to Jökulsárlón.

There is often a consistent background of automobile noise due to the proximity to Highway 1 (figure 15). Precipitation and wind noise are also common occurrences, but these have unique tonal aspects at this location because of the ice and rocks that focus the wind and rain in unique ways. The transition to spring brings interesting acoustic changes with animal activity markedly increasing and the tonal aspects of rain and wind transforming from the winter. Further study into seasonal acoustic transformations is needed, but the recordings from this site indicate a higher than normal impact of season on Icelandic soundscapes generally, and especially in this area.

The acoustic indices for Jökulsárlón West show a stable level throughout most of the night and an increase of anthropogenic noise during the day relative to the level of biophony (figure 18). This is likely caused by traffic noise patterns throughout the day rather than only as a result of lower biologic activity.

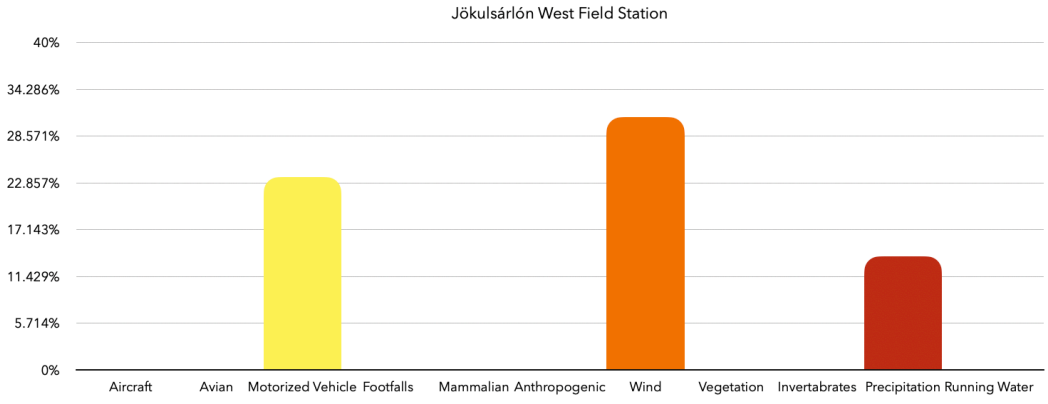

Figure 15, Distrubution of Sound Types, Jökulsárlón West

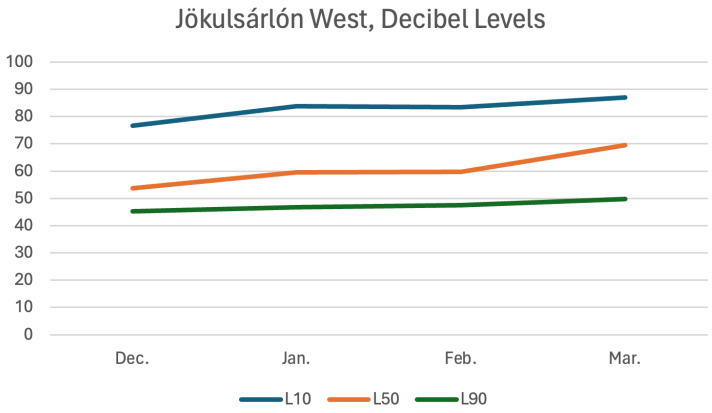

Figure 16, Decibel Levels Over Time, Jökulsárlón West

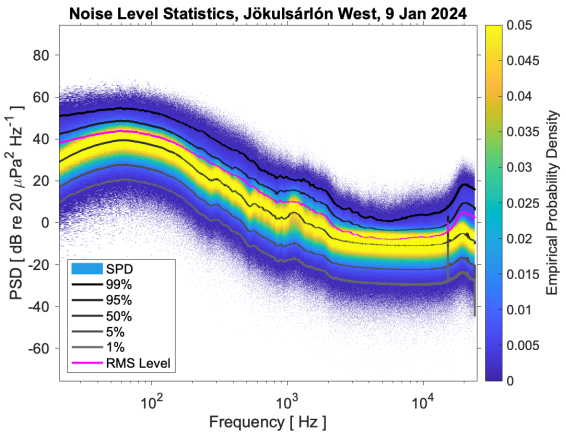

Figure 17, Power Spectrum, Jökulsárlón West

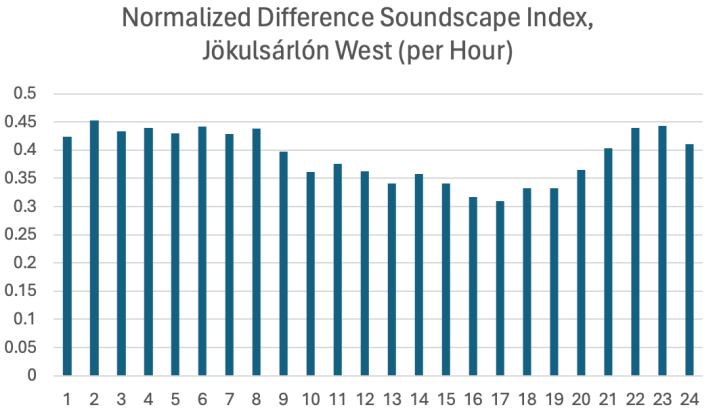

Figure 18, NDSI, Jökulsárlón West

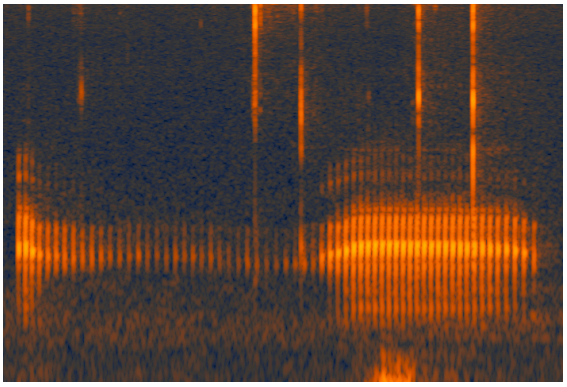

Figure 19, Ptarmigan Call, Jökulsárlón West

Skaftafell

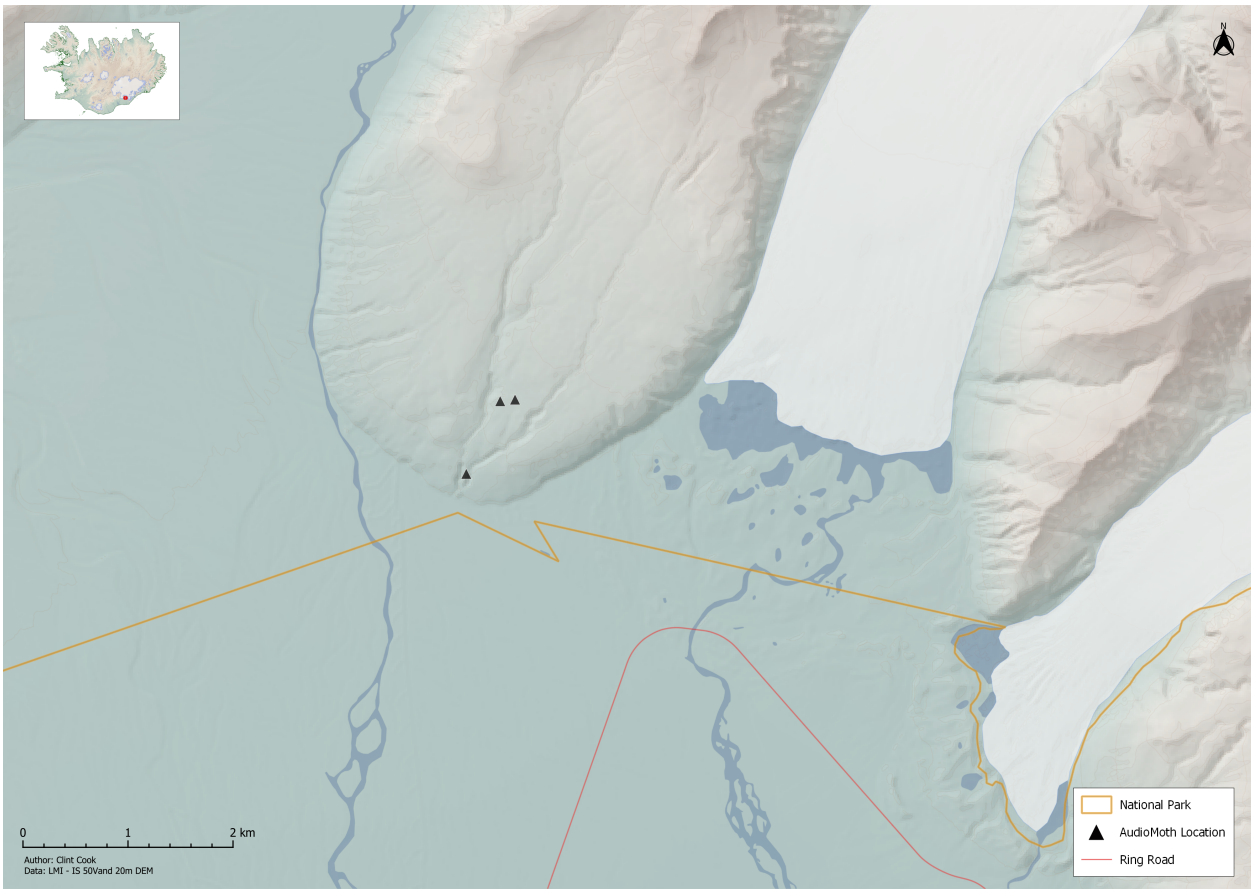

Figure 20, AudioMoth Locations, Skaftafell

Field Station	Latitude	Longitude	Deployment Start	Deployment End
Skaftafell High-Traffic Trail	64.019	-16.979	14 Oct 2023	Ongoing
Svartifoss	64.025	-16.973	14 Oct 2023	15 Dec 2023
Skaftafell Low-Traffic Trail	64.025	-16.970	14 Oct 2023	Ongoing

Field Station 1 – High-Traffic Trail

	L_{90}	L_{nat}	L_{50}	L_{10}	Noise Free Interval	Audible Motor Noise
Skaftafell High-Traffic Trail	41.8	44.9	45.5	62.9	2.05	7.5%

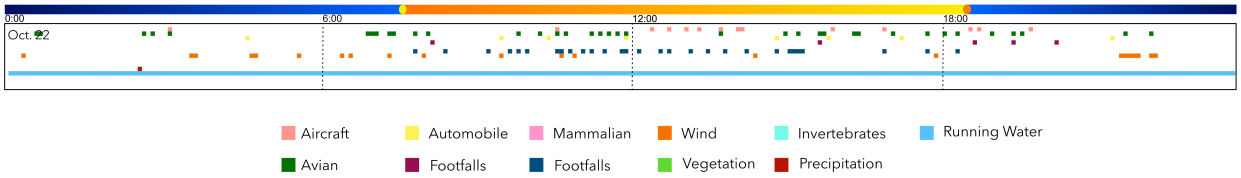

Figure 21, Temporal Audibility of Sounds – Skaftafell, High-Traffic Trail

The first recording site in Skaftafell is located approximately 500 meters into the main trail leading toward Svartifoss. Approximately 50 meters from the trail itself, this location captures the levels of biophony in an area frequented by human traffic.

Due to its proximity to two rivers, the first field station consistently picks up the sound of moving water. Despite the masking effect of the water sound, aircraft and automobile noise is audible approximately 7.5% of the time. Avian activity is also present throughout the day, with a higher concentration around sunrise and sunset.

Depending on the day, aircraft is audible over Skaftafell 5%-10% of the time (the functional percentage during the day is higher, since aircraft activity is concentrated in the day time hours). Of further note, many of the aircraft events have a relatively high sound pressure level, as can be seen in the graph to the right, showing a sustained SPL peak above 60 dBA (figure 26). A general goal is to keep aircraft sound below 40 dBA or natural ambient levels (44.9 dB at this field station).

The Normalized Difference Soundscape Index captures a predictable pattern at this site, with a peak at both dawn and dusk hours. This level of activity reflects the audible dawn and dusk chorus and the fact that most hiking activity is concentrated between 10:00 and 17:00. This pattern is particularly notable in contrast to the patterns at Svartifoss and at more remote areas of the trail system which show an increase in biophony between the dawn and dusk choruses.

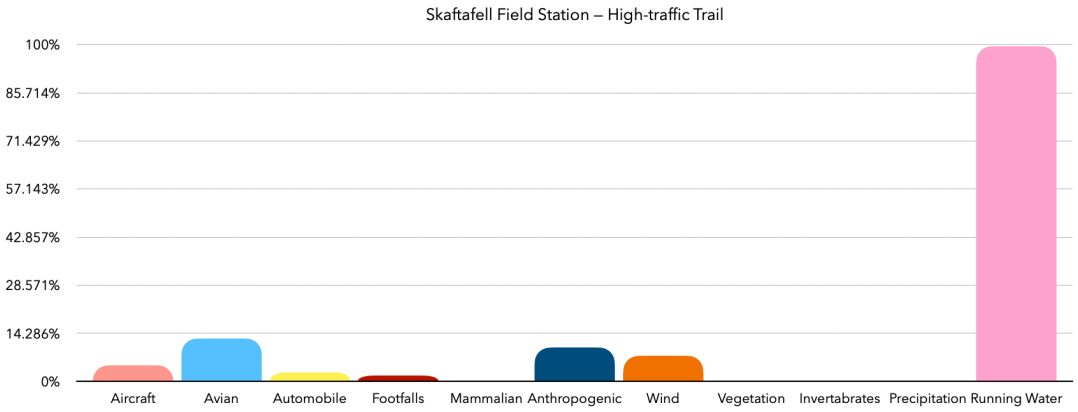

Figure 22, Distribution of Sound Types, Skaftafell High-Traffic Trail

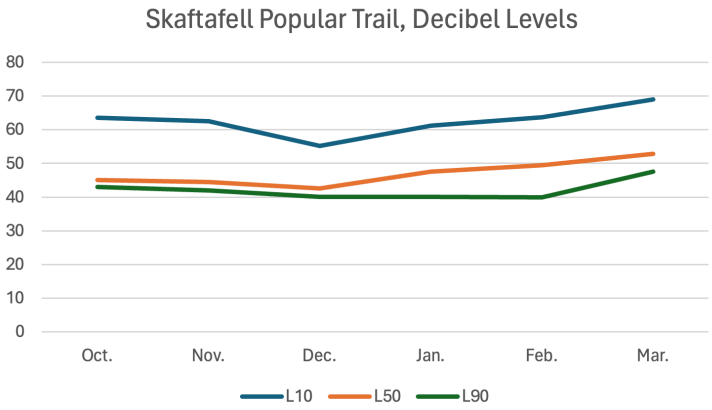

Figure 23, Decibel Levels Over Time, Skaftafell High-Traffic Trail

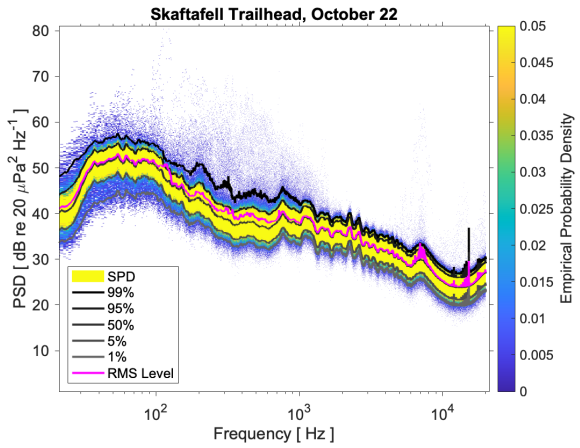

Figure 24, Power Spectrum, Skaftafell High-Traffic Trail

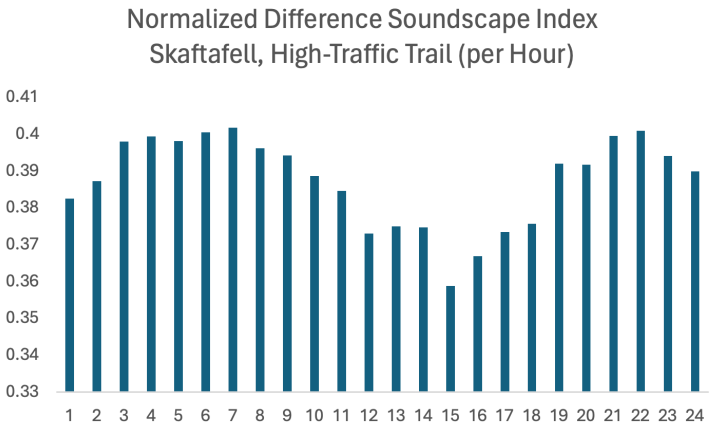

Figure 25, NDSI, Skaftafell High-Traffic Trail (Averaged per Hour)

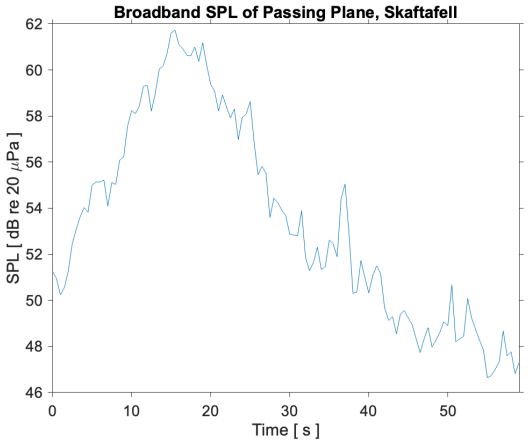

Figure 26, Sound Level of Passing Aircraft

Field Station 2 – Svartifoss

	L_{90}	L_{nat}	L_{50}	L_{10}	Noise Free Interval	Audible Motor (Aircraft/Boat)
Svartifoss	37.4	40.4	40.7	65	1.75	5%

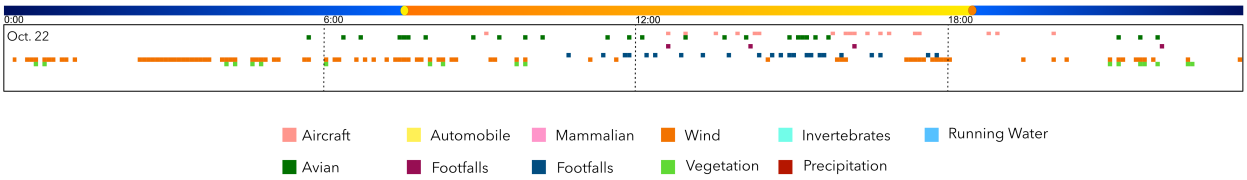

Figure 26, Temporal Audibility of Sounds at Svartifoss

Located near the main overlook of Svartifoss, the second field station captures a similar soundscape to the first, but with some notable differences. First, the greater distance from the highway means that automobile sound is almost never present. Second, the higher elevation means that the vegetation is noticeably sparser, and ice and snow gather more quickly during the winter and persist longer, changing the frequency distribution of sounds.

The power spectrum sound distribution shows an interesting pattern with wind variability concentrated around 10,000 hz—normally, wind noise would be more evenly distributed (figure 28). This unique wind sound distribution is likely due to the species and distribution of trees in the area as well as the topology of the region. This presents the possibility that bird species may adjust their vocalizations based on the acoustic properties of the area.

The NDSI shows a similar pattern to that of the isolated trail area, further indicating that bird species are likely heading to higher altitudes during the day as vehicle traffic increases and is more audible closer to the visitor center (figure 29). Overall biophony levels are considerably lower here compared with the isolated trail however, likely due to human activity both being represented in the index and causing birds to travel to more isolated areas.

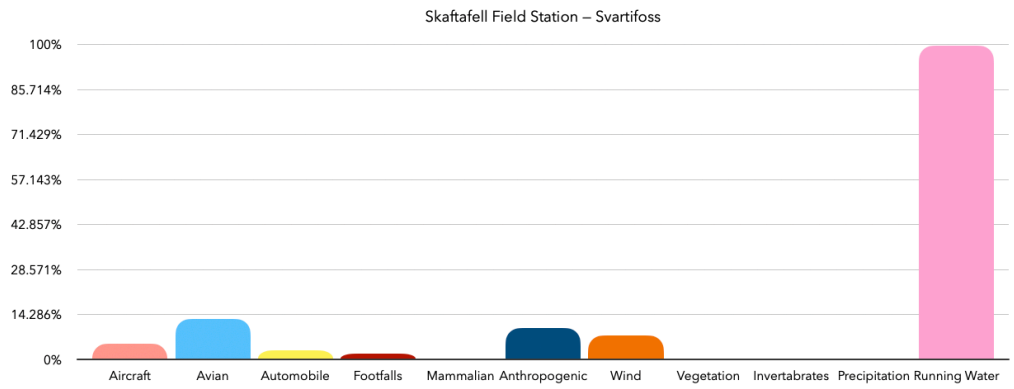

Figure 27, Distribution of Sound Types, Svartifoss

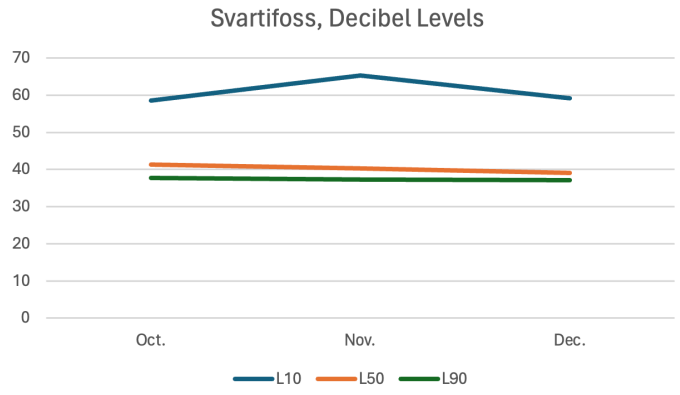

Figure 28, Decibel Levels Over Time, Svartifoss

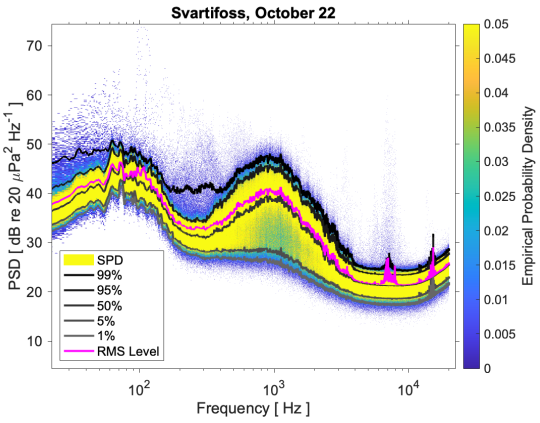

Figure 29, Power Spectrum, Svartifoss

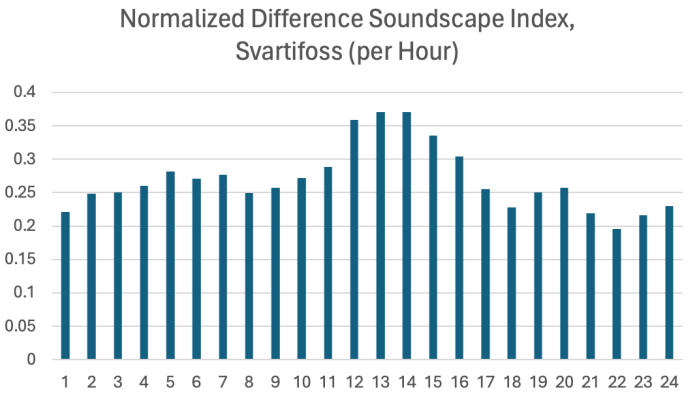

Figure 30, NDSI, Svartifoss (Averaged per Hour)

Field Station 3 – Low-Traffic Trail

	L_{90}	L_{nat}	L_{50}	L_{10}	Noise Free Interval	Audible Motor Noise
Skaftafell Low-Traffic Trail	36.4	37.7	37.8	61.6	2.5	7.8%

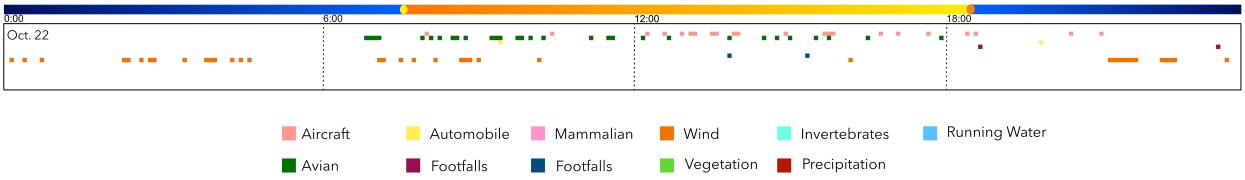

Figure 31, Temporal Audibility of Sounds at Low-traffic Trail, Skaftafell

The third field station at Skaftafell bears some similarities with the other two: notably, aircraft noise is just as prevalent as at the other sites. The most striking difference comes in average measured sound levels. L_{90} and L_{50} are remarkably close together at 36.4 dbA and 37.8 dbA respectively. These levels are the lowest recorded in the park, and their proximity means that noise levels are consistently quiet in this area (figure 33). This pattern can be seen in the power spectrum distribution, showing consistently low-level sounds, with infrequent high-intensity events such as wind and passing planes (figure 34).

The relatively quiet of this area is striking given its proximity to both other field stations within Skaftafell. While less than a kilometer away from both other field stations, every metric, from the NDSI to decibel levels, shows drastically less human noise and increased biologic activity. Some of the difference can be attributed to lower levels of water noise, but this fails to explain the consistently low sound levels (particularly the measurement of L_{50} at 37.8 db).

The acoustic indices for this area illustrate a unique pattern not seen at other field stations within the park. Whereas most locations show the expected increase in biophony around sunrise and sunset, this location exhibits a marked increase during the day. This is confirmed by listening to the recordings which show high levels of bird activity during the day not exhibited at the locations in Skaftafell close to higher human traffic levels. This suggests that birds are moving out of more congested areas to try to find locations where they can more safely communicate. Further, it suggests that these birds are expressing their stress acoustically (and thereby expending energy).

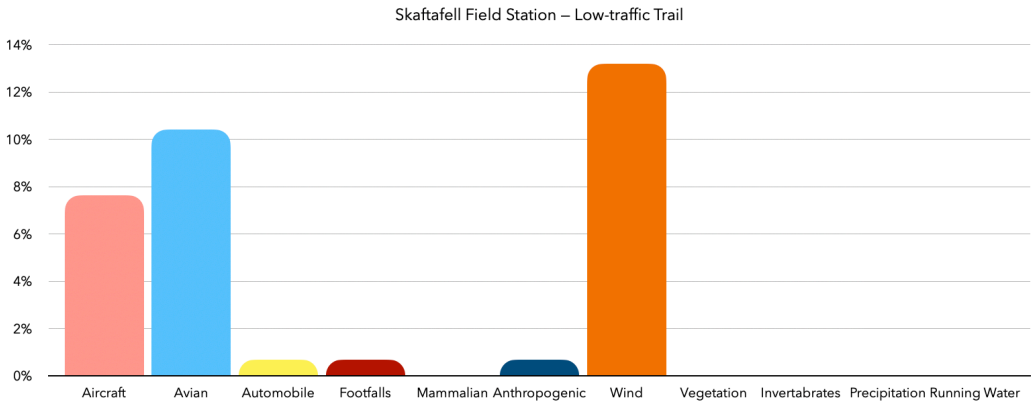

Figure 32, Distribution of Sound Types, Isolated Trail, Skaftafell

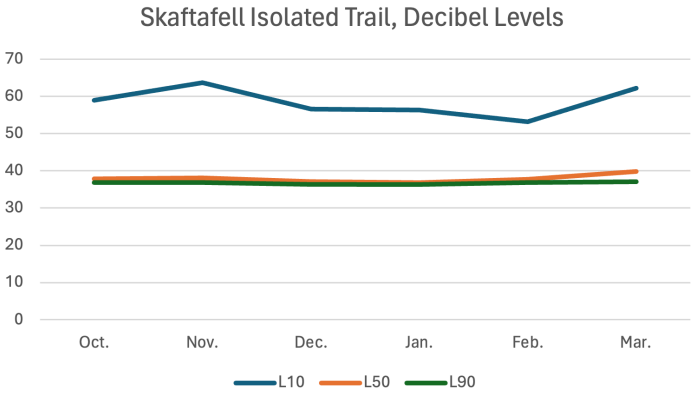

Figure 33, Decibel Levels Over Time, Isolated Trail, Skaftafell

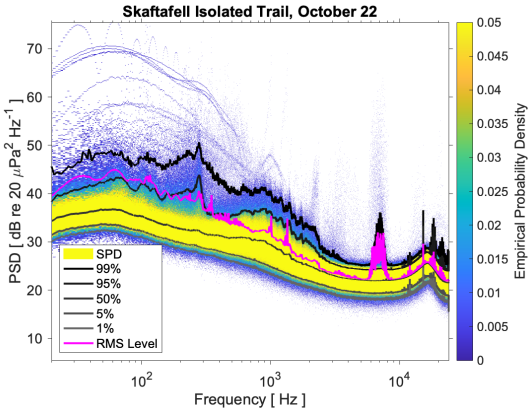

Figure 34, Power Spectrum, Isolated Trail, Skaftafell

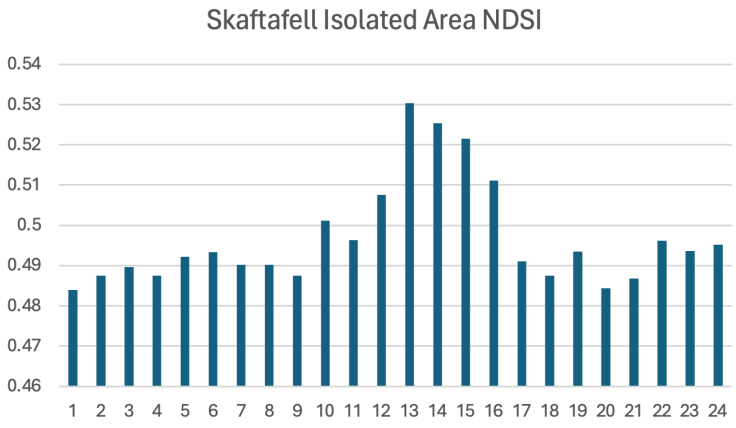

Figure 35, NDSI, Isolated Trail, Skaftafell

Comparisons Between Locations

Each of the locations surveyed here exhibits unique aspects in at least one metric; comparisons of the sites highlights some useful trends across areas, especially in regards to practices to maintain ecosystems that are acoustically conducive to biologic activity and human appreciation.

When comparing the loudness of all six sites, both sites close to Jökulsárlón are consistently the loudest (figure 36). This can partly be attributed to high wind levels, but the consistent anthrophony in the area suggests that human-produced noise plays a role in this change. This is not to suggest that the other sites are exempt from any human impact: All sites show some decrease throughout winter, concentrated in December and January. This reflects a general decrease in tourist numbers during this time.

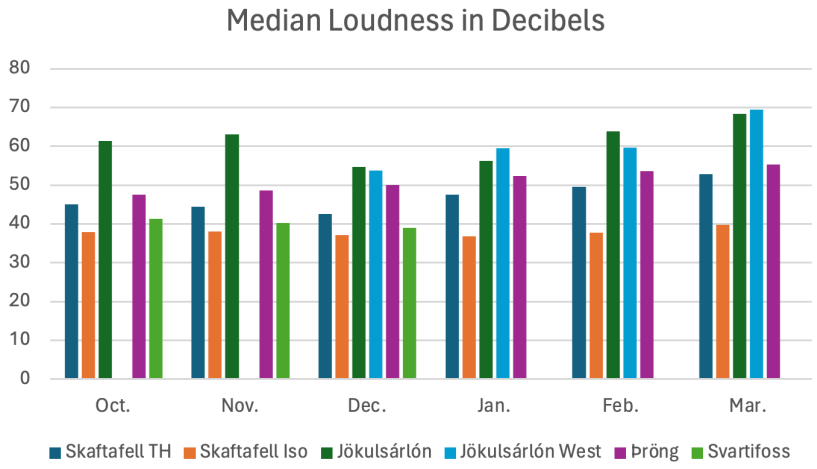

Figure 36, Median Loudness Across All Recording Sites, in Decibels

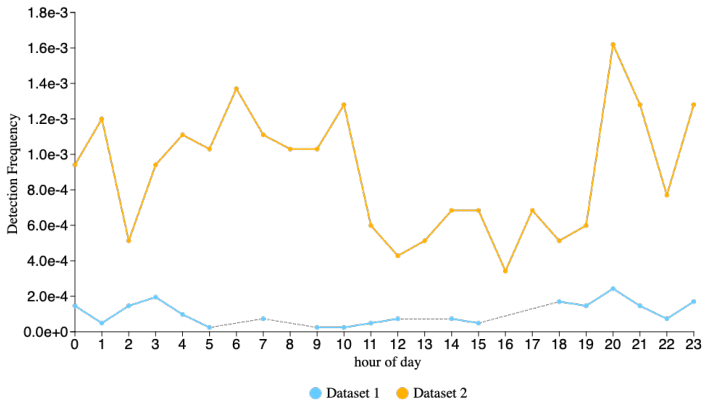

Figure 37, Detection Frequency of Birds at Jökulsárlón (Dataset 1) and Solander's Eye Field Station (Dataset 2)

These trends are represented not only in the loudness data, but in other metrics as well. For instance, the detection of bird species drastically decreases in proximity to high levels of anthrophony. At the Solander's Eye Field Station, bird activity is consistently orders of magnitude higher than close to the parking area where boat activity is more common (figure 37).

Glossary of Terms

Anthrophony: All human-produced noise. This includes machines that are created by humans as well as human vocalizations—i.e. any sounds that originates from the actions of a human. Commonly between 500-2000 hz.

Bioacoustic Index: The "Bioacoustic Index" is a measure of how much activity there is in the biologic band (2000-8000 hz). It is measured by combining sound levels under a curve

Biophony: All sounds originating from organic life (excluding humans). Bird calls and insect choruses are two of the most common examples. Commonly between 200-800- hz.

Decibel (dB): A logarithmic scale measuring loudness. Normal human conversation is around 40-60 dB; a jet engine from around 50 feet away is roughly 120 dB. dBA represents a decibel scale that is weighted to account for how humans perceive different frequencies

Geophony: All sounds originating from natural processes, but not from the actions of a living being. Earthquakes, volcanoes, and wind are all examples of geophony.

Hertz (hz): A measurement of sound frequency. Each hz correlates to one change in air pressure per second. Higher hertz equal higher frequencies.

NDSI: The "Normalized Difference Soundscape Index." A ratio from -1 to 1 that compares the amount of biophony to anthrophony. In practice this is accomplished by comparing the amount of sound between 500-2000 hz (anthrophony) with that between 2000-8000 hz (biohony)

L_x: A metric representing the percent of time that sound levels exceed the stated level.

L_{nat}: An estimate of what the median sound level would be without human-produced noise.

Noise-Free Interval: A measurement of the average time between instances of human-produced noise.

Soundscape: All the audible sounds in a given area (incorporates human perception and so focuses on sounds between 20-20,000 hz.