Glacier National Park 2019 Ambient Sound Study

An Interdisciplinary Qualifying Project

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Abstract

Noise pollution is becoming a greater threat throughout the world as both population and levels of man-made sounds increase. The goal of this project was to determine ambient sound levels at strategic locations in Glacier National Park. This data was compared to a baseline study completed in 2004 through careful analysis to determine the current state of noise in the park, causes of noise, and strategies for managing it. Using modern technology and methods derived from previous studies, it was determined that the overall natural soundscape of the park has remained similar since 2004. However, situational noise was determined at multiple locations, masking much of the natural soundscape. If the data collection period was extended, we believe the situational noise would become insignificant.

Acknowledgements

We would like to thank many different members of the Glacier National Park staff. We would like to thank our liaisons Tara Carolin and Mary Riddle for helping make this project possible and giving insight for future improvements. We also appreciate the assistance Ginger Rigdon provided in planning the transportation of our equipment to Sperry Campground. Furthermore, thank you to Mr. Baron, Woody the horse, and Red the Mule for taking our heavy equipment up to and down from the Sperry Chalet.

From NTi we would like to thank Brian MacMillan for his help in configuring the recording equipment to best suit the project as well as providing the XL2 Data Explorer software necessary for data analysis. We would also like to thank Rick Stillmaker for his useful instructions in the proper use of the aforementioned software.

Finally, we would like to thank professors Frederick Bianchi and Thomas Balistrieri. Dr. Balistrieri was helpful in assessing the feasibility and logistical planning during ID 2050. His instruction regarding presentation skills and design allowed us to perform a clear and professional final presentation to the National Park Service. As our on-site advisor, Professor Bianchi facilitated the process of finalizing our presentation and assisted us in the organization, writing and formatting of our final paper.

Executive Summary

The goal of this project was to recreate the 2004 Glacier National Park Baseline Ambient Sound study. The study was executed to establish the baseline ambient sound levels of the park and understand the effects of noise pollution generated from the various aircraft over the park. The objectives of the 2019 study were to:

1. Record the sounds and ambient sound levels at various locations designated by the 2004 study
2. Analyze the data from 2019 and compare it to 2004
3. Report the results and offer recommendations on how to address noise in Glacier National Park

The project was executed from August 26^{th} to October 11^{th} in which recordings were taken at four sites with each recording running for a seven-day period. The 2004 study had conducted research at eight sites, however given the time constraints of the 2019 study it was determined that only four sites could be completed in time. These sites were selected by using several key criteria: acoustic zone, visitor use, and aircraft use. Visitor and aircraft use were based upon the foot and air traffic at each location while acoustic zones were based upon several environmental factors. The acoustic zones established by the 2004 study are as follows:

- **Alpine/subalpine:** This zone includes "alpine communities beginning on mountains above or just below the timberline of spruce and fir, either on gentle slopes where the soil has developed large meadows areas or on windswept slopes where cushion plants dominate."
- **Deciduous forest:** Deciduous forests include "aspen/poplar and cottonwood" and is "found at lower elevations, usually along lakes and streams."
- **Coniferous forest:** Glacier National Park is "predominantly coniferous forest," making up approximately 62% of the park. Species of trees in this zone include spruce, fir, subalpine fir, limber pine, and western larch.
- **Herbaceous:** These areas are mainly grassland but include shrubland, and pastures.

- **Water:** This zone includes the lakes in Glacier National Park. There will be no study conducted for zone five.[1]

Figure 1 shows a map of the sites selected for the 2019 study. A Gantt chart showing the recording schedule of each site is represented in Figure 2.

Figure 1: Selected sites 2019

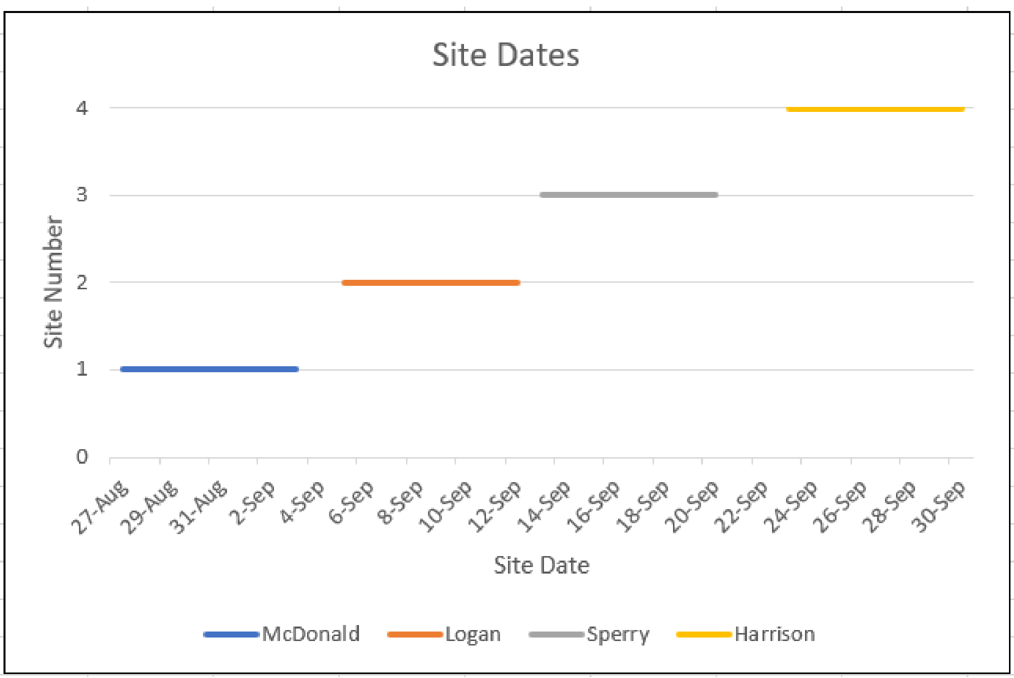

Figure 2: Site dates 2019

[1] National Park Service. Glacier National Park: Baseline ambient sound levels 2004.

To complete the project and to recreate the previous study several kinds of readings were taken. These readings were:

- **Sound Intensity:** The level of sound measured in A-weighted decibels associated with a timestamp sampled every second. Decibels (dB) are logarithmic, which means that a sound that is 50 dB is ten times louder than a sound that is 40 dB.
- **1/3 Octave Frequency Distribution:** Continuous, one second readings of A weighed levels, split into 1/3 octave frequencies from 12.5-20,000 Hz
- **Audio Recordings:** Recordings of the sounds audible during the noise measurement period of each site; used in describing the soundscape of each site, as well as generating observer logs

In 2004, collecting this data required the use of a sound level meter and an audio recorder. The NTI XL2 was designated as capable of collecting all the necessary information in one device without the use of an external audio recorder. Also, in order to comply with the requirements set by IEC 61672 and ANSI S1.4, a Class 1 microphone was needed. The NTI M2230-WP was selected as it was compatible with the XL2 and would be able to withstand the harsh elements out in the field. A photo of the XL2 sound logger and M2230-WP microphone are shown in Figure 3 below.

Figure 3: XL2 Sound logger and microphone

Table 1 has the averages of all the necessary acoustical sound level (dBA) statistics collected during the project. The same type of data was collected from each site. The descriptors used in the table headers are defined below:

- Site ID: A descriptor used by the 2004 study to designate each site in a concise manner. Beginning with one each site is designated by the order in which it was completed.
- Overall: these are the overall sound levels taken during the entire seven-day period.
- Daytime: the average of the levels collected during the daytime. The 2004 study designates daytime as the time from 7am to 7pm.
- Nighttime: the average of the levels collected during the nighttime. The 2004 study designates nighttime as the time from 7pm to 7am.

The statistical models necessary for analyzing the data and used throughout this project are explained below:

- L_{Aeq}: The A-weighted equivalent continuous sound level. Essentially the average of the entire data set.
- L_{50}: The 50th percentile calculated from L_{Aeq}, meaning that 50% of the data is above this number
- L_{90}: The 10th percentile calculated from L_{Aeq}, meaning that 90% of the data is above this number

Tables 2, 3, and 4 show the hourly readings of each site, labeled using the 24-hour system

Table 1: Overall readings

Site	Overall (entire 7 day period)			Daytime (7 AM - 7 PM)			Nighttime (7 PM - 7 AM)		
	L_{Aeq} (dBa)	L_{50} (dBa)	L_{90} (dBa)	L_{Aeq} (dBa)	L_{50} (dBa)	L_{90} (dBa)	L_{Aeq} (dBa)	L_{50} (dBa)	L_{90} (dBa)
McD	38.8	26.5	22.4	40.0	26.9	22.4	37.1	26.3	22.4
Log	33.3	31.0	26.5	34.1	31.2	26.4	32.2	30.8	26.7
Spry	52.9	31.4	28.6	55.9	31.8	29.1	31.6	31.1	27.7
Harr	42.2	34.4	25.3	43.2	37.6	31.1	40.8	29.8	23.8

Table 2: LAeq hourly readings

Site ID	Hours of the day L_{Aeq}																							
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
McD	24.7	26.2	25.3	26.1	26.3	25.7	41.1	35.6	34.0	35.0	35.2	37.1	37.4	41.2	41.3	35.6	35.9	36.9	42.1	32.3	31.0	29.6	26.5	26.7
Log	31.3	30.5	30.6	30.2	29.3	31.1	31.5	31.7	31.5	31.5	32.3	33.1	33.5	34.9	32.3	31.4	32.3	30.1	30.4	31.7	33.5	32.7	31.9	30.7
Spry	31.5	31.8	31.7	30.9	31.4	31.4	32.1	31.6	32.7	32.6	33.8	36.2	35.1	35.6	34.7	40.2	34.6	32.1	32.3	31.7	31.6	30.9	31.7	31.7
Harr	41.6	37.5	38.9	36.6	42.8	38.7	37.7	42.5	39.7	39.0	41.6	39.0	40.1	37.9	43.6	44.6	43.4	45.4	42.2	43.1	40.5	41.8	34.4	43.8

Table 3: L50 hourly readings

Site ID	Hours of the day L_{50}																							
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
McD	24.2	26.6	25.2	25.7	25.5	25.2	27.1	28.6	27.5	26.9	24.5	23.3	24.4	27.4	26.8	26.7	26.0	27.4	29.2	26.2	29.9	28.9	26.2	26.7
Log	31.3	30.5	30.4	30.2	28.8	30.8	31.2	31.5	31.1	30.3	31.0	32.2	31.5	31.8	31.6	30.7	31.0	29.5	29.9	31.3	31.7	30.7	30.5	30.5
Spry	31.5	31.8	31.6	31.0	31.3	31.2	31.4	31.5	31.9	31.6	31.6	31.8	30.6	31.8	32.4	31.5	31.3	31.6	31.8	30.8	30.9	30.4	30.9	31.7
Harr	26.7	29.4	27.7	23.7	27.2	30.4	32.0	32.6	34.2	34.9	37.1	37.3	37.3	35.5	36.4	39.6	39.4	39.7	37.7	33.2	31.7	29.5	26.6	26.0

Table 4: L90 hourly readings

Site ID	Hours of the day L_{90}																							
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
McD	22.3	24.8	24.1	23.9	23.6	23.8	25.4	26.3	25.8	24.3	22.0	21.5	21.9	25.1	23.3	23.3	23.7	24.9	26.2	25.2	26.7	27.3	25.1	25.1
Log	30.2	29.3	28.3	28.2	27.9	28.4	30.6	30.6	30.0	29.0	29.9	30.6	30.1	30.6	30.4	29.4	29.3	30.3	28.8	30.0	30.4	32.2	29.3	29.2
Spry	30.8	30.9	30.7	29.5	30.3	30.0	30.2	30.3	30.6	30.0	30.2	29.7	29.2	29.5	31.2	30.1	29.4	30.4	30.6	29.8	29.9	29.4	29.7	30.8
Harr	24.8	25.9	23.6	24.0	24.6	26.6	26.7	29.2	30.0	31.1	31.9	32.1	32.1	31.0	31.5	34.6	33.3	34.9	33.1	27.9	26.1	25.3	24.2	24.1

To compare the data sets from 2004 and 2019, it was decided to look at the delta (the change/difference between the two) and the observer log (a record of all the sounds heard over a period of time). The observer log done in 2004 was completed manually at each site, recording sound heard over a period of approximately five hours. The 2019 study utilized the NTi software and the audio files to indicate each sound over a twelve-hour period, Table 6 shows the delta of the overall readings for each site below. Figures 4, 5, 6, 7 are the observer logs from 2004 and 2019 for each site.

Table 6: Delta readings for the four sites

Site	Study	L_{Aeq} (dBa)	L_{50} (dBa)	L_{90} (dBa)
McDonald Ranger Station	2019	38.8	26.5	22.4
	2004	36.7	28.8	24.9
	Delta	2.1	-2.3	-2.5
Logan Pass	2019	33.3	31.0	26.5
	2004	35.2	31.9	28.6
	Delta	-1.9	-0.9	-2.1
Sperry Campground	2019	52.9	31.4	28.6
	2004	36.3	34.2	32.3
	Delta	16.6	-2.8	-3.7
Harrison Creek	2019	42.2	34.4	25.3
	2004	42.9	31.3	24.1
	Delta	-0.7	3.1	1.2

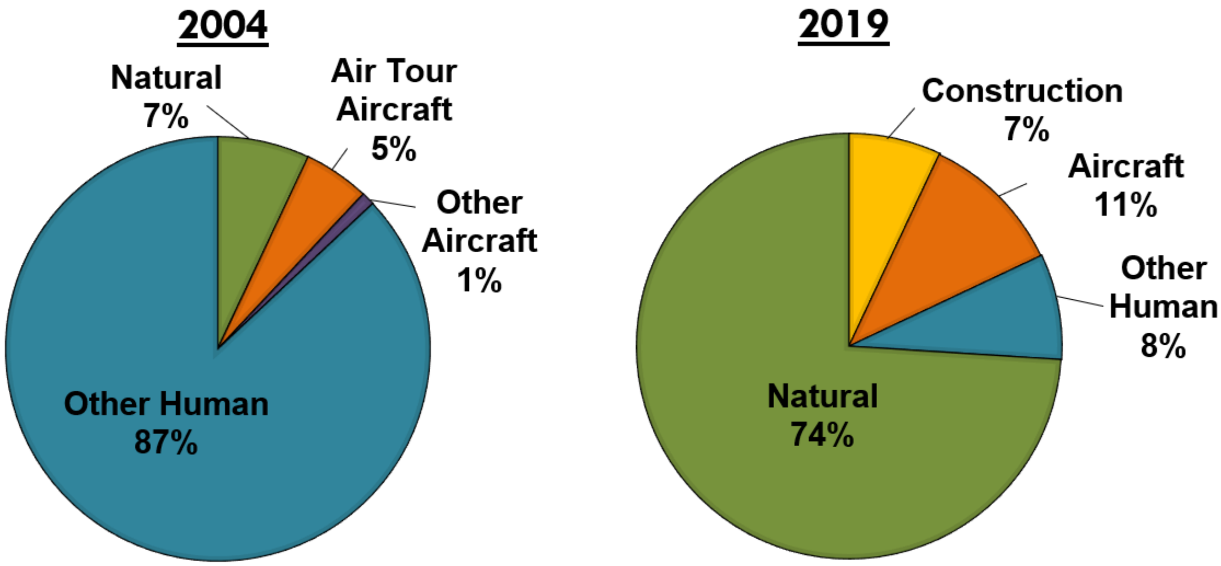

Figure 4: McDonald Ranger Station observer log

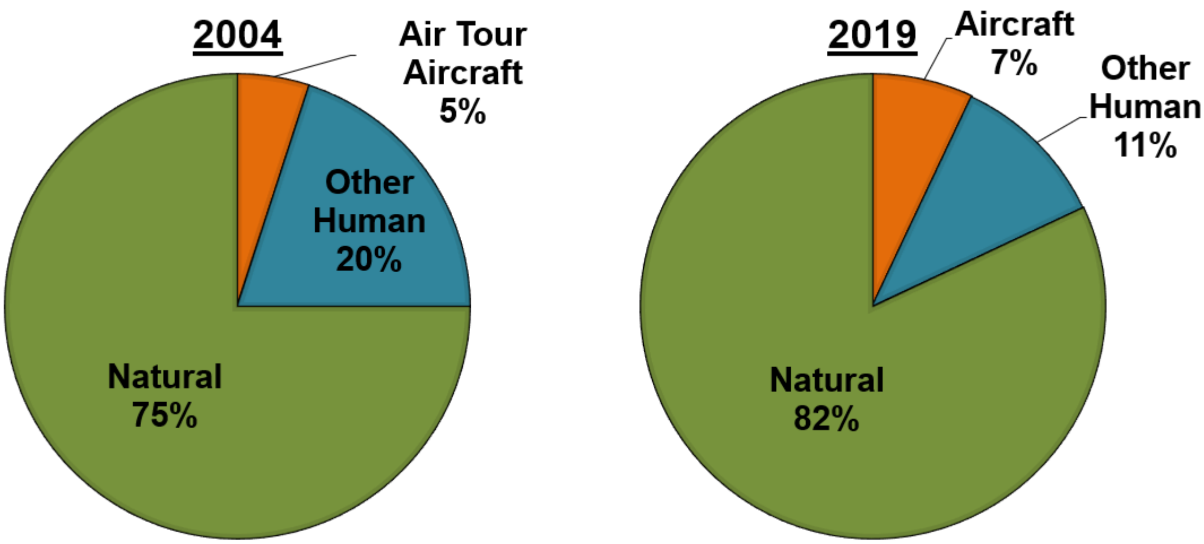

Figure 5: Logan Pass observer log

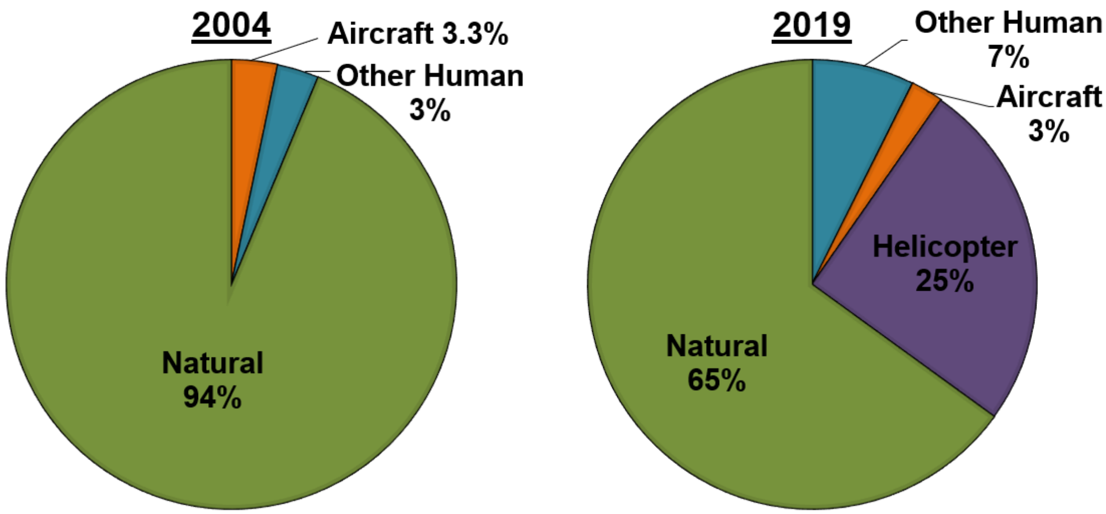

Figure 6: Sperry Campground observer log

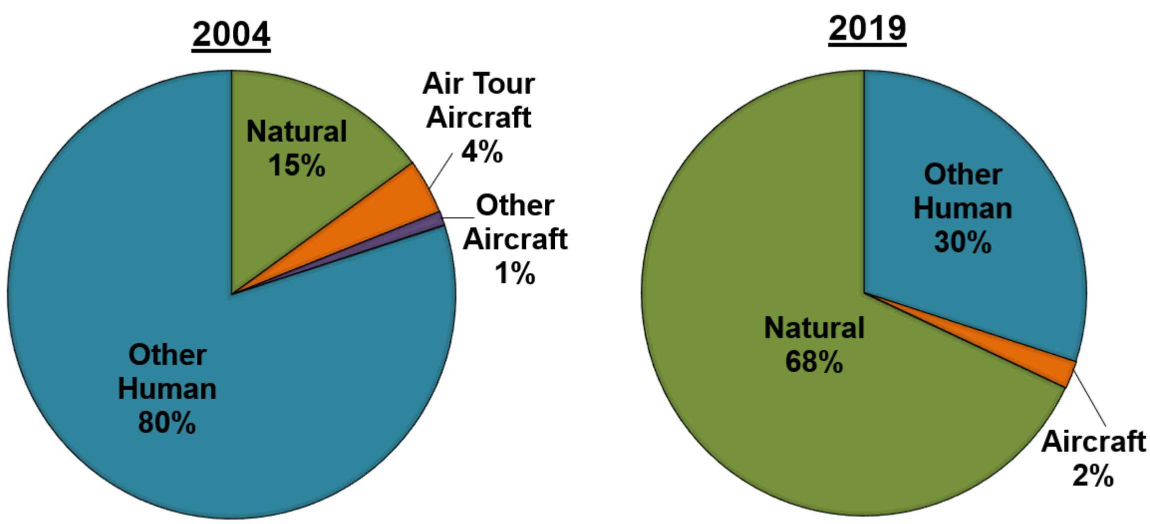

Figure 7: Harrison Creek observer log

The delta for McDonald Ranger Station indicated that the L_{Aeq} was higher in 2019, but the L_{50} and the L_{90} where lower, meaning there were louder sounds present, but they were not there for very long. The causes of this are linked to the fire that occurred in 2018. The fire resulted in the road to the station being closed off and parts of the area needing to be rebuilt. Looking at the observer log in figure 4 it can be seen that the level of human sound has decreased. This was a result of the road being closed. Logan Pass was quieter across the board in terms of the L_{Aeq}, L_{50} and L_{90}. This was attributed to the study in 2019 being conducted in September and the 2004 study being done during August, which is known to have higher visitation levels. The observer log in figure 5 is almost identical with the human factor being lower given the same reasoning as above. Sperry Campground experienced a significant increase in the L_{Aeq}. Looking at the observer log, it was understood that this was linked to the helicopters that were appearing at the location to drop off equipment and supplies to rebuild the chalet that was burned down in 2017. At Harrison Creek the L_{Aeq} was lower but the L_{50} and L_{90} were higher. The observer log indicated that most of the sounds heard were from humans, while that level was much lower in our log. It was found that the 2004 group could hear people going down the Middle Fork river. This is a result of this site's recording being conducted after the major rafting and hiking season, resulting in no human voices being heard.

In conclusion, the 2019 study provided data that showed minimal changes to the natural soundscape, excluding situational noise. Aircraft noise also remained approximately equal. Based off these findings, it is recommended to the park that future sound studies focus on the Going-To-The-Sun Road Corridor. Beyond moving the focus of the road, extending the length of the study to a minimum of 25 days limits uncertainty of the data collected to less than three decibels.

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2.2 Sound	Aidan, Alec	Carson
2.3 Noise Pollution	Aidan, Carson	Niall
2.4 Aircraft Tours	Carson	Niall
2.5 Sound Management	Alec	Carson
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1 Introduction

Noise pollution is an increasing problem in the National Park System. Beyond dissatisfaction of visitors, "noise pollution is a strong environmental force that may alter key ecological processes and services."[2] Continuously increasing annual visitation in the national parks is associated with an increased amount of unnatural noise. Glacier National Park is no exception to this increase in visitation, and the status of its natural soundscape is under question. Taken from the NPS Natural Sounds Division, "human noise sources stress this system, which creates a domino chain of effects for both animals and humans."[3] Cars, motorcycles, and aircrafts are the main causes of disturbances to humans and wildlife in Glacier National Park.

A baseline ambient sound study was last conducted in Glacier National Park 15 years ago. In 2004, there were roughly two million visitors to Glacier. Since then, the park's annual visitation has increased by approximately one million people.[4] The increased number of visitors alludes to the likelihood of increased noise pollution. This project was necessary because the 2004 study is now outdated, and noise pollution has become more of a concern to Glacier and the entirety of the park system.

The goal of this project was to compare Glacier National Park's ambient noise levels in 2019 to the ambient noise levels taken in 2004. The establishment of two studies allowed for the data to be compared and any changes to be identified. The first objective to complete the project was to place a sound level meter at the exact locations as selected in 2004 and gather data. Second, the data from 2004 and 2019 was analyzed, compared and the associated conclusions were drawn. From the information gathered, recommendations were offered to Glacier National Park on managing the changing soundscape of the park.

[2] Francis, C.D. Noise pollution alters ecological services.
[3] National Park Service. Effects of noise on wilderness.
[4] National Park Service. Visitation numbers.

2 Background

2.1 Glacier National Park

Located in the northwest corner of Montana, Glacier National Park attracts roughly three million visitors annually. This made Glacier the tenth most visited national park in 2018.[5] The most popular time to visit the park is the summer. For Glacier, the peak visitation months include June, July, and August. More than 71% of the annual visitors visit during these three months. Figure 8 displays the increasing number of annual visitors to Glacier National Park from 1910 to 2018.[6]

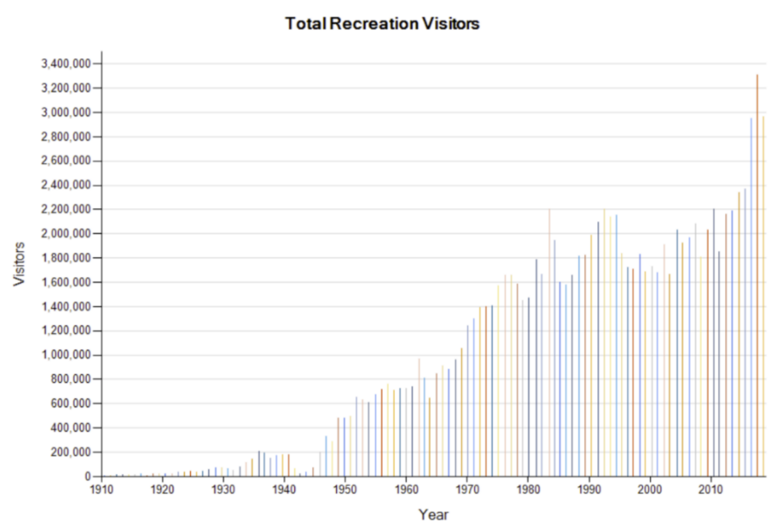

Figure 8: Annual Recreation Visitors from 1910-2018

Glacier National Park offers numerous outdoor attractions including glaciers, lakes, mountains, and wildlife. Along the 50-mile Going-to-the-Sun Road, the only road which traverses the national park, visitors can view the beautiful scenery as well as find several of the more popular trailheads and attractions.[7] The environment within the park differs greatly from the east to the west side. As the park surrounds a portion of the Continental Divide the varied environment includes grasslands, forests, alpine/subalpine areas, and rocky mountain faces.[8] Figure 9 shows a descriptive map of the park.

[5] National Park Service. Visitation numbers.
[6] National Park Service. NPS stats.
[7] National Park Service. Going-to-the-Sun Road.
[8] National Park Service. Glacier National Park: Baseline ambient sound levels 2004.

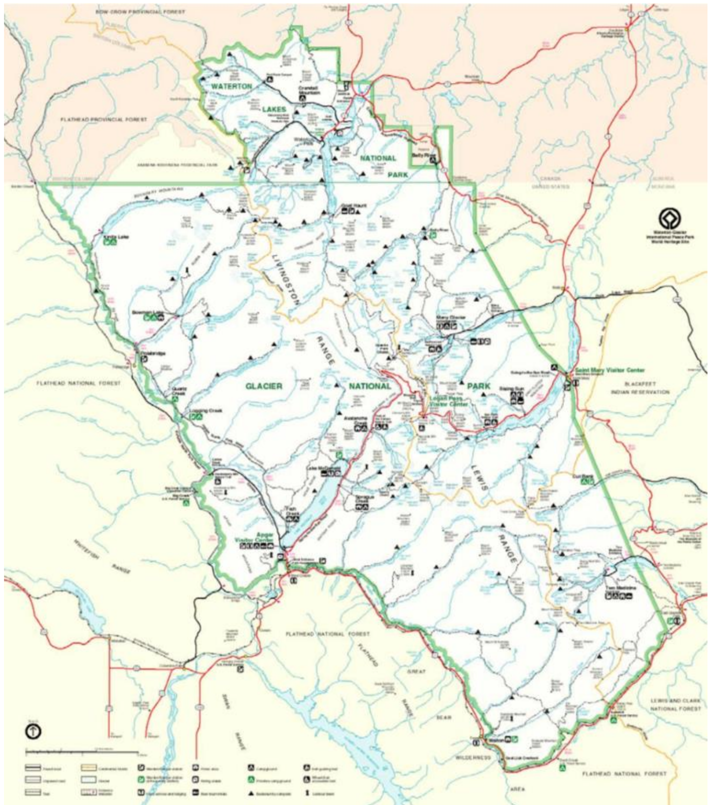

Figure 9: Overview map

2.2 Sound

Sound is created when an object vibrates and causes mechanical motion of the molecules that make up the air. This motion creates a pressure wave that mimics the original object's motion and is eventually picked up by the sensory organs of humans and animals. Most sound waves are complicated combinations of different waves with varying amplitudes and frequencies determined by the origin of the sound. Humans perceive sound frequency as pitch: how high or low a noise sounds, and wave amplitude: the volume of noise. Humans can perceive sounds ranging from 20 to 20,000 hertz, but sound waves with high frequency or amplitude can cause discomfort or damage to human ears.[9] However, animals have varying sensitivities to noise frequencies and amplitudes, and thus respond to and are affected differently by loud sounds or sounds of certain frequencies.

[9] Cutnell and Johnson. Physics. 4th ed.

2.2.1 Sound Measurement

Sound frequency is measured in hertz, which is a representation of how many times a sound wave completes a cycle in one second. The inverse of hertz is period, which is a measurement of the time a sound wave takes to complete one cycle. Sound amplitude is measured in decibels (dB) and is a representation of the intensity of a sound wave. The decibel scale is logarithmic, so for example, a sound that is 30 dB is ten times louder than a sound that is 20 dB and 100 times louder than a sound that is 10 dB.[10]

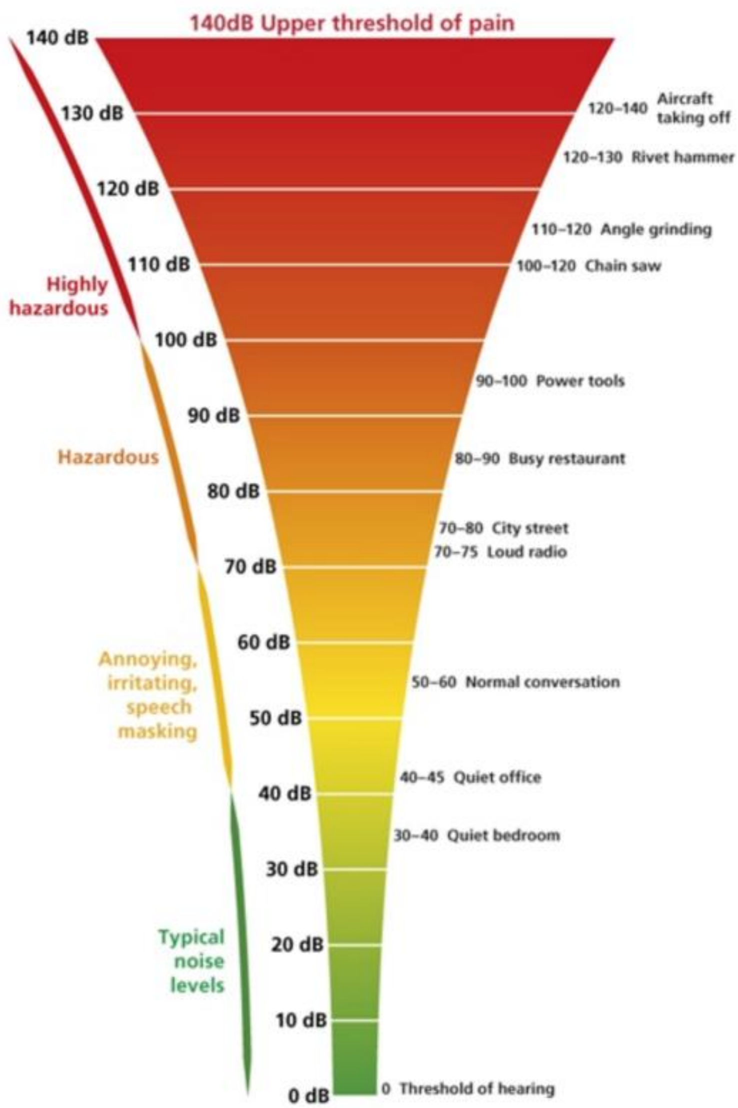

Figure 10: Noise level chart with examples

[10] Cutnell and Johnson. Physics. 4th ed.

2.3 Noise Pollution

Noise is all around us, from the rustling of leaves to the cars on the road. Some noise is natural, but when humans contribute excessive amounts of unnatural noise to the existing soundscape, it becomes noise pollution. Noise pollution is defined as harmful or annoying levels of noise, as from automobiles, airplanes, industry, etc.[11]

In a world of cars, planes, dense population, and modern machinery, noise pollution is present throughout all aspects of human life. A study conducted in Michigan in 2012 revealed that the median average noise level that a person is subjected to is 79 dB of noise throughout the day. 71% of men and 68% of women have experienced average noise levels that were greater than the 75-dB maximum healthy noise level set by the ANSI S3.44 sound standard.[12] Additionally, long-term exposure to sounds louder than 80 dB have been connected to hearing loss and hypertension, but also adverse psychological effects such as disrupted sleep, increased stress levels, difficulties with learning and concentration, and overall reduction in mental efficiency.[13]

Noise pollution does not just occur in cities and densely populated areas. It also has a major impact on the nation's national parks. According to Sarah Kaplan from The Washington Post, "[Noise pollution] can also frighten, distract or harm animals that inhabit the wilderness, setting off changes that cascade through the entire ecosystem."[14] In order to survive, animals rely on their ability to hear minute sounds, like a predator's movement or a stream's trickle. Masking those natural sounds with the sounds of cruising cars and chatty hikers puts these animals at risk. Human noise can also frighten and distract animals, leading them to change their behavior. According to the National Park Service, "Some birds in noisy environments have taken to singing at night in order to be heard over the din of the city."[15] Noise pollution is an issue that has detrimental effects on both the human and animal population.

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[11] Merriam-Webster Online.
[12] Flamme, G.A. Typical noise exposure in daily life.
[13] Goswami, M. Noise levels and sound pollution associated with various operative procedures and equipments in a pediatric dental environment.
[14] Kaplan, S. Human noise pollution is everywhere, even in the national parks.
[15] National Park Service. Effects of noise on wildlife.

2.4 Aircraft Tours

Aircraft tours are taken by visitors of the park to see large scenic areas without having to do any of the hiking. These tours are completed using either a helicopter or a small plane. In the past year there have been 298 tours completed over Glacier National Park. These tours have been known to interfere with visitor experience and the environment. In order to combat these issues, there have been several acts passed by the NPS and the FAA. These air tours were the driving factor behind the sound study completed in 2004.[16]

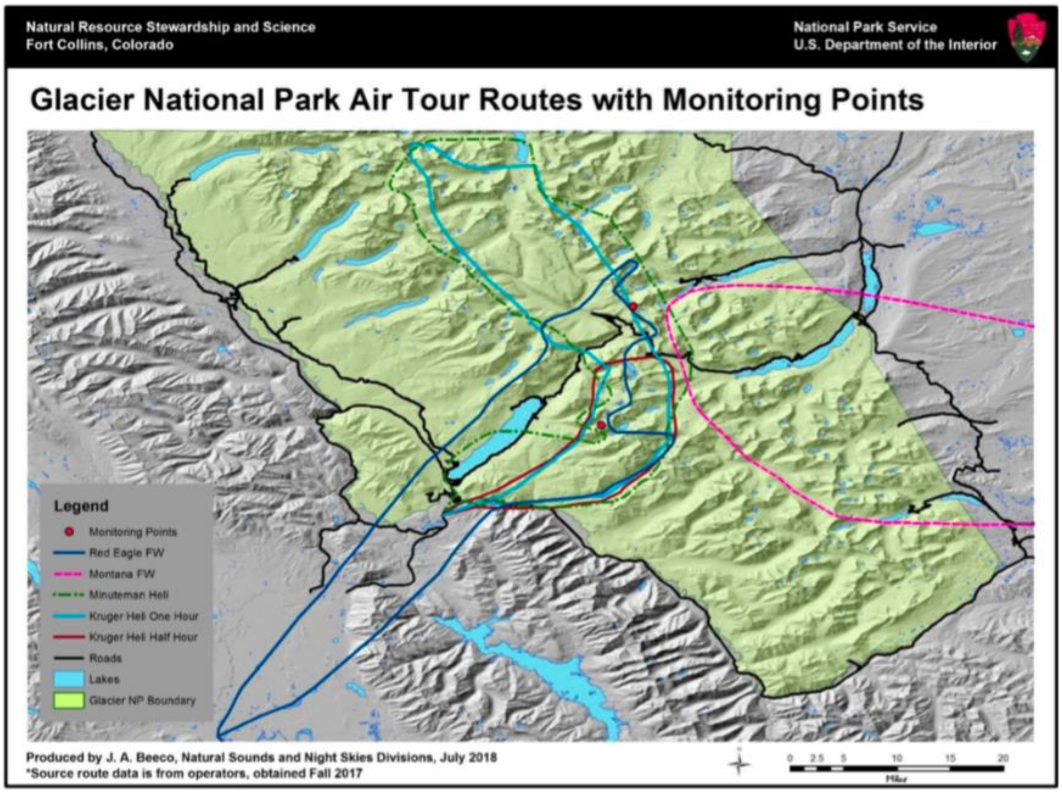

Figure 11: Current flight paths over Glacier National Park

2.4.1 FAA regulations

On April 5th, 2000, the National Parks Air Tour Management Act of 2000, which regulates commercial air tour operations in national parks, was enacted. The FAA and NPS are required "to develop air tour management plans for units of the national park system where an operator

[16] National Park Service. Reporting information for commercial air tour operations over units of the NPS.

has applied for authority to conduct commercial air tours."[17] The purpose of this act is to ensure that there are no adverse effects on the cultural and natural resources of the park.

The FAA passed the Modernization and Reform Act of 2012 in order to amend provisions of the National Parks Air Tour Management Act of 2000. This act required that commercial air tour operators submit the number of scheduled tours to both the NPS and the FAA. The act also allows parks to make agreements with operators instead of having to make air tour management plans. These agreements must ensure that the park resources and visitor use are protected without conflicting with the air traffic control system or aviation safety. When an agreement is made, it is set for public review and consultation with tribes. Once this is done, they are enacted without the need of administrative or environmental process.[18]

2.4.2 NPS and FAA

The NPS and FAA have passed the above laws and regulations as the sounds created from air tours have had a negative impact on wildlife in national parks.[19] Loud noises have resulted in major behavioral changes in animals, as mentioned in a previous section, and aircrafts are known for creating loud noises. In 2001, the FAA conducted a study of all aircrafts to determine their noise level. Through the report, it was discovered that when measured from 450 meters, the sound level ranged from 78.90 to 112.0 EPNdB (effective perceived noise level in decibels). For helicopters, flying over produced a sound level range from 78.7 to 93.4 EPNdB. According to the CDC, hearing loss in humans can occur after being exposed to sounds above 100 dB for at least 15 minutes.[20]

2.5 Sound Management

The United States is making efforts to reduce noise pollution. In Boston, the Air Pollution Control Commission works to maintain healthy air quality and noise levels in the city. Under Boston Municipal Code, "Unreasonable or excessive noise shall mean noise measured in excess

[17] Federal Aviation Administration. Air tour management plan.
[18] National Park Service. Reporting information for commercial air tour operations over units of the NPS.
[19] National Park Service. Report on effects of aircraft overflights on the NPS.
[20] Federal Aviation Administration. AC 36-1H, Noise levels for U.S. certified and foreign aircraft.

of 50 decibels between the hours of 11 pm and 7 am, or in excess of 70 decibels at all other hours."[21] The Environmental Protection Agency (EPA), a U.S. federal agency founded in 1970, investigates and studies noise and its effect, advocates the adverse health effects of noise pollution, and evaluates the effectiveness of existing regulations in accordance with acts such as the Noise Control Act of 1972. The agency also regulates major sources of noise, including trains, automobiles, motorcycles, and construction equipment. The Noise Control Act of 1972 was put in place to promote an environment without noise that would otherwise have adverse effects on people's health and welfare. The Clean Air Act of 1963 established the Office of Noise Abatement and Control within the EPA, responsible for identifying and classifying causes and sources of noise, and determining effects at various noise levels, projected growth of noise levels, the psychological and physiological effect on humans, and effect on wildlife.[22] Though noise pollution is not regarded as one of the more significant sources of pollution such as garbage or industrial waste, its effects are widespread and are historically becoming more severe. Several national authorities are developing more of an interest in addressing the potentially harmful effects of changing soundscapes, thus meriting the exploration, monitoring and mitigation of ambient noise.[23]

More specifically, the National Park Service has established several specific policies regarding the regulation of noise pollution in the national parks. Of these, NPS director's order #47 has the most direct impact on this project, as it makes it the responsibility of park managers to "(1) measure baseline acoustic conditions, (2) determine which existing or proposed human-made sounds are consistent with park purposes, (3) set acoustic management goals and objectives based on these purposes, and (4) determine which noise sources are impacting the park and need to be addressed by management."[24] Additionally, the NPS website cites several of their regulations regarding the use of motorized vehicles and equipment, which aim to reduce mechanical noise from automobiles and airplanes.

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[21] American Legal Publishing Corporation. Chapter XVI: Prohibitions, penalties and permits.
[22] Environmental Protection Agency. Clean air act title IV – Noise pollution.
[23] Owen, D. Is noise pollution the next big public-health crisis?
[24] National Park Service. Policies and authorities.

While visitors make up a significant portion of the noise in national parks, several parks have taken to directly changing their facilities to adapt to the changing soundscape. In 2000, the park service in Zion National Park re-outfitted a portion of their shuttle bus fleet to run on propane instead of gasoline, which produces less noise when used in the internal combustion engines that power park shuttles. Currently, the fleet is being evaluated in preparation for another bus retrofit, this time to electric engines in an attempt to further lower running costs and noise emissions.[25] A study conducted in Europe in 2012 to assess the perception of electric and hybrid vehicles found that battery-powered electric vehicles are, on average, quieter than vehicles that run on gasoline in internal combustion engines, especially at speeds under 30 km/h.[26]

Muir Woods National Monument experiences similar issues regarding noise, as a national study concluded that 72% of Americans surveyed believed that the national parks should be protected as quiet places to experience the natural soundscape. In response to increased levels of noise, the park service at Muir Woods selected random days to be declared “quiet days” and a series of signs designating a location called Cathedral Grove in the park as a “quiet zone.” It was found that the quiet days reduced the average noise level by 1.84 dBA and quiet zones reduced the average noise level by 2.77 dBA.[27]

2.5.1 2019 Glacier Management Proposal

In September of 2019, the National Park Service of Glacier National Park drafted a management proposal designed to present desired strategies and actions for “managing transportation, visitation and visitor use, trail use, and access throughout the corridor, including at developed areas, to meet desired conditions established for the park’s fundamental resources and values, including providing high-quality visitor experiences.”[28] These desired strategies include expanding the shuttle system, implementing a timed entry parking permit system, and making

[25] National Renewable Energy Lab. Zion National Park propane-to-electric shuttle bus evaluation.
[26] Dudenhöffer, K. Sound perception of electric vehicles.
[27] Journal of the Acoustical Society of America. Reducing visitor noise levels at Muir Woods National Monument using experimental management.
[28] National Park Service. Going-to-the-Sun Road corridor management plan environmental assessment.

changes to the circulation and parking availability in the Avalanche Developed Area. These changes are aimed at protecting the natural soundscape.

If the preferred/proposed management plan is put into effect, the National Park Service intends to perform noise monitoring studies like this project accomplished. "The desired conditions for backcountry in the GTSR corridor is that visitors have the opportunity for solitude and experience mostly natural sounds with few intrusions of non-natural sounds." The plans for construction will inevitably produce large amounts of noise audible several miles away by visitors and wildlife, thus disturbing the natural soundscape. Noise levels throughout the park will play an important role in future managerial decisions regarding the use and construction of the road and surrounding trails.[29]

2.6 Validity of this project

Sound is an integral part of the experience at a national park. According to Rachel Buxton, an acoustic ecologist at Colorado State University,

> "[Sound] enhances our experiences in protected areas… Imagine walking in Yellowstone, seeing beautiful vistas. You've got bird songs filling the landscape. You might hear a pack of wolves howling on your way home at night. All these things are magnificent. That's something that deserves protection."[30]

The mission of the NPS is to preserve the environment for the enjoyment of people and the preservation of wildlife. With the harmful effects that sound has on both the people and the environment, it has come to the National Park Service's attention to do something about it. By recording and analyzing noise data, the project determined which areas are being impacted the most and what sources of noise are the most prominent.

2.7 Glacier National Park Baseline Ambient Sound Levels 2004

The Glacier National Park Baseline Ambient Sound Levels study in 2004 acted as a guideline for this project. The 2019 research replicates the goal of this study to provide the park service an

[29] National Park Service. Going-to-the-Sun Road corridor management plan environmental assessment.
[30] Kaplan, S. Human noise pollution is everywhere, even in the national parks.

updated analysis of the sound levels within the park. Similar procedures for site selection, data collection, and analysis have been used to provide a comparison to 2004.

The 2004 study provides eight locations where sound data was collected. These eight locations were selected to be representative of the different environments within the park. There was a blend of different biomes, visitation levels, wind speeds, and degrees of air traffic for each location.[31] The figure below provides a map of the eight locations used in the 2004 study.

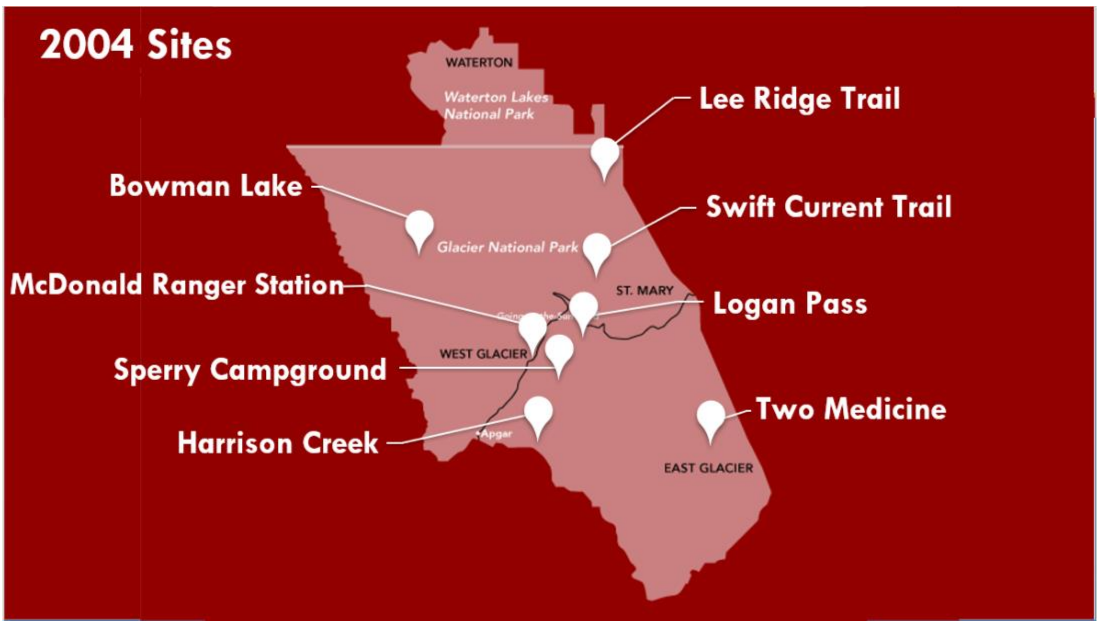

Figure 12: Determined acoustic zones and selected sites

The focus of the study was on sound created by aircraft above and around the park. Based off this focus, sound was categorized into the following groups: air tour aircraft, other aircraft, non-aircraft/man-made sources, and natural sources. Then over the course of 10 to 18 days, the duration, frequency, and intensity of each sound group was recorded and documented for each location. Using NLcrunch, a program developed by the Volpe Center, the large volume of data collected at the park was reduced, analyzed, and archived. The data files from the Noise Logger were uploaded to the program, which then converted the files to text showing the dates, times, battery levels, wind speeds and directions, and noise levels for every second of operation.[32]

[31] National Park Service. Glacier National Park: Baseline ambient sound levels 2004.
[32] National Park Service. Glacier National Park: Baseline ambient sound levels 2004.

3 Methodology

Noise pollution is a problem that is becoming increasingly significant to Glacier National Park. To combat this issue, a projection of the soundscape was established by recreating a study done in 2004 and comparing the results. The overall objective was to discover the main causes of noise pollution in Glacier National Park and to offer recommendations on how to manage them. The project was executed from August 26, 2019 to October 11, 2019 in which the following objectives were completed:

1. Recorded the sounds and ambient sound levels at various locations designated by the 2004 study
2. Analyzed the data from 2019 and compared it to 2004
3. Reported the results and offered recommendations on how to address noise in Glacier National Park

3.1 Site selection

To encapsulate the soundscape of Glacier National park, sites were selected using several key criteria: Acoustic Zones, Visitor Use, and Air Tour Activity. The study conducted in 2004 selected eight sights that had variety in all these criteria which allowed for the diverse environment in the park to be captured.

3.1.1 Glacier Acoustical zones

The 2004 sound study used a Geographic Information System (GIS) to determine different acoustic zones within Glacier National Park. Environment and vegetation are key factors that affect acoustics within the park. In 2004, there were five different acoustic zones decided by NPS experts:

- **Alpine/subalpine:** This zone includes "alpine communities beginning on mountains above or just below the timberline of spruce and fir, either on gentle slopes where the soil has developed large meadows areas or on windswept slopes where cushion plants dominate."

- **Deciduous forest:** Deciduous forests include “aspen/poplar and cottonwood” and is “found at lower elevations, usually along lakes and streams.”
- **Coniferous forest:** Glacier National Park is “predominantly coniferous forest,” making up approximately 62% of the park. Species of trees in this zone include spruce, fir, subalpine fir, limber pine, and western larch.
- **Herbaceous:** These areas are mainly grassland but include shrubland, and pastures.
- **Water:** This zone includes the lakes in Glacier National Park. There will be no study conducted for zone five.[33]

3.1.2 Visitor use

With the increase of visitors to the park over the years it was essential that the level of visitor use be taken into consideration when selecting the necessary sites. The 2004 study designated three different levels of visitor use:

- **High Visitor-Use:** Locations that experience substantial foot traffic, or ones easily accessible by automobiles, and can be traversable within 30 minutes.
- **Moderate Visitor-Use:** Locations that experience moderate to substantial human activity or can be reached within one hour of hiking.
- **Low Visitor-Use:** Locations that experience low human activity - designated wilderness areas or restricted, and backcountry hiking or camping areas. These locations take one hour or more from front country locations

3.1.3 Air traffic

After analyzing air traffic patterns and flight paths, the 2004 study categorizes the sites into the following three different levels:

- **High:** Locations with high concentration on the flight map are designated with this descriptor.
- **Medium:** Locations with medium concentration on the flight map are designated with this descriptor.

[33] National Park Service. Glacier National Park: Baseline ambient sound levels 2004.

- **Low:** Locations with low to no concentration on the flight map are designated with this descriptor.

3.1.4 Selected sites

With the seven-week time constraint it was decided that only four sites would be selected. These four sites were picked with the aforementioned criteria such that all the different types of areas were selected for study. This allows for the most accurate data being collected regarding the current state of sound in the park while also recreating the study completed in 2004 as closely as possible.

The sites selected by the 2004 study are listed below in Table 5, and the ones that were selected for this project are highlighted in yellow. Figure 13 showcases where the locations are in the park.

Table 5: Location description

Site ID	Site Name	Acoustic Zone	Visitor Use	Air Tour Activity
G01	Lake McDonald - Ranger Station	Coniferous Forest	High	High
G02	Logan Pass	Alpine/ Subalpine/ Herbaceous	High	High
G03	Lee Ridge Trail	Coniferous Forest	Low	Low
G04	Two Medicine - Main Valley	Coniferous Forest	High	Low
G05	Harrison Creek	Deciduous Forest	Medium	High
G06	North Fork Foot - Bowman	Coniferous Forest	Medium	Low
G07	Swiftcurrent Trail	Coniferous Forest	Medium	Medium
G08	Sperry	Alpine/ Subalpine/ Coniferous Forest	Medium	High

Figure 13: Site locations

After selecting the sites, it was important to decide the order in which they were to be recorded. Since the 2004 study was completed in late August, as that is the highest peak of visitor travel, it was imperative that sites with high visitor traffic were done as early as possible. The state of the Going-to-the-Sun Road was also a factor that needed to be considered, as snowfall can lead to road closures and make it impossible to travel on. This meant that the sites that required its use took priority. A minor complication arose when it was found that from September 16th to the 29th the road from Avalanche to Logan was going to be closed for repair. This meant that sites that used that section of the road had to be completed either before that time frame.

With all these factors to be considered, the order in which the sites were recorded were as follows**:**

1. Lake McDonald Ranger Station: August 27th to September 3rd
2. Logan Pass: September 5th to September 12th
3. Sperry: September 13th to September 20th
4. Harrison Creek: September 23rd to September 26th

Note: The Harrison Creek recording period was unfortunately cut short due to severe weather

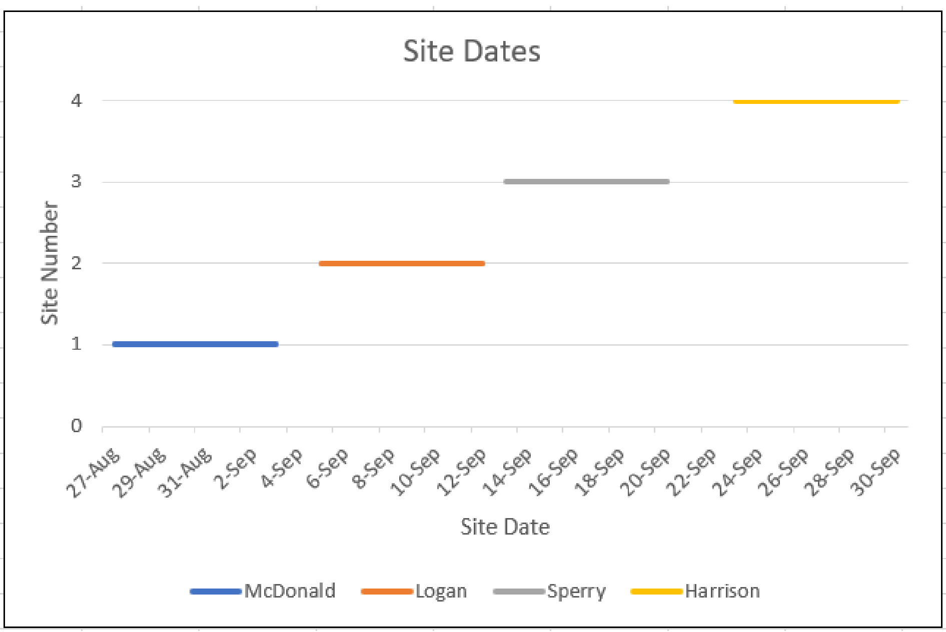

Figure 14: Gantt chart

3.2 Device Deployment

In order to best recreate the 2004 study, the locations' coordinates noted in the 2004 report were used. Using a Garmin GPS, the sound measurement setup was able to be stationed in the same spots that were used in 2004.

When the location was reached, the team set up a mic stand, the microphone, NTi device in the pelican case, and a battery. After the equipment was tested and functioning, it was left in each location for a continuous seven-day period. This time frame was selected due to the limited time in the park and the minimum amount of time needed to ensure that the data was accurate. After a seven-day period, the device was retrieved, and data analysis was conducted.

3.3 Data Analysis

The data which was analyzed included the decibel levels, the ⅓ octave frequency levels, and the sounds recorded. After each seven-day recording period, the large amount of data that had been accumulated by the recording and measuring device was transferred to a software by NTi. This software processed the data to generate graphs and calculated the various numbers needed for proper noise analysis.

3.3.1 Data sorting

Once the data had been processed, several tables and graphs were generated. Overall L_{Aeq}, L_{50} and L_{90} were listed, as well as their corresponding hourly medians and the difference compared to 2004. The 1/3 octave band frequency distribution was depicted in its own table

The audio recordings at each site were then reviewed extensively by a team member. Every sound event was flagged and categorized as either aircraft, natural, or other human.

3.3.2 Statistical tools

The values of A-weighted sound intensity and their associated timestamps were organized by the XL2 data explorer software following device retrieval. Then, various calculations were run in order to generate the statistical models used to properly represent the data.

- L_{Aeq}: The A-weighted equivalent continuous sound level. The logarithmic average of every 1-second sample taken throughout the entire period of the recording at each site. This model is designed to depict the best representation of the level of sound experienced at a certain site.

- L_{50}: The 50th percentile calculated from L_{Aeq}, meaning that 50% of the data is above this number.
- L_{90}: The 10th percentile calculated from L_{Aeq}, meaning that 90% of the data is above this number.

3.4 Equipment

3.4.1 NTi System

The device used to collect sound data in Glacier National Park was the NTi XL2 with an NTi M2230 Class 1 microphone shown in Figures 15 and 17 respectively.

Figure 15: NTi sound XL2 sound analyzer

The combination of the XL2 and the M2230-WP microphone create a sound-logging device that meets the Class 1 requirements of the IEC 61672 and ANSI S1.4 recording standards. Figure 16 displays our system (black), the XL2 with a M2461 class 2 microphone (blue) and the previously mentioned standards (red). This system will be able to record sound pressure waves with amplitudes and frequencies ranging from 24 dB(A) to 137 dB and 6.3 Hz to 20,000 Hz respectively.[34]

[34] NTi.

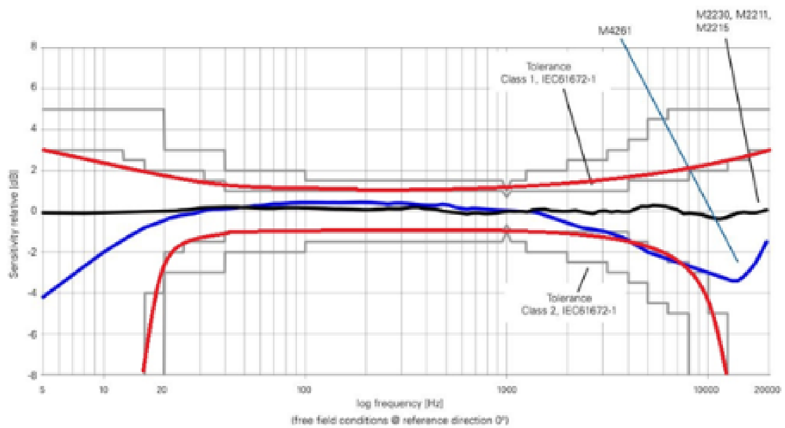

Figure 16: Class 1 tolerances

3.4.2 Microphone

The NPS requires the use of a Class 1 sound recording device for replicating the 2004 noise pollution study. This is because Class 1 devices are much more accurate than Class 2 devices, as their recording tolerances are +/- 1.9 dB and +/- 2.2 dB respectively, which are set by the IEC 61672 and ANSI S1.4 sound recording standards. In addition to the accuracy of the recording device, a recording period of seven days was used as it includes the entire week and was feasible given time constraints.

With the costly price of the microphone, it was important to ensure that it would be protected while in the field. Given the odd size and shape of the microphone, it was decided to use the NTi specific weatherproof system, as it was already proven to work and meet the needs for the project. The microphone and weatherproof system are shown in Figure 17 below:

Figure 17: M2230 Class 1 microphone and waterproofing

3.4.3 Headphones

Working with a large expanse of audio files that needed to be analyzed, studio headphones were required to correctly identify the recorded noises during audio examination.

Figure 18: Audio-Technica ATH-M40x monitor headphones

3.4.4 Pelican case

With the XL2 needing to be outside for an extended period and the likely chance of inclement weather occurring, a protective case became a necessity. A Pelican© case was selected as it would be able to handle any expected weather conditions.

Figure 19: Pelican waterproof case

3.4.5 Battery

As previously mentioned, the system is needed to run for a minimum of seven days straight. With some of the locations taking an entire day just to reach, it would have been impossible to change the power every day. Thus, to ensure that a power failure would not occur, it was decided to use a 55 Ah 12-volt marine battery. This could both provide sufficient power to the XL2 system for at least seven days, along with the weatherproof in case of inclement weather. After talking with NTi, it was confirmed that 55 Ah at 12 volts would be more than enough to power the system for the required time frame.

Figure 20: 12-volt, 55 Ah SLI marine battery

4 Findings

In this section, the results from the study are discussed and explained in great detail. Starting with the overall analysis, followed by the results from each location. Then the observer log of when each category of noise and their duration at each site is explored. Finally, the data will be compared to the study completed in 2004 to determine the state of noise in the park.

4.1 Overall readings

After all the data had been collected, it was formatted into several tables in order to complete the goals of the project. Table 6 is a general table filled with the overall averages for each site over each of the seven-day periods. Tables 7, 8 and 9 are the hourly readings of each site specified by the specific statistical models used. Table 10 is the distribution of the intensity of each 1/3 octave frequency band.

Table 6: Overall readings

Site	Overall (entire 7 day period)			Daytime (7 AM - 7 PM)			Nighttime (7 PM - 7 AM)		
	L_{Aeq} (dBa)	L_{50} (dBa)	L_{90} (dBa)	L_{Aeq} (dBa)	L_{50} (dBa)	L_{90} (dBa)	L_{Aeq} (dBa)	L_{50} (dBa)	L_{90} (dBa)
McD	38.8	26.5	22.4	40.0	26.9	22.4	37.1	26.3	22.4
Log	33.3	31.0	26.5	34.1	31.2	26.4	32.2	30.8	26.7
Spry	52.9	31.4	28.6	55.9	31.8	29.1	31.6	31.1	27.7
Harr	42.2	34.4	25.3	43.2	37.6	31.1	40.8	29.8	23.8

Table 7: LAeq hourly readings

Site ID	Hours of the day L_{Aeq}																							
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
McD	24.7	26.2	25.3	26.1	26.3	25.7	41.1	35.6	34.0	35.0	35.2	37.1	37.4	41.2	41.3	35.6	35.9	36.9	42.1	32.3	31.0	29.6	26.5	26.7
Log	31.3	30.5	30.6	30.2	29.3	31.1	31.5	31.7	31.5	31.5	32.3	33.1	33.5	34.9	32.3	31.4	32.3	30.1	30.4	31.7	33.5	32.7	31.9	30.7
Spry	31.5	31.8	31.7	30.9	31.4	31.4	32.1	31.6	32.7	32.6	33.8	36.2	35.1	35.6	34.7	40.2	34.6	32.1	32.3	31.7	31.6	30.9	31.7	31.7
Harr	41.6	37.5	38.9	36.6	42.8	38.7	37.7	42.5	39.7	39.0	41.6	39.0	40.1	37.9	43.6	44.6	43.4	45.4	42.2	43.1	40.5	41.8	34.4	43.8

Table 8: L50 hourly readings

Site ID	Hours of the day L_{50}																							
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
McD	24.2	26.6	25.2	25.7	25.5	25.2	27.1	28.6	27.5	26.9	24.5	23.3	24.4	27.4	26.8	26.7	26.0	27.4	29.2	26.2	29.9	28.9	26.2	26.7
Log	31.3	30.5	30.4	30.2	28.8	30.8	31.2	31.5	31.1	30.3	31.0	32.2	31.5	31.8	31.6	30.7	31.0	29.5	29.9	31.3	31.7	30.7	30.5	30.5
Spry	31.5	31.8	31.6	31.0	31.3	31.2	31.4	31.5	31.9	31.6	31.6	31.8	30.6	31.8	32.4	31.5	31.3	31.6	31.8	30.8	30.9	30.4	30.9	31.7
Harr	26.7	29.4	27.7	23.7	27.2	30.4	32.0	32.6	34.2	34.9	37.1	37.3	37.3	35.5	36.4	39.6	39.4	39.7	37.7	33.2	31.7	29.5	26.6	26.0

Table 9: L90 hourly readings

Site ID	Hours of the day L_{90}																							
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
McD	22.3	24.8	24.1	23.9	23.6	23.8	25.4	26.3	25.8	24.3	22.0	21.5	21.9	25.1	23.3	23.3	23.7	24.9	26.2	25.2	26.7	27.3	25.1	25.1
Log	30.2	29.3	28.3	28.2	27.9	28.4	30.6	30.6	30.0	29.0	29.9	30.6	30.1	30.6	30.4	29.4	29.3	30.3	28.8	30.0	30.4	32.2	29.3	29.2
Spry	30.8	30.9	30.7	29.5	30.3	30.0	30.2	30.3	30.6	30.0	30.2	29.7	29.2	29.5	31.2	30.1	29.4	30.4	30.6	29.8	29.9	29.4	29.7	30.8
Harr	24.8	25.9	23.6	24.0	24.6	26.6	26.7	29.2	30.0	31.1	31.9	32.1	32.1	31.0	31.5	34.6	33.3	34.9	33.1	27.9	26.1	25.3	24.2	24.1

Table 10: Frequency levels

Frequency (Hz)	Average sound level For Each Site (dBA)			
	1	2	3	4
12.5	-15.0	-9.3	-6.4	-14.4
16	-9.4	-4.9	-10.4	-10.2
20	-4.3	-1.3	6.8	0.4
25	0.7	2.2	10.4	4.2
31.5	5.2	5.1	16.2	7.4
40	9.7	7.5	18.9	5.9
50	15.5	10.2	24.0	8.1
63	18.7	12.8	26.6	14.5
80	19.6	14.5	27.5	19.9
100	22.1	15.4	31.8	23.8
125	21.5	16.0	35.8	23.3
160	21.9	15.3	37.2	21.2
200	22.2	15.8	38.5	27.4
250	22.9	17.3	41.2	31.1
315	23.3	17.5	42.6	32.5
400	24.6	18.7	43.9	32.8
500	25.9	20.7	43.8	31.3
630	27.7	22.4	43.3	31.3
800	28.9	23.9	43.1	32.4
1000	29.1	24.4	43.4	32.7
1250	29.4	24.1	41.3	31.2
1600	29.0	23.1	39.7	29.9
2000	28.3	21.6	37.2	28.5
2500	26.9	19.5	34.4	27.0
3150	25.1	17.0	30.9	25.2
4000	22.1	15.0	26.3	22.7
5000	19.1	14.5	21.8	20.7
6300	17.6	15.8	17.7	19.6
8000	16.0	15.0	14.3	17.3
10000	13.5	12.2	11.3	14.2
12500	10.7	11.1	8.7	11.6
16000	6.5	8.3	6.4	8.1
20000	2.0	4.9	4.1	4.6

4.2 Site Breakdown

In this section, the breakdown of each site's findings and observations are presented. Each site section will include:

- A table describing the location
- A photo depicting the area the equipment was set up in
- A graph depicting the daily A-weighted sound levels using the Statistical models L_{Aeq}, L_{50} and L_{90}
- A graph depicting the hourly A-weighted sound levels using the Statistical metrics L_{Aeq}, L_{50} and L_{90}
- A graph of the number of samples of each sound pressure level measured during both daytime and nighttime hours
- A pie chart of the different sounds that were identified at each site
- A table with the readings from 2004, 2019, and the delta between the two

4.2.1 Lake McDonald

Table 11: Lake McDonald description

Site ID	G01
Site Name	McDonald Ranger Station
# Measurement Days and Dates	7 days 8/27/19 to 9/3/19
Latitude / Longitude (decimal degrees)	48.64263 / 113.87556
Approximate Elevation (ft)	3933
Ecological Domain	300 North American Dry Domain
Ecological Division	306 Rocky Mountain
Land Cover Class	4 Forested Upland
Land Cover Subclass	42 Evergreen Forest
General Management Plan Zone	Visitor Service
Site Category	Overlook
Site Description	Evergreen forest off road and horse corral
Access Considerations	Vehicle accessible
Potential Sound Sources	Aircraft, Vehicles, Visitors, Horses, Birds, Insects, Wind

Figure 21: Lake McDonald photograph

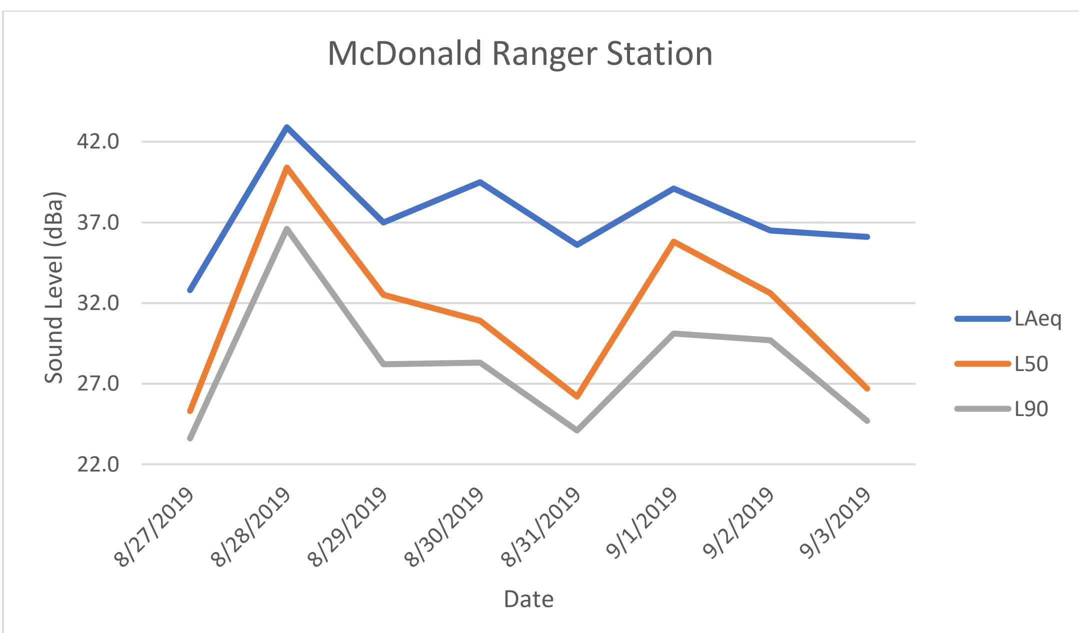

Figure 22: Lake McDonald daily sound levels

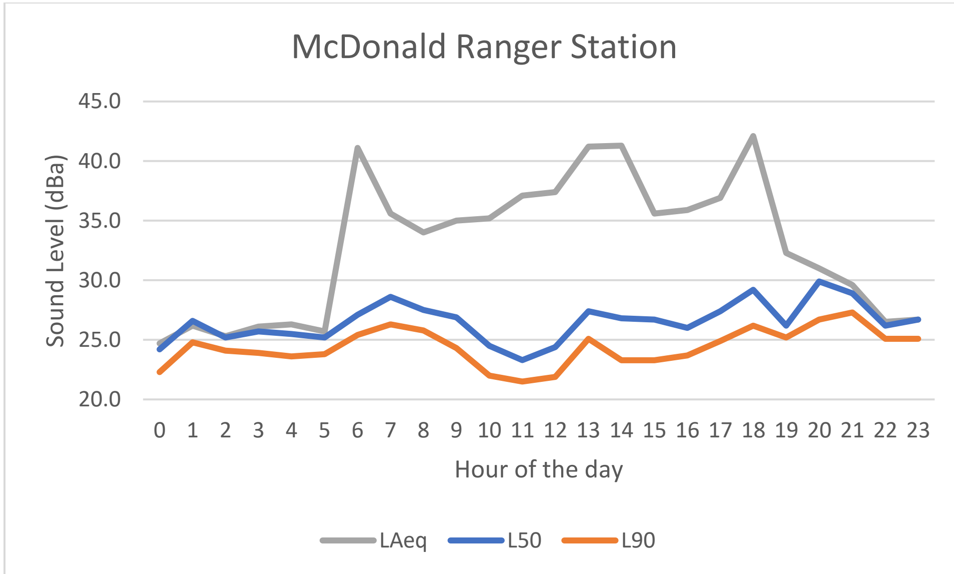

Figure 23: Lake McDonald hourly sound levels

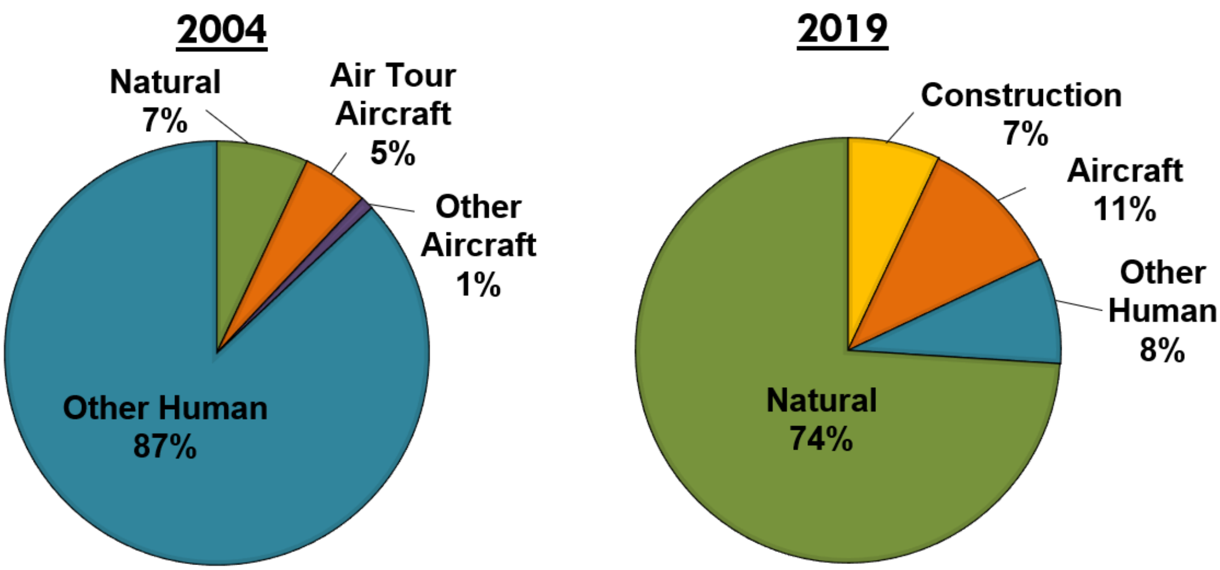

Figure 24: Lake McDonald distribution of sound sources audible during acoustic observer logging

Table 12: Lake McDonald 2004, 2009, and delta

Study	L_{Aeq} (dBa)	L_{50} (dBa)	L_{90} (dBa)
2004	36.7	28.8	24.9
2019	38.8	26.5	22.4
Δ	2.1	-2.3	-2.5

4.2.1.1 Location Analysis

Located a half mile down the road from the pull off at the top of the lake, the equipment was set up towards the edge of the forest across from the ranger station. Due to wildfires in 2018 much of the area around the Station was burned. The damage caused by these fires made it necessary for the park to close off the path to the ranger station and to several popular hikes. With the passage blocked off, hikers were no longer able to go the ranger station, greatly reducing these instances of noise. The damage from the fire in 2018 also required repairs to be made to parts of the area.

For McDonald Ranger Station the L_{Aeq} was higher in 2019 than it was in 2004 while the L_{50} and L_{90} were lower. This means that overall the site was louder, however the noise was made up of loud, infrequent sounds rather than moderately loud and frequent hiker traffic. The lack of human sound from hikers resulted in the lower levels while the loud sounds from the construction vehicles resulted in the large spikes of sound that caused the higher average level.

4.2.2 Logan Pass

Table 13: Logan Pass description

Site ID	G02
Site Name	Logan Pass
# Measurement Days and Dates	7 days 9/5/19 to 9/12/19
Latitude / Longitude (decimal degrees)	48.69345 / 113.71692
Approximate Elevation (ft)	6675
Ecological Domain	300 North American Dry Domain
Ecological Division	306 Rocky Mountain
Land Cover Class	7 Herbaceous Upland Natural/Semi-natural Vegetation
Land Cover Subclass	71 Grasslands/Herbaceous
General Management Plan Zone	Day Use
Site Category	Overlook
Site Description	Grassy meadow behind visitor center
Access Considerations	Vehicle accessible
Potential Sound Sources	Aircraft, Vehicles, Visitors, Wind

Figure 25: Logan Pass photograph

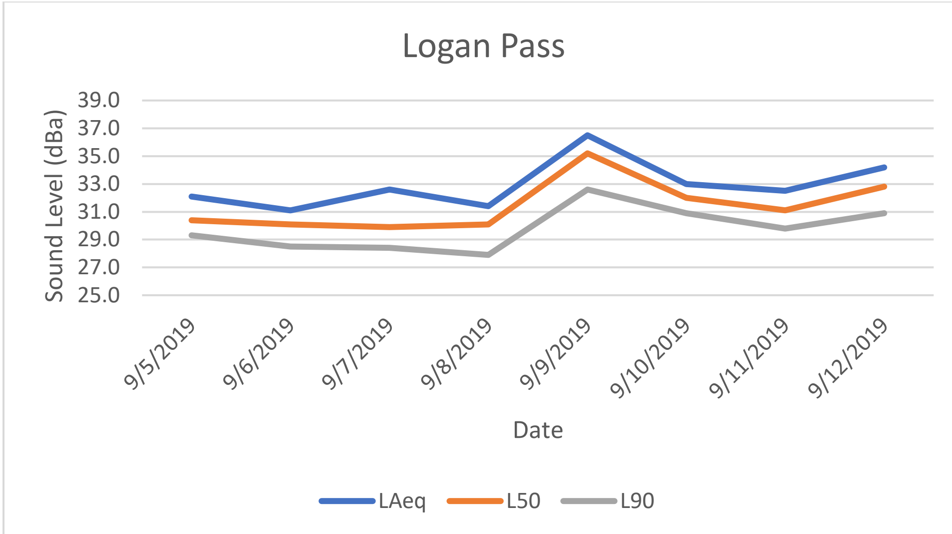

Figure 26: Logan Pass daily sound levels

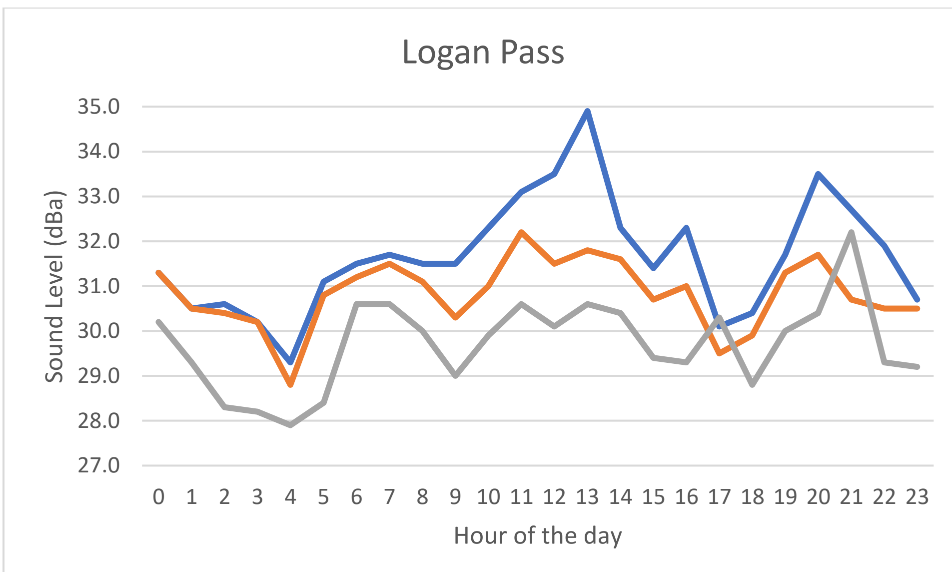

Figure 27: Logan Pass hourly sound levels

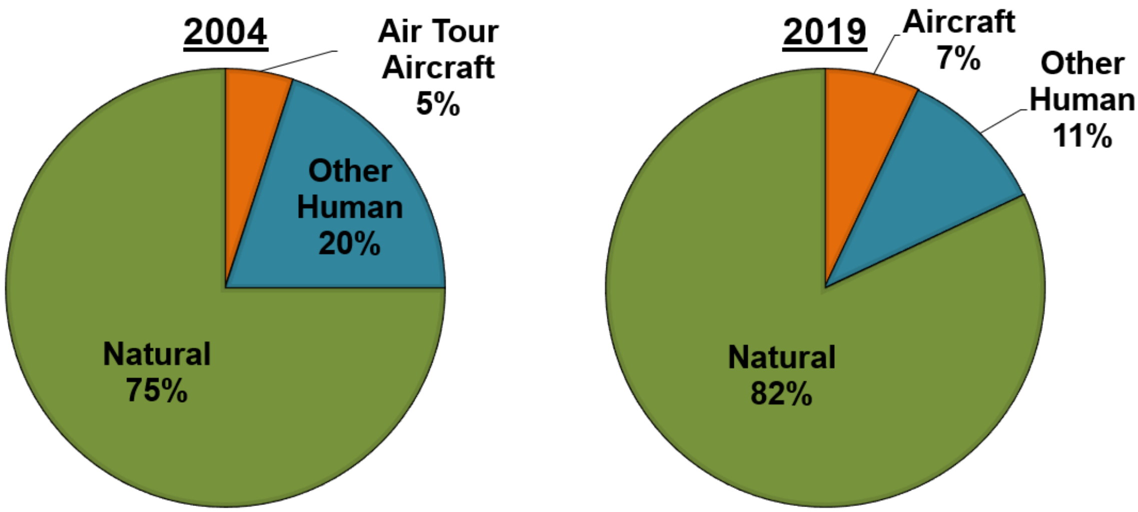

Figure 28: Logan Pass distribution of sound sources audible during acoustic observer logging

Table 14: Logan Pass 2004, 2019, and delta

Study	L_{Aeq} (dBa)	L_{50} (dBa)	L_{90} (dBa)
2004	35.2	31.9	28.6
2019	33.3	31.0	26.5
Δ	-1.9	-0.9	-2.1

4.2.2.1 Location Analysis

The equipment was set up in a clearing approximately a quarter mile from the Logan Pass Visitor Center. The observer log showcases that natural sound takes up most of the soundscape, with air traffic taking up 7%, and human noise taking up 11%. The decrease in sound due to other human sources is a result of the seasonal change. The study conducted in 2004 was completed in August during peak visitation, while the study in 2019 was completed in September, which sees a significant decrease. The main causes for human sound in this area were from motorcycles, sounds from humans themselves were barely audible. These changes of conditions are the causes for each value being lower.

4.2.3 Sperry

Table 15: Sperry campground description

Site ID	G03
Site Name	Sperry Campground
# Measurement Days and Dates	7 days 9/13/19 to 9/20/19
Latitude / Longitude (decimal degrees)	48.6024 / 113.7872
Approximate Elevation (ft)	6619
Ecological Domain	300 North American Dry Domain
Ecological Division	306 Rocky Mountain
Land Cover Class	4 Forested Upland
Land Cover Subclass	42 Evergreen Forest
General Management Plan Zone	Backcountry
Site Category	Backcountry
Site Description	Rocky / grassy surface just before campground entrance
Access Considerations	6.5-mile hike up Gunsight Mountain
Potential Sound Sources	Aircraft, Visitors, Goats, Wind

Figure 29: Sperry Campground photograph

Figure 30: Red the mule

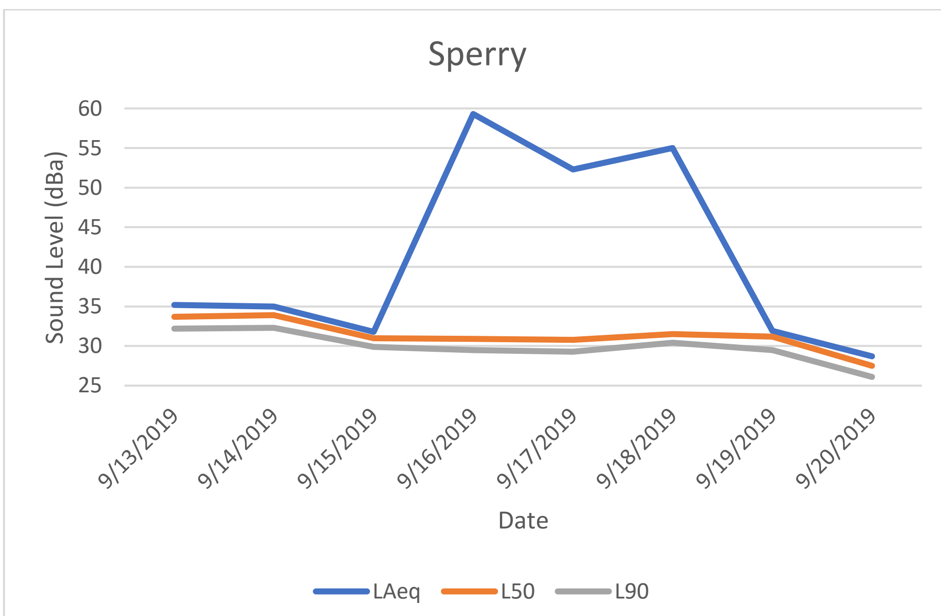

Figure 31: Sperry Campground daily sound levels

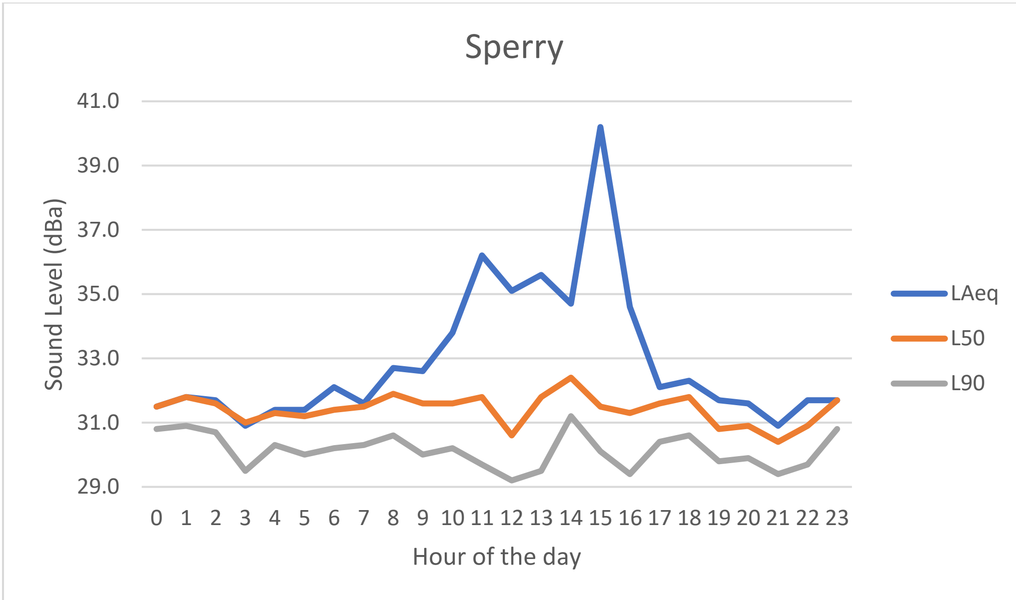

Figure 32: Sperry Campground hourly sound levels

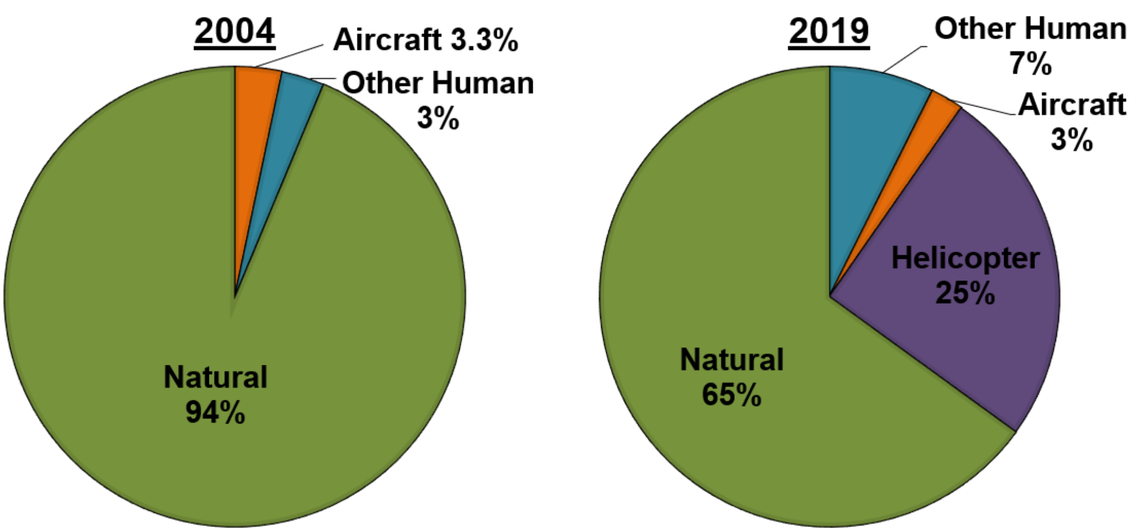

Figure 33: Sperry Campground distribution of sound sources audible during acoustic observer logging

Table 16: Sperry Campground 2004, 2019, and delta

Study	L_{Aeq} (dBa)	L_{50} (dBa)	L_{90} (dBa)
2004	36.3	34.2	32.3
2019	52.9	31.4	28.6
Δ	16.6	-2.8	-3.7

4.2.3.1 Location Analysis

A quarter mile from the Sperry Chalet, the equipment was set up on a hillside/clearing. The Sperry Chalet burned down during a wildfire in 2017, which lead to the park rebuilding it over the next couple of years. This construction resulted in sounds being heard from construction workers, equipment, and helicopters flying in to drop off supplies. As noted in the observer log, helicopters took up 25% of the sound. Had there been no situational noise, all the noises at Sperry would have been natural.

The reason the L_{Aeq} had increased so drastically, while the L_{50} and L_{90} had decreased, was a result of the helicopters. At one point, the sound levels had gone over 60 dB, which is enough for people to start losing hearing.

4.2.4 Harrison Creek

Table 17: Harrison Creek description

Site ID	G04
Site Name	Harrison Creek
# Measurement Days and Dates	7 days 9/21/19 to 9/28/19
Latitude / Longitude (decimal degrees)	48.49885 / 113.85956
Approximate Elevation (ft)	3393
Ecological Domain	300 North American Dry Domain
Ecological Division	306 Rocky Mountain
Land Cover Class	4 Forested Upland
Land Cover Subclass	41 Deciduous Forest
General Management Plan Zone	Backcountry
Site Category	Backcountry
Site Description	On a hillside in an evergreen forest
Access Considerations	2-mile hike after fording Flathead River
Potential Sound Sources	Aircraft, Train Horn, Watercraft, Visitors, Birds, Insects, Water, Wind

Figure 34: Harrison Creek photograph

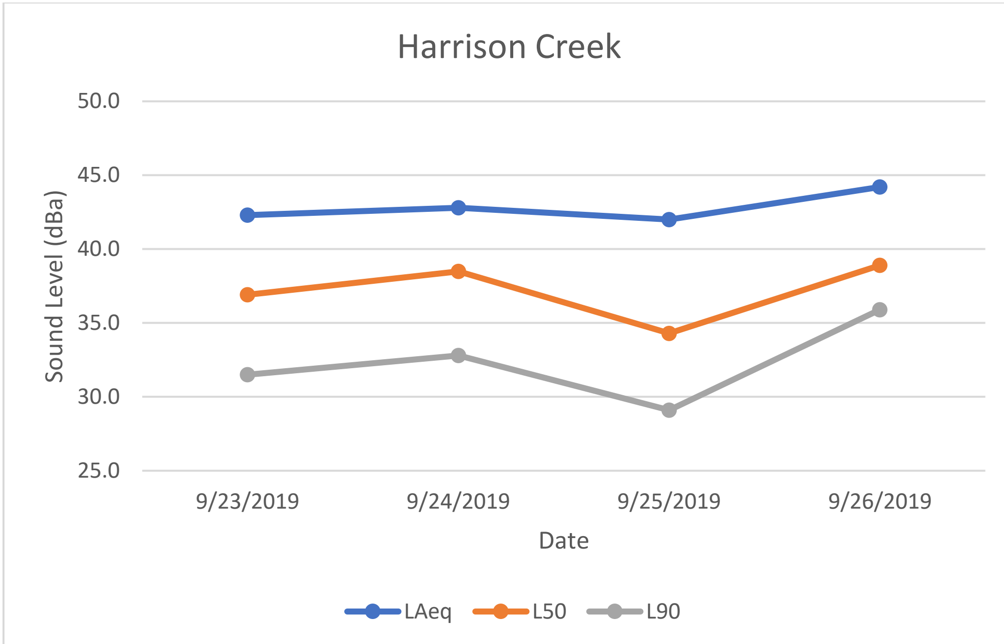

Figure 35: Harrison Creek daily sound levels

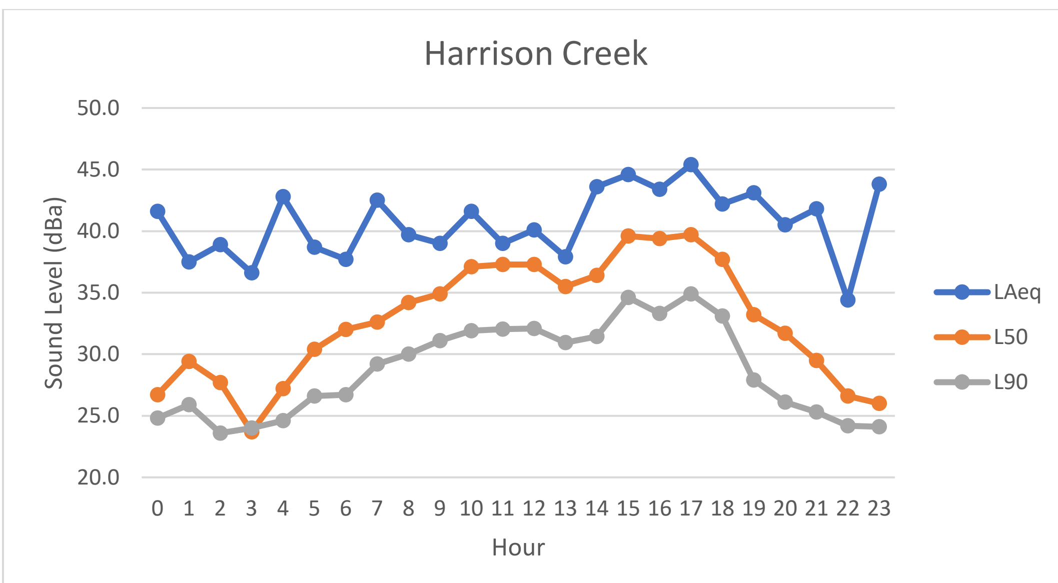

Figure 36: Harrison Creek hourly sound levels

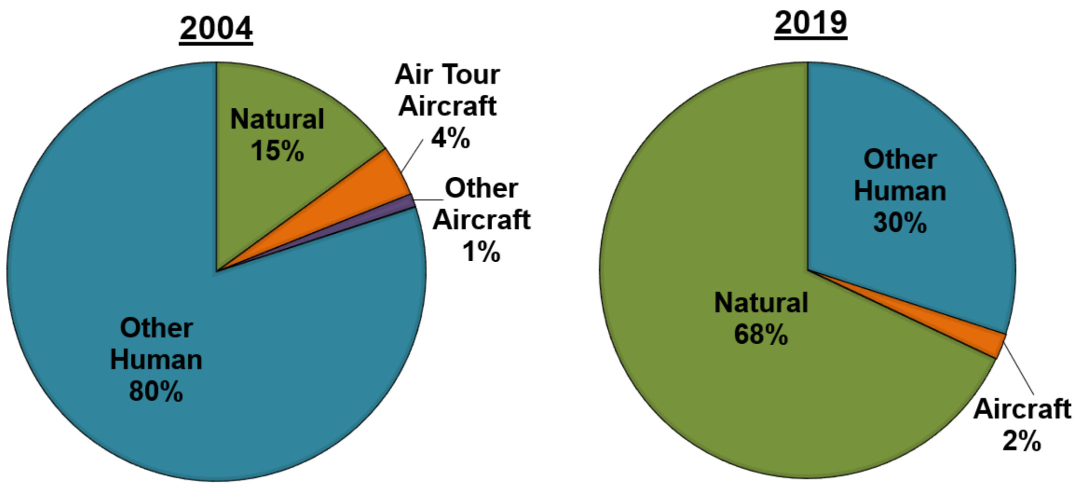

Figure 37: Harrison Creek distribution of sound sources audible during acoustic observer logging

Table 18: Harrison Creek 2004, 2019, and delta

Study	L_{Aeq} (dBa)	L_{50} (dBa)	L_{90} (dBa)
2004	42.9	31.3	24.1
2019	42.2	34.4	25.3
Δ	-0.7	3.1	1.2

4.2.4.1 Location Analysis

A half mile from a stop off the Middle Fork, the equipment was set up in a heavily wooded area. Due to complications from weather, the equipment had to be pulled several days early. As a result, the findings from the data collection are not as accurate as a full 7-day recording. Therefore, only the observer log will be discussed.

The 30% human noise was primarily sounds heard from the train that passed through the area. The later season was believed to be a main contributor for the sharp decrease in human sound, as in 2004, human sound took up over 80% of the soundscape. In 2004, they had reported that they could hear people going down the Middle Fork. When the 2019 equipment was set up, there was not a single person to be heard in the area. The percentage of aircraft sound has remained roughly the same.

5 Conclusions & Recommendations

5.1 State of noise in the park

Based off the findings from the 2019 study, aircraft noise over the 15-year period from 2004 to 2019 has stayed relatively the same, especially as a result of the park's policies regarding air tours and overflights.[35] More specifically, McDonald ranger station had a 5% increase, Logan Pass a 2% increase, Sperry Campground a .3% decrease and Harrison Creek a 3% increase in the duration of noise due to aircraft when compared to 2004. The slight increase in aircraft noise at some sites may be partially attributed to the increased accuracy and larger timeframe allocated for observer log recording.

Regarding the condition of natural sound throughout the park, this study found that overall, the park effectively preserves the natural soundscape as shown in the duration of noise-free natural sound that was recorded. McDonald ranger station's sound was 74% natural, Logan Pass' was 82%, Sperry Campground's 65% and Harrison creek's 68% natural.

It is worthwhile to note that there were several situational changes in the audible noise during this study that may be considered as outliers. The recent fire near Lake McDonald brought a sizable amount of noise from construction and heavy vehicles and a significant decrease in hiker noise. Harrison creek's recordings did not include the regular rafting traffic as a result of recording later in the season rather than at its peak. The Sperry Chalet was experiencing significant construction due to fire damage, and the period of recording for observer logs included a large amount of noise as a result of the frequent material deliveries via helicopters. Without the situational noise the sound at Sperry Campground would be roughly 90% natural.

Based off the study's findings, natural sound did not drastically change since 2004 even though there has been a significant increase in annual visitors, thus complimenting the effectiveness of the currently implemented sound preservation policies.

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[35] National Park Service. Policies and authorities.

5.2 Recommendations for the park

Due to this project aligning with the 2004 study, the locations were directed towards determining aircraft noise. Recommendations to Glacier would be to redirect the focus of sound studies towards visitors and vehicles along the GTSR corridor instead of aircraft. As mentioned in the previous section, there has been no concerning increase of aircraft noise, thus it can be concluded that for the park to better manage sound, working to monitor other causes of noise pollution would be beneficial. This would include developing new sites and creating another baseline study. By shifting analysis to along the Going-to-the-Sun Road, noise levels caused by vehicles could be better determined and modeled. This would open possibilities for Glacier management to work to mitigate and control noise in areas that are largely populated.

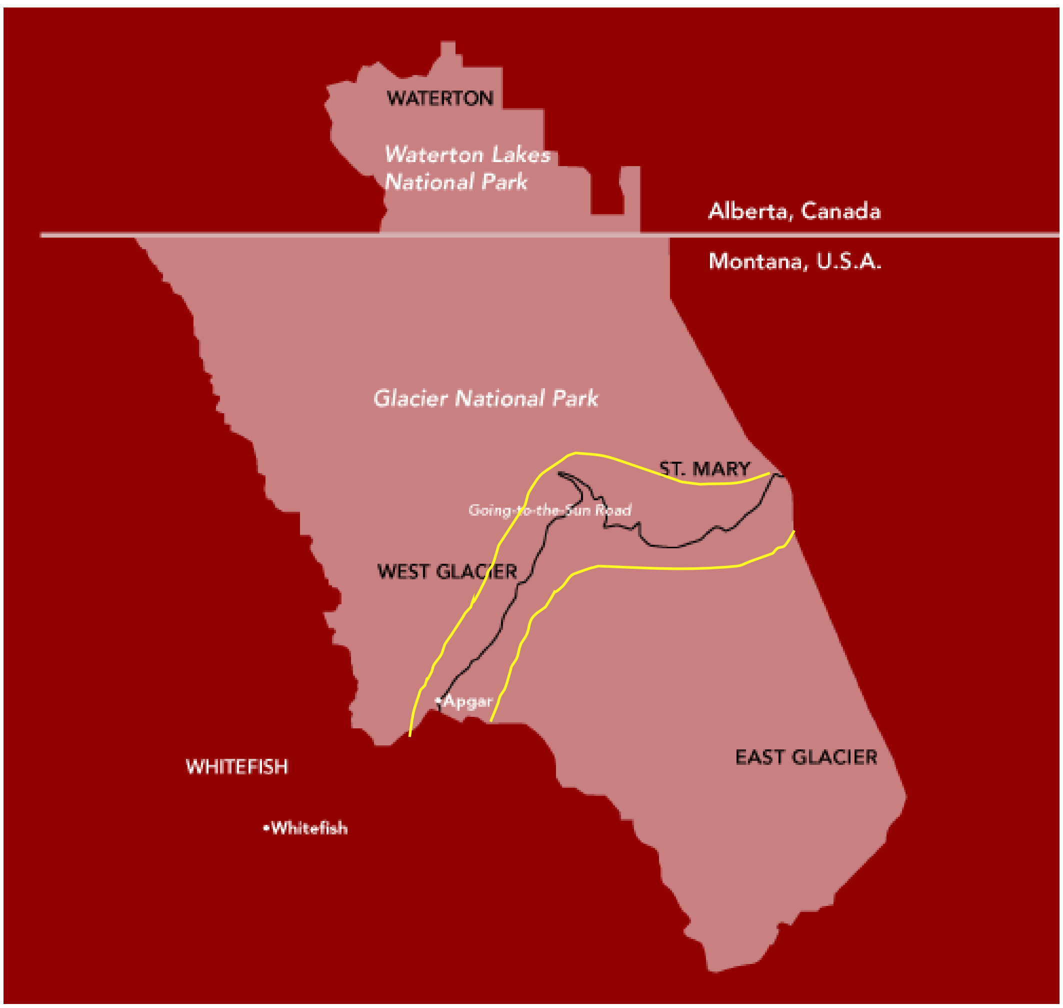

Figure 38: Going-to-the-Sun Road map

Complimenting moving the study to focus on the GTSR, extending the time period of the study would allow for more accuracy and eliminate outliers. As the NPS Natural Sounds states, "Periods of at least 25 days limit the uncertainty of ambient data to less than 3dB." [36] We suggest Glacier National Park extends future sound studies to 25 days at a minimum and repeats the studies annually or more frequently than 15-year periods. Having 15 years between studies cause for a lot of skewed results due to major changes to the park and its environment, this makes data more difficult to analyze.

Secondly, we recommend implementing an educational effort to inform the public of noise, the negative effects of unnatural sound, and how they can help. Most visitors to national parks plan their visit prior to arrival.[37] This implies most visitors access the Glacier National Park website. The current website has a single page regarding noise, then redirects to the Natural Sound website. The website should increase educating factors focused on noise and the effects of noise. In addition, on the website, whether under noise, or under planning your visit, the park should offer simple ways for visitors to help protect the natural soundscape. This could be as simple as making visitors aware that loud cars and reckless driving on the GTSR causes a large amount of noise pollution affecting other visitors and wildlife. Knowing that Glacier supports making noise while hiking for bear safety, suggesting visitors stay quiet in the woods is unnecessary. Educating visitors will at minimum make them aware of the effects of noise on the park.

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[36] National Park Service. In the field.
[37] Barrameda, C. Congestion management in Glacier National Park.

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7 Appendices

7.1 Appendix A Interview Questions and Answers

Question: What program does the NTi XL2 device used to collect the data on a computer?

Answer: The NTi devices can dump the data directly into excel.

Question: What is the battery life on the NTi XL2? We will need to have it running for 8 full days at a time.

Answer: The XL2 will need a large battery such as a car battery to be self-sufficient for 8 days.

Question: If we have a microphone that is not weather proof, is there any way to weather-proof the mic without purchasing a weather-proof mic?

Answer: Yes, it depends on how much cover is available and the expected weather conditions.

Question: What devices is the WB-30 attachment compatible with?

Answer: It is for the M2230 mic, it is the only physical connection for the two devices.

Question: Could you provide the costs for an M2230 mic along with the WB30? Is there an education discount?

Answer:

Table 19: NTi Pricing

Item Number	Description	Unit Price	Quantity	Ext. Price
600 040 050	M2230 Measurement Microphone class 1 certified according to IEC 61672, 16-137 dB	$1,740.00	1	$1,740.00
600 040 060	Weather Protection WP30 for M2230 Measurement Microphone	$945.00	1	$945.00
			Discount	-$187.95
			Total	**$2,497.05**

Question: Is there any way to rent the WB30 attachment?

Answer: Yes, rental would be 15% of the purchase cost for two weeks or 20% for one month.

General information Brian offered during interview:

- NTi offers a program to easily analyze the data and reduce the time you need to listen to the data
- If there is 3G service, NTi can check if the device is working via cell connection so we will not have to go and check the device frequently
- Walked through the NTi website to show the team how to access directional videos, basic device information, and FAQ's
- If the university is okay will letting NTi have the data, then NTi can offer free additions and programs to ease our collection and analyzing process

7.2 Appendix B 2004 Study Data

Site ID	**Overall (entire 7-day period)**			**Daytime (7 AM - 7 PM)**			**Nighttime (7 PM - 7 AM)**		
	L_{Aeq} (dBa)	**L_{50} (dBa)**	**L_{90} (dBa)**	**L_{Aeq} (dBa)**	**L_{50} (dBa)**	**L_{90} (dBa)**	**L_{Aeq} (dBa)**	**L_{50} (dBa)**	**L_{90} (dBa)**
G01 Lake McDonald	36.7	28.8	24.9	37.4	29.3	24.8	35.8	38.8	24.9
G02 Logan Pass	35.2	31.9	28.6	36.1	30.5	27.9	34.1	33.1	30.1
G08 Sperry Campground	36.3	34.2	32.3	36.3	34.1	32.2	36.2	34.2	32.4
G05 Harrison Creek	42.9	31.3	24.1	41.6	32.9	26.5	43.9	29.0	22.9

Site ID	Hours of the day L_{Aeq}																							
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
G01	36.1	38.5	34.0	32.0	32.8	32.5	33.4	34.8	34.7	35.9	39.2	36.8	36.3	35.2	35.2	39.6	35.2	42.3	35.9	35.4	34.9	35.9	40.2	36.0
G02	35.3	34.1	33.9	33.6	32.6	31.7	33.7	33.6	35.1	35.4	35.6	36.7	37.6	38.5	35.3	39.8	33.6	33.3	33.9	34.6	34.5	34.6	35.0	33.7
G08	35.5	35.8	37.2	34.8	35.5	35.6	35.6	35.7	35.9	35.4	36.0	36.6	36.2	36.0	35.3	35.6	35.2	39.5	36.2	33.7	35.9	37.4	38.3	37.5
G05	44.6	45.1	43.3	43.1	42.0	42.1	42.9	43.1	43.1	42.0	42.6	41.2	41.3	43.3	41.8	40.1	40.5	40.0	40.0	41.5	43.9	42.4	48.3	42.0

Site ID	Hours of the day L_{50}																							
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
G01	28.7	28.5	27.8	27.6	27.5	27.6	28.6	28.5	29.6	27.8	28.3	29.1	29.3	29.2	29.2	30.0	30.4	30.7	31.2	30.9	30.3	29.5	28.5	28.2
G02	33.7	33.7	33.8	33.3	32.2	30.8	31.5	32.0	29.9	29.5	29.3	29.9	30.5	30.7	30.5	30.6	30.4	30.6	30.9	32.2	33.6	33.7	33.7	33.1
G08	34.3	34.3	34.4	34.2	34.4	34.6	34.7	34.5	34.4	34.3	34.5	34.6	34.9	34.7	34.0	33.6	33.3	32.9	33.1	33.1	33.9	34.2	34.8	34.5
G05	28.2	27.4	26.5	26.0	25.7	25.9	30.2	32.4	33.0	33.2	33.0	32.9	33.7	33.9	33.4	32.9	32.3	31.9	32.0	32.5	33.5	32.0	30.8	28.4

Site ID	Hours of the day L_{90}																							
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
G01	23.5	25.4	24.9	25.1	24.7	25.1	25.9	25.2	25.2	24.8	24.4	24.9	25.1	24.9	25.0	25.1	24.6	24.1	24.5	25.4	26.7	24.8	23.4	24.6
G02	31.2	30.6	30.4	29.7	29.5	28.8	29.1	29.0	27.2	26.7	27.1	27.8	28.4	28.5	28.6	28.2	28.4	28.6	28.8	30.0	31.0	31.6	31.5	30.9
G08	32.3	32.1	32.4	32.4	32.6	32.8	32.8	33.0	33.2	33.0	33.1	32.9	33.4	33.0	32.0	31.7	31.5	30.8	31.3	31.7	32.3	32.5	32.6	32.6
G05	23.0	22.6	21.6	20.5	20.4	21.4	23.6	24.7	26.2	26.5	26.8	27.0	27.2	28.3	27.5	27.1	26.4	26.0	25.2	26.3	26.5	25.6	24.7	23.5