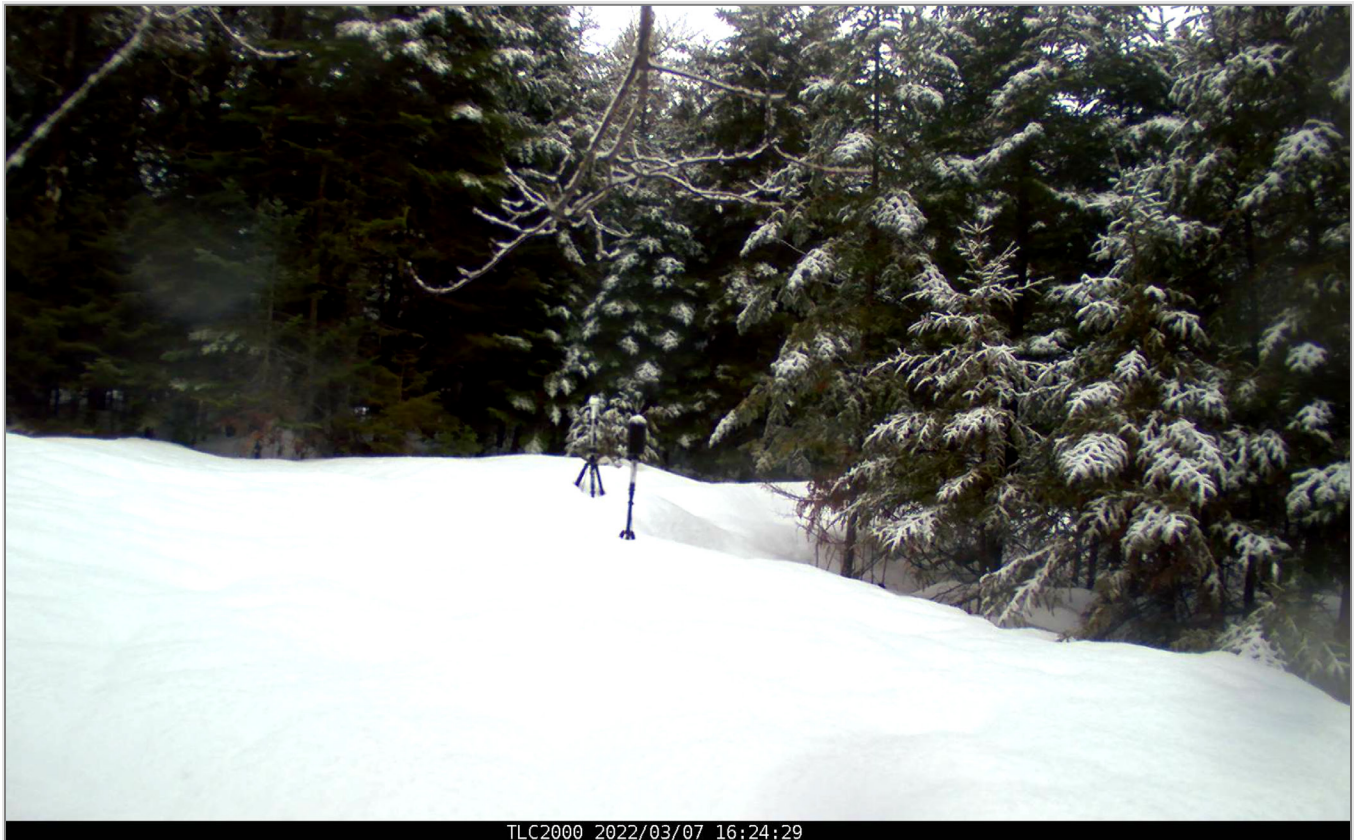




Katahdin Woods and Waters National Monument

Acoustic Monitoring Report 2022



Acoustic monitoring in Katahdin Woods and Waters National Monument
NPS / NATURAL SOUNDS PROGRAM

Katahdin Woods and Waters National Monument: Acoustic monitoring report 2022

Science Report NPS/SR—2025/305

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Please cite this publication as:

Olstad, T. A., and E. Meyer. 2025. Katahdin Woods and Waters National Monument: Acoustic monitoring report 2022. Science Report NPS/SR—2025/305. National Park Service, Fort Collins, Colorado. <https://doi.org/10.36967/2313208>

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Abstract

This study arose from Technical Assistance Request 17695 submitted by Katahdin Woods and Waters National Monument (KAWW) in 2020. As park managers and partners embarked on planning efforts for facilities, roads, and trails, they sought an acoustic inventory to better understand baseline conditions and sources of noise throughout the unit. In winter 2022, the National Park Service (NPS) Natural Sounds and Night Skies Division (NSNSD) successfully gathered acoustic data at 3 sites in KAWW: near Grondin Road, Katahdin Loop Road Entrance, and Haskell Gate. Overall, existing ambient sound levels (L_{A50}) at sites within KAWW during the sample period ranged from 27.5–30.5 dB during the day and 21.0–31.2 at night, with the lowest daytime levels at Haskell Gate and lowest nighttime levels at the Loop Road entrance. Natural ambient sound levels (L_{Anat}) ranged from 25.8–27.4 dB during the day and 19.7–30.5 dB at night. Impacts, defined as the difference in dB between the existing L_{A50} and natural L_{Anat} , were between 0.7–4.5 dB. Across all the monitoring locations, noise was present 19–48 percent of the time. The most common noise sources were over-snow vehicles and aircraft, with both most commonly audible at the Loop Road entrance. Natural sounds included wind, precipitation, and birdcalls.

Acknowledgements

Warren Deeds and Scott McFarland collected the data for the Natural Sounds and Night Skies Division. The authors would like to acknowledge the staff at Katahdin Woods and Waters National Monument for their support with fieldwork, logistics, and data interpretation, notably Isabel Ashton and Mark Wimmer. We also thank Emma Brown and Davyd Betchkal for their thoughtful review, and recommendations that improved this series of reports.

List of Terms or Acronyms

A-weighting: A-weighting is applied to sound levels to account for the sensitivity of the human ear (Harris, 1998). To approximate human hearing sensitivity, A-weighting discounts sounds below 1 kHz and above 6 kHz.

Acoustic Environment: A combination of all the physical sound resources within a given area. This includes natural sounds and cultural sounds, and non-natural human-caused sounds. The acoustic environment of a park can be divided into two main categories: intrinsic and extrinsic.

Acoustic Resources: Includes both natural sounds like wind, water, and wildlife, and cultural and historic sounds like tribal ceremonies, quiet reverence, and battle reenactments.

Amplitude: The relative strength of a sound wave, described in decibels (dB). Amplitude is related to what we commonly call loudness or volume.

ANS Weighting: The Natural Sounds modification to A-weighting eliminates high-frequency sound (leaf rustle, equipment noise, and biologic sounds) allowing for more accurate comparisons of low-frequency ambient sound levels across different land use types (e.g., urban, protected areas; ANSI S3/SC1.100, 2014 [R2020]). This frequency weighting scheme improves ambient sound level measurements in quiet environments.

Audibility: The ability of animals with normal hearing, including humans, to hear a given sound. It can vary depending upon the frequency content and amplitude of sound and by hearing ability of individual animals.

Decibel (dB): A unit of sound energy. Sound levels are measured on a logarithmic scale relative to the reference sound pressure for atmospheric sources, 20 μ Pa. The logarithmic scale is a useful way to express the wide range of sound pressures perceived by the human ear. Every 10 dB increase represents a tenfold increase in energy. Therefore, a 20 dB increase represents a hundredfold increase in energy.

Existing ambient sound level (L_{A50}): Sound level ($L_{Aeq,1s}$) exceeded 50% of the time (50th percentile) for a specified duration. This level is referred to as the existing ambient sound level and the preferred metric for chronic conditions, as it is insensitive to infrequent loud events.

Frequency: Related to the pitch of a sound, and defined as the number of times per second that the wave of sound repeats itself and is expressed in terms of hertz (Hz). Sound levels are often adjusted (“weighted”) to match the hearing abilities of a given animal. In other words, different species of animals and humans are capable of hearing (or not hearing) at different frequencies. Humans with normal hearing can hear sounds between 20 Hz and 20,000 Hz, and as low as 0 dB at 1,000 Hz. Bats, on the other hand, can hear sounds between 20 Hz and 200,000 Hz.

Percentile sound levels (L_{A10} , L_{A50} , L_{A90}): Metrics used to describe A-weighted sound pressure levels (L), in decibels, exceeded 10, 50, and 90 percent of the time, respectively. Put another way, half the time the measured levels of sound are greater than the L_{A50} value, while 90 percent of the time the measured levels are higher than the L_{A90} value and 10 percent of the time measured levels are higher than the L_{A10} value.

Day-Night average sound levels (L_{dn}): Average equivalent sound level over a 24-hour period, with a 10-dB penalty added for sound levels between 10 p.m. and 7 a.m.

Energy Equivalent Sound Level (L_{Aeq}): The sound energy level averaged over the measurement period. Generally, refers to A-weighted 1-second time averaged sound levels measured between 12.5 Hz and 20 kHz. This is a standard measurement collected using NSNSD acoustic monitoring protocol for sound level meters. Sound levels measured over 1 second intervals are used to calculate summary statistics, specifically percent of the time a sound level of interest is exceeded.

Natural Ambient Sound Level (L_{Anat}): The natural sound conditions in parks, which would exist in the absence of any human-caused noise sources. L_{Anat} is the preferred metric to represent baseline or reference conditions.

Noise Free Interval (NFI): The length of the continuous period during which no human-caused sounds are audible.

Time Above: Within a defined period, the percent of the time sound levels ($L_{Aeq,1s}$) are above a specified sound level ($L_{Aeq,1s}$). Commonly used levels are 35, 45, 52 dB ($L_{Aeq,1s}$).

Time Audible: The amount of time that various sound sources are audible to humans with normal hearing, commonly expressed in percent of day, or percent of daytime hours and nighttime hours. A sound may be above natural ambient sound pressure levels, but still not audible. Similarly, some sounds that are below the natural ambient can be audible. Time Audible is useful because of its simplicity. It is a measure that correlates well with visitor complaints of excessive noise and annoyance. Most noise sources are audible to humans at lower levels than virtually all wildlife species. Therefore, time audible is a protective proxy for wildlife. These data can be collected either by a trained observer (on-site listening) or by making high-quality digital recordings for later playback (off-site listening).

Sound Exposure Level (SEL): The total sound energy of the actual sound during a specific time period. SEL is usually expressed using a time period of one second.

Sound Pressure: Minute change in atmospheric pressure due to passage of sound that can be detected by microphones.

Sound vs. Noise: Sound and noise are often used interchangeably to describe an acoustic source. A common definition of noise is unwanted sound or sounds that interfere with a signal of interest (Harris 1998; Templeton 1997). However, noise is not a purely subjective designation. Any sound

that serves no function is noise. Most sounds produced by human transportation and other machinery are unintended and serve no function, therefore are noise regardless of the attitudes of the listener. While there are unintended sounds in nature, like the footfalls of an animal, these sounds provide vital cues for some receivers and are therefore considered sounds to the receiver, yet noise from the perception of the producer.

Soundscape: The human perception of physical sound resources.

Executive Summary

This report presents acoustic data gathered by the Natural Sounds and Night Skies Division (NSNSD) at Katahdin Woods and Waters National Monument (KAWW) in winter 2022. Data were collected successfully at 3 sites to provide park managers with information about the acoustical environment, sources of noise, and the existing ambient sound levels within the park: near Grondin Road (KAWW001), Katahdin Loop Road Entrance (KAWW002), and Haskell Gate (KAWW004).

In these deployments, sound pressure level (SPL) was measured continuously every second by a calibrated sound level meter. Other equipment included an anemometer to collect wind speed and a digital audio recorder collecting continuous recordings to document sound sources. In this document, “sound pressure level” refers to broadband (12.5 Hz–20,000 Hz), A-weighted, 1-second time averaged sound level ($L_{Aeq,1s[12.5-20,000\text{ Hz}]}$), and hereafter referred to as “sound level.” Sound levels are measured on a logarithmic scale relative to the reference sound pressure for atmospheric sources, 20 μPa . The logarithmic scale is a useful way to express the wide range of sound pressures perceived by the human ear. Sound levels are reported in decibels (dB). A-weighting is applied to sound levels to account for the response of the human ear (Harris, 1998). To approximate human hearing sensitivity, A-weighting discounts sounds below 1 kHz and above 6 kHz. For reference, Table 1 provides examples of sound levels measured in parks compared to sound levels of common sources.

Table 1. Sound level examples.

Park Sound Sources	Common Sound Sources	Sound Level dB ^A
Volcano crater (HALE)	Human breathing at 3 m	10
Leaves rustling (CANY)	Whispering	20
Crickets at 5 m (ZION)	Residential area at night	40
Conversation at 5 m (WHMI)	Car at 15 m, 30 mph	60
Cruiser motorcycle at 15 m (BLRI)	Curbside of busy street	80
Thunder (ARCH)	Jackhammer at 2 m	100
Military jet at 100 m AGL (YUCH)	Train horn at 1 m	120

^A dB re 20 μPa A-weighted broadband (12.5 Hz–20 kHz), sound level measured over varied measurement durations and at the distances indicated.

Overall, existing ambient sound levels (L_{A50}) at sites within KAWW ranged from 27.5–30.5 dB during the day and 21.0–31.2 dB at night during the sampling period. Table 2 reports the percent of time that measured levels at the monitoring locations were above four key sound level values. The first value, 35 dB ($L_{Aeq,1s}$), is used by the NPS as an indicator of overall quality of the acoustic environment. Beyond this level, noise begins to negatively affect the visitor experience in an otherwise natural acoustic environment (Pilcher et al., 2009; Watts et al., 2020; Betchkal et al., 2023). Moreover, sound events as low as 35 dB can adversely affect sleeping humans (Haralabidis *et al.* 2008). The second value addresses the World Health Organization’s recommendations that noise

levels inside bedrooms remain below 45 dB ($L_{Aeq,1s}$) (Berglund et al. 1999). As wildlife begin to exhibit signs of disturbance at noise levels as low as 40 dB (Shannon et al. 2016), 45 dB also represents a conservative estimate of negative effects on wildlife. The third value, 52 dB ($L_{Aeq,1s}$), is based on the EPA's speech interference level for speaking in a raised voice to an audience at 10 meters (EPA 1974). This value addresses the effects of sound on interpretive presentations in parks. The final value, 60 dB ($L_{Aeq,1s}$), provides a basis for estimating speech interference on normal voice communications at 1 meter. Visitors viewing scenic areas in the park would likely be conducting such conversations.

Sound levels are often measured over narrow frequency bands (typically in one-third octave bands between 12.5 Hz–20 kHz) because these smaller bands closely represent how humans distinguish between frequencies of sound. In this study, we examine how often sound levels exceeded key values in two frequency ranges. The top value in each split-cell of Table 2 uses the full frequency range (12.5 Hz–20 kHz) collected, whereas the bottom value focuses on frequencies affected by low frequency noise sources (20–1,250 Hz). This Natural Sounds modification to A-weighting (referred to as A-weighted Natural Sounds (ANS) weighting, ASA/ANSI S3/SC1.100-2014 [2020]) eliminates high-frequency sound (leaf rustle, equipment noise, and biologic sounds) allowing for more accurate comparisons of low-frequency ambient sound levels across different land use types (e.g., urban, protected areas; ASA/ANSI S3/SC1.100-2014 [2020]). This frequency weighting scheme improves ambient sound level measurements in quiet environments. For instance, in the full frequency range, the 35 dB ($L_{Aeq,1s}$) level was exceeded 12.19–31.17% of the time during the day and 8.29–35.97 % of the time at night, but in the 20–1,250 Hz range, the 35 dB functional sound level value was exceeded 7.35–23.84 % of the time during the day and 3.51–32.18 % of the time at night. Notably, 60 dB ($L_{Aeq,1s}$)—the level at which conversational speech may be interrupted—was not exceeded at any of the sites, and 52 dB ($L_{Aeq,1s}$)—the level at which interpretive programs may be interrupted—was exceeded 0.56% of the time or less.

After data collection was complete, trained technicians listened to the audio recordings to identify noise sources and calculate how often they were audible. See Methods section for protocol details, equipment specifications, and metrics calculations. Sound source analysis revealed that noise was audible about 19.2–47.5% of the time during the sampling period, averaged across all hours of the day (Table 3). The most common noise sources observed during this study were over-snow vehicles and aircraft. Natural sources such as wind, precipitation, and birdcalls were also commonly audible, especially during daytime hours. Natural ambient sound levels (L_{Anat}) ranged between 25.8–27.4 dB during the day and 19.7–30.5 dB at night. Calculating the difference between estimated natural ambient sound levels and existing ambient sound levels, anthropogenic noise increases noise levels by about 1.7–4.5 dB during the day and a mere 0.7–1.3 dB at night. As an increase of 3 dB is detectable by humans, the acoustic environment at KAWW experienced some noticeable effects of noise during the daytime, but the nighttime acoustic environment remained remarkably natural during the sampling period.

Table 2. Percent time above metrics for acoustic records collected in Katahdin Woods and Waters National Monument (KAWW) in Winter, 2022. Sound level functional values are displayed in decibels (dB LAeq, 1s re 20 µPa). The percent of time ANS-weighted sound levels (20–1,250 Hz) are above functional values.

Site Name	Frequency Range (Hz)	Time Above Sound Level (% of Daytime Hours, 07:00–19:00)				Time Above Sound Level (% of Nighttime Hours, 19:00–07:00)			
		35 dB	45 dB	52 dB	60 dB	35 dB	45 dB	52 dB	60 dB
KAWW001	Full (12.5–20,000)	12.19	0.26	0.02	0	8.29	0.16	0.00	0
KAWW001	ANS (20–1,250)	7.35	0.16	0.03	0	3.51	0.05	0.00	0
KAWW002	Full (12.5–20,000)	31.17	1.84	0.13	0	15.15	0.99	0.03	0
KAWW002	ANS (20–1,250)	23.84	0.93	0.07	0	10.46	0.27	0.00	0
KAWW004	Full (12.5–20,000)	19.03	1.44	0.09	0	35.97	7.44	0.56	0
KAWW004	ANS (20–1,250)	12.73	0.82	0.03	0	32.18	5.11	0.32	0

Table 3. Summary sound levels at Katahdin Woods and Waters National Monument (KAWW) in Winter, 2022. Included for each site are 90th percentile (LA10), existing (LA50), and 10th percentile (LA90) ambient sound levels (dB re 20 µPa, A-weighted broadband, 12.5 Hz–20 kHz) during the day (0700–1900) and night (1900–0700). L_{Anat} is calculated based on sound source identification from audio recordings.

Site Name	Mean Time Audible for Noise (% Of 24-Hour Period)				Median Existing Ambient (LA50) In Db		Median Natural Ambient (L _{Anat}) In Db	
	Noise	Aircraft	Motors	Over-snow Vehicles	Day	Night	Day	Night
KAWW001	41.0	10.1	13.5	17.8	29.4	26.8	27.4	26.0
KAWW002	47.5	16.7	8.5	21.5	30.5	21.0	26.0	19.7
KAWW004	19.2	11.4	2.1	4.2	27.5	31.2	25.8	30.5

Introduction

A 1998 survey of the American public revealed that 72 percent of respondents thought that providing opportunities to experience natural quiet and the sounds of nature was a very important reason for having national parks, while another 23 percent thought that it was somewhat important (Haas & Wakefield 1998). In another survey specific to park visitors, 91 percent of respondents considered enjoyment of natural quiet and the sounds of nature as compelling reasons for visiting national parks (McDonald et al. 1995). A 2018 comprehensive survey of the American public revealed that 88 percent of respondents indicated hearing the sound of nature/quiet was an important or very important reason for their last visit to a NPS unit (Resource Systems Group and Wyoming Survey and Analysis Center 2019). Acoustic monitoring provides a scientific basis for assessing the status of acoustic resources, identifying trends in resource conditions, quantifying impacts from other actions, assessing consistency with park management objectives and standards, and informing management decisions regarding desired future conditions.

The Natural Sounds and Night Skies Division (NSNSD) helps parks manage sounds in a way that protects park resources and the visitor experience. The NSNSD addresses acoustic issues raised by Congress, NPS Management Policies, and NPS Director's Orders. The NSNSD works to protect, maintain, or restore acoustic environments throughout the National Park System. Its goal is to provide coordination, guidance, and a consistent approach to soundscape protection with respect to park resources and visitor use. The program also provides technical assistance to parks in the form of acoustic monitoring, data processing, park planning support, and comparative analyses of acoustic environments.

The National Park Service Organic Act of 1916 states that the purpose of national parks is "... to conserve the scenery and the natural and historic objects and the wild life therein and to provide for the enjoyment of the same in such manner and by such means as will leave them unimpaired for the enjoyment of future generations." In addition to the NPS Organic Act, the Redwoods Act of 1978 affirmed that, "the protection, management, and administration of these areas shall be conducted in light of the high value and integrity of the National Park System and shall not be exercised in derogation of the values and purposes for which these various areas have been established, except as may have been or shall be directly and specifically provided by Congress." NPS Management Policies 2006 Chapter 4.9 provides direction for management of natural soundscapes:

"The National Park Service will preserve, to the greatest extent possible, the natural soundscapes of parks..."

"The Service will restore to the natural condition wherever possible those park soundscapes that have become degraded by unnatural sounds (noise) and will protect natural soundscapes from unacceptable impacts."

"Using appropriate management planning, superintendents will identify what levels and types of unnatural sound constitute acceptable impacts on park natural soundscapes. The

frequencies, magnitudes, and durations of acceptable levels of unnatural sound will vary throughout a park, being generally greater in developed areas. In and adjacent to parks, the Service will monitor human activities that generate noise that adversely affects park soundscapes [acoustic resources], including noise caused by mechanical or electronic devices. The Service will take action to prevent or minimize all noise that through frequency, magnitude, or duration adversely affects the natural soundscape [acoustic resource] or other park resources or values, or that exceeds levels that have been identified through monitoring as being acceptable to or appropriate for visitor uses at the sites being monitored” (NPS 2006a).”

It should be noted that under Management Policies 2006 Chapter 8.2.3, “[t]he natural ambient sound level—that is, the environment of sound that exists in the absence of human-caused noise—is the baseline condition, and the standard against which current conditions in a soundscape [acoustic resource] will be measured and evaluated” (NPS 2006c). However, the desired acoustic condition may also depend upon the resources and the values of the park. For instance, “culturally appropriate sounds are important elements of the national park experience in many parks” (NPS 2006b). In this case, “the Service will preserve soundscape resources and values of the parks to the greatest extent possible to protect opportunities for appropriate transmission of cultural and historic sounds that are fundamental components of the purposes and values for which the parks were established” (NPS 2006b).

Further guidance is provided in Management Policies 2006 §4.1.4 Partnerships, §4.1.5 Restoration of Natural Systems, §8.2 Visitor Use, §8.2.2 Recreational Activities, §8.2.3 Use of Motorized Equipment, and §8.4 Overflights and Aviation Uses (NPS 2006).

Director’s Order 47, Soundscape Preservation and Noise Management (2000) builds on the principles set out in Management Policies, directing park management how and when to consider acoustic resources. Through this order, parks are guided to manage noise by: identifying noise sources, minimizing noise from park operations, considering the acoustic environment in park planning documents, and promoting park sounds and noise management through communication, education, and outreach.

Focal Park Unit

Katahdin Woods and Waters National Monument (KAWW) was established in 2016 to

“...preserve the nationally significant natural, cultural, and ecological resources associated with Maine’s North Woods; to facilitate the shared stewardship of the resources, landscapes, and environments that contribute to the culture and identity of Penobscot Nation within their traditional homeland; to safeguard the character of the free-flowing and scenic rivers and streams within its boundaries; and to provide a broad range of opportunities for public enjoyment, recreation, and inspiration.”

Sitting within the traditional and current homeland of the Penobscot Nation, the 87,653 acre monument draws on a legacy of more than 11,000 years of stewardship. Once busy with logging

activity (and still surrounded by tracts that are actively logged), the monument now protects some of the least-developed watersheds and intact wildlands in the northeastern United States. Streams tumble down from mountainsides, rivers flow through valleys, and wetlands and ponds pool in flatlands, connecting the region in a vast hydrologic network that provides habitat for Atlantic salmon and brook trout and served as travel routes for Wabanaki peoples as well as transportation corridors for loggers. Lynx and moose pad and stomp through a mosaic of boreal forests and broadleaf deciduous woodlands, part of Maine’s famed North Woods. To the west, Katahdin—the “greatest mountain” in Penobscot, seen as sacred by Wabanaki people—dominates viewsheds and sits at the heart of Baxter State Park, a tract mandated to be kept forever wild. Recreational visitors enjoy opportunities for biking, hiking, fishing, hunting, scenic drives, skiing, snowshoeing, and snowmobiling. Lean-tos, huts, and campsites are available year-round, though as most roads aren’t plowed, winter adventurers have to work harder to get to reach overnight destinations. As the park’s website encourages, visitors can typically “enjoy the peace and quiet of the winter woods” (KAWW 2024a).

Compared with other NPS units, the park has limited infrastructure and services. The newly-constructed Tekəḱəpimək Contact Station, nestled near Lookout Mountain, is scheduled to open in summer 2025. Road access is limited, and all roads are unpaved. Notably, speed limits are set at 25 mph or, for the Loop Road and Seboeis River Road, just 15 mph. (Traffic at higher speed limits generates more noise.) Access beyond the road network is limited to non-motorized travel. In the winter, snowmobile use is limited to about 22 miles of trails in the eastern portions and corners of the park, following present and former logging roads. Routes may vary slightly by year (KAWW 2024b).

Beyond park boundaries, nearby and adjacent logging operations can generate what the park recognizes as “considerable noise” (KAWW, Plan Your Visit: Snowmobiling, 2024), but the park is otherwise remote from typical noise sources such as major urban areas, highways, airports, and industrial development.

As park managers and partners embarked on planning efforts for facilities, roads, and trails, they sought an acoustic inventory to better understand baseline conditions and sources of noise throughout the unit. In 2020, they submitted a Technical Assistance Request (#17695) to collect, analyze, and interpret acoustic data and provide park management with actions to protect the park’s natural acoustic environment. KAWW’s Foundation Document (2023) also identified a soundscape inventory as one of the data needs to help establish effective NPS Resource Stewardship.

Study Area

This report covers results from an acoustic inventory conducted at KAWW in February and March 2022. While the wintertime deployment wouldn’t capture typical summer sounds such as flowing water, rustling leaves, or human-caused car and boat traffic, it does enable better evaluation of quietude as well as understanding of noise caused by snowmobiles.

Originally, four sites were selected to represent a range of visitation, noise source, and habitat type (Table 4, Figure 1). KAWW001 in the northeast parcel was 50 meters from Grondin Road—a local

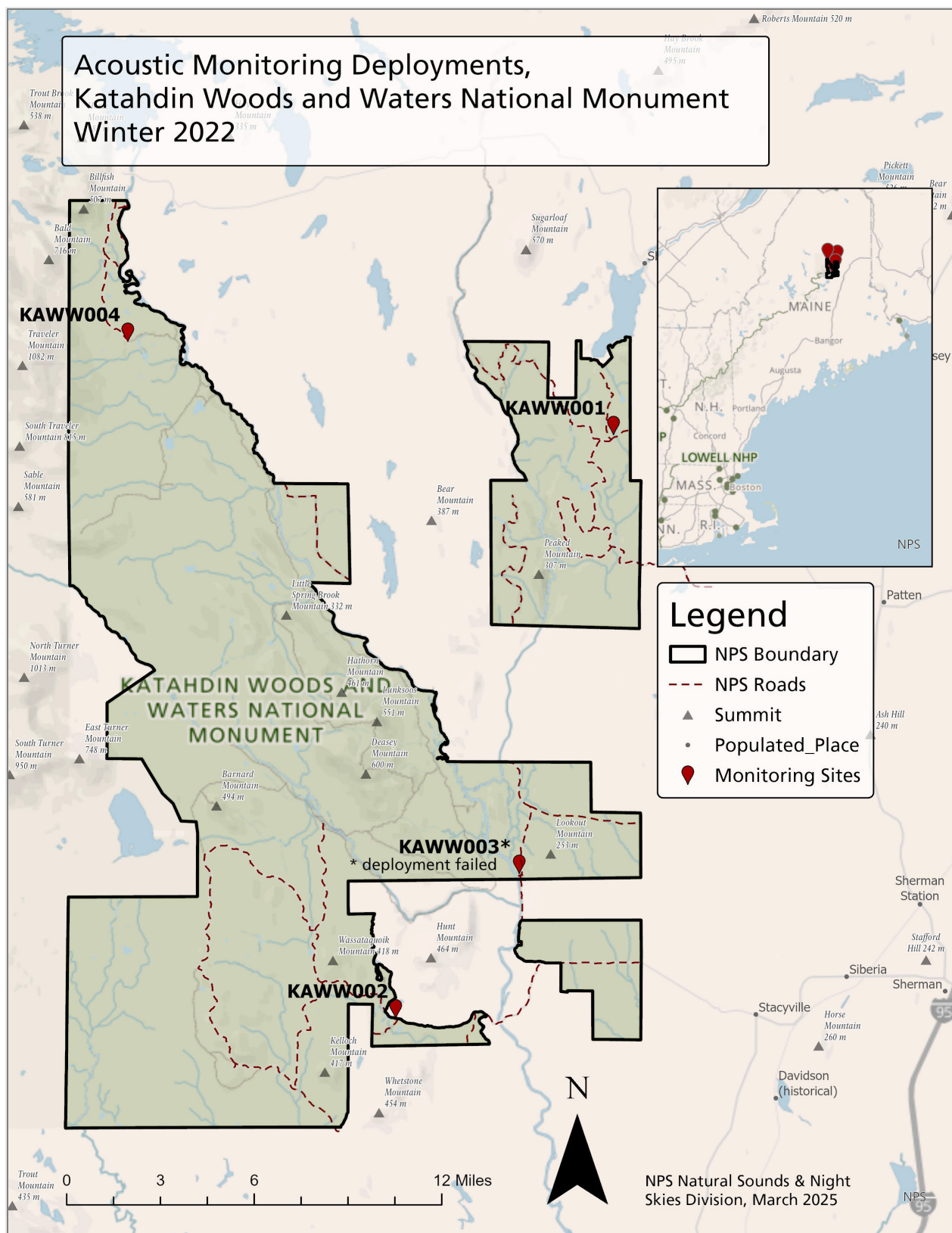
road open only to private traffic including logging vehicles. Official traffic counts documented 0 vehicles entering the park at this site in February 2022, though subsequent years saw 535 and 701 vehicle entries each February (NPS Stats). Notably, the acoustic monitoring site at Grondin was also frequented by wildlife, including an animal that seems to have interfered with the equipment on February 09, 2022. KAWW002 was just 25 meters south from the Katahdin Loop Road Entrance, near a heavily-used snowmobile route (Maine's Interconnected Trail System Corridor Trail [ITS] 85/86). KAWW003 was set up 50 meters north of the Lunksoos Boat Launch—a site that would be busy with boats and flowing water in the summer, but that was frozen in the winter. It too was near popular snowmobile route ITS 85, as well as Seboies Road, which experienced 6,106 vehicle entries in February 2022—the greatest number of documented vehicle entries for any entrance in any single month in park history (NPS Stats). Unfortunately, a malfunction in the equipment caused this deployment to fail and the data could not be analyzed. KAWW004 was tucked amid temperate coniferous forest and bare broadleaf deciduous trees near Haskell Gate in the northern part of the park—an area accessible to skiers, but with snowmobile use limited to park staff grooming trails.

In February through early March 2022, weather in the vicinity of KAWW (measured at the Millinocket Wastewater Treatment Facility and Millinocket Municipal Airport, NOAA NCEI) was slightly cooler and much wetter than usual for late winter in the North Woods. Low temperatures dropped into the -20°F – 0°F range, swinging up to lows in the 10°F – 20°F with near-weekly periodicity. February 17–18 saw a warm spell with lows above freezing. Highs also oscillated on about a weekly basis, between the 10°F – 20°F range to the 40°F – 50°F range. Maximum highs of 53 – 54°F occurred on February 23–24. Over the course of the month, the trend was for the temperature to increase, but only slightly, by a degree or two. Precipitation events were infrequent but intense, with 14” of snow falling between February 4–5 and another 9” on February 8–9. Moreover, the warm temperatures of February 23–24 accompanied a 1.36” rainfall event, bringing the total precipitation to 5.43”—nearly double the normal 2.48”.

Wind gusts only exceeded 5 m/s briefly in the afternoon of February 23. Otherwise, winds were consistent but very light, typically averaging 1 m/s or below across each hour, increasing slightly during daytime hours and quieting slightly overnight.

Table 4. Metadata for acoustical monitoring sites at Katahdin Woods and Waters National Monument, 2022.

Site	Site Name	Dates	Vegetation	Site Description	Elevation (m)	Latitude	Longitude
KAWW001	Grondin Road	• 02/01/2022–03/01/2022* • Wildlife interference 02/09/2022	Heavy vegetation & snow cover	50 m from road and possibly a trail. Local traffic on Grondin Road	260	46.050169	-68.571118
KAWW002	Katahdin Loop Road Entrance	02/02/2022–03/02/2022	Temperate coniferous forest, 25–50% canopy cover	25 m south from park road, 300 m from intersecting road. Near heavily-used snowmobile route. Very accessible in summer.	214	45.86244	-68.67193
KAWW003	Lunksoos Boat Launch	02/02/2022 - ?	Temperate broadleaf/mixed forest, 50–75% canopy cover	50 m north of boat ramp. 75 m east of river bank (frozen)	112	45.90900	-68.61474
KAWW004	Haskell Gate	02/03/2022–03/06/2022	Temperate coniferous and broadleaf/mixed, 25–50% canopy cover	50 m from trail. Park staff only allowable snowmobile use (grooming)	207	46.08011	-68.79582



Methods

Automatic Monitoring

A Larson Davis sound level meter (SLM) type 831-A was deployed at 3 monitoring sites. The SLM is a hardware-based, real-time analyzer which constantly records one-third octave band sound pressure level (SPL) data. This Larson Davis-based site met American National Standards Institute (ANSI) Type 1 standards (ANSI 1968 [R2020], 1983 [R2006], 1992 [2018]) for accurate survey-grade instrumentation. The sound level meter provided the information needed to calculate metrics described below in Calculation of Metrics.

Acoustic monitoring equipment is used by many practitioners to determine noise levels in different environments, both indoors and outdoors. The NPS uses equipment like that used by other practitioners but has developed a unique configuration that stands up to the potentially harsh environment encountered in national parks (National Park Service 2013). The microphone with environmental shroud was set up on a tripod at 1.5 m above the ground, which approximates the average height of the human ear. The digital audio recorder recorded continuous audio through the entire monitoring period (see details below on the acoustic record). An anemometer was attached to a tripod and placed approximately 10 feet from the microphone to capture local wind conditions.

The sampling station consisted of:

- Type 1 sound level meter
- Microphone with environmental shroud
- Preamplifier
- 12 V battery pack
- Ultrasonic anemometer (wind speed)
- Digital audio recorder

The sampling station was designed to collect:

- Flat-weighted, time-average sound level ($L_{Zeq,1s}$) for each one-third octave frequency band, 12.5–20,000 Hz in dB re 20 μ Pa [collected by Type 1 sound level meter].
- A-weighted, time-average sound level ($L_{Aeq,1s[12.5-20000\text{ Hz}]}$) in dB re 20 μ Pa [collected by Type 1 sound level meter].
- Continuous meteorological data for wind speed [collected by anemometer].
- Continuous digital audio recordings.

Monitoring Period

It is typical to monitor a minimum of 25 days to capture daily differences within a sampling period that occur at each site within a reasonable margin of error (NPS 2005). For this study, the monitoring period ranged from 21–38 days.

Calculation of Metrics

The status of the acoustical environment can be characterized by sound level (L_{A50} , L_{Anat} , L_{A90} , L_{A10} , L_{Aeq}) and frequency content, and event durations (through off-site listening). NPS uses descriptive figures and metrics to interpret these characteristics.

Two fundamental descriptors are existing ambient (L_{A50}) and natural ambient (L_{Anat}) sound levels. These are both examples of percentile levels, where each L_x value refers to the sound level that is exceeded x % of the time. The L_{A50} represents the median sound level and is drawn from a full dataset (removing data with wind speed > 5 m/s to eliminate error from microphone distortion). The L_{A50} is the preferred metric to represent prevailing acoustic conditions. The natural ambient (L_{Anat}) is an estimate of what the sound levels for a site would be if all human-caused noise sources were removed. L_{Anat} is the preferred metric to represent baseline or reference conditions.

For a given hour (or other specified time period), L_{Anat} is calculated to be the sound level exceeded x percent of the time, where x is defined by equation (1):

$$x = \frac{100 - P_H}{2} + P_H$$

where P_H = percentage of samples containing noise for the hour.

For example, if human caused sounds are present 30% of the hour, $x = 65$, and the L_{Anat} is equal to the L_{65} , or the level exceeded 65% of the time. To summarize and display these data, the median of the hourly L_{Anat} values for the daytime hours (0700–1900) and the median of the hourly L_{Anat} values for the nighttime (1900–0700) are displayed in graphical format in the following sections.

Off-Site Listening and Spectrogram Analysis

Listening Center Software Analysis

Off-site analysis is completed by listening to the audio record while simultaneously viewing its spectrogram representation (for more information on Listening Center software, see Appendix A). Auditory analysis was used to calculate the audibility of sound sources at each location. Trained technicians at Colorado State University (Figure 2) listened back to 8–10 days of the audio record per site. Technicians considered only a subsample of each day representing the first 10 seconds of every two-minute period. Within each subsample every audible sound source was categorized. This allowed the temporal extent of audibility for each source type to be estimated. The total percent time noise was audible was then used to calculate the natural ambient sound level (L_{Anat}) for each hour (see Equation 1 above for more information). For any off-site audio playback listening techniques, Bose Quiet Comfort Noise Canceling headphones were used to minimize limitations imposed by the office acoustical environment.



Figure 2. A Colorado State University student identifies sound sources using Acoustic Monitoring Toolbox (NPS) software.

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On-Site Listening

In addition to sound pressure level and audio data, knowledge of the type, context, duration, and distribution of sound sources is crucial for characterizing natural and non-natural acoustic conditions. This information can be acquired during periods of observer data collection, called on-site listening. During an on-site listening session, one inconspicuously listens to the soundscape and takes note of all audible events as they occur. For this technique, an observer sits quietly at a location at least 15 m from the acoustic monitor for one hour. At the top of the hour and once the observer is acclimated to the listening area, each sound heard is entered into a handheld device. Sound type, event count, and event duration are calculated from these sessions.

Results

Frequency Content

To determine the effect that noise has on the acoustic environment, it is useful to examine percentile metrics across a frequency range. High frequency sounds (such as a cricket chirping) and low frequency sounds (such as flowing water) often occur simultaneously, so the frequency spectrum is split into 33 narrower bands, each encompassing one-third of an octave. These narrow bands closely represent how humans distinguish between frequencies of sound. The percentile sound levels for 33 one-third octave band frequencies over the day and night periods are shown in Figures 3–5.

Examining the sound energy in each one-third octave band (combined with digital audio recordings) allows acoustic technicians to determine what types of sounds are contributing to the overall sound levels at a site. The grayed areas of Figures 3–5 represent sound levels outside of the typical range of human hearing. The percentile levels (L_x) are also shown for each one-third octave band. They represent the sound levels exceeded x percent of the measurement period. For example, L_{90} is the sound level that has been exceeded 90% of the time, and only the quietest 10% of the samples can be found below this point. On the other hand, the L_{10} is the sound level that has been exceeded 10% of the time, and 90% of the measurements are quieter than the L_{10} . The bold portion of the column represents the difference between L_{50} and L_{nat} . The height of this bold portion is a measure of the contribution of anthropogenic noise to the existing sound levels at this site. The size of this portion of the column is directly related to the percent time that human caused sounds are audible. When bold portions of the column do not appear the natural and existing sound levels were either very close to each other or were equal. The typical frequency levels for transportation, conversation, and songbirds are presented on the figure as examples for interpretation of the data. These ranges are estimates and are not vehicle-, species-, or habitat-specific.

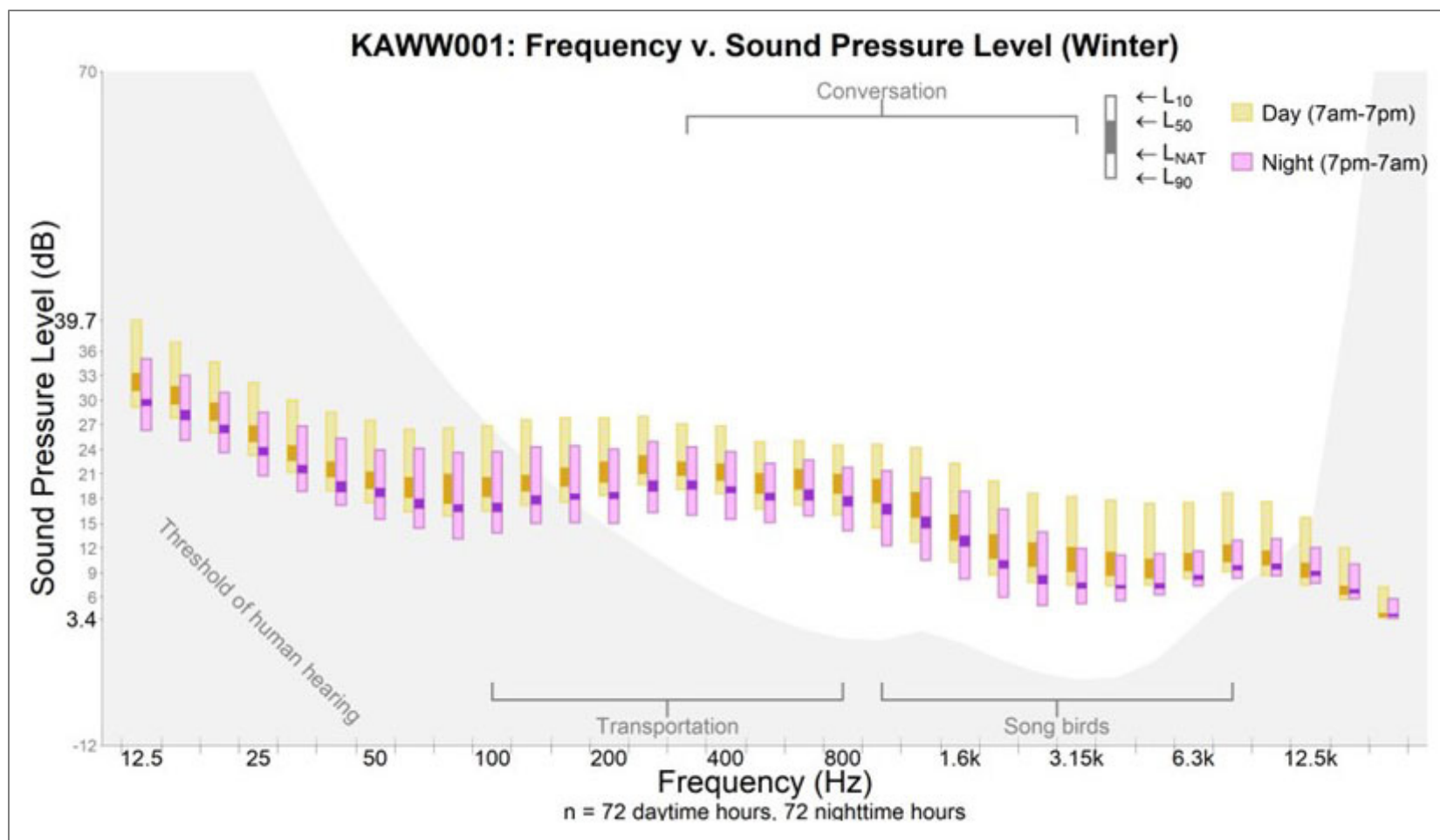


Figure 3. Day and night percentile sound pressure levels for 33 one-third octave bands at KAWW001 in winter, 2022. For each bar, the bold color indicates the range of existing (L_{50} ; upper) and natural (L_{nat} ; lower) sound pressure levels and visualizes the measured noise impact. For KAWW001, the very slim bars suggest that there is little difference between existing and natural sound pressure levels, or minimal noise impacts. Sound levels depicted are not A-weighted.

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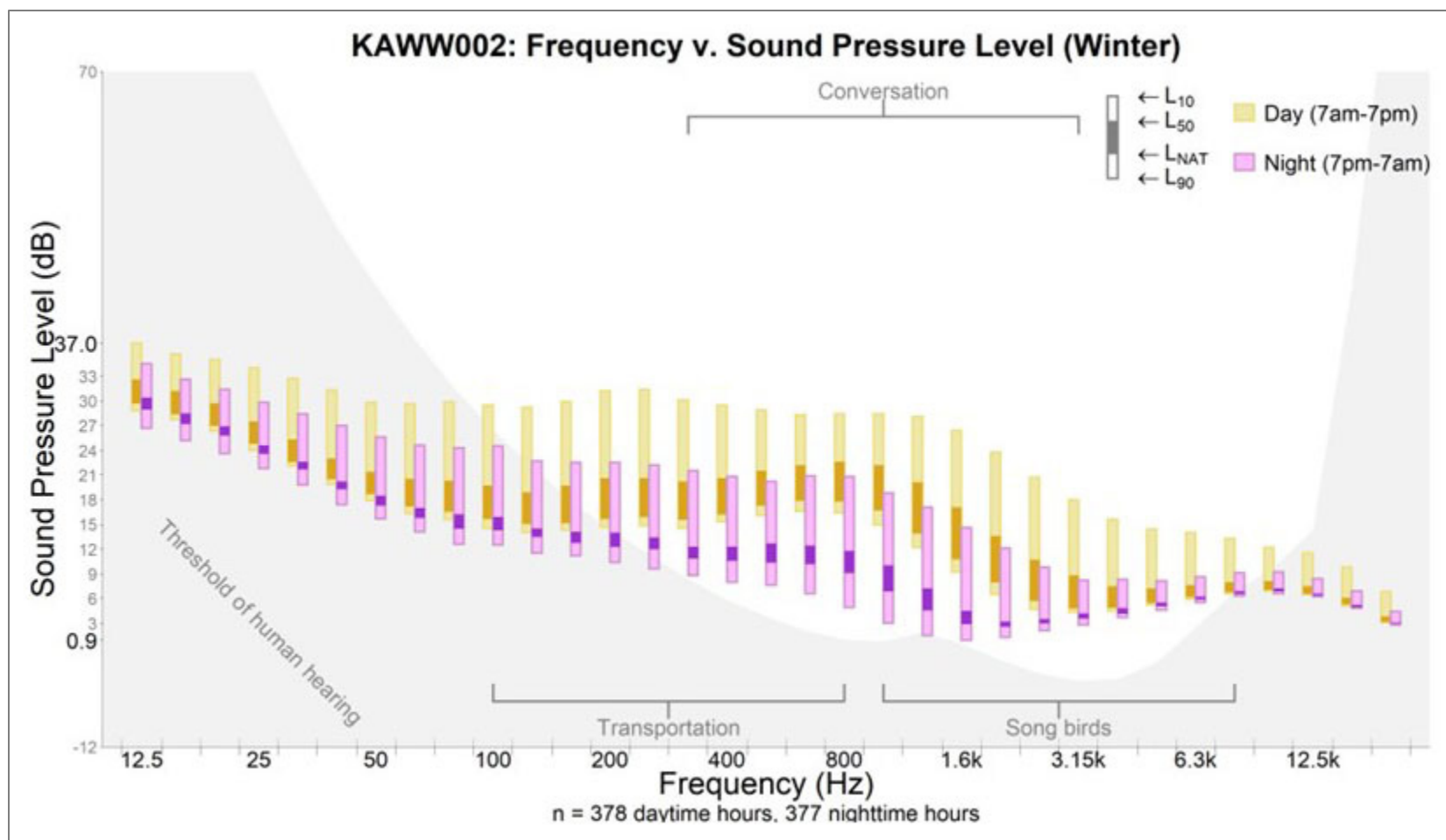


Figure 4. Day and night percentile sound pressure levels for 33 one-third octave bands at KAWW002 in winter 2022. For each bar, the bold color indicates the range of existing (L_{50} ; upper) and natural (L_{nat} ; lower) sound pressure levels, and visualizes the measured noise impact. For KAWW002, the larger bars suggest there is more noticeable difference between existing and natural sound pressure levels during the day. Also, the taller bars for daytime values suggest that the loudest sound levels are much greater than the quietest sound levels in the transportation frequencies. Sound levels depicted are not A-weighted.

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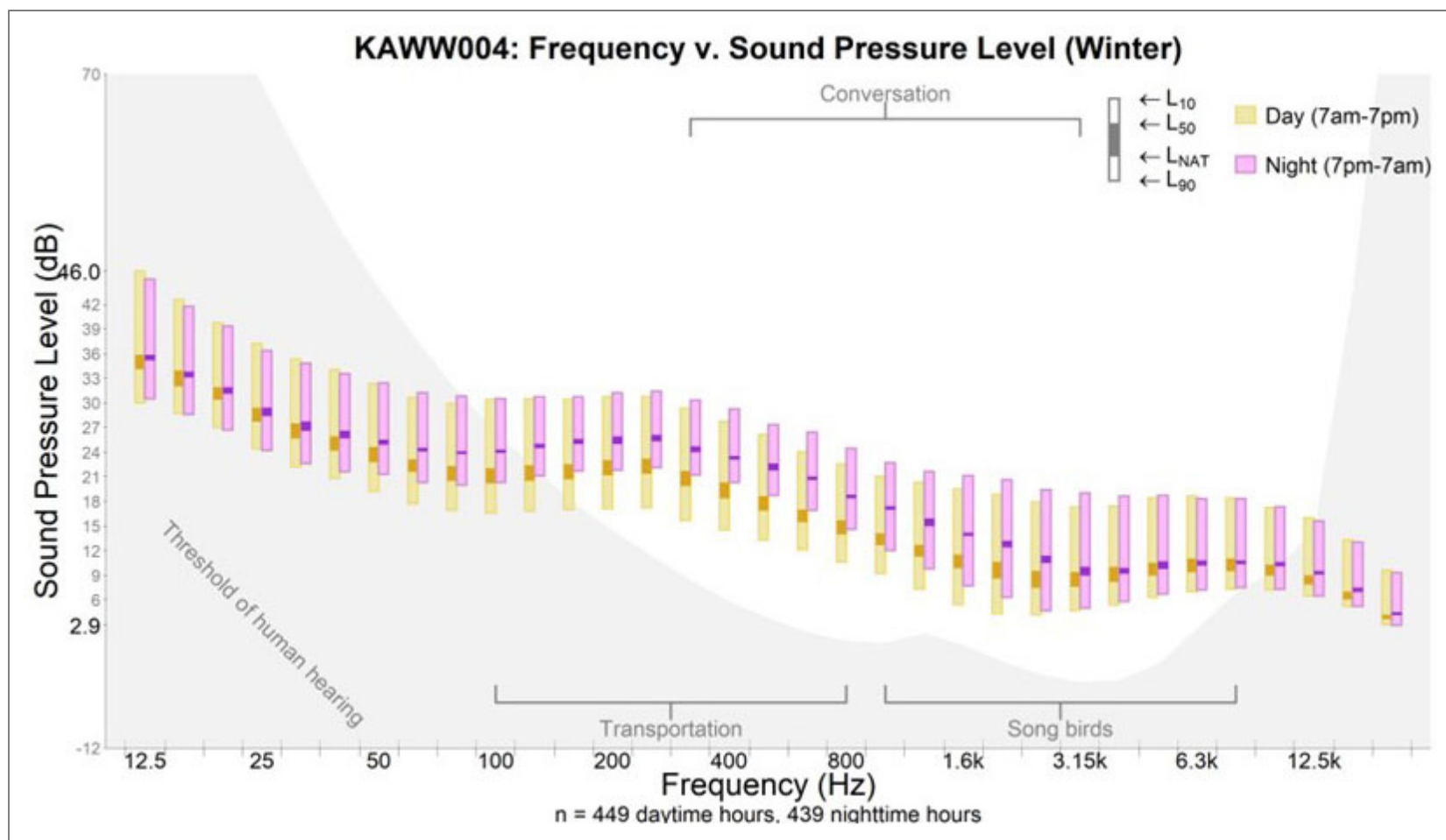


Figure 5. Day and night percentile sound pressure levels for 33 one-third octave bands at KAWW004 in winter 2022. For each bar, the bold color indicates the range of existing (L₅₀; upper) and natural (L_{nat}; lower) sound pressure levels. Sound levels depicted are not A-weighted.

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Sound level: Time Above

To understand how acoustic conditions in the park might affect visitors, measured sound levels are compared to sound levels of interest. Specifically, Table 5 reports the percent of time that measured sound levels ($L_{Aeq,1s}$) were above four key functional effect levels during the monitoring periods (daytime and nighttime). The top value in each split-cell uses the full frequency range, whereas the bottom values report the percentage of the sample that ANS-weighted sound levels (20–1,250 Hz) were above functional effect thresholds. Most motorized human-caused noise is confined to the truncated, lower-frequency range, while many natural sounds, including insects and birds, are higher in pitch. ANS weighting eliminates high-frequency sound (leaf rustle, and biologic sounds) allowing for more accurate comparisons of low-frequency ambient sound levels across different land use types (e.g. urban, protected areas; ANSI S3/SC1.100, 2014 [R2020]). This frequency weighting scheme improves ambient sound level measurements in quiet environments.

The first functional effect in Table 5, at 35 dB ($L_{Aeq,1s}$), is used by the NPS as an indicator of overall quality of the acoustic environment. Beyond this level, noise begins to negatively affect the visitor experience in an otherwise natural acoustic environment (Pilcher et al., 2009; Watts et al., 2020; Betchkal et al., 2023). Moreover, sound events as low as 35 dB can adversely affect sleeping humans (Haralabidis et al. 2008). At KAWW, the 35 dB ($L_{Aeq,1s}$) effect level was exceeded 12.19–31.17% of the time during the day and 8.29–15.15% of the time at night in the full frequency range. In the 20–1,250 Hz range, the 35 dB functional sound level value was exceeded less often: 7.35–23.84% of the time during the day and 3.51–32.18% of the time at night. Unusually, time above was longer at KAWW004 during nighttime hours than daytime hours, perhaps due to increased wind activity. Visual analysis of spectrograms (a type of plot showing sound levels by frequency over time) doesn't indicate any increase in non-natural sound sources at the site overnight (Appendix C).

The second functional effect is expected to occur around 45 dB ($L_{Aeq,1s}$). It addresses the World Health Organization's recommendations that noise levels inside bedrooms remain below 45 dB ($L_{Aeq,1s}$) (Berglund et al. 1999). As wildlife begin to exhibit signs of disturbance at noise levels as low as 40 dB (Shannon et al. 2016), 45 dB also represents a conservative estimate of negative effects on wildlife. At KAWW, this threshold was rarely exceeded during daytime hours in the full frequency range: just 0.26–1.84% of the time. As with the 35 dB threshold, however, sound levels at KAWW004 exceeded 45 dB more often in nighttime hours, up to 7.44% of the time.

The third functional effect is expected to occur around 52 dB ($L_{Aeq,1s}$), based on the EPA's speech interference threshold for speaking in a raised voice to an audience at 10 meters (EPA 1974). This threshold addresses the effects of sound on interpretive presentations in parks. The final functional effect at 60 dB ($L_{Aeq,1s}$) provides a basis for estimating impacts on normal voice communications at 1 meter, such as conversations visitors may have at an overlook or along a trail. Notably, the 60 dB threshold was exceeded 0.00% of the time at KAWW during the sampling period.

Table 5. Percent time above metrics for acoustic records collected in Katahdin Woods and Waters National Monument (KAWW) in Winter, 2022. Sound level functional values are displayed in decibels (dB $L_{Aeq, 1s}$ re 20 μ Pa). The percent of time ANS-weighted sound levels (20–1,250 Hz) are above functional values.

Site Name	Frequency Range (Hz)	Time Above Sound Level (% of Daytime Hours, 07:00–19:00)				Time Above Sound Level (% of Nighttime Hours, 19:00–07:00)			
		35 dB	45 dB	52 dB	60 dB	35 dB	45 dB	52 dB	60 dB
KAWW001	Full (12.5–20,000)	12.19	0.26	0.02	0	8.29	0.16	0.00	0
KAWW001	ANS (20–1,250)	7.35	0.16	0.03	0	3.51	0.05	0.00	0
KAWW002	Full (12.5–20,000)	31.17	1.84	0.13	0	15.15	0.99	0.03	0
KAWW002	ANS (20–1,250)	23.84	0.93	0.07	0	10.46	0.27	0.00	0
KAWW004	Full (12.5–20,000)	19.03	1.44	0.09	0	35.97	7.44	0.56	0
KAWW004	ANS (20–1,250)	12.73	0.82	0.03	0	32.18	5.11	0.32	0

Sound Level: Percentile Levels

Percentile sound levels improve understanding of the range of acoustic conditions at the park (Table 6, Figures 6–8). In Table 6, the A-weighted percentile sound levels (L_{A90} , L_{Anat} , L_{A50} , and L_{A10}) are shown for each site, day and night. Median values (L_{A50}) for each site at KAWW range from 27.5–30.5 dB during the day and 21.0–31.2 dB at night, with levels at KAWW002 being most variable, ranging from loudest during the day to quietest overnight. Oppositely, KAWW004 was quietest during the day and loudest overnight. Natural sound levels range from 25.8–27.4 dB during the day and 19.7–30.5 dB at night. Calculating the difference between estimated natural ambient sound levels and existing ambient sound levels, anthropogenic noise increases noise levels by about 1.7–4.5 dB during the day and a mere 0.7–1.3 dB at night.

Table 6. Summary of sound levels at Katahdin Woods and Waters National Monument (KAWW) in Winter 2022. Included for each site are 90th percentile (L_{A10}), existing (L_{A50}), natural (L_{Anat}) and 10th percentile (L_{A90}) ambient sound levels (dB re 20 μ Pa, A-weighted broadband, 12.5 Hz–20 kHz) during the day (0700–1900) and night (1900–0700).

Time	Site Name	L_{A10}	L_{A50}	L_{Anat}	L_{A90}
Day	KAWW001	34.0	29.4	27.4	25.8
Night	KAWW001	31.1	26.8	26.0	23.3
Day	KAWW002	38.0	30.5	26.0	25.0
Night	KAWW002	29.4	21.0	19.7	17.4
Day	KAWW004	34.2	27.5	25.8	22.4
Night	KAWW004	36.2	31.2	30.5	26.9

An increase in sound levels by 3 dB is detectable by humans, suggesting that KAWW002, in particular, experiences a noticeable increase in noise levels during daytime hours. Moreover, sound level impacts can be translated into functional effects for human visitors and resident wildlife. An increase in background sound level of 3 dB produces an approximate decrease in listening area of 50%. In other words, by raising the sound level by just 3 dB, the ability of listeners to hear the sounds around them is effectively cut in half. An increase of 4.5 dB, as with KAWW002, leads to an approximate decrease in listening area of 65%. For example, if a predator can hear potential prey in an area of 100 square feet in a setting with natural ambient sounds, that animal’s ability to hear would be reduced to 35 square feet if the sound levels were increased by 4.5 dBA.

For Figures 6–8, hourly percentile sound levels are calculated from the broadband (12.5 Hz–20,000 Hz) A-weighted, 1-second time averaged sound levels ($L_{Aeq,1s}$) within each hour of the day. For instance, in Figure 6, the L_{A50} (median) sound level for KAWW001 during the 8:00 hour is 24.1 dB. The sound level exceeded 10% of the time (L_{A10}) for the same hour at this site is 29.3 dB, meaning 90% of the measurement period is quieter. Conversely, the sound level exceeded 90% of the time (L_{A90}) is 21.3 dB, meaning 10% of the measurement period is louder at that hour.

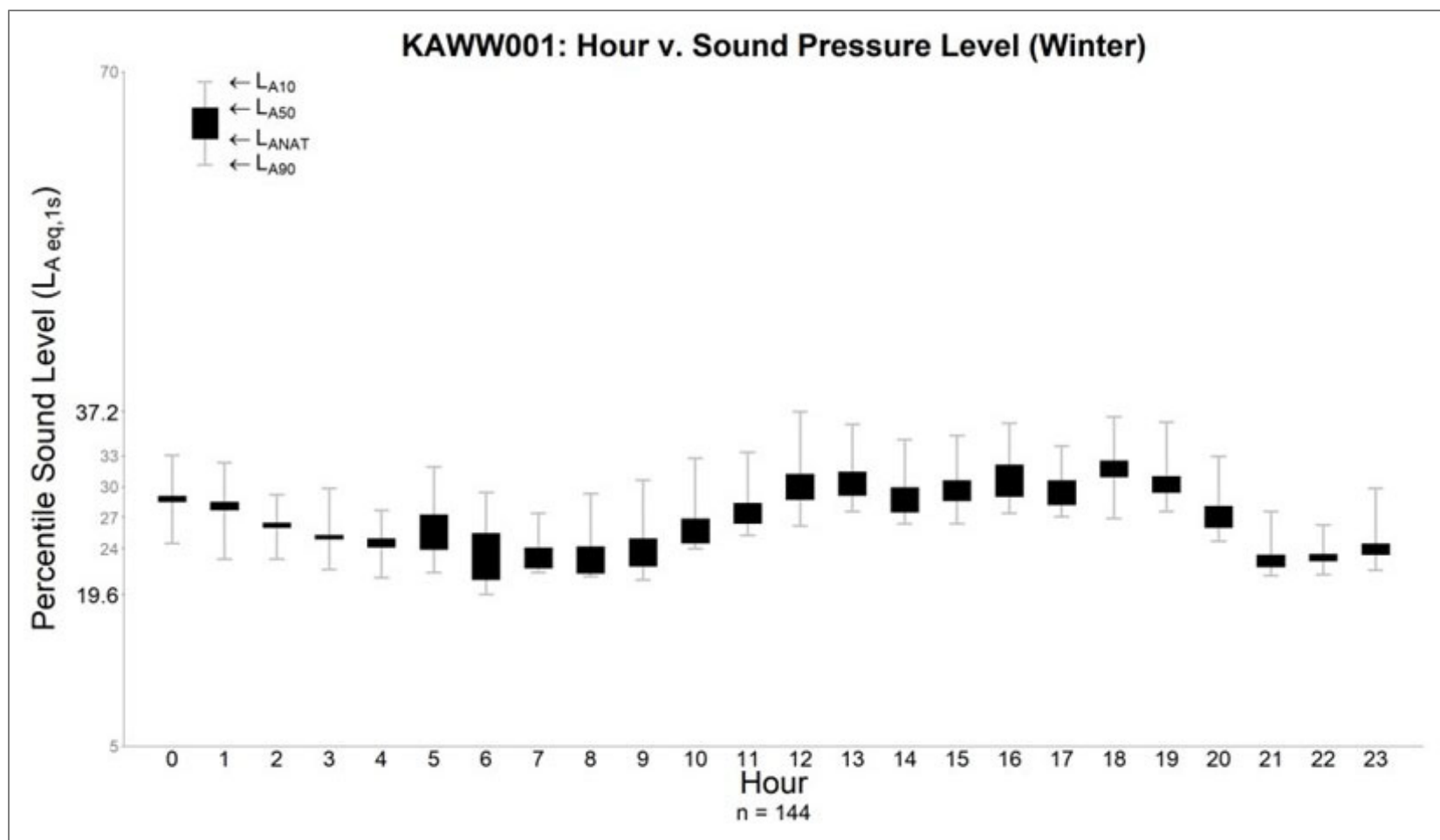


Figure 6. Median percentile sound levels ($L_{Aeq,1s}$), in dB re 20 μ Pa, at KAWW001, Winter 2022.

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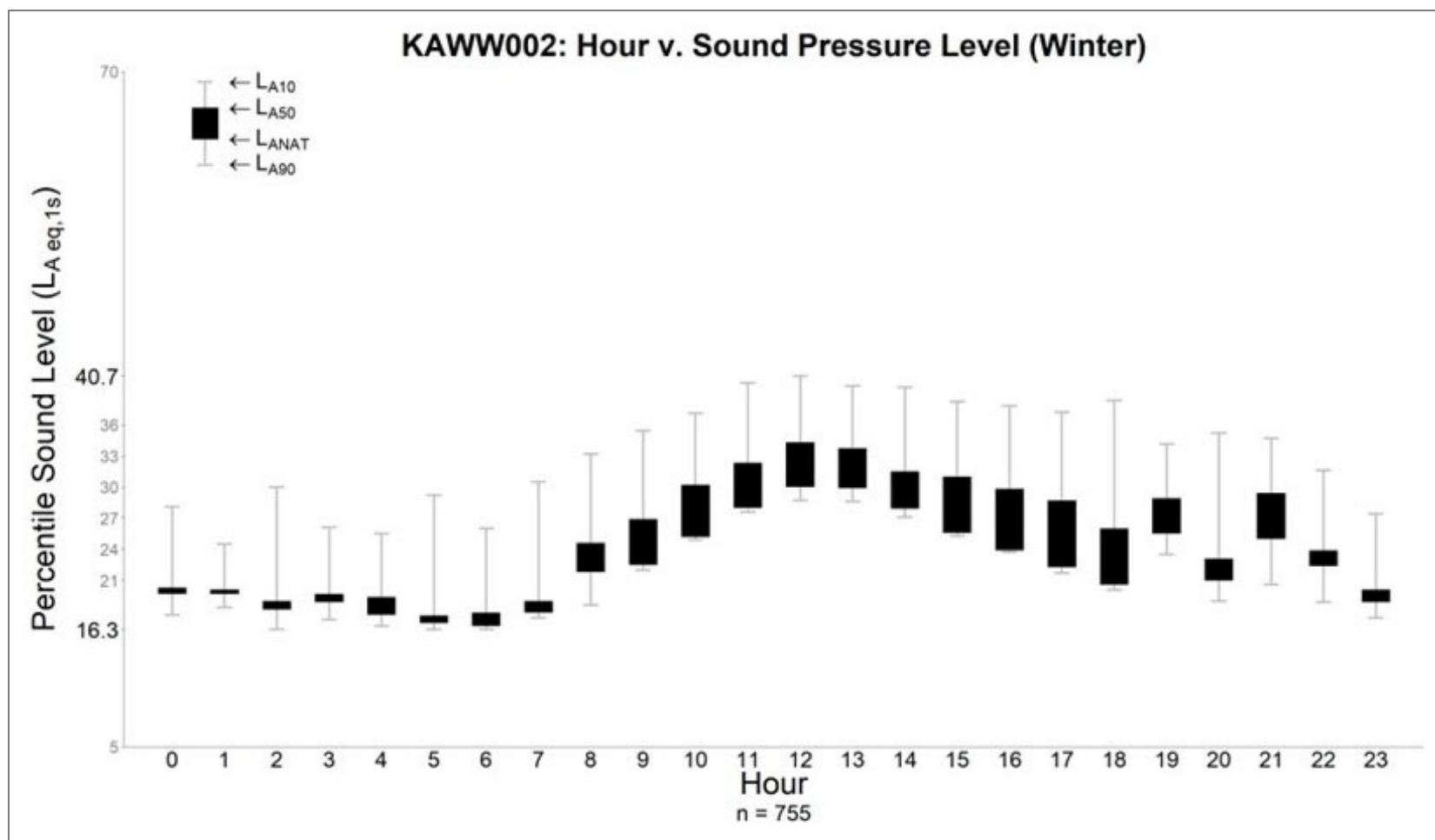


Figure 7. Median percentile sound levels ($L_{Aeq,1s}$), in dB re 20 μ Pa, at KAWW002, Winter 2022.

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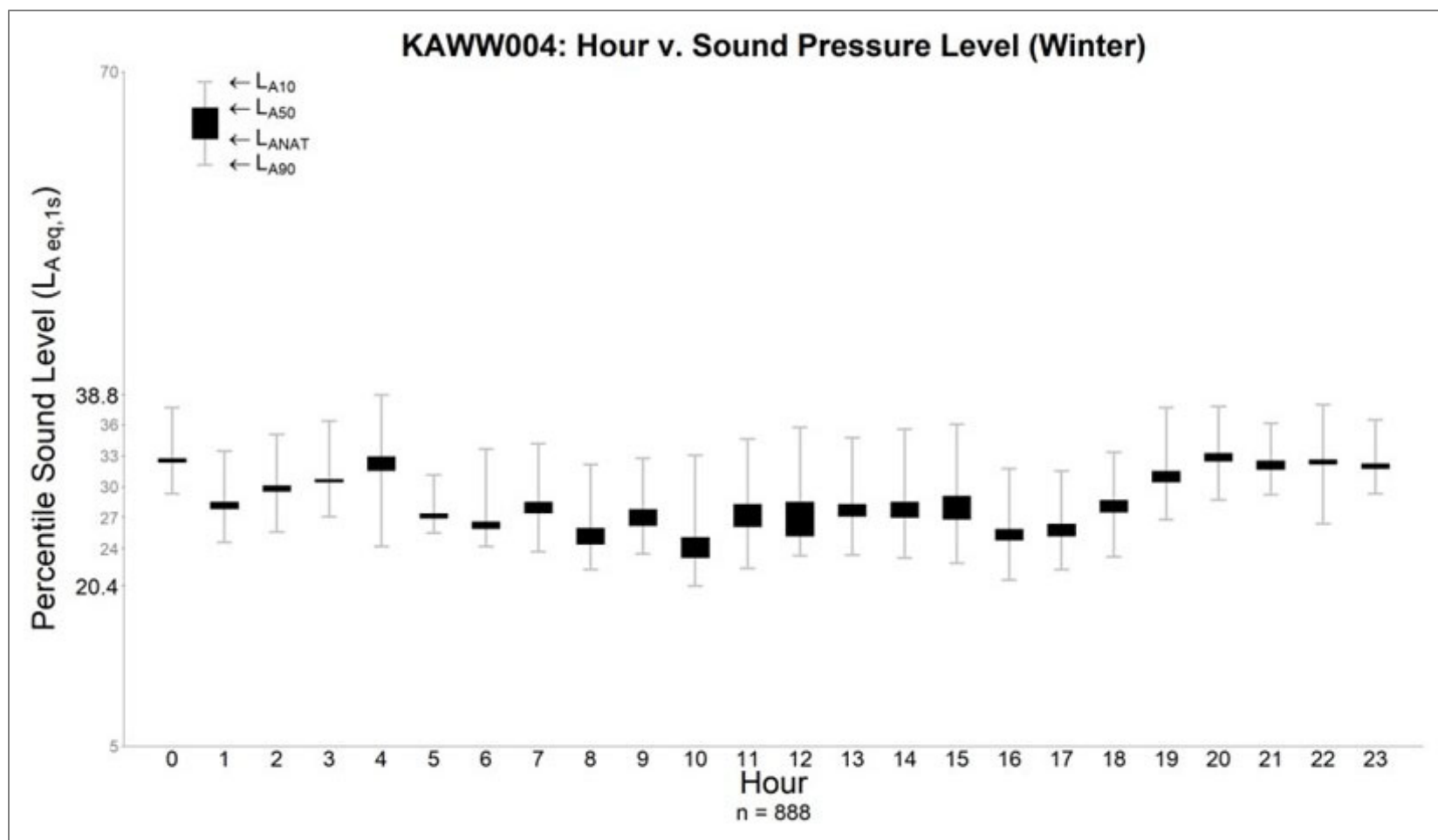


Figure 8. Median percentile sound levels ($L_{Aeq,1s}$), in dB re 20 μ Pa, at KAWW004, winter 2022.

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As with Figures 3–5, the height of the bold portion between the L_{A50} and the L_{Anat} indicates the contribution of anthropogenic noise to the existing sound levels for each hour. At all sites, existing sound levels are extremely close to natural conditions in nighttime hours, about 11 p.m. to 4 a.m. The greatest differences between L_{A50} and L_{Anat} occur at KAWW002 in daytime hours, with a difference up to 6.4 dB during the 17:00 hour (Figure 7). While Figure 8 shows generally minor increases over natural conditions at KAWW004, it also reveals an unusual increase in all sound levels, including natural sounds, in evening hours from about 8:00 p.m. – 4 a.m., with the highest sound levels in the 04:00 hour.

Event Duration

Listening Center Software

Through off-site listening analysis, event duration for all audible sounds is calculated and averaged over the listening period. For both sites, mean hourly audibility was obtained for each hour of the day over an 8- to 10-day listening period (Olstad 2022). Hourly audibility is also displayed for all non-natural sources, while also highlighting the top two sources at each site (Figures 9–11). At KAWW001, noise was audible less than 15% of the time between midnight and 4 a.m., but began increasing in early morning hours and peaked at over 70% audibility in the 8 a.m. hour (Figure 9). Over-snow vehicles were one of the main contributors of noise, audible more than 30% of the time mid-morning and late afternoon, and audible as late as the 11 p.m. hour. Over-snow vehicles contributed even more noise at KAWW002, peaking at more than 50% in the 4 p.m. hour (Figure 10). Early to mid-morning, aircraft were also audible. Meanwhile, KAWW004 experienced far less noise overall, especially overnight (Figure 11). Aircraft were the most continuous noise source. Visual analysis of spectrograms indicates that most of the aircraft noise comes from jet overflights, rather than propeller planes or helicopters.

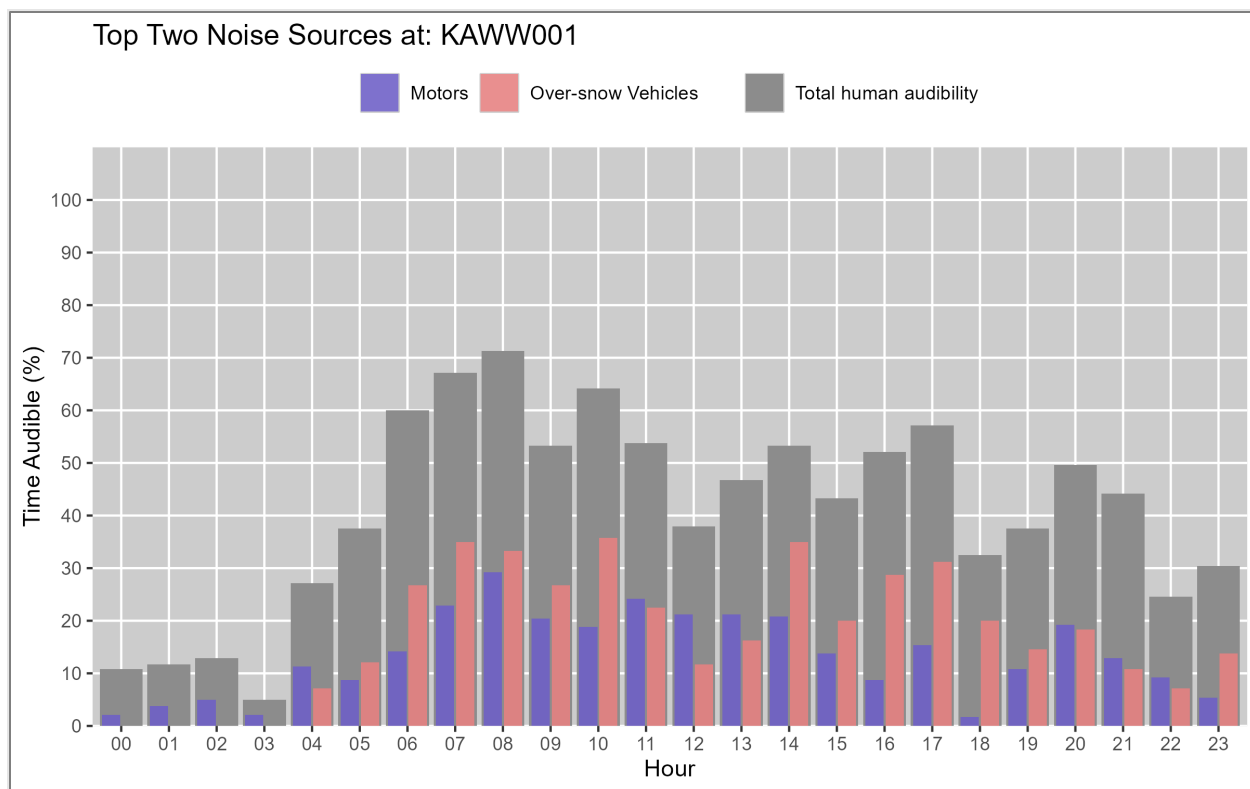


Figure 9. Hourly time audible for the top noise sources and all noise sources at KAWW001, winter 2022.
NPS / NATURAL SOUNDS PROGRAM

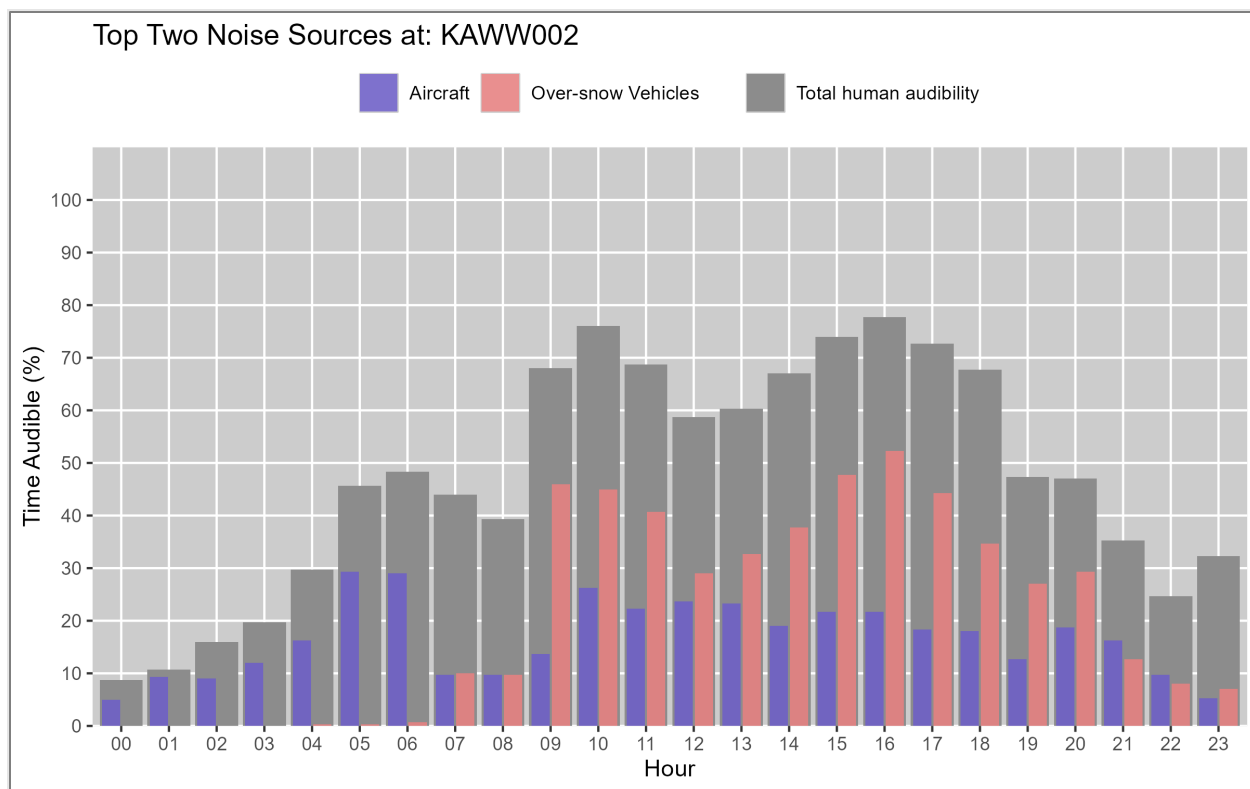


Figure 10. Hourly time audible for the top noise sources and all noise sources at KAWW002, winter 2022.
NPS / NATURAL SOUNDS PROGRAM

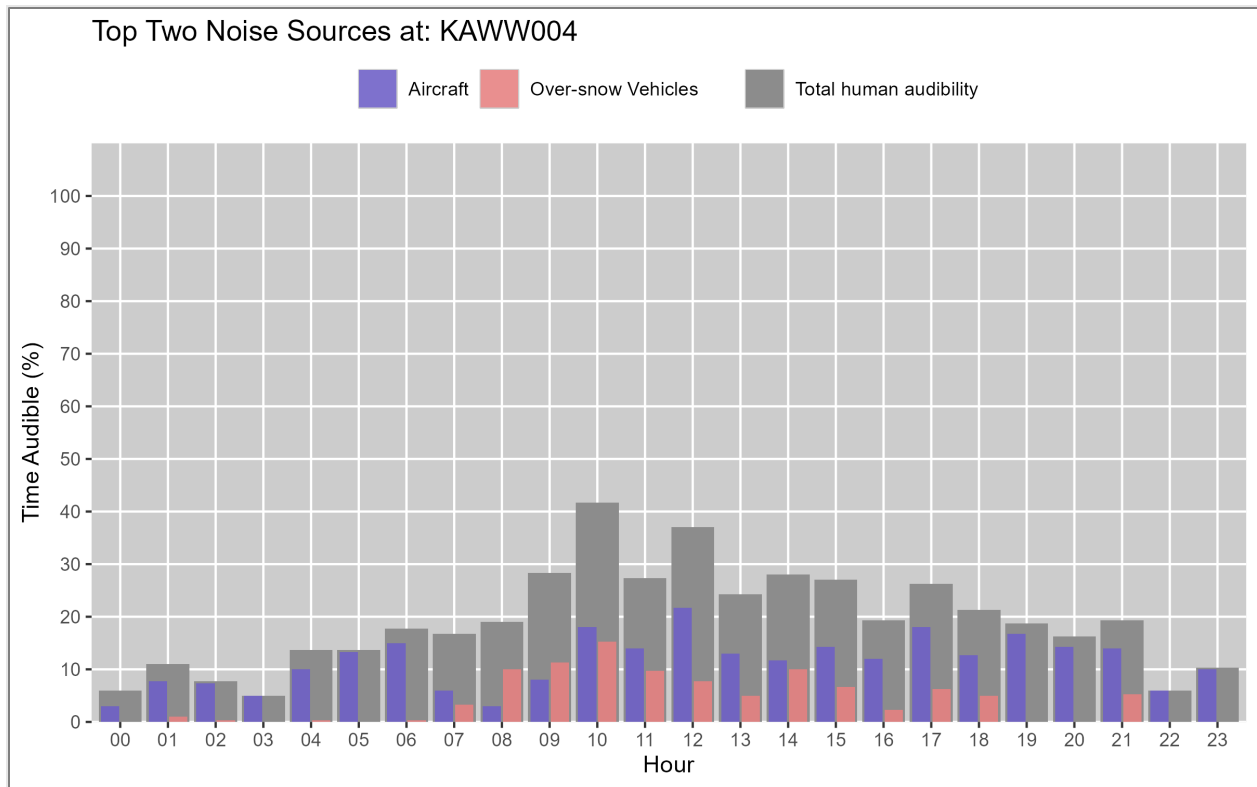


Figure 11. Hourly time audible for the top noise sources and all noise sources at KAWW004, winter 2022.
NPS / NATURAL SOUNDS PROGRAM

According to the listening center analysis, wind, wind-induced natural events (such as branches creaking or falling), precipitation (snowfall, rainfall, or dripping), and birdcalls were the most typical natural sounds. Light winds were audible about 20–50% of the time during all hours, though stronger winds tended to pick up in late afternoon, about 4–6 p.m. Snowfall tended to be most audible overnight, especially between midnight and 6 a.m., though both rain and snow were common throughout the monitoring period. Birdsong showed the most pronounced diurnal patterns: almost silent overnight, then starting at about 7 a.m. and reaching a peak at 11 a.m. Sounds coded as “mammal” also quieted overnight and increased midday.

Conclusions

Noise has the potential to affect a visitor's experience in parks by causing annoyance (Rapoza et al. 2015), reducing the perceived scenic beauty (Weinzimmer et al. 2014) and tranquility (Watts et al. 2020), and by limiting opportunities for solitude or a wilderness experience at this park. Increased sound levels may also have wide ranging effects on wildlife such as reduced predatory success (Mason 2015), changes in vocal communication, and increased vigilance by keystone species (Shannon et al. 2014). In a review of literature addressing the effects of noise on wildlife published between 1990 and 2013, wildlife responses to noise were observed beginning at about 40 dB (L_{Aeq} , as a composite of multiple metrics with varying time-averaging). Of the papers reviewed, 20% showed impacts to terrestrial wildlife at or below noise levels of 50 dB ($L_{Aeq,1s}$) (Shannon et al. 2016).

This study arose from a technical assistance request from KAWW, which identified the need to improve understanding of the park's acoustic environment. Acoustic measurements allow parks to gain insight into levels of extrinsic noise and biological activity. The results can help estimate the effects of noise on park visitors and wildlife, as well as the condition of the acoustic environment.

To carry out this study, 4 monitoring sites were placed in distinct areas of the monument that captured varied noise levels, sources, and patterns that exist across KAWW. Results from 3 of these sites (due to equipment malfunction at KAWW003) included measures of existing ambient sound levels, calculations of sound source audibility through off-site listening, and estimates of natural ambient sound levels.

At KAWW001, functional effect thresholds were exceeded at the most sensitive sound threshold, 35 dB ($L_{Aeq,1s}$), 7.4% of the day and 3.5% of the night in the ANS-weighted frequency ranges (Table 5). These results are lower than those in the full frequency range, which indicates that some of the sound energy contributing to this threshold is from higher frequency sources such as birds or wind-induced events. Existing median sound levels (L_{A50}) of 29.4 dB during the day and 26.8 dB at night were 2.0 and 0.8 dB higher than natural sound levels (L_{Anat}) (Table 6). The primary noise sources were identified as over-snow vehicles and motor sounds, with early morning hours (06:00 a.m. – 11:00 a.m.) experiencing the greatest amount of noise (Figure 9). KAWW001 had the highest natural sound level of the three monitoring sites, with light wind, snowfall, and birdcalls dominating. Birdcalls coincided with over-snow vehicle noise, peaking in the 07:00 a.m. to 11:00 a.m. hours. Recent research indicates that birds may alter their vocalizations before and after passage of snowmobiles (Cretois et al. 2024), but only in a matter of minutes; any shift in calls wouldn't be revealed on an hourly scale.

At KAWW002, functional effect thresholds were exceeded at the most sensitive sound threshold, 35 dB ($L_{Aeq,1s}$), 23.8% of the day and 10.46% of the night in the ANS-weighted frequency ranges (Table 5). Natural sound levels (L_{Anat}) were lower here than at other sites, but the daytime existing median sound levels (L_{A50}) and daytime 10th percentile sound levels (L_{A10}), in particular, were highest of all the sites. Differences between existing sound levels (30.5 dB during the day and 21.0 during the night) and natural sound levels were greater here than at other sites: 4.5 dB higher during the day and

1.3 dB higher at night (Table 6). Over-snow vehicles and aircraft—primarily, jets—were the primary noise sources, with aircraft present at all hours, and snowmobiles audible mostly from mid-morning through evening (Figure 10). Light wind, rain or dripping sounds, and birdcalls were the most common natural sounds, with birds audible more than 60% of the time in the 07:00 a.m. hour.

Unusually, KAWW004 had higher sound levels at night than during daytime hours. Functional effect thresholds were exceeded at the most sensitive sound threshold, 35 dB ($L_{Aeq,1s}$), 12.73% of the day in the ANS-weighted frequency ranges, but 32.18% of the time overnight (Table 5). Existing median sound levels (L_{A50}) increased from 27.5 dB during the day to 31.2 dB at night. However, this is more attributable to increased natural nocturnal sound levels, with L_{Anat} of 30.5 overnight, compared to 25.8 during the day. Existing sound levels were just 0.7–1.7 dB higher than natural sound levels (Figure 11). Over-snow vehicles and aircraft were the most common noise sources. As with other sites, light winds, precipitation, and birds were the most common natural sounds.

To supplement the measured L_{Anat} results, Appendix A includes modeled sound levels. The models suggest that the median modeled whole-park noise impact is just 2.1 dBA greater than the measured noise impact, ranging from 0.7 dBA in the more remote areas to 5 dBA in areas near roads. However, the model tends to overestimate sound levels in very quiet areas. In the case of KAWW, it predicted an existing average L_{50} of 34.6 dBA—up to 10 dB higher than measured sound levels. While natural sound levels would likely be higher on summer days than during February–March, due to wind rustling through leaves, water flowing through creeks, and more activity by mammals, it's unlikely that levels would be that much greater than those measured.

Appendix B uses software called the Attenuation Calculator to model the level and geographic extent of potential noise from snowmobiles in KAWW, using the acoustic monitoring locations, known snowmobile routes, and two snowmobile makes and models at two different speeds as inputs. The software predicted that noise levels from snowmobiles traveling on established trails would be greatest at KAWW003 (the site for which field data collection failed), though would exceed 52 dB only under the loudest circumstances—with pass by of a two-stroke engine vehicle traveling at a higher speed. The snowmobiles used for the model would not be likely to be audible from KAWW004 under the modeled conditions. On average, the model predicted that increasing speed from 35 km/h (15.5 mph) to 50 km/h (31 mph) increases sound levels by 5–6 dB. Changing from a vehicle with a four-stroke engine to one with a two-stroke engine also increases sound levels by 4–6 dB. Differences of that magnitude would be audible to listeners.

Based on the results of this study, wildlife and visitors to KAWW in late winter likely experience some noise—particularly, from snowmobiles and aircraft—but overall, noise levels are fairly quiet. Remoteness from busy roads, airports, or urban, suburban, or industrial development limits noise sources. Especially in areas such as the northwestern region of the park, wildlife and visitors can enjoy a fairly unimpeded acoustic environment, dominated by the sounds of light wind, precipitation, and birds and mammals.

The information presented in this report will be used to inform park managers and planners, and it will also serve as a permanent record of what the park sounded like in the winter of 2022. Sound level data as well as continuous digital audio recordings will be archived with the Natural Sounds and Night Skies Division office in Fort Collins, Colorado.

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Appendix A: Modeled Impact Levels Parkwide

NSNSD developed a model (Mennitt et al. 2014, NPS 2021) that predicts the median sound level using measurements made in hundreds of national park sites as well as 109 explanatory variables such as location, climate, land cover, hydrology, wind speed, and proximity to noise sources such as roads, railroads, and airports. The resulting model can predict sound levels anywhere in the contiguous United States and estimate how much lower these sound levels would be in the absence of human activities. Of particular importance to KAWW, the model tends to overestimate existing and natural sound levels in very quiet areas. It also tends to underestimate noise levels in areas with a very loud existing acoustic environment. Each pixel in the graphic shown in Figures 12 to 14 represents 270 m and represents the acoustic conditions in a typical summer day.

Within KAWW, the model predicted an existing average L_{50} of 34.6 dBA (Figure 12) and a natural average L_{50} of 32.5 dBA (Figure 13). The modeled difference (Figure 14) between the existing and predicted natural sound levels ($L_{50\text{impact}}$) at KAWW provides a measure of how much anthropogenic noise is increasing the existing sound level above the natural sound level on an average summer day in the park. Across KAWW, the mean modeled sound level impact is just 2.1 dBA, ranging from 0.7 dBA in the least impacted areas to 5 dBA in the most impacted areas.

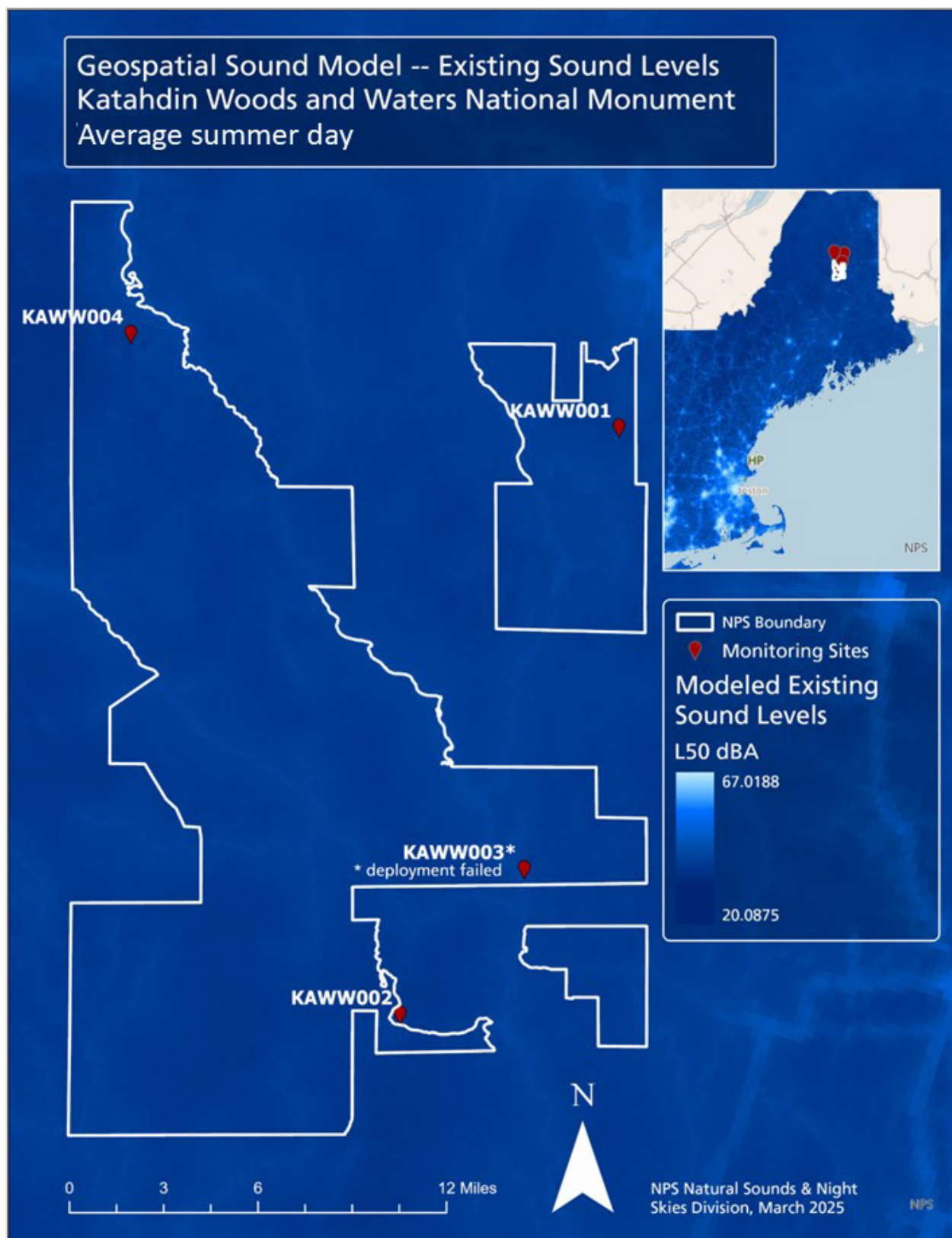


Figure 12. Map of predicted existing acoustic levels in KAWW for an average summer day.
NPS / NATURAL SOUNDS PROGRAM

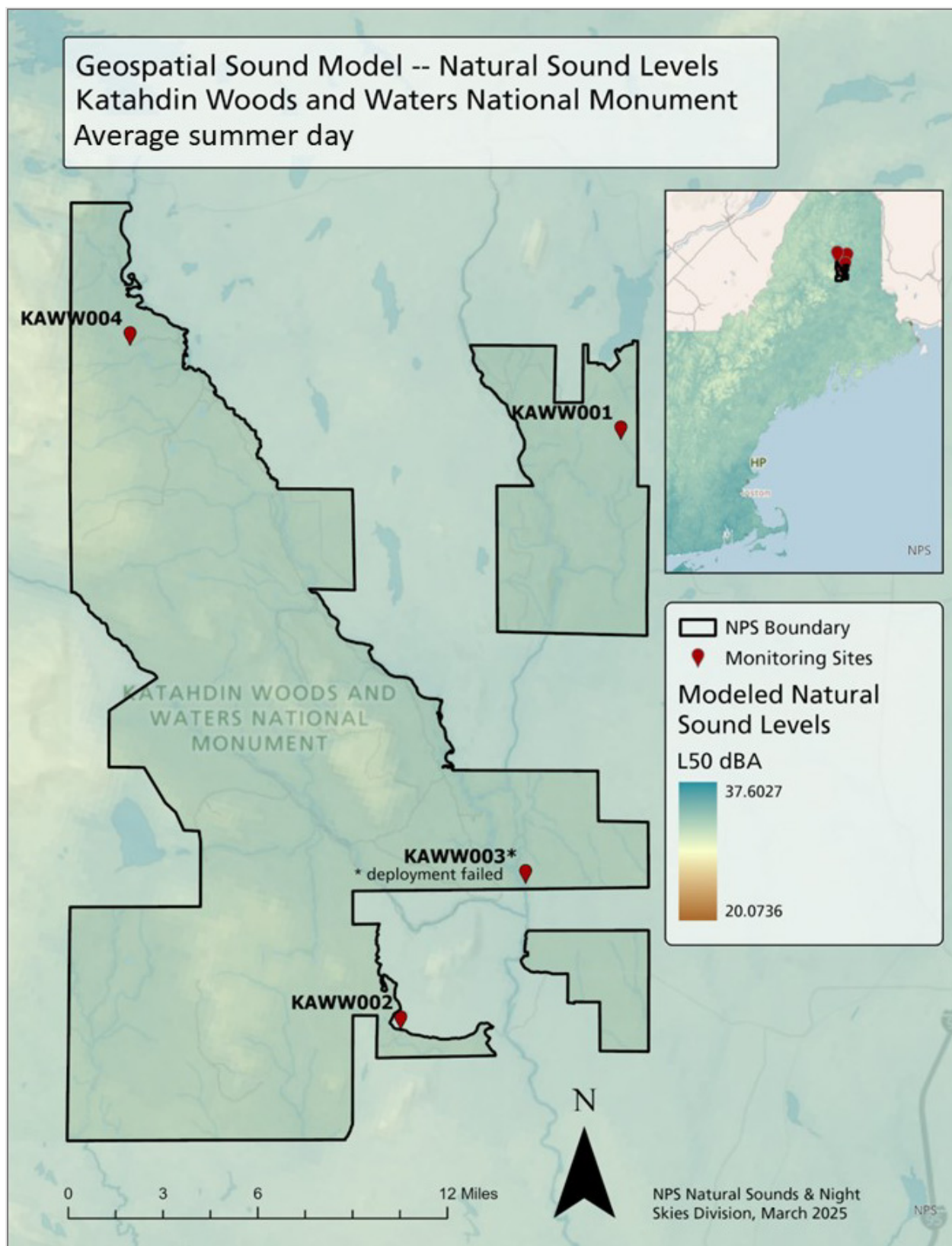


Figure 13. Map of predicted natural acoustic sound levels in KAWW for an average summer day.
NPS / NATURAL SOUNDS PROGRAM

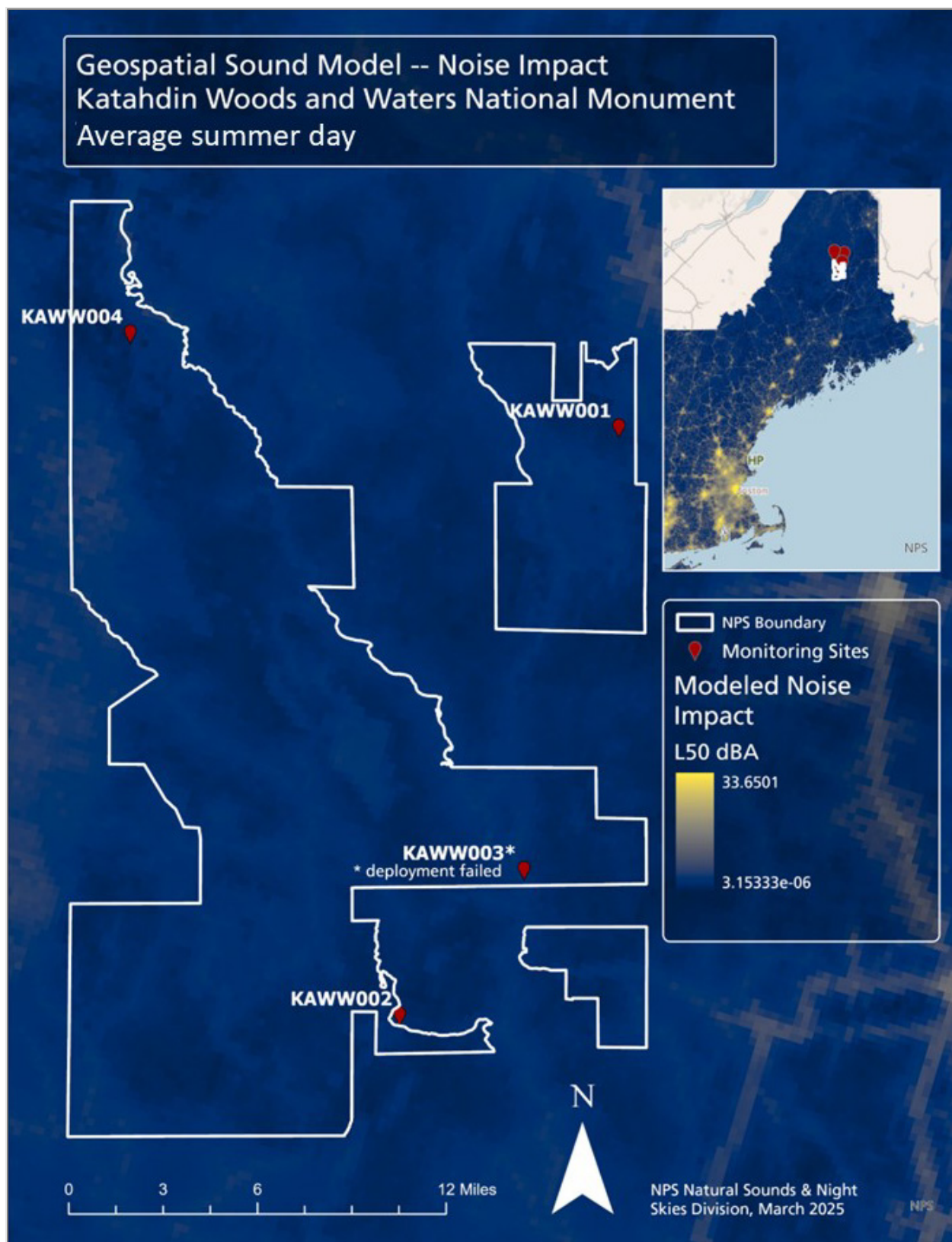


Figure 14. Map of predicted acoustic impact levels in KAWW for an average summer day.

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Appendix B: Modeled Impact Levels from Snowmobile Use

Attenuation Calculator

The Natural Sounds and Night Skies Division (NSNSD) has created a sound mapping tool called the Attenuation Calculator, which implements a standard method of calculating the attenuation of noise with distance (ISO 9613-2, 1996). Sound level inputs to Attenuation Calculator are of 1/3rd octave band resolution. The tool assumes that noise is radiated equally in all directions (an omnidirectional source). It accounts for the effects of divergence (spherical spreading loss) at a standard rate, -20 dB per 10-fold increase in distance. It also computes frequency-dependent effects of atmospheric attenuation, according to standard formulae (ISO 9613-1, 1996) and includes a simplified approximation of ground absorption along the transmission path.

The model allows the user to input several variables that affect sound propagation, including: the elevation of the source above ground level (AGL), the height of the receiver (e.g., a person or animal receiving the sound), ambient temperature, relative humidity, atmospheric pressure values, and the porous ground values.

However, the Attenuation Calculator does not account for several additional environmental factors, which require substantially more complex analyses to evaluate effects on sound propagation. The first is terrain shadowing. Topographic features such as mountains alter how sound travels, causing impedance, diffraction, and/or reflection whose effects on attenuation vary by location and frequency. But accounting for terrain shadowing requires detailed digital elevation models, very precise noise source locations, and more complicated algorithms than this software is programmed to use. For the purposes of this analysis, the calculator assumes flat ground.

It also neglects the role of vegetation, not accounting for the ability of dense foliage to increase attenuation by a few decibels. Receiver level estimates may therefore be inflated slightly, though the effects of vegetation on sound propagation tend to be less than those of terrain shielding.

Next, the ISO 9613-2 standard used by the Calculator assumes that sounds are propagating downwind or equivalently, under a moderate temperature inversion favorable to long-range propagation. Under weather conditions that produce inversions, the Attenuation Calculator will underestimate the noise produced by the noise source.

Lastly, determining cumulative noise levels from multiple contemporaneous events is very complex, depending not only on the intensities of different sound sources and the logarithmic nature of the decibel scale, but also on the interaction between the different waves, particularly whether or not sounds are correlated or uncorrelated. Due to this complexity, the Attenuation Calculator can only model noise from individual discrete events, assuming no overlap in time.

Model Inputs

Noise Evaluation Locations

Acoustic monitoring locations KAWW001 – KAWW004 (Table 4) were used as noise evaluation locations.

Routes for snowmobiles were digitized from maps provided by the Bowlin Matagamon Shin Pond Snowmobile Club, which maintains the trail system in the vicinity of KAWW. KAWW002 and KAWW003 are located along the routes of Maine’s Interconnected Trail System (ITS) 85 and 85/86. Meanwhile, KAWW001 is about 1/3-mile away from Local Club Trail 64, and KAWW004 is about 2 miles away from Route 85.

Environmental Conditions

Values for meteorological conditions were set to account for the weather in late winter 2022, assuming an air temperature of 25°F, 60% relative humidity, barometric pressure of 101.325 kPa, and ground porosity of 50% (a mix of hard ice, which reflects sound waves, and soft snow, which absorbs sound waves.) The receiver height was set at 5.0 feet, a typical height for measuring sound levels. Ambient sound levels were set to measured existing median daytime L_{A50} for each site: 29.4 dBA for KAWW001, 23.1 dBA for KAWW002, estimated at 27 dBA for KAWW003, and at 24.4 dBA for KAWW004.

Snowmobile Configurations

The attenuation calculator uses inputs for measurements of sound levels for each noise source across 1/3rd octave intervals. In order to compare two-stroke engines to four-stroke engines at multiple reasonable speeds, noise inputs included an Arctic Cat 2012 XF 800 HIGH COUNTRY Sno Pro OS BLK (two-stroke) and 2012 Yamaha RS Venture GT (four-stroke), each at 25 km/h (15.5 mph) and 50 km/h (31 mph). Original measurements were taken by Zhang (2012).

Model Outputs

This analysis calculated four noise metrics at each location: $L_{A_{max}}$, time audible (TAUD), time above 35 dB (TA35), and time above 52 dB (TA52) for each model snowmobile at each speed (Table 7). The model predicted that noise levels from snowmobiles traveling on established trails would be greatest at KAWW003, though time audible would be slightly longer at KAWW002, likely due to the extremely quiet ambient sound level. Noise levels would rarely exceed 52 dB, except briefly at KAWW003 with the two-stroke engine vehicle traveling at a higher speed. The snowmobiles used for the model would not be likely to be audible from KAWW004 under the entered conditions. On average, the model predicted that increasing speed from 35 km/h (15.5 mph) to 50 km/h (31 mph) increases sound levels by 5–6 dB. Changing from the Yamaha (four-stroke engine) to the Arctic Cat (two-stroke) also increases sound levels by 4–6 dB. Changes of that magnitude would be audible to listeners.

Table 7. Results of Attenuation Calculator modeling of snowmobile noise at sites in KAWW.

Site	Snowmobile	L _{Amax}	Time Above 52 dB (sec)	Time Above 35 dB (sec)	Time Audible (sec)
KAWW001	Arctic Cat at 25 km/h	20.4	0	0	0
KAWW001	Arctic Cat at 50 km/h	25.5	0	0	56
KAWW001	Yamaha at 25 km/h	15.6	0	0	0
KAWW001	Yamaha at 50 km/h	21.6	0	0	2
KAWW002	Arctic Cat at 25 km/h	30.5	0	0	279
KAWW002	Arctic Cat at 50 km/h	36.6	0	24	186
KAWW002	Yamaha at 25 km/h	25.3	0	0	187
KAWW002	Yamaha at 50 km/h	31.1	0	0	159
KAWW003	Arctic Cat at 25 km/h	47.0	0	61	226
KAWW003	Arctic Cat at 50 km/h	53.8	7	52	157
KAWW003	Yamaha at 25 km/h	41.7	0	35	157
KAWW003	Yamaha at 50 km/h	47.8	0	17	78
KAWW004	Arctic Cat at 25 km/h	3.5	0	0	0
KAWW004	Arctic Cat at 50 km/h	4.6	0	0	0
KAWW004	Yamaha at 25 km/h	0.0	0	0	0
KAWW004	Yamaha at 50 km/h	4.7	0	0	0

The Attenuation Calculator also predicts and visualizes the geographic extent of noise caused by noise sources along the input routes. Figures 15–17 provide example maps comparing the spread of noise from a four-stroke Yamaha snowmobile traveling past KAWW002 at 25 km/h (Figure 15) to a two-stroke Arctic Cat at 25 km/h (Figure 16) to a two-stroke Arctic Cat at 50 km/h (Figure 17).

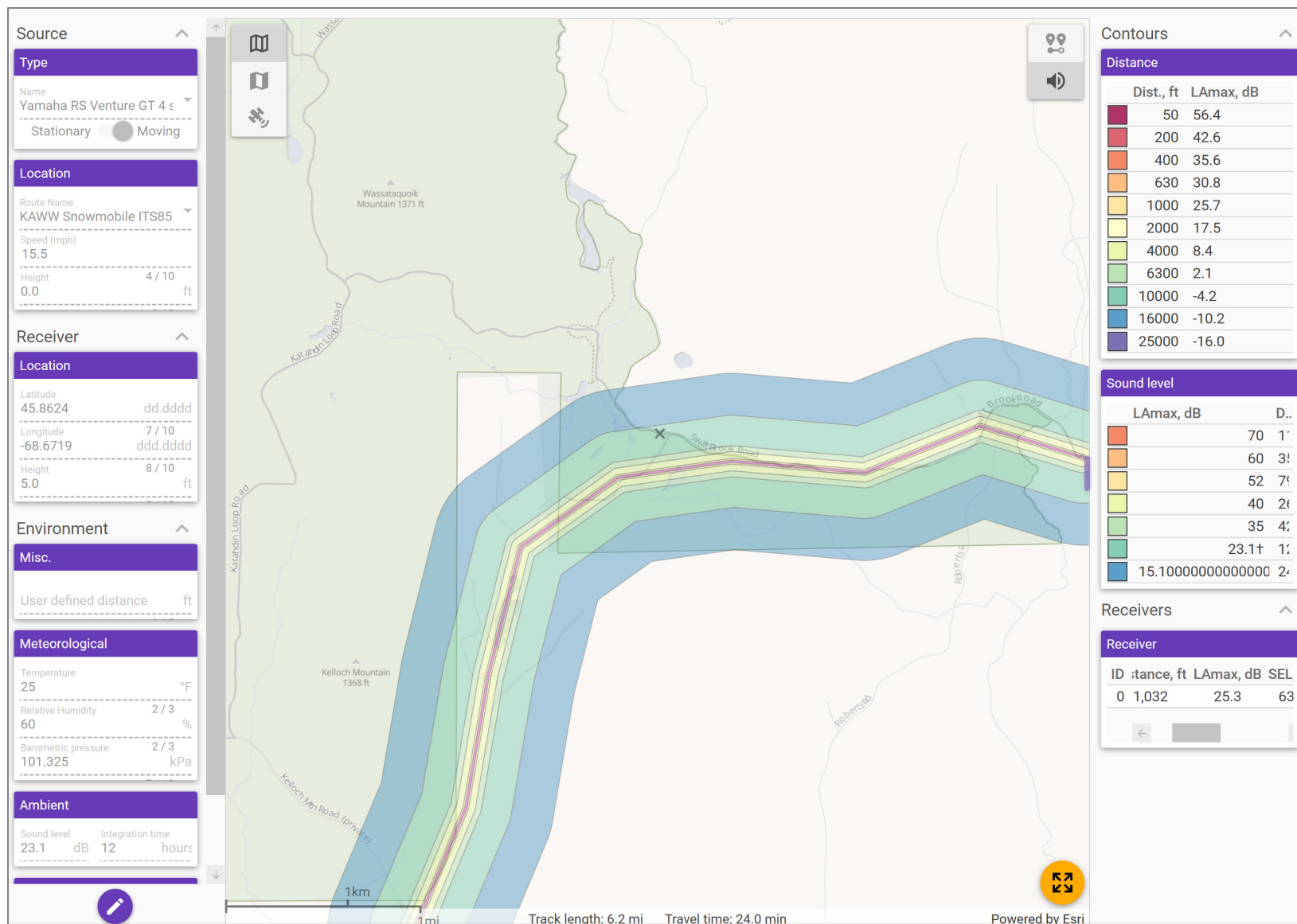


Figure 15. Attenuation Calculator model of the geographic extent of noise caused by a Yamaha snowmobile traveling 25 km/h past KAWW002.
NPS / NATURAL SOUNDS PROGRAM

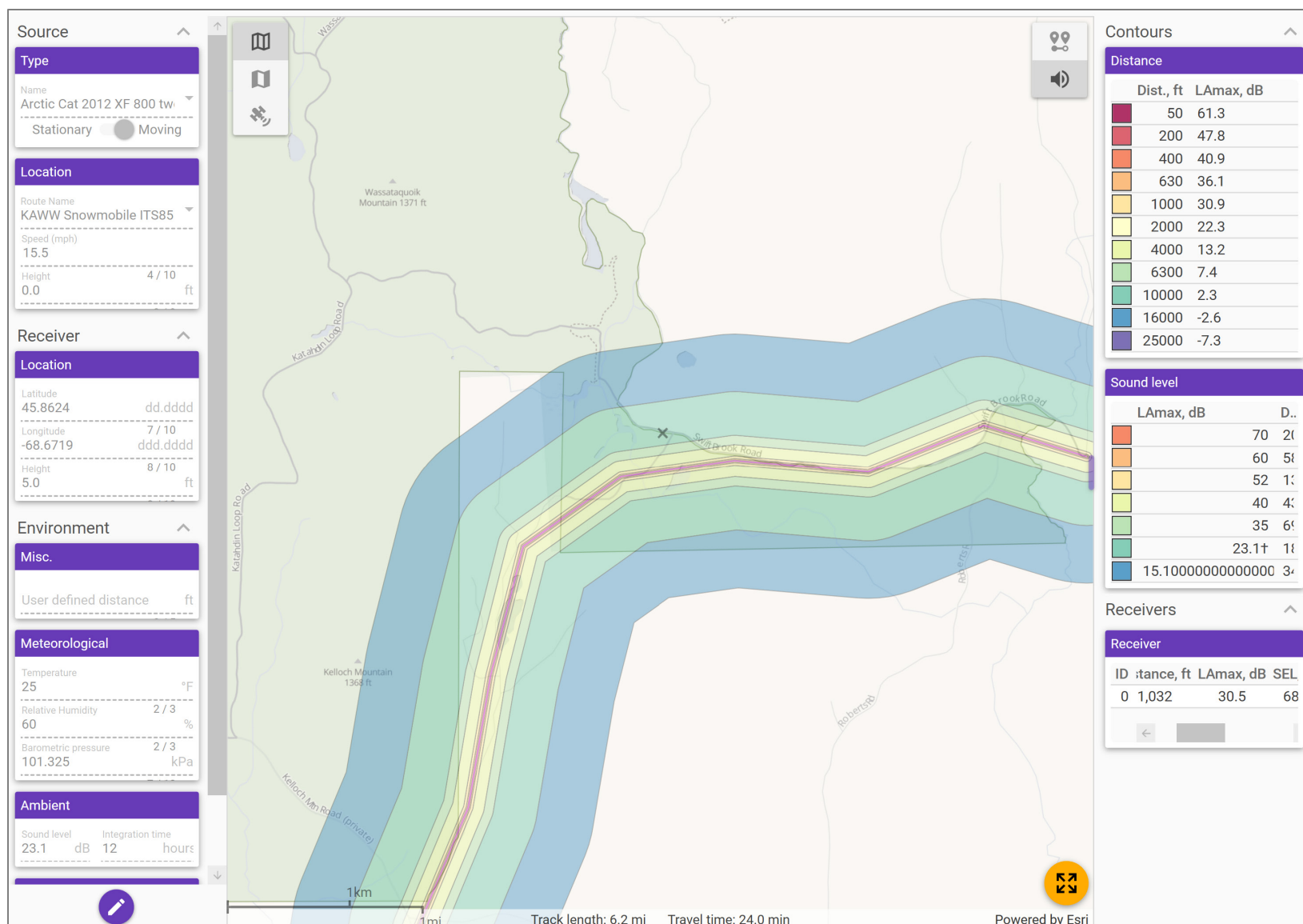


Figure 16. Attenuation Calculator model of the geographic extent of noise caused by an Arctic Cat snowmobile traveling 25 km/h past KAWW002.
NPS / NATURAL SOUNDS PROGRAM

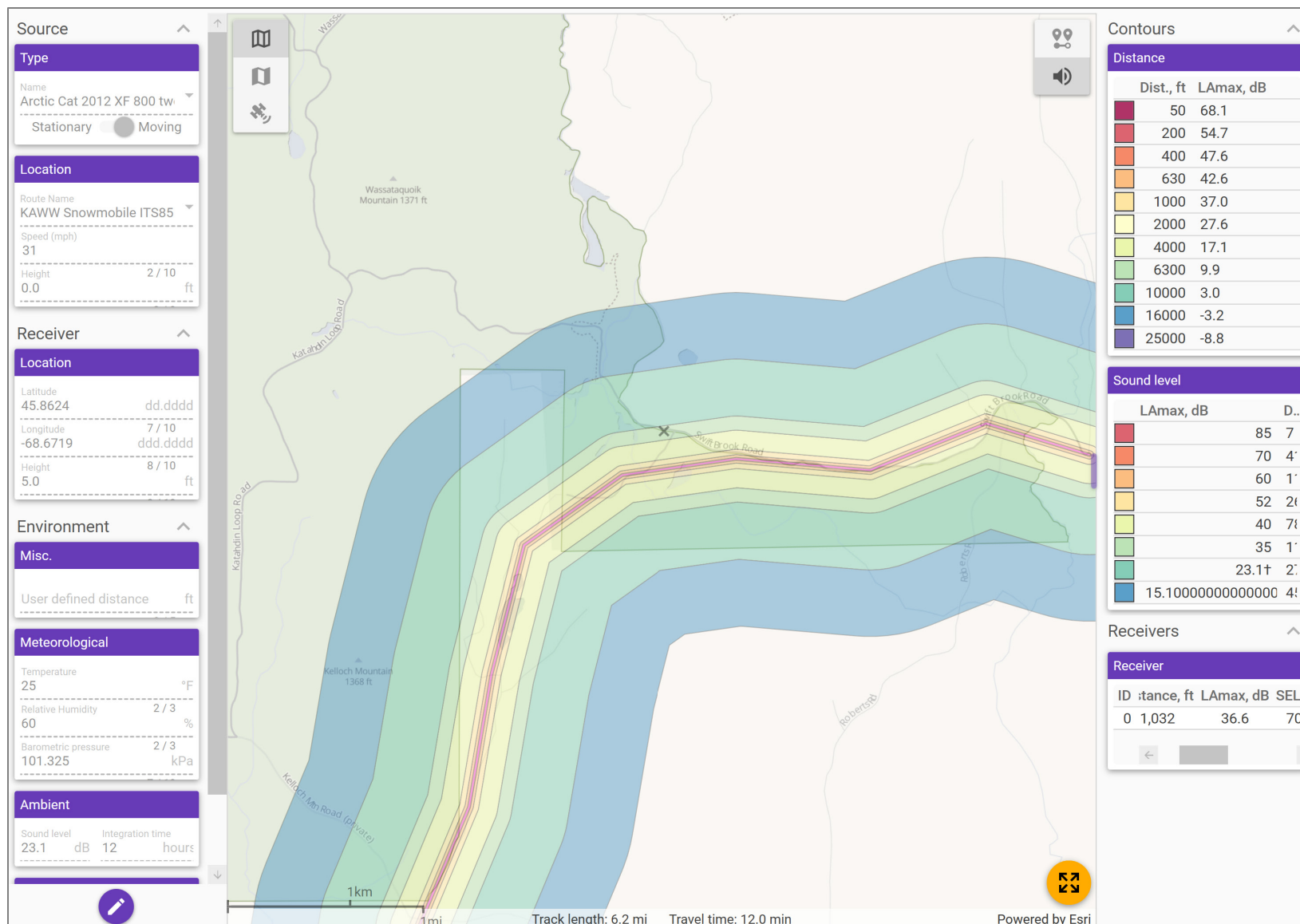


Figure 17. Attenuation Calculator model of the geographic extent of noise caused by an Arctic Cat snowmobile traveling 50 km/h past KAWW002.
NPS / NATURAL SOUNDS PROGRAM

Appendix C: Visual Analysis of Spectrograms

Acoustic monitoring equipment records sound pressure level (loudness) in decibels and the frequency (pitch) of a sound in hertz (Hz). Spectrograms visualize these sound pressure levels over time, with the brightness of the color indicating loudness or amplitude at different frequencies, broken into 33 1/3-octave intervals (y-axis) at each second (x-axis).

As different sound events—such as the quick, high trill of a bird singing or the low, lingering roar of a jet flying overhead—emit sound pressure levels differently across frequencies, they each have an identifiable visual signature in a spectrogram. Trained analysts can annotate spectrograms to identify sound events and determine their number and duration throughout a sample period.

Simple visual analysis also reveals telling patterns. Figures 18 and 19 are examples of spectrograms for KAWW004. Each displays a full 24-hour period of recorded sound pressure levels, with 2 hours per row. Dark blues and purples indicate very low sound pressure levels across frequencies, while brighter yellows indicate louder sound events. Figure 18 (February 07, 2022) shows fairly low sound levels overall, with overflights by jet aircraft, occasional propellor planes, and snow machines creating the loudest sound events, and birdsong, light rain, and rustling winds also present, especially midday. Oppositely, Figure 19 (February 23, 2022) shows continuously loud sound levels, with torrential rain in the early hours transitioning to strong winds for most of the day, especially after 4 p.m.

Figure 20 is extracted from the midday hours of February 22, 2022, selected to show common wintertime sound events at KAWW004. The large, bright, lower-frequency blobs such as one early in the 15:00 hour are associated with jet overflights. Bright candle-shaped events that cross nearly all frequencies, such as two in the latter portion of the 14:00 hour, are created by snowmobiles. Note the lingering audibility that may occur between snowmobile pass-bys, seen as bright connections between the two 14:00 hour events. Bright dashes contained to higher frequencies, such as those in the 12:00 hour, are animal sounds, including bird cheeps and calls, potential squirrel chatter, and woodpecker rat-a-tat-tats. Thin stripes brightest in lower frequencies and reaching into higher frequencies indicate light winds. Very thin stripes across all frequencies, such as in the latter part of the 15:00 hour, are caused by precipitation. The 12:00 and 13:00 hours also featured intermittent distant thunder, visible as faint peaks in lower frequencies.

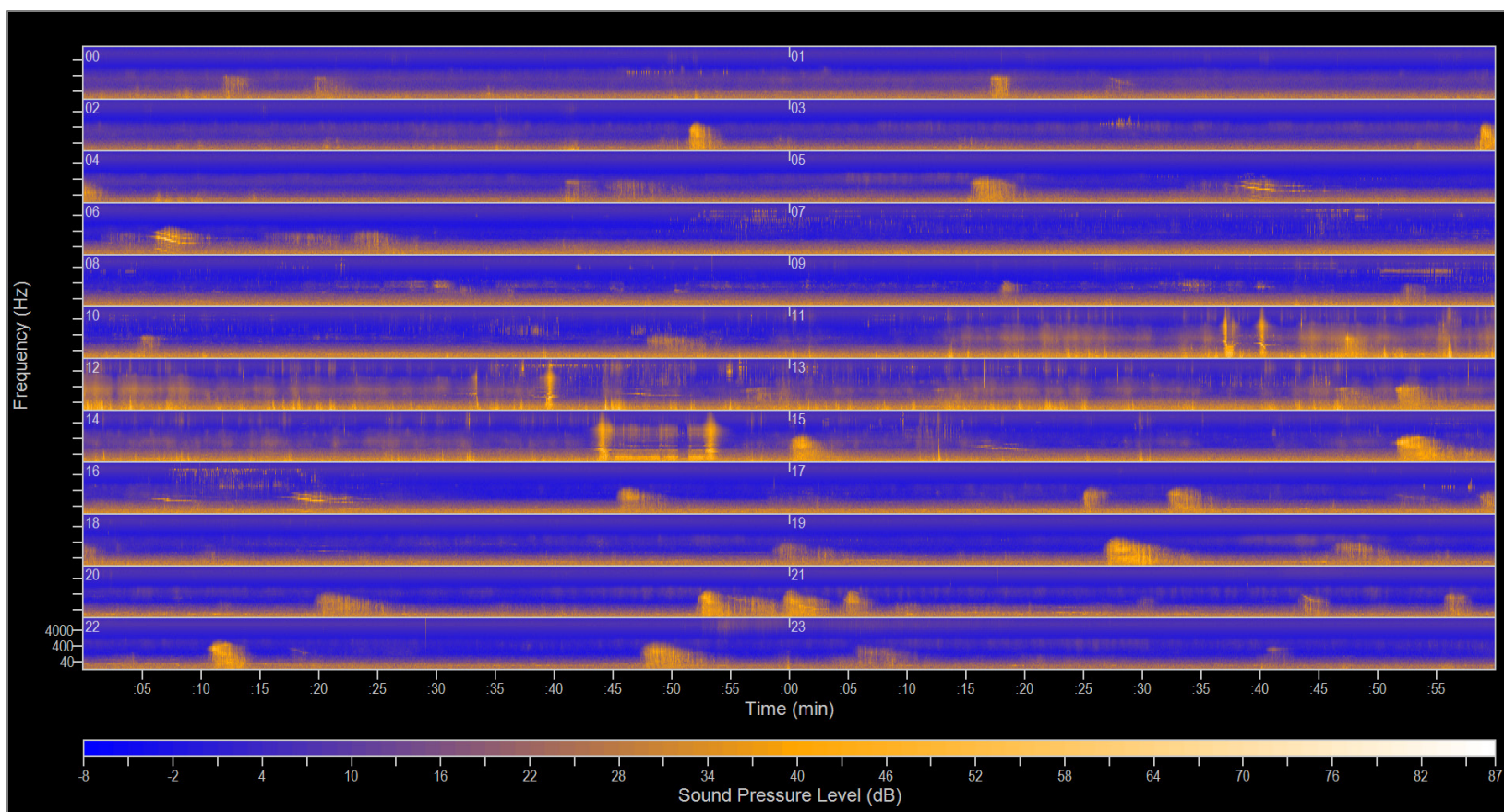


Figure 18. Spectrogram for 2022-02-07 at KAWW004.

NPS / NATURAL SOUNDS PROGRAM

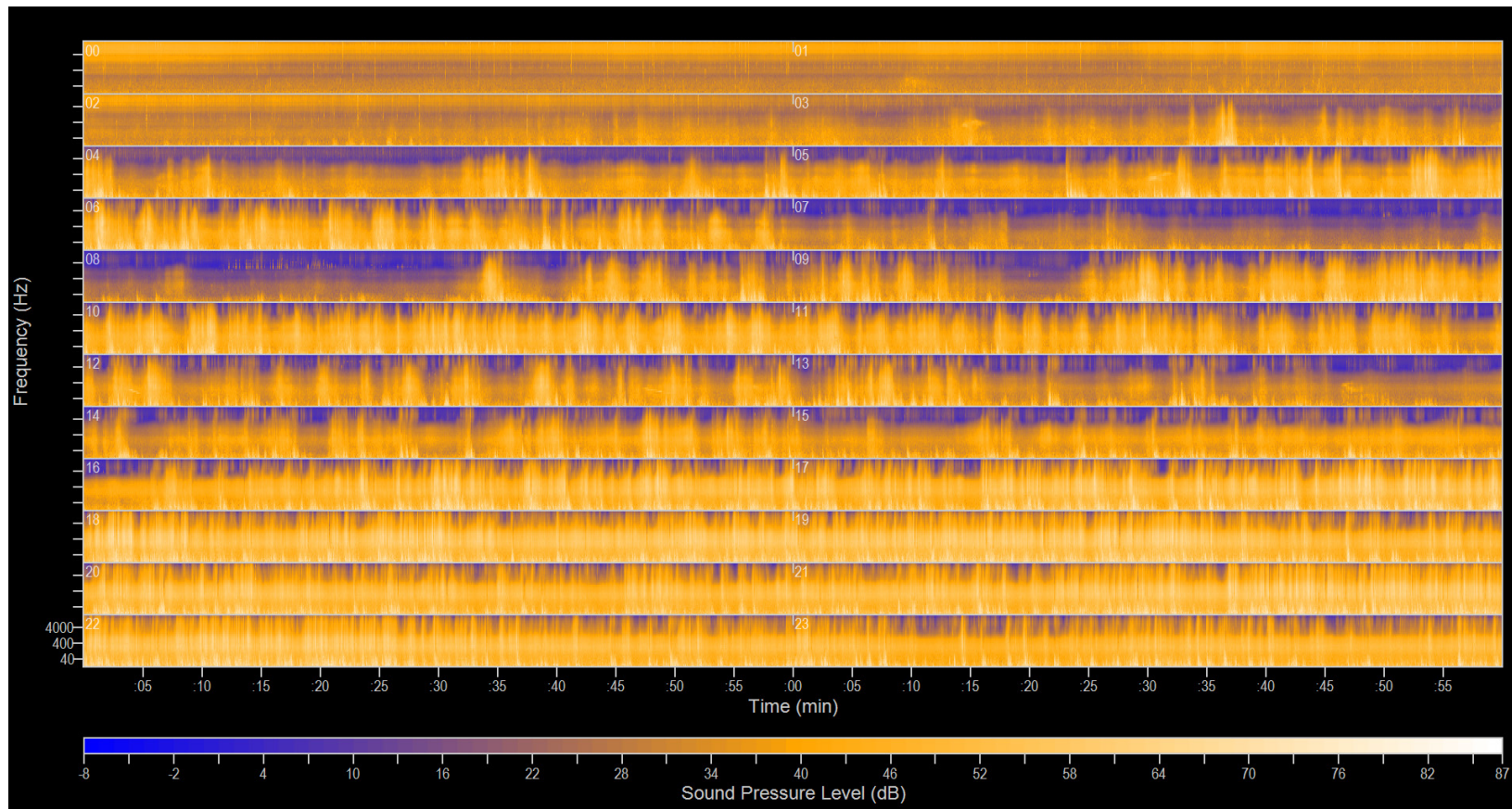


Figure 19. Spectrogram for 2022-02-23 at KAWW004.
NPS / NATURAL SOUNDS PROGRAM

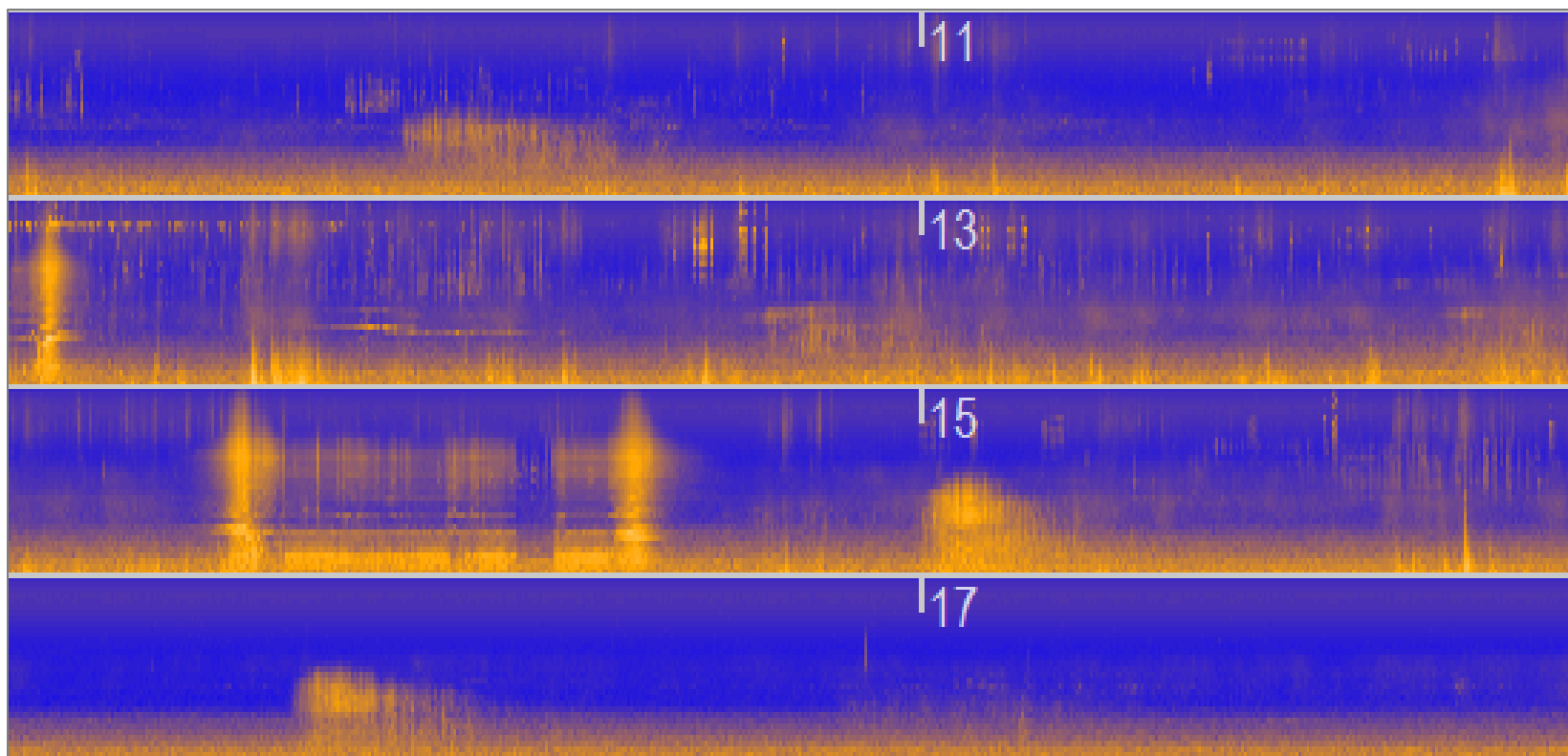


Figure 20. Spectrogram extract from 2022-02-07, mid-10:00 through mid-17:00 hours.
NPS / NATURAL SOUNDS PROGRAM

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U.S. Department of the Interior



Science Report NPS/SR—2025/305
<https://doi.org/10.36967/2313208>

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