Natural Soundscape Monitoring in Yellowstone National Park December 2008-March 2009

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Shan Burson/NPS Photo

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Abstract:

Sounds associated with oversnow vehicles (snowmobiles and snowcoaches) are an important management concern at Yellowstone National Park. Acoustical standards and thresholds have been defined in park planning documents for the winter use season. The primary purpose of this study was to monitor the impact of oversnow vehicles on the natural soundscape. Acoustical data were collected at two winter-long sites and three shorter-term sites (two near a plowed road used by wheeled vehicles) in Yellowstone National Park during the winter use season, 15 December 2008- 15 March 2009.

Oversnow vehicles were audible in the most heavily used developed area, Old Faithful, an average of 55% of the day between 8 am and 4 pm. Oversnow vehicles were audible for an average of 45% of the day at the two travel corridor monitoring sites; 47% of the day near Madison Junction along the busiest corridor between Old Faithful and the West Entrance, and for 26% adjacent to the road at North Twin Lake between Norris and Mammoth. At Madison Junction oversnow vehicles were audible over 50% for 8 (33%) of 24 days analyzed and 0 (0%) of 7 days analyzed at the North Twin Lake site. Wheeled vehicles were monitored and were audible at one roadside and one backcountry monitoring site; 26% at Blacktail Roadside (100 feet (30m) from the plowed road between Mammoth and Tower), and 16% at Blacktail Backcountry (one and one half mile [2.4 km] from the same section of road as the Blacktail Roadside monitor. The maximum sound levels of oversnow vehicles sometimes exceeded 70 A-weighted decibels (dBA) along the groomed travel corridor between Madison Junction and the West Yellowstone entrance (Madison Junction 2.3) and between Norris and Mammoth (North Twin Lake). The majority of these higher sound levels were caused by old technology snowcoaches. Sounds from both visitor and administrative oversnow vehicles were included in this study.

Although snowmobiles were audible more than snowcoaches, snowcoaches in general had higher sound levels, especially at higher speeds. The overall impact on the natural soundscape from oversnow vehicles was lower than the past five seasons, likely due to the decrease in daily average number of oversnow vehicles that entered the park; an average decrease of about 95 oversnow vehicles/day from last season. Consistent with acoustic data collected during the previous five winter seasons, the sound level and the percent time oversnow vehicles were audible remained substantially lower than during the 2002-2003 winter use season. The reduced sound and audibility levels were largely explained by fewer snowmobiles, the change from two to four-stroke engine technology, and the guided group requirements. The value of this monitoring study increases with each additional year because trends can emerge in addition to detailed information about specific winters and locations.

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Introduction:

Natural soundscapes are a valued resource at national parks including Yellowstone National Park. The 2006 National Park Service (NPS) Management Policies state that natural soundscapes (the unimpaired sounds of nature) are to be preserved or restored as is practicable. Natural soundscapes are intrinsic elements of the environment and are necessary for natural ecological functioning and therefore associated with park purposes. The existing winter soundscape at Yellowstone consists of both natural and non-natural sounds. Common natural sounds include bird calls, mammal vocalizations, flowing water, wind, and thermal activity. Non-natural sounds include motorized sounds of snowmobiles, snowcoaches, snow-grooming, wheeled vehicles, aircraft, and the sounds associated with facility utilities and other human activity in destination and support areas.

The 2000, 2003, and 2007 Winter Use Plans Environmental Impact Statement of Yellowstone (YNP) and Grand Teton National Parks and the John D. Rockefeller, Jr., Memorial Parkway (NPS 2000, 2003, and 2007) and the 2004 Temporary Winter Use Plans (WUP) Environmental Assessment (NPS 2004) concluded that historical oversnow vehicle use created unacceptable adverse impacts on natural soundscapes (and other resources). To minimize the impact of sounds from oversnow vehicles (OSVs) on the natural soundscape and other resources, the 2004 Winter Use Plans Environmental Assessment of Yellowstone and Grand Teton National Parks and the John D. Rockefeller, Jr., Memorial Parkway (NPS 2007) established limits on the number and group sizes of OSVs and a commercial guiding requirement. The 2007 WUP was implemented beginning the winter of 2007-2008 but in September 2008 the 2007 WUP was vacated and as of this writing the NPS reverted back to the 2004 winter use plan. The 2004 impact definitions describing the acoustical thresholds (Table 1) can be compared to the acoustic field measurements collected in Yellowstone during the 2008-2009 winter use season. The primary purpose of this acoustical monitoring was to measure the impact of snowmobile and snowcoach sound on the park's natural soundscape. Data collected by automated sound monitors included sounds from both guided visitor and unguided administrative oversnow vehicles (but see Appendix E). For comparative purposes, this report also includes similar acoustical data collected during the winter of 2007-2008 in Appendix F. See Burson (2004, 2005, 2006, 2007, and 2008) for additional information on park soundscapes during the previous winters, and the 2000, 2003, 2004, and 2007 Winter Use Plans (NPS 2000, 2003, 2004, and 2007) for additional details of oversnow vehicle management. During the winter of 2008-2009, the sound levels of snowcoaches were experimentally measured at three locations along travel corridors (for details see draft Volpe Center report 2009).

Table 1. Impact definitions for the natural soundscape in the 2004 Winter Use Plans (WUP) Environmental Assessment. Also see Appendix C.

Impact Category Definition[1]	Management Area	Audibility[2, 3]	Maximum Sound Level[3,4]
No Effect An action that does not affect the natural soundscape or the potential for its enjoyment.	Na	Na	Na
Adverse Negligible Effect An action that may affect the natural soundscape or potential for its enjoyment, but with infrequent occurrence and only for short duration at low sound levels. At this impact level, unique soundscape characteristics (such as bubbling hot springs or geysers are rarely affected).	Developed	Sound created by action is audible < 25%	Maximum sound level created by action is < 45 dBA
	Travel Corridor	<5%	< 40dBA
	Backcountry	<5%	<40 dBA
Adverse Minor Effect An action that may affect the natural soundscape or potential for its enjoyment.	Developed	>25% <45%	<60 dBA
	Travel Corridor	>15% <25%	<60 dBA
	Backcountry	>5% <10%	<40 dBA
Adverse Moderate Effect An action that may affect the natural soundscape or potential for its enjoyment.	Developed	>45% <75%	<70 dBA
	Travel Corridor	>25% <50%	<70 dBA
	Backcountry	>10% <20%	<45 dBA
Adverse Major Effect An action with an easily recognizable adverse effect on the natural soundscape and potential for its enjoyment.	Developed	>75%	>70 dBA
	Travel Corridor	>50%	>70 dBA
	Backcountry	>20%	>45 dBA

[1]Thresholds are calculated using the period 8 am-4 pm. Measurements are at 100 feet (30 m) from sound source in developed areas and travel corridors.

[2] Audibility is the ability of humans with normal hearing to hear a certain sound.

[3] To remain within impact category listed audibility and maximum sound level thresholds shall not be violated more than 15% of the measurement days.

[4]Typical natural soundscape sound levels on a calm winter day can range from 0-30 dBA. Snowmobile best available technology (BAT) sound level requirements of 73 dBA measured at 50 feet (15 m) is roughly equivalent to 67 dBA at 100 feet. The maximum sound level for all non-natural sounds in national parks other than OSVs and motorboats is 60 dBA [36 CFR (2.12)(a)(1)(i)].

Study Area:

Yellowstone National Park occupies the northwest corner of Wyoming and extends a short distance into Montana and Idaho. The park is at high elevation and has extensive stands of lodgepole pine forests, grasslands, and open thermal areas. Large areas of Yellowstone are in early stages of lodgepole pine regrowth after the fires of 1988. The two million acre park was divided into two acoustic zone categories (open and forested) in a previous winter acoustical study (HMMH 2001) for the purpose of describing areas with similar natural acoustic properties. This categorization is generally maintained for habitat descriptions in this present study. The major roads within YNP that are open to vehicles during the summer are groomed for oversnow vehicle travel during the winter use season (December to March) with the exception of the road between Canyon and Tower and the plowed road between Mammoth and Cooke City along YNP's northern boundary. As measured just east of Mammoth, an average number of 373 wheeled vehicles per day traveled on this plowed road between 15 December 2008 and 28 February 2009. During the winter use season, between 15 December 2008 and 15 March 2009, 17,252 snowmobiles and 2,389 snowcoaches, totaling 19,641 oversnow vehicles, entered YNP (NPS unpublished data). The majority (16,819; 97.5%) of these oversnow vehicles entered through the West and the South entrances. Most of these winter visitors traveled to Old Faithful. Both snowmobiles (average of 9/day) and snowcoaches (average 3/day) originated from Old Faithful and may not be included in the number of OSVs given above and elsewhere in this report.

Instrumentation and Methods:

Automated acoustic monitors (developed by Skip Ambrose, Sandhill Company, Castle Valley, UT and Mike Donaldson, Far North Aquatics, Fairbanks, AK) collected continuous one-second sound levels, digital recordings using a systematic sampling scheme (10 seconds every four minutes for a daily total of 360 samples), and 20-second recordings of sound events exceeding user-defined thresholds of sound level (decibel) and duration (seconds). These two event threshold triggers were set at 70 dBA and 1 second (fast) and 60 dBA and 10 seconds (slow). Calibrated Type 1 Larson Davis (Provo, Utah) 824 sound level meters, PRM902 microphone preamplifiers, and G.R.A.S. (North Olmsted, Ohio) 40AE microphones with windscreens were used to collect A-weighted wideband and 33 unweighted one-third octave band frequency (12.5-20,000 Hz) sound pressure levels each second during the sampling period. SoundMonitor051210™ (Far North Aquatics, Fairbanks, Alaska) software running on a Windows™-based Panasonic™ laptop computer controlled and stored the acoustical data. Sound level data were collected at the Blacktail Backcountry, Blacktail Roadside, and North Twin Lake monitoring sites using a calibrated Type 1 Larson Davis (Provo, Utah) 831 sound level meter, PCB PRM831 preamplifier, PCB 377B02 microphone (Provo, UT) with windscreen. Digital recordings were made at these sites with an Edirol R-09 (Bellingham, WA) mp3 digital recorder. Each system collected high quality digital recordings (44.1 KHz, 16-bit). B&K (Naerum, Demark) Model 4231 and Larson Davis LD200 calibrators were used for field calibration. The sound level meters, microphone preamplifiers, microphones, and calibrators were tested and calibrated at a laboratory that conforms to and operates under the requirements of ANSI/NCSL Z540-1. During the initial deployment, the sound level meter noise floor was measured using a Larson Davis ADP005 dummy microphone. The actual system noise floor (3-7 dBA above the level measured with a dummy microphone) is the lowest sound level that the system can measure. During quiet periods the actual ambient sound level was often lower than the noise floor (Burson 2006). Hobo™ wind speed sensors (Onset Computer Co., Pocasset, MA) and CV3F ultrasonic wind sensors (LCJ Capteurs, France) collected continuous wind speed data.

After the initial deployment, each monitor was visited at least biweekly. A field data sheet was completed during each visit. Basic site information, time arrive/time depart, latitude and longitude, habitat/vegetation types, equipment type and serial numbers, and software settings were documented. During each visit, time offsets were noted (global positioning system (GPS) time versus computer time), computer clocks were reset to GPS time, data were downloaded to a portable hard drive, and calibration levels were checked (differences from 94.0 dBA at 1000 Hz were noted and the system was recalibrated if >0.1 dBA).

The acoustic monitors, contained within weatherproof containers, were either plugged into electricity outlets (Old Faithful) or powered by 12-volt batteries with or without photovoltaic charging systems. Systems with solar panels or plugged into electrical outlets could operate continuously for weeks between site visits.

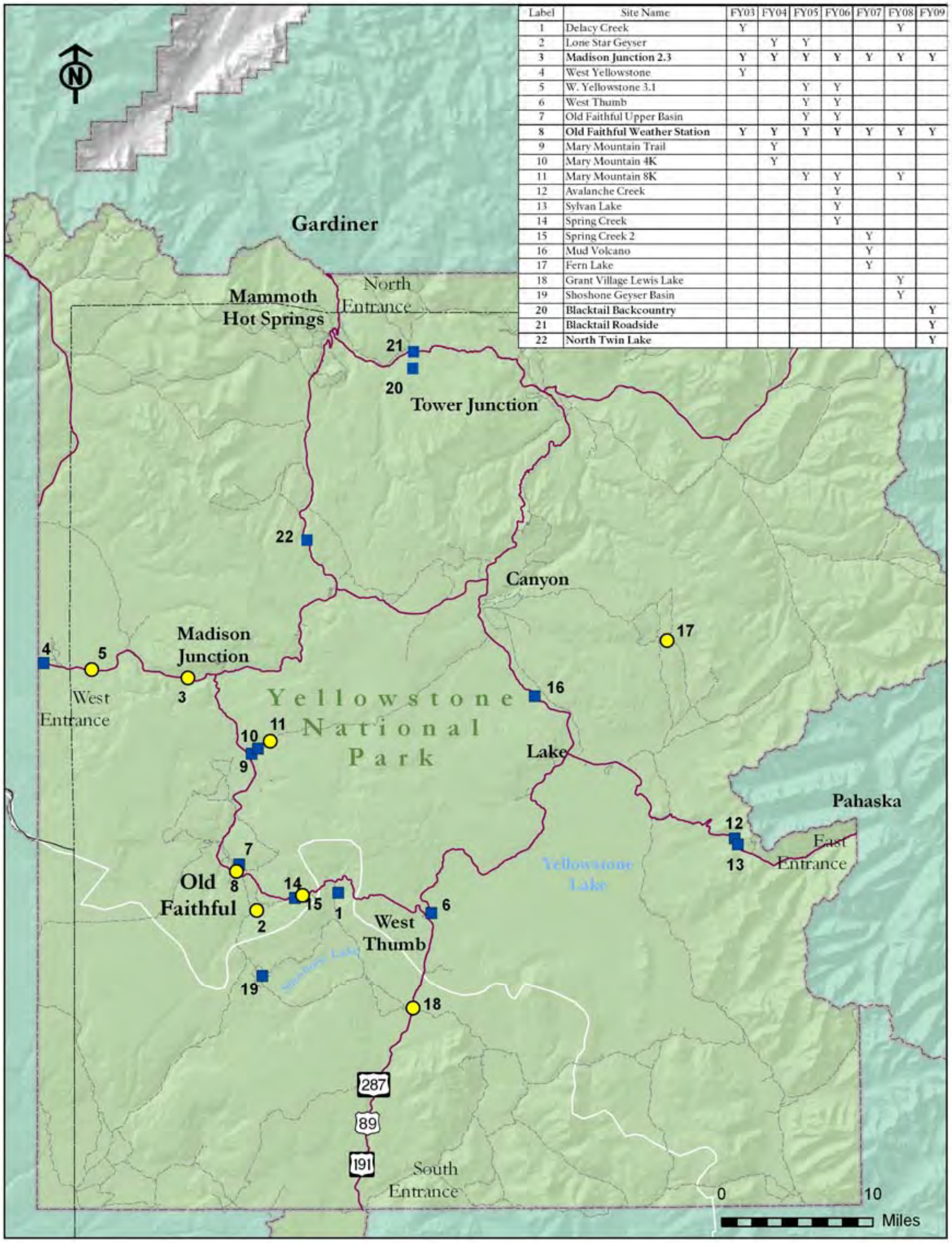
Specific methodologies (protocols) for equipment type, microphone placement, height, and other factors are summarized in Appendix A. These protocols followed guidance of Ambrose and Burson (2004) and were based on American National Standards Institute (ANSI) S12.9-1992, Part 2 (ANSI 1992), Federal Aviation Administration's "Draft Guidelines for the Measurement and Assessment of Low-level Ambient Noise" (Fleming et al. 1998), and "Methodology for the Measurement and Analysis of Aircraft Sound Levels within National Parks" (Dunholter et al. 1989). Appendix B contains a glossary of acoustical terms.

Acoustic Measurement Locations:

The 2008-2009 sound monitoring locations (Fig. 1) were chosen to include high, medium, and no OSV use areas and represented three soundscape management zones (Developed, Travel Corridor, and Backcountry). The specific placement relative to sound sources of interest was mainly determined by staffing and logistical constraints. The logistical constraints included open south facing sky for solar exposure for charging systems, proximity to electricity outlets, and placement of instrumentation in locations protected from large mammals. Habitat cover percentages listed below were measured in a 500 meter radius of the sound monitor.

The Blacktail Roadside and Backcountry sites were the first to monitor soundscapes along a winter wheeled vehicle travel corridor in Yellowstone National Park. The sites were chosen along the Mammoth to Tower road segment in the general vicinity of a popular winter backcountry ski and snowshoe area. Both roadside and backcountry systems were run simultaneously.

Similarly, the North Twin Lake site was included to provide monitoring information along a groomed travel corridor that had not been previously monitored.



Label	Site Name	FY03	FY04	FY05	FY06	FY07	FY08	FY09
1	Delacy Creek	Y					Y	
2	Lone Star Geyser		Y	Y				
3	**Madison Junction 2.3**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
4	West Yellowstone	Y						
5	W. Yellowstone 3.1			Y	Y			
6	West Thumb			Y	Y			
7	Old Faithful Upper Basin			Y	Y			
8	**Old Faithful Weather Station**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
9	Mary Mountain Trail		Y					
10	Mary Mountain 4K		Y					
11	Mary Mountain 8K			Y	Y		Y	
12	Avalanche Creek				Y			
13	Sylvan Lake				Y			
14	Spring Creek				Y			
15	Spring Creek 2					Y		
16	Mud Volcano					Y		
17	Fern Lake					Y		
18	Grant Village Lewis Lake						Y	
19	Shoshone Geyser Basin						Y	
20	**Blacktail Backcountry**							**Y**
21	**Blacktail Roadside**							**Y**
22	**North Twin Lake**							**Y**

Figure 1. Locations of sound monitoring sites (yellow circles- multiple seasons, and blue squares- winter-only) within Yellowstone National Park, December 2003-March 2009. See inserted table for key to year and labels. Only FY09 sampling locations are included in detail in this report (but see Appendix F and Burson [2004, 2005, 2006, 2007, and 2008] for previous winters' sampling results).

Old Faithful Weather Station

Latitude:	44.45688
Longitude:	110.83178
Elevation:	7400 feet (2255 m)
Habitat:	50% open (parking lot, road, buildings), 30% open (wetlands, thermal area), 20% forested (sparse lodgepole pine)
Management Zone:	Developed

Photo 1. Old Faithful Weather Station sound monitor location.

The Old Faithful Weather Station monitor was located within the fenced area of the weather station (in the center background of the photo above) adjacent to the Ranger Station. The site and nearby motorized routes were in a mostly flat long wide valley. The microphones were located 40 feet (12 m) from a walking/ski trail, 200 feet (61 m) from the Ranger Station, 230 feet (70 m) from the entrance road used by oversnow traffic, 300 feet (91 m) from the large parking lot between the Ranger Station and the Visitors Center, 600 feet (183 m) from the Old Faithful Inn, and 700 feet (213 m) from the Snow Lodge. The monitor was powered by AC electricity. See Tables 2 and 3 for dates of operation.

Madison Junction 2.3

Latitude:	44.64253
Longitude:	110.89645
Elevation:	6800 feet (2073 m)
Habitat:	80% forested (small post-burn lodgepole pines), 20% open (road, river)
Management Zone:	Travel Corridor

Photo 2. Madison Junction 2.3 sound monitor location.

The Madison Junction 2.3 monitor (in the center of the photo above in trees) was located 2.3 miles (3.7 km) west of Madison Junction, 100 feet (30 m) from the West Entrance-Madison Junction Road within a large area of small (4 to 8 feet [1-2 m]) lodgepole pines, and 275 feet (84 m) from the Madison River. The site and nearby motorized route were in a long mostly flat valley, one mile (1.6 km) wide, bounded on both sides by steep bluffs. The Madison Junction 2.3 monitor was powered from 12 volt batteries charged by solar panels. See Tables 2 and 3 for dates of operation.

Blacktail Roadside

Latitude:	44.95517
Longitude:	110.59513
Elevation:	6700 feet (2042 m)
Habitat:	90% open (sage/meadow), 5% open (road), 5% forested (conifers)
Management Zone:	Travel Corridor

Photo 3. Blacktail Roadside sound monitor location.

The Blacktail Roadside monitor (in the center right of the photo above) was located 100 feet (30 m) from the road between Mammoth and Tower Junction. The site was next to a large downed conifer within sage brush dominated landscape. The microphone was 950 feet (290 m) from the Blacktail Deer Plateau parking area. The site and nearby motorized route was on a slight incline to the north. The monitor was powered from 12 volt batteries. See Tables 2 and 3 for dates of operation.

Blacktail Backcountry

Latitude:	44.93441
Longitude:	110.59263
Elevation:	7100 feet (2164 m)
Habitat:	90% open (sage/meadow), 10% forested (conifers)
Management Zone:	Backcountry


Photo 4. Blacktail Backcountry sound monitor location.

The Blacktail Backcountry monitor was placed within a small conifer forest (center of photo above) within an extensive sage brush/meadow area. The microphone was located 1.5 miles (2.4 km) from the nearest motorized route (between Mammoth and Tower Junction) and 1.4 miles (2.2 km) from the Blacktail Roadside monitor. The site was within rolling hills sloping to the north. The monitor was powered by 12 volt batteries. See Tables 2 and 3 for dates of operation.

North Twin Lakes

Latitude:	44.77484
Longitude:	110.73576
Elevation:	7500 feet (2286 m)
Habitat:	15% open (lake), 5% open (road), 80% forested (conifer)
Management Zone:	Travel Corridor

Photo 5. North Twin Lake sound monitor location.

The North Twin Lake monitor (in center of the photo above) was located 100 feet from the groomed road between Mammoth and Norris. The monitor was within a mature forest of lodgepole pines, 50 feet (15 m) from the edge of North Twin Lake and 1500 feet (457 m) from Roaring Mountain thermal area. The site was within an extensive area of rolling hills. The monitor was powered by 12 volt batteries. See Tables 2 and 3 for dates of operation.

Analyses:

Audibility

The daily 360 10-second digital recordings were calibrated, combined, and replayed using Adobe's Audition™ software, Sound Devices USBPre™ acoustical interface, and professional grade headphones. The Soundscape Database software (Ric Hupulo, formerly of the Natural Sounds Program, Ft. Collins, CO) was used to analyze the audibility data. The entire 24 hour period was analyzed but the time period 8 am to 4 pm (120 samples totaling 20 minutes per day) is reported here as prescribed in the 2004 Yellowstone and Grand Teton National Park Winter Use Plans Environmental Assessment (NPS 2004).

When determining sound sources via playback of field recordings, the volume of the playback was adjusted to the recorded calibration tone decibel level and was further increased by 10 dBA to approximate field audibility. This value was determined from comparisons between field observations with simultaneous recordings and subsequent office playback. Humans have directional hearing and observers in the field can and do turn toward faint sounds and thus can hear those sounds better than when we cannot turn to face the sound, as in an office playback. This difference cannot be accounted for in an office environment. In addition, instrumentation used for recording and playback add artificial noise that may mask very quiet sounds that may be heard in the field. As a result, audibility determined through office playback of digital recordings likely represents an approximate, but minimum assessment of time audible of various sound sources. All investigators had normal hearing as tested by certified audiologists. Investigators replayed the daily recordings and determined the source (snowmobile, animal, aircraft, wind, thermal activity, etc.) for each audible sound.

The percent time audible for each sound source was calculated using the 10-second samples every four minutes as surrogate for all periods of the day. For example, if a particular sound source was audible for half of the samples (180 of 360 samples) its percent time audible was calculated as 50%. Although any sampling scheme may miss a rare sound, comparison with attended logging, other sampling schemes and continuous recordings demonstrated that analyses using a 10 seconds/4 minute scheme closely approximate actual percent time audible of frequent sound sources (e.g., oversnow vehicles).

It was increasingly difficult to identify sound sources as distances increased from the recording location to the sound source. Therefore sound source codes are hierarchal (e.g., snowmobile; oversnow vehicle; motorized sound; non-natural sound; unknown). The most specific identification possible was used. Four-stroke snowmobiles were sometimes difficult to distinguish from snowcoaches. When the two categories could not be distinguished they were combined in the analyses (Fig. 3 and 6 provide examples of the relative proportions of snowmobiles, snowcoaches, and the combined category at two locations). When sound sources could only be identified as motorized vehicles they were not included in the oversnow vehicle category, although it is likely that many were oversnow vehicles.

Event Analysis
The event recordings of loud sounds were replayed and each sound source identified and tallied.

Sound levels
Sound pressure levels (decibels) were compiled and common acoustic metrics were calculated using HourlyMetrics™ software (Ric Hupalo, formerly of the NPS Natural Sound Program, Ft. Collins, CO). Wind contamination (distortion) caused false sound levels when wind speeds exceeded the capacity of the microphone windscreens. Therefore, data collected when wind speeds exceeded 11 mph (5 meters per second) were deleted from analyses. Strong wind is a natural phenomenon and deleting periods of time with strong winds would artificially lower estimates of natural ambient sound levels during these wind events. This potential bias is not a major concern because the number of seconds that were deleted was small compared to the total number of seconds, and estimating natural ambient sound levels was not a primary objective of this study. Data influenced by visits to the monitoring site were also deleted from analyses.

This report relies on a number of common acoustical metrics for the sound level data and descriptive statistics, mostly medians, for the audibility data. The real distribution of data points is not revealed when only medians are displayed. A disadvantage of using only medians is that knowledge of these other values is often valuable for interpretation, therefore minimum and maximum values are also given. Although estimates of variability beyond the minimum and maximum values are also desirable no easily understood, yet informative, methods have been developed.

The 2000, 2003, 2004, and 2007 Winter Use Plans (Appendix C) contain previous standards and thresholds for further comparison.

Results and Discussion:

Winter-long acoustical measurements were collected at Old Faithful Weather Station and Madison Junction 2.3. Additional acoustic data were collected for shorter time periods at Blacktail Roadside, Blacktail Backcountry and North Twin Lake (see previous section for site details). Data collection began on 15 December 2008 and continued throughout the winter use season (15 December 2008-15 March 2009). Selected data (Tables 2 and 3) of those available were chosen for analysis based on random sampling stratified by day of the week and month. The recent WUP impact thresholds applied only to motorized oversnow vehicle sounds from 8 am-4 pm so for the audibility analyses only those periods are presented in this report. Because the majority of OSV use was during 8 am to 4 pm, using the full 14-hour period of the day when OSV use was permitted would lower the resulting percent time audible values (see Appendix G). A wealth of biological data, as well as sound level data, is contained within this study's acoustic dataset. These additional data, substantially not yet analyzed, are available for future study. For comparative value the sound levels are presented for the 24 hour day although the WUP thresholds applied only to 8 am-4 pm.

The very low natural ambient sound levels documented at near Sylvan Pass and Craig Pass (Ambrose et al. 2006, Burson 2007) were similar to many monitoring locations measured for this study. Audibility of oversnow vehicles is determined, in part, by the natural ambient sound levels. Lower natural ambient sound levels result in higher OSV percent time audible. At several monitoring locations the lowest minimum sound levels were below the range (noise floor) of the instrumentation for many hours of the day. The actual minimum levels are therefore unknown. Because of this uncertainty, at the lowest sound levels the association between the number of OSVs, the natural ambient sound levels, and the distances OSVs are audible remains ambiguous (see pg. 19-20 for more on this topic).

Acoustic data were collected at Yellowstone National Park during the past seven winter seasons, although the first winter consisted of only short-term data collection. This dataset is beginning to provide information on trends, similarities among years and variability in time and location (Table 4). Soundscapes are highly variable over time, both in minutes and seasons. All attempts to summarize long-term datasets therefore fail to describe or fully explain this inherent variability. This study suffers from this weakness; however, methods and techniques to completely address the soundscapes variability are currently unavailable. Attempts to draw tight correlations or associations between certain actions, such as the daily number of oversnow vehicles allowed to enter YNP and the percent time audible at a particular location require more detailed analyses than can be presented here. Nevertheless, the acoustic dataset that has been collected during the winter-use season and upon which this report is based is one of the most extensive national park winter acoustic datasets in existence and a substantial amount of useful information can be gathered from the data as presented.

See Appendix C for acoustical standards and thresholds of the 2000, 2003, 2004, and 2007 Winter Use Plans of Yellowstone and Grand Teton National Parks and the John D. Rockefeller, Jr., Memorial Parkway. See Appendix D for a discussion and examples of a technique to visualize daily sound levels. This technique provides another avenue to understand the natural soundscape and the sound impact of oversnow vehicles. See Appendix E for the results of a multi-year observational study designed to determine the proportion of several usage categories for oversnow vehicles (e.g., percent of total snowmobiles driven by park visitors). See Appendix F for related sound monitoring data from the previous winter season, and Appendix G for additional considerations of OSV percent time audible summaries.

Perhaps the most intuitive and easily understandable results come from the digital recordings and audibility analyses. These results will be presented first followed by the sound level analyses.

Table 2. Dates used for audibility analyses at five locations in Yellowstone National Park, December 2008-March 2009. Daily average number of snowmobiles was 190/day for the 91-day winter use season, excluding OSVs originating from Old Faithful. Daily average number of wheeled vehicles was 373/day during 15 December 2008- 28 February 2009*. Total number of days analyzed, 82.

Old Faithful Weather Station	Madison Junction 2.3	Blacktail Backcountry	Blacktail Roadside	North Twin Lakes
29 days	24 days	14 days	8 days	7 days
17-Dec-08	15-Dec-08	20-Dec-08	19-Dec-08	11-Feb-09
19-Dec-08	16-Dec-08	23-Dec-08	20-Dec-08	13-Feb-09
20-Dec-08	31-Dec-08	24-Dec-08	21-Dec-08	15-Feb-09
21-Dec-08	1-Jan-09	25-Dec-08	24-Dec-08	17-Feb-09
22-Dec-08	13-Jan-09	26-Dec-08	25-Dec-08	19-Feb-09
25-Dec-08	16-Jan-09	28-Dec-08	26-Dec-08	21-Feb-09
26-Dec-08	19-Jan-09	29-Dec-08	27-Dec-08	23-Feb-09
3-Jan-09	21-Jan-09	4-Jan-09	28-Dec-08	
4-Jan-09	25-Jan-09	5-Jan-09		
5-Jan-09	31-Jan-09	7-Jan-09		
12-Jan-09	1-Feb-09	9-Jan-09		
16-Jan-09	2-Feb-09	10-Jan-09		
20-Jan-09	7-Feb-09	13-Jan-09		
21-Jan-09	11-Feb-08	15-Jan-09		
29-Jan-09	17-Feb-08			
1-Feb-09	19-Feb-08			
7-Feb-09	27-Feb-08			
10-Feb-09	1-Mar-08			
11-Feb-09	2-Mar-08			
16-Feb-09	3-Mar-08			
19-Feb-09	4-Mar-08			
27-Feb-09	5-Mar-08			
2-Mar-09	13-Mar-08			
3-Mar-09	14-Mar-09			
4-Mar-09				
5-Mar-09				
8-Mar-09				
13-Mar-09				
14-Mar-09				
Daily # of snowmobiles entering Yellowstone NP during sampling days.[1]				
163/day	173/day	318*/day	350*/day	230/day

[1]Listed at bottom of table are daily snowmobile averages for the days included in the analysis. Average number of snowmobiles was calculated using all snowmobiles entering Yellowstone. Not all snowmobiles would pass by each site. Daily average number of snowcoaches for the winter use season was 26/day. See text for further details. * Wheeled vehicles as collected by a traffic counter (2702) just beyond Mammoth on road to Tower.

Table 3. Dates used for sound level analyses at five locations in Yellowstone National Park, December 2007-March 2008. Total hours, 5,380.

Old Faithful (2,044 hours)	Madison Junction 2.3 (1,632 hours)
15 December 2008-15 March 2009	15-18 December 2008
	30 December-2 January 2009
Blacktail Backcountry (667 hours)	12 January- 15 March 2009
18 December 2008-16 January 2009	
	North Twin Lake (356 hours)
Blacktail Roadside (681 hours)	10-25 February 2009
19 December 2008-16 January 2009	

Audibility:

The source of each sound (snowmobile, wheeled vehicle, animal, aircraft, wind, thermal activity, etc.) that was audible was identified from the 120 10-second digital recording samples each day during 8 am-4 pm. The proportion of each sound source sample out of the possible 120 was used to calculate the percent time audible for each sound source; however, only the snowmobile, snowcoach and wind percent time audible is presented. Oversnow vehicles were often audible outside the 8 am- 4 pm time period, but these data are generally not presented, but see Appendix G. Often multiple snowmobiles or snowmobiles and snowcoaches were audible simultaneously, but other times one masked the sound of the other so all percent time audible statistics should be considered minimum values. Audibility of OSVs were calculated using existing ambient conditions, that is, other non-natural sound sources could have been present and may have masked OSV sounds. This potential masking was only regularly present at developed areas. The only non-natural sounds other than OSVs (or wheeled vehicles) at travel corridors and backcountry sites were occasional aircraft. The average number of snowcoaches entering YNP during the winter season was 26/day (range 9-51) with an additional daily average of three snowcoaches originating from Old Faithful. The average number of snowmobiles entering YNP during the winter season was 190/day (range 32-408) with an additional daily average of nine snowmobiles originating from Old Faithful. See Table 2 for further details. The percent time audible calculations were based on days throughout the entire winter use season, but because of inadequate snowcover on the travel corridors, snowmobiles and snowcoaches with metal tracks or skis were first allowed into the park on 18 December, three days after the winter use season began.

For the first time, acoustic data were collected along the plowed road between Mammoth and Tower. Vehicle traffic along the road increased through the winter season. The daily average number of vehicles was 284/day for 15-31 December, 354/day in January, and 449/day in February. Acoustic data were collected during December and January. Most traffic occurred between 7 am and 6 pm.

Regarding oversnow vehicles, an important question is the relationship between the number of snowmobiles and snowcoaches entering YNP and the percent of time that they are audible at a particular measurement location. At first glance this appears an easily answered question. It seems intuitively obvious that more snowmobiles and snowcoaches would make more sound and that they would be heard a greater proportion of the day. This is true in general and is obvious in the acoustic data collected during the past six winters, and especially this past winter. Several factors, though, complicate the relationship. First, not all snowmobiles are part of guided groups; there are NPS and concession snowmobiles and snowcoaches used within the park, especially in destination areas such as Old Faithful (see Appendix E). Second, not all OSVs that enter the park travel along the same route. Therefore the number of snowmobiles entering the park is not directly related to the number passing any particular section of the road and hence their impact on the natural soundscape of that area. Third, as the numbers of visitors entering the park increases, additional snowmobiles are often added to existing groups enlarging group size, but not creating additional groups. The percent time that snowmobiles are audible is more closely associated with the number and distribution of groups rather than the number of individual snowmobiles. Fourth, audibility also depends on environmental conditions, such as temperature, wind conditions, inversions, the natural ambient sound level and other factors (as discussed in the next paragraph) that vary spatially and temporally. These factors added together reduce the potentially close relationship between the number of visitor snowmobiles and their percent time audible.

A related issue involves an acoustical metric called the noise-free interval (NFI). NFIs measure the uninterrupted periods of time when only natural sounds are audible. For the purposes of this report, NFIs were the times when no oversnow vehicles were audible. Using logic and common sense, the number and distribution of oversnow vehicles largely determine the NFI. Given the same number of oversnow vehicles, NFIs measured near travel corridors would be longer with larger rather than smaller groups (however as group size increases OSVs would likely be heard at increasing distances). A particular percent time audible can have varying NFIs. For example, if oversnow vehicles were audible for 50% of an hour, depending on the distribution of these vehicles they could all be audible in the first 30 minutes and not audible the remaining 30 minutes. Or oversnow vehicles could be audible every other 10 minute period during the hour. The NFI of the first scenario would be 30 minutes but only 10 minutes for the second. Groups of guided snowmobiles have increased the NFIs at YNP compared to unguided snowmobiles (personal observation, and Appendix D; Fig. D-6 and D-7).

Audibility depends on the sound level of and distance from the sound source as well as the presence of natural sounds, and non-sound source variables such as atmospheric conditions, wind speed and direction, topography, snow cover, and vegetative cover. These various factors influenced day to day audibility at any given location including the sound monitoring sites. In general, distant oversnow vehicles were masked by wind if it was present. The presence or absence of wind made the most appreciable difference in the percent time that OSVs were audible at sites where OSVs could be heard at low sound levels during calm wind conditions. All audibility results reported here are from the analyses of actual field recordings from the monitoring sites. Therefore, all sounds, both natural and non-natural influenced the reported audibility of OSVs. No two days were identical, but patterns were regularly observed and differences among monitoring locations are apparent.

Old Faithful Weather Station

Acoustic data were collected at this site for the seventh winter (Table 4). Even though this site was Yellowstone's busiest developed area accessed by OSVs, many natural sounds were present, including wind, snow, wolves, coyotes, bison, red squirrels, ravens, ducks and geese. Non-natural sounds of building utilities, construction activities, and people's voices were frequently audible along with oversnow vehicles. The average daily percent time audible for snowmobiles and snowcoaches was 55% within the developed area at Old Faithful, (Fig. 2). This compares to 67-69% during the previous four winter use seasons (Table 4 and Appendix F). The lower percent time audible value is likely due to a decrease in the daily average of about 95 snowmobiles/day and that there were no snowmobiles or snowcoaches with metal skis or tracks allowed the first three days of the season. No (0%) of the 27 days analyzed exceeded the 2004 WUP audibility threshold of 75% for developed areas.

Oversnow vehicles traveling on the main road and within the Old Faithful developed area were audible at this site. Wind, depending on direction and speed, can increase or decrease the distance OSV sounds are audible. However, typically OSVs are heard at greater distances during calm wind conditions, and there appears to be no strong association between days with low to moderate wind and oversnow vehicle percent time audible at Old Faithful (Fig. 2). This is logical because the higher ambient sound levels at Old Faithful mask distant OSV sounds.

Percent time audible can be calculated by hour to understand the pattern of oversnow vehicle use between 8 am and 4 pm (Fig. 3). Early in the day (8 am and 9 am) snowcoaches were audible for more time than snowmobiles. On average, however, snowmobiles were audible for 26% of the day versus 18% for snowcoaches (Fig. 3). Oversnow vehicles were audible on average at least 60% of the time during each of the three mid-day hours (11 am, 12 pm, and 1 pm). Oversnow vehicles were audible over 90% of the hour during 12 pm and 1 pm during some days of the winter season (Fig. 3).

The analyses for the WUP measurement period are restricted to 8 am-4 pm but oversnow vehicle sounds were commonly audible outside that time period (e.g., Fig. 4). Many of these OSVs were driven by employees.

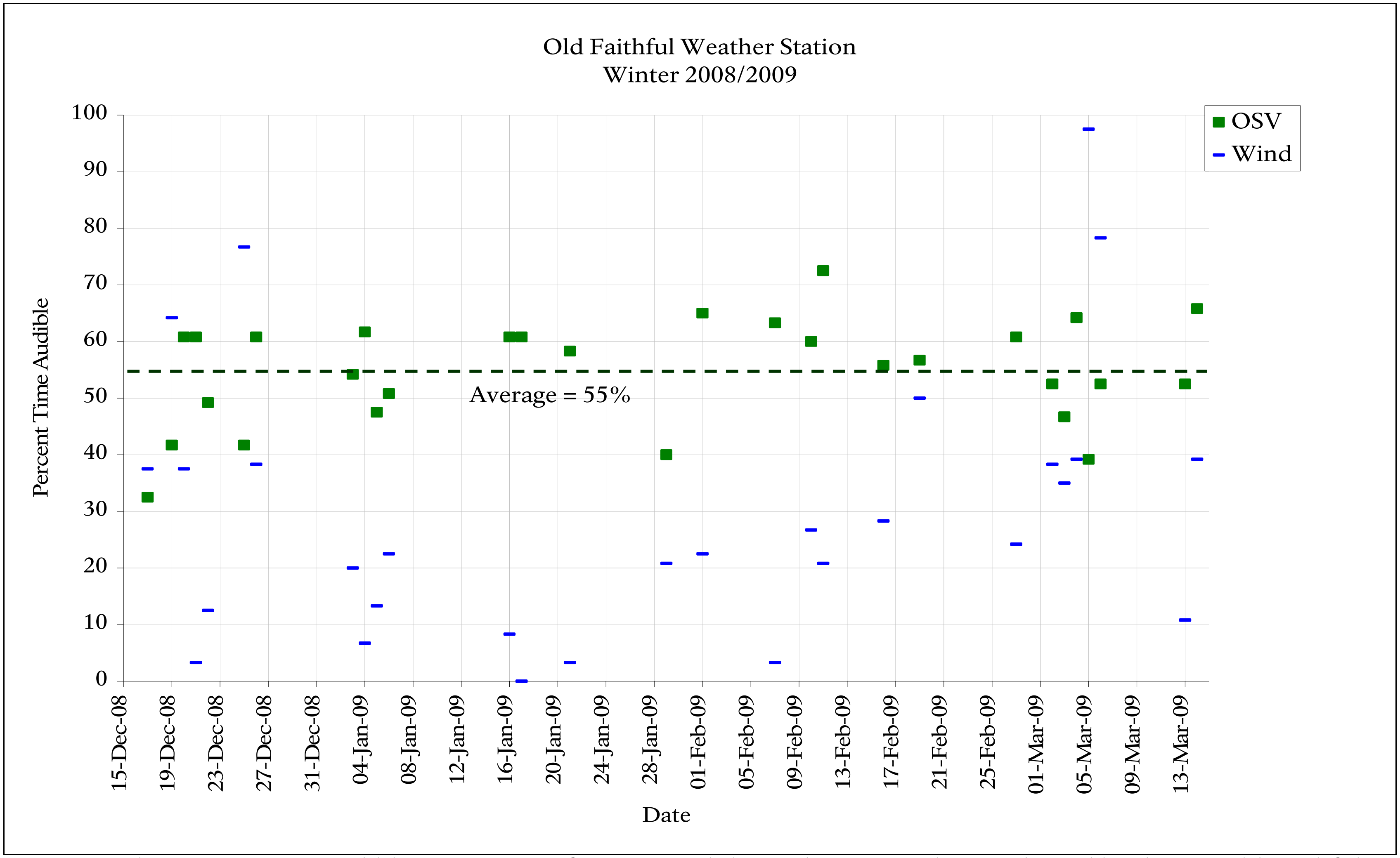


Figure 2. The percent time audible (8 am-4 pm) for snowmobiles and snowcoaches, and wind by date at Old Faithful Weather Station, Yellowstone National Park, 15 December 2008 to 15 March 2009.

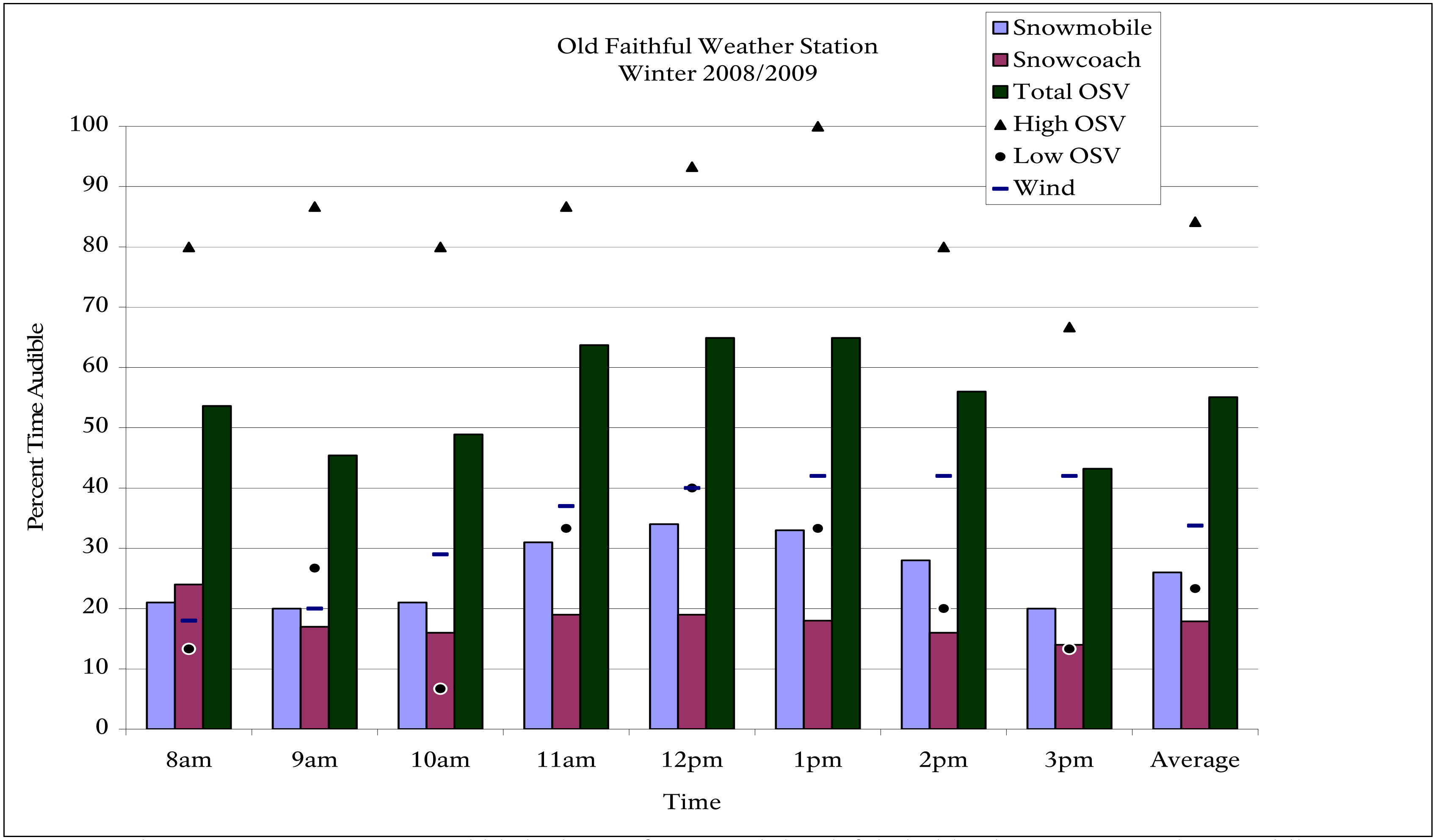


Figure 3. The average percent time audible by hour of snowmobiles (left light blue bar), snowcoaches (middle maroon bar), and combined category (right dark green bar), and high and low OSV values at Old Faithful Weather Station, Yellowstone National Park from 8 am to 4 pm, 15 December 2008 to 15 March 2009.

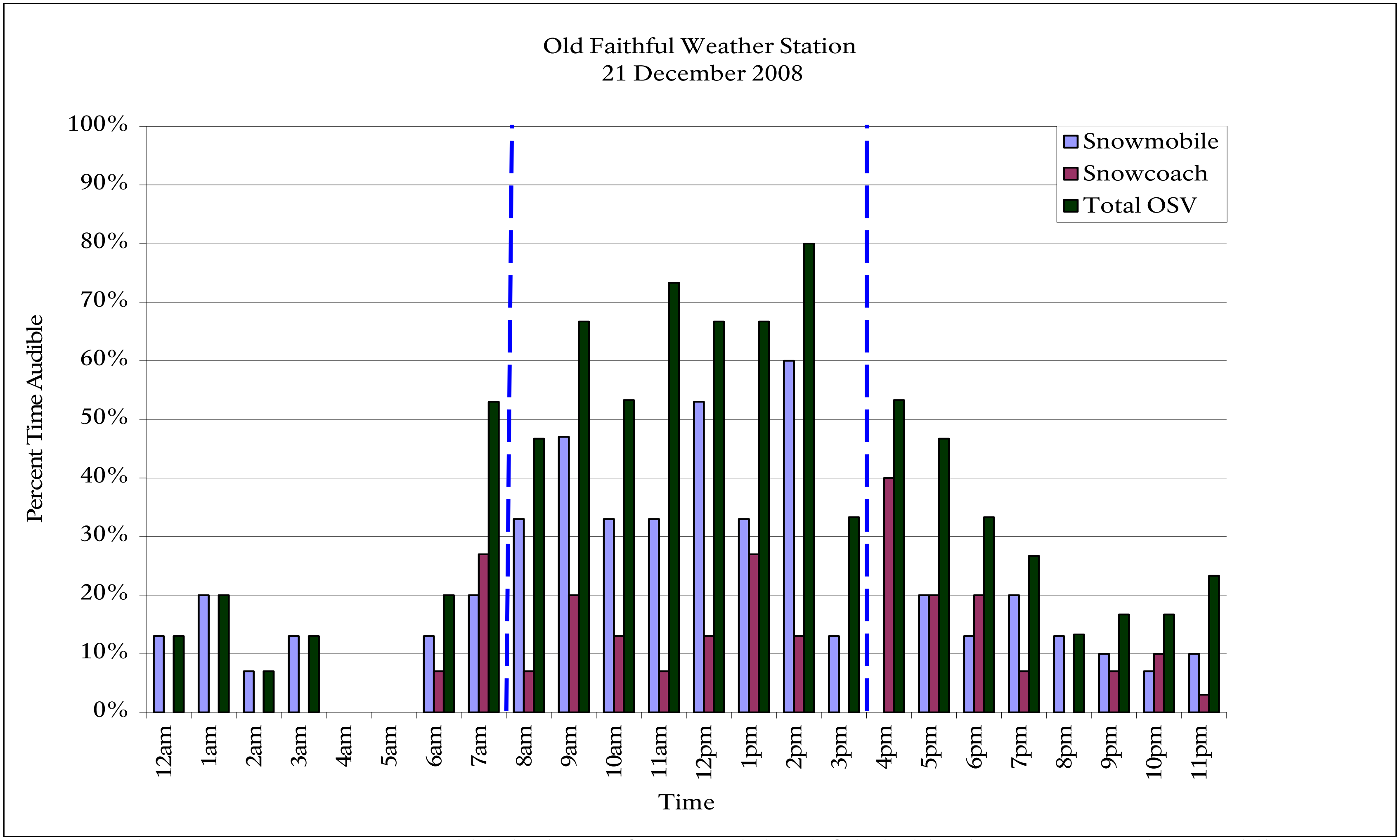


Figure 4. The average percent time audible by hour of snowmobiles (left light blue bar), snowcoaches (middle maroon bar), and combined category (right dark green bar) at Old Faithful Weather Station, Yellowstone National Park, 21 December 2008. The winter use analysis time period is between the vertical dashed lines.

Madison Junction 2.3

Madison Junction 2.3 monitoring site was located 100 feet (30 m) off the West Entrance Road 2.3 miles (3.7 km) west of Madison Junction along Yellowstone's busiest OSV travel corridor. Acoustic data were collected for all or parts of the past seven winter use seasons (Table 4) at this location. Quiet riffles of the Madison River were audible when not masked by the sounds of wind, swans, coyotes, wolves, ducks, geese, ravens, and oversnow vehicles. Snowmobiles and snowcoaches were audible for an average of 47% of the time during the entire winter use season (Fig. 5). This compares to 53% during the winter of 2007-2008. The 2008-2009 winter's lower percent time audible value is likely due to a decrease in the daily average of about 95 snowmobiles/day and that there were no snowmobiles or snowcoaches with metal skis or tracks allowed the first three days of the season. The daily average OSV percent time audible was 49% if the first two sampled days (when only rubber-tracked snowcoaches were allowed) are excluded. The OSV percent time audible exceeded 50% for 8 (33%) of 24 days analyzed during the winter 2008-2009 (Fig. 5). Wind speed was associated with the audibility of OSVs at this site. OSVs were less audible on days with more wind due to the masking effect of wind on the distant and faint OSV sounds.

The hourly pattern follows a bimodal distribution (Fig. 6) documenting the pulse of OSVs passing by the site in the morning on the way into the park and in the afternoon on the way back to West Yellowstone. The average OSV percent time audible exceeded 50% during the hours of 9 am, 10 am, and 3 pm. Figure 6 also shows that many of the OSVs could not be distinguished as a snowmobile or a snowcoach. This is because it was not possible to identity as either snowmobile or snowcoach many distant faint OSVs.

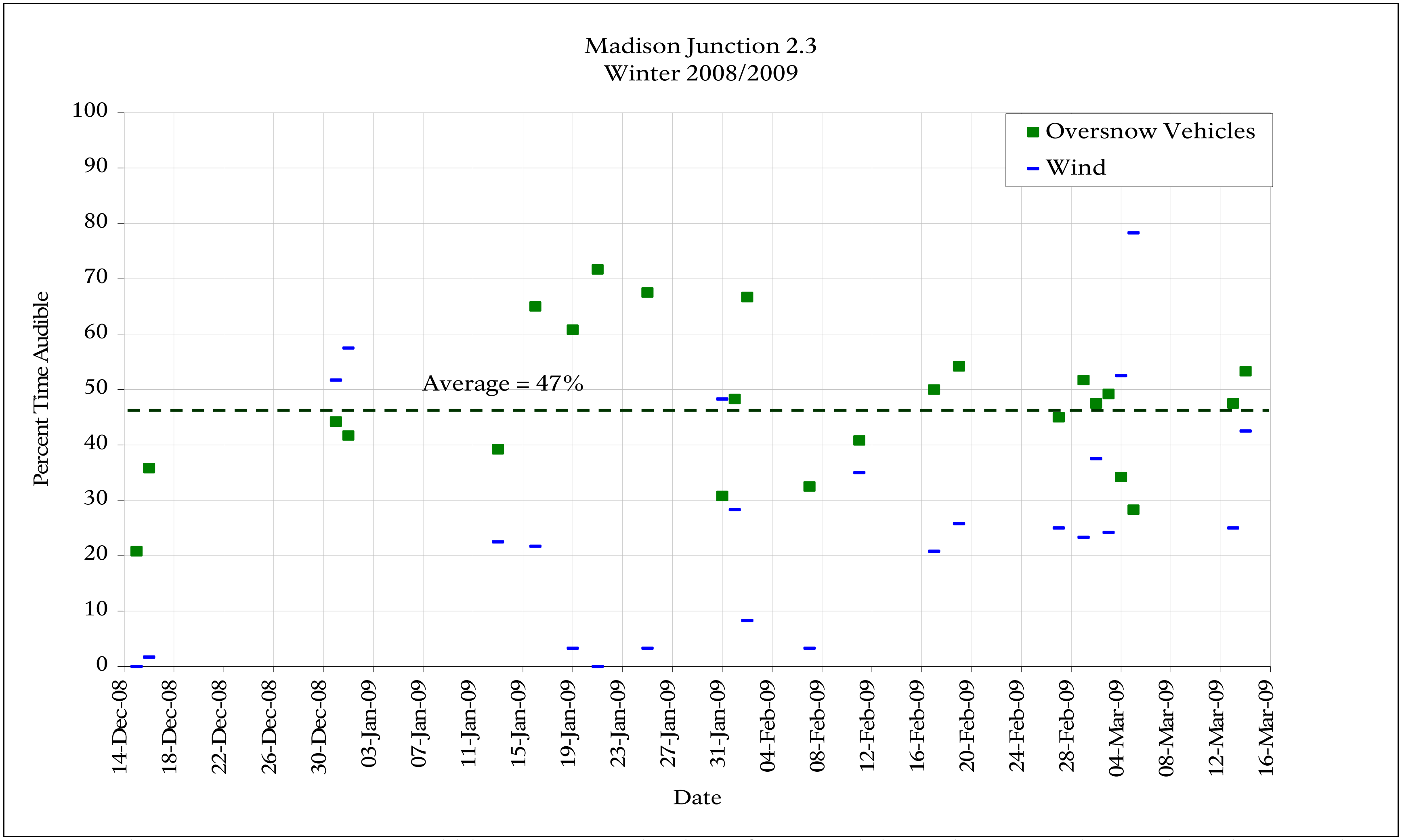


Figure 5. The average percent time audible (8 am-4 pm) by date of snowmobiles and snowcoaches, and wind at 2.3 miles (3.7 km) west of Madison Junction along the West Entrance Road Yellowstone National Park, 15 December 2008-15 March 2009.

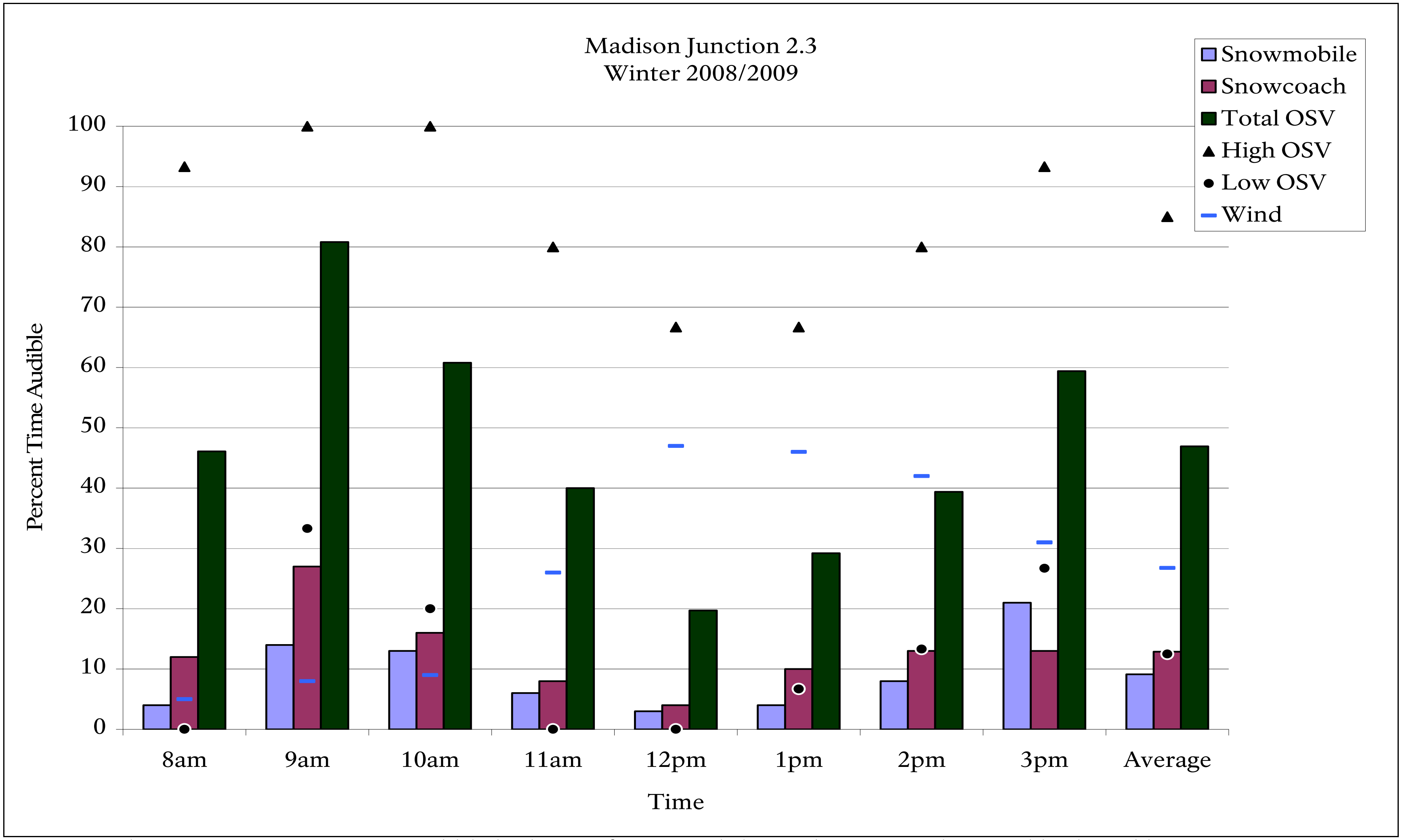


Figure 6. The average percent time audible by hour of snowmobiles and snowcoaches, and high and low OSV percent time audible at 2.3 miles (3.7 km) west of Madison Junction along the West Entrance Road, Yellowstone National Park, 15 December 2008- 15 March 2009.

Blacktail Backcountry

Acoustic monitoring data were collected on Blacktail Deer Plateau at Blacktail Backcountry for the first time this winter season. This location was adjacent to and 1.5 (2.4 km) miles from the plowed road between Mammoth and Tower Junction. The closest oversnow vehicle use was over six miles away on the groomed road between Mammoth and Norris. Wheeled vehicles (Fig. 7) and aircraft were the only motorized sounds audible at Blacktail Backcountry.

Wheeled vehicles were audible an average of 12% of the time between 8 am and 4 pm during the 14 days analyzed in December and January (Fig. 7). Wind was audible and strong on the majority of days. Wind likely masked the low sound levels of distant vehicle sounds most days (see 4 January 09; Fig. 7). Aircraft were audible an average of 4% from 8 am to 4 pm.

Only the 8 am hour had average wheeled vehicle audibility above 20% (Fig. 8). Every hour had a minimum wheeled vehicle audibility of zero on at least one day that was analyzed (Fig. 8). Snowplows were tallied separately and included in "Total Vehicles" (Fig. 8).

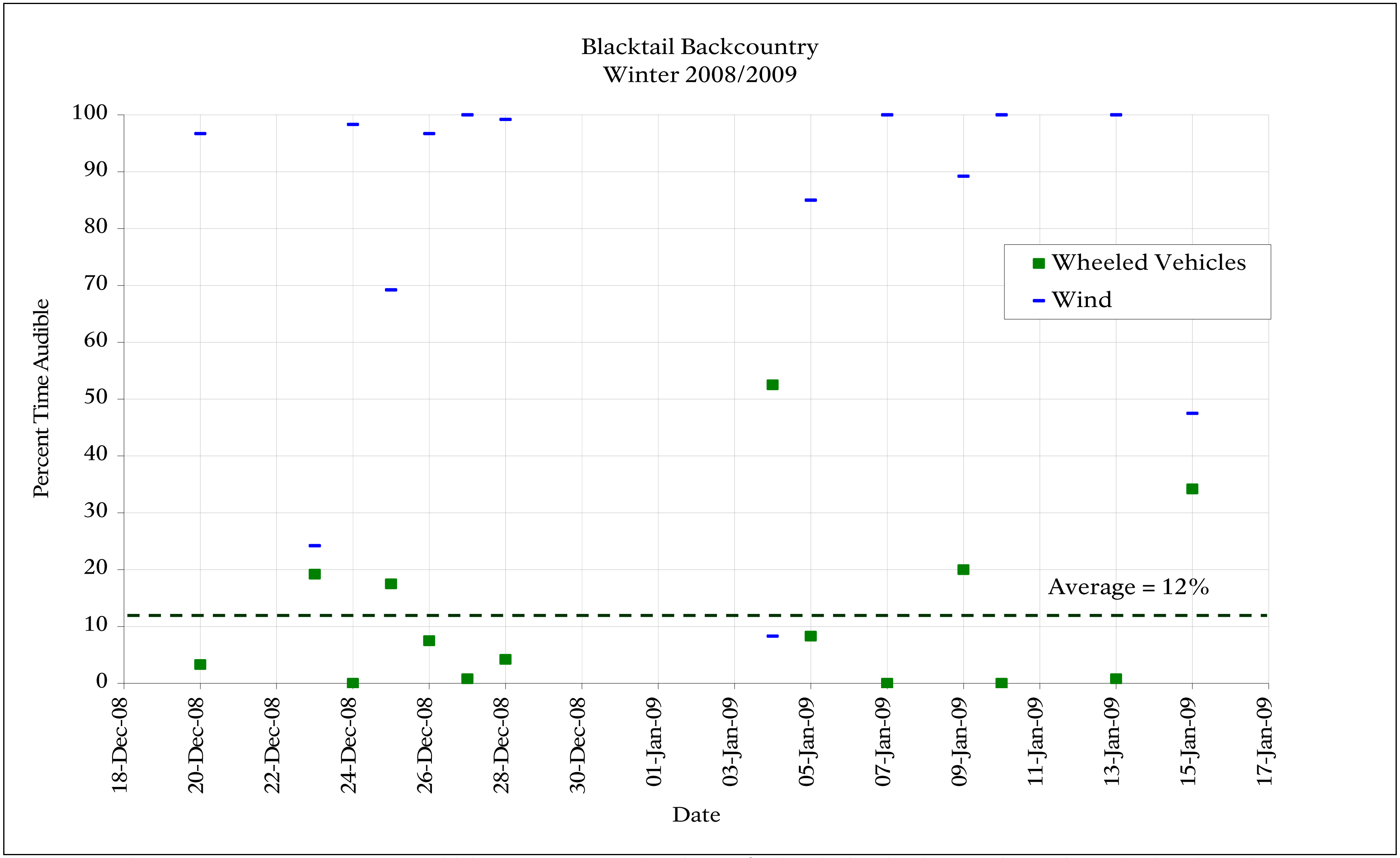


Figure 7. The average percent time audible (8 am-4 pm) by date of wheeled vehicles, and wind at Blacktail Backcountry, Yellowstone National Park, 20 December 2008-15 January 2009.

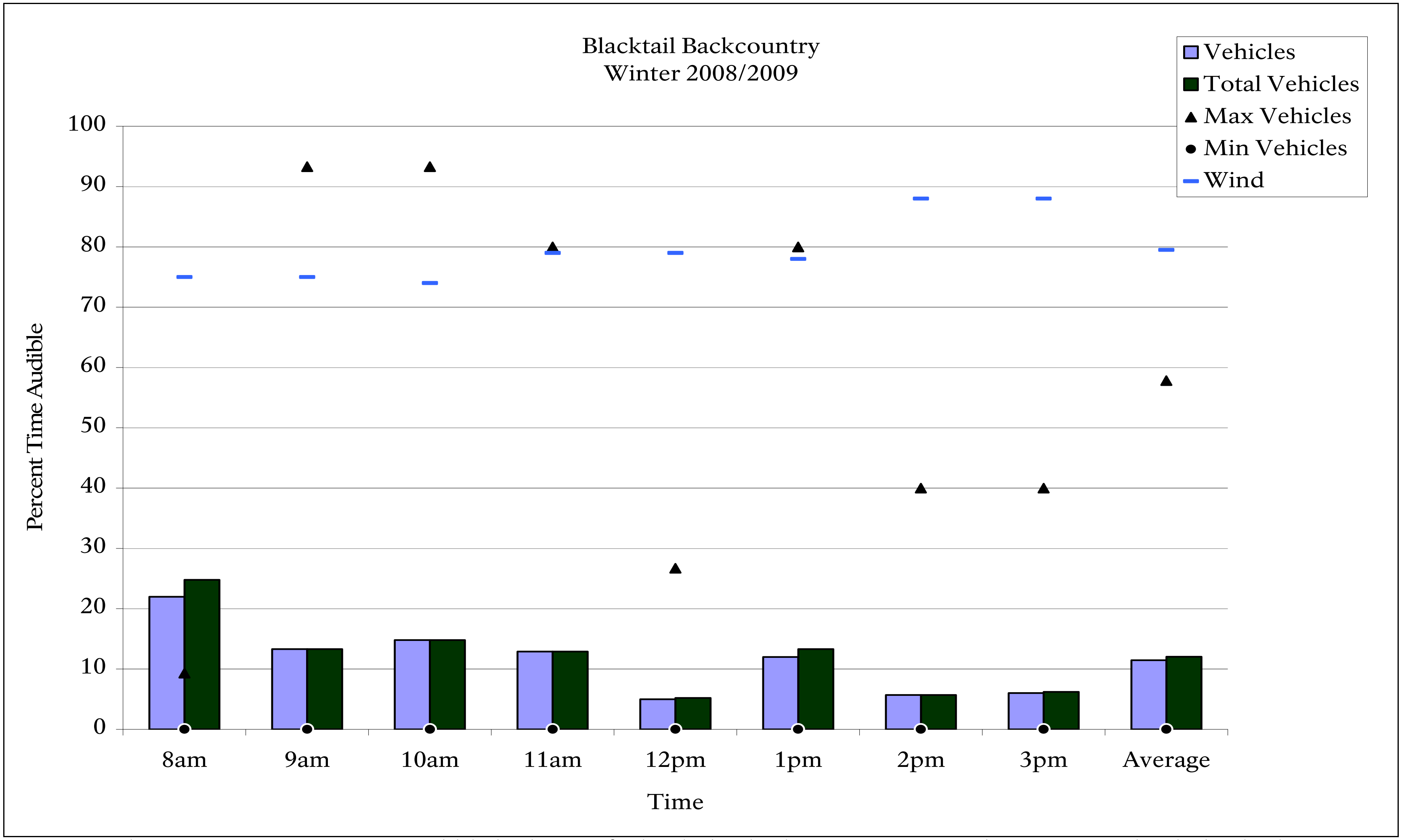


Figure 6. The average percent time audible by hour of wheeled vehicles, maximum and minimum wheeled vehicle percent time audible, and wind at Blacktail Backcountry, Yellowstone National Park, 20 December 2008- 15 January 2009.

Blacktail Roadside

Acoustic monitoring data were collected on Blacktail Deer Plateau at Blacktail Roadside for the first time this winter season. This location is adjacent to and 100 feet (30.5 m) from the plowed road between Mammoth and Tower Junction. The closest oversnow vehicle use was over six miles away on the groomed road between Mammoth and Norris. Wheeled vehicles (Fig. 9) and aircraft were the only motorized sounds audible at Blacktail Roadside.

Wheeled vehicles were audible an average of 34% of the time between 8 am and 4 pm during the eight days analyzed in December 2008 (Fig. 9). Wind was audible for over 50% of the time on all days analyzed. Wind likely masked the low sound levels of distant vehicle sounds most days (Fig. 9). Aircraft were audible an average of 3% from 8 am to 4 pm.

Only the 9 am hour had average wheeled vehicle audibility below 20%; the other hours were consistently between 40% and 50% (Fig. 10). Snowplows were tallied separately and included in "Total Vehicles" (Fig. 10).

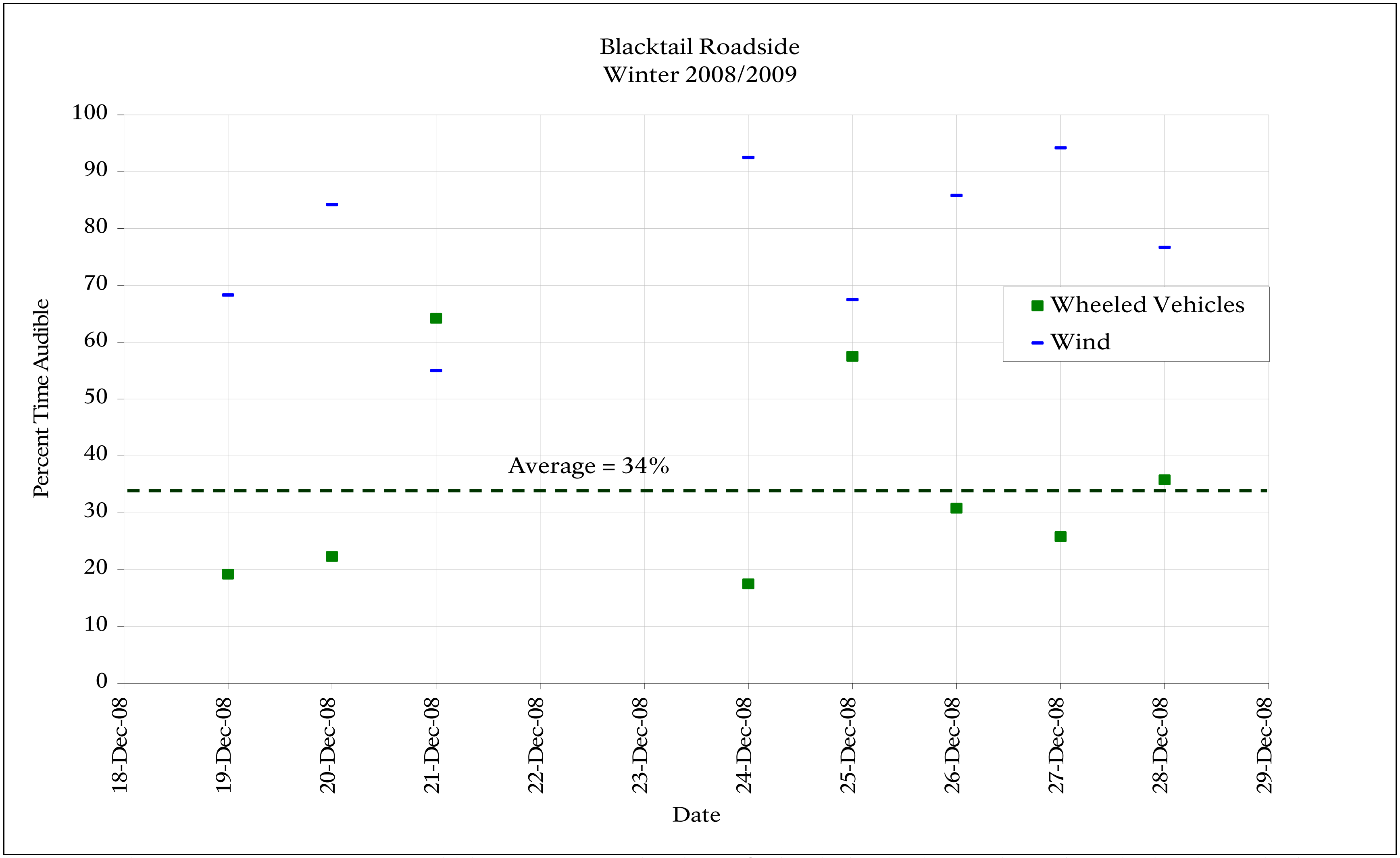


Figure 9. The average percent time audible (8 am-4 pm) by date of wheeled vehicles, and wind at Blacktail Roadside, Yellowstone National Park, 19-28 December 2008.

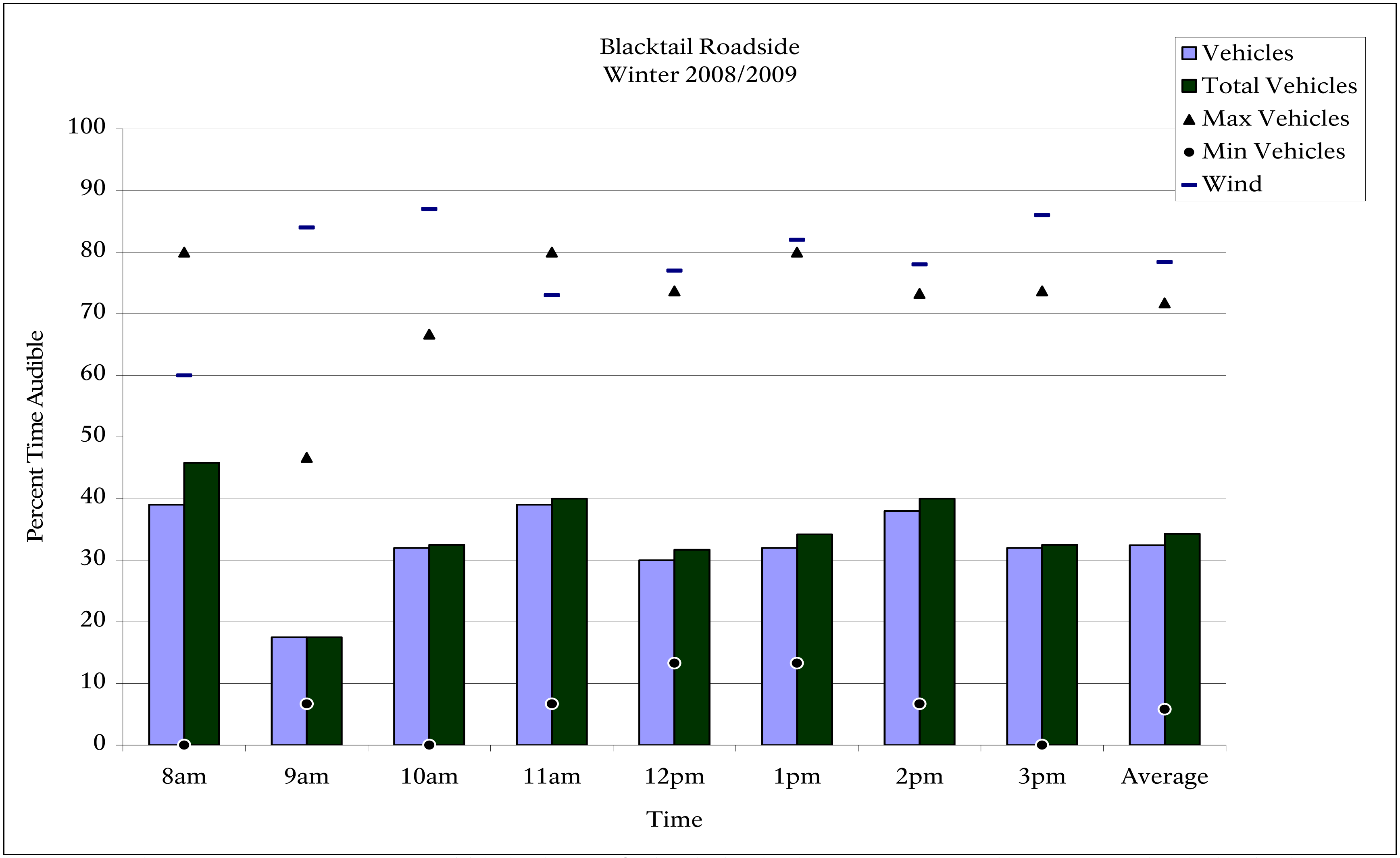


Figure 10. The average percent time audible by hour of wheeled vehicles, maximum and minimum wheeled vehicle percent time audible, and wind at Blacktail Roadside, Yellowstone National Park, 19-28 December 2008.

North Twin Lake

Winter soundscape monitoring was conducted adjacent to the groomed road between Mammoth and Norris at North Twin Lake for the first time in February 2009. Oversnow vehicles were audible an average of 24% of the time between 8 am and 4 pm (Fig. 11) for the seven days analyzed.

Wind was audible for over 50% of the time during six of the seven days analyzed. Wind likely masked the low sound levels of distant OSV sounds most days (Fig. 11). Aircraft were audible an average of 4% from 8 am to 4 pm.

The hourly OSV pattern of audibility had a strong bimodal pattern characteristic of travel corridors close to park entrances (Fig. 12). Snowcoaches were audible more than snowmobiles during the 8 am, 9 am, 11 am, 1 pm hours and overall (Fig. 12).

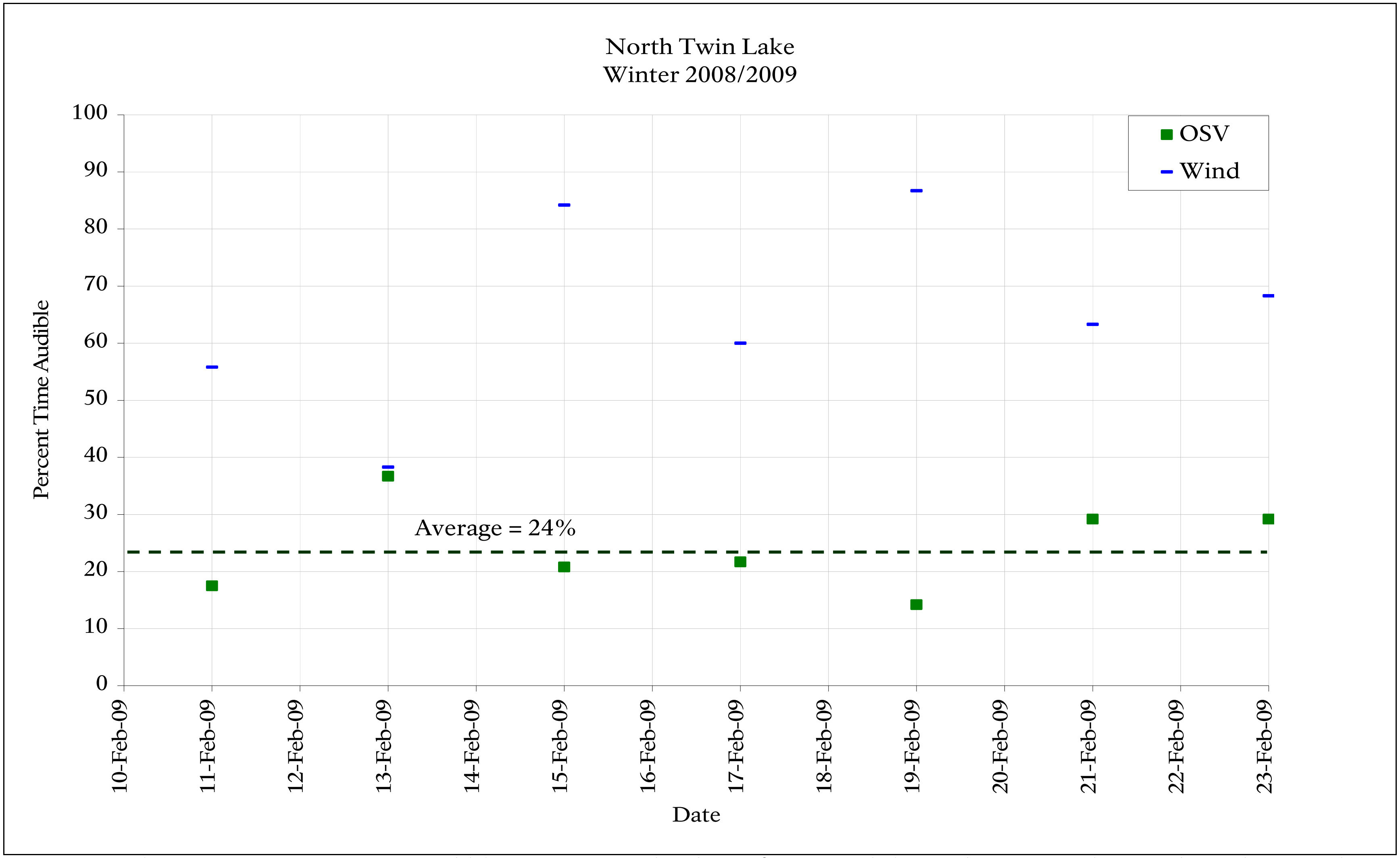


Figure 12. The average percent time audible (8 am-4 pm) by date of snowmobiles and snowcoaches, and wind at North Twin Lake, Yellowstone National Park, 11-21 February 2009.

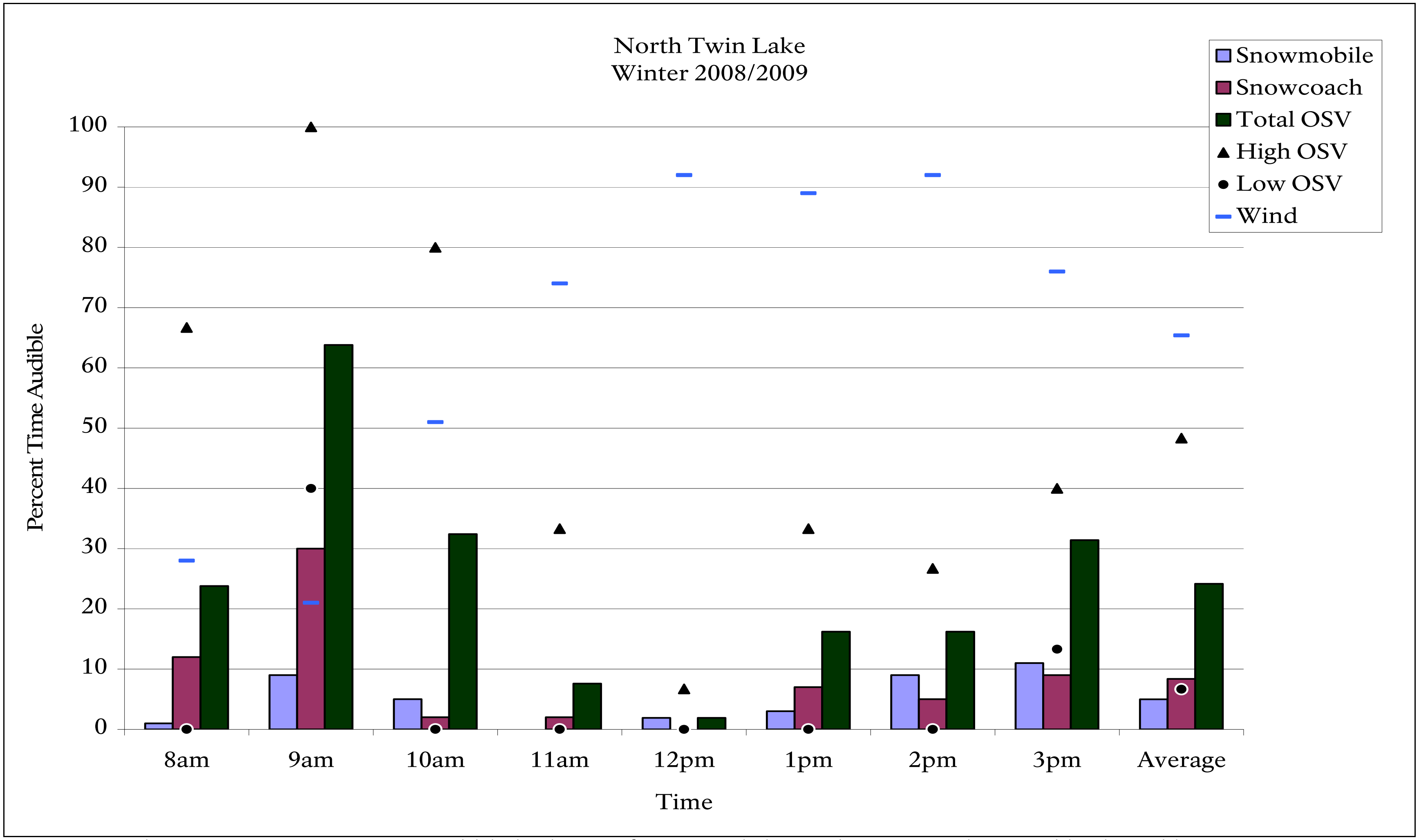


Figure 12. The average percent time audible by hour of snowmobiles and snowcoaches, and high and low OSV percent time audible at North Twin Lake, Yellowstone National Park, 11-21 February 2009.

Audibility Trends:

Oversnow audibility is summarized for 17 locations in Yellowstone National Park during the past six winters (Table 4). These locations include the four winter use plan management zones (developed, travel corridors, transition and backcountry). The monitoring sites in Table 4 are ordered left to right from most busy (closer to OSV activity or busier road corridor) to most distant to OSV activity. Interpret sites with small sample sizes, those with seven or fewer days of data, with caution. Acoustic conditions vary widely due to wind and other atmospheric conditions, and depend on the daily number of OSVs; therefore small sample sizes often do not represent typical or average acoustic conditions.

The percent time audible values illustrate the expected pattern that sites farthest from OSV activity have the lowest OSV audibility. Based on all monitoring data, the average percent time audible was 60% for developed areas, 39% for travel corridors, 20% for transition zone, and 15% for backcountry areas. Sites that had more than seven days of analysis had consistent audibility values when monitored in multiple years. Sites along the same segment of road (WY31 and MJ23) had similar OSV audibility. OSVs operating outside YNP were often audible at WY31, three miles from the park boundary. Backcountry sites ranged from just over one and a half mile from the busy Old Faithful to West Yellowstone road (MM8K) to eight miles from the less busy East Entrance Road (FLBC). The Shoshone Geyser Basin (SHGB) monitoring site was five miles from the busy Old Faithful to West Thumb road. The two Spring Creek sites (SPCR and SPC2) were 100 feet from this same road. The monitor at Lone Star Geyser (LSGY) was also along this route one mile from the road. Topography and frequent prolonged geyser activity were likely the reasons that OSVs were less audible at Lone Star Geyser than at Shoshone Geyser Basin more than four miles farther from the road.

Table 4. Percent time audible (8 am-4 pm) of oversnow vehicle sounds at monitoring sites by management zone during six winters (2003-2009), Yellowstone National Park.

	Management Zone: Sites[1]																
	Developed[2]		Travel Corridor[2]							Transition[3]					Backcountry[3]		
Year	OFWS	WETH	MJ23	WY31	SPCR	SPC2	GVLL	MUVO	NTLA	MMTR	OFUB	MM4K	DLCR	LSGY	MM8K	SHGB	FLBC
2003-2004	61%		25%[4]							32%		13%		3%			
2004-2005	69%	47%	61%	55%							29%			4%	26%		
2005-2006	67%	62%	55%		34%						35%						
2006-2007	68%		59%			44%		26%									0%
2007-2008	68%		53%				37%						20%		26%	18%	
2008-2009	55%		47%						24%								
Site Average	65%	55%	55%	55%	34%	44%	37%	26%	24%	32%	32%	13%	20%	4%	26%	18%	0%
Management Zone Average		60%							39%					20%			15%

	# of Oversnow Vehicles (OSVs) /day		
	Snowmobile	Snowcoach	All OSVs incl. OF[5]
2003-2004	254	23	281
2004-2005	206	25	236
2005-2006	267	30	302
2006-2007	299	30	336
2007-2008	290	32	338
2008-2009	196	29	234
Average	252	28	299

1	OFWS-Old Faithful Weather Station; WETH-West Thumb Geyser Basin; MJ23-Madison Junction 2.3; WY31-West Yellowstone 3.1; SPRC-Spring Creek; SPC2-Spring Creek 2; GVLL-Grant Village Lewis Lake; MUVO-Mud Volcano; NTLA-North Twin Lake; MMTR-Mary Mountain Trail; OFUB- Old Faithful Upper Basin; MM4K-Mary Mountain 4K; DLCR-Delacy Creek Trail; LSGY-Lone Star Geyser Basin; MM8K-Mary Mountain 8K; SHGB-Shoshone Geyser Basin; FLBC-Fern Lake Backcountry
2	Sites ordered from left to right, busiest to less busy
3	Sites ordered from left to right, closest to motorized route to most distant
4	Red underlined indicates 7 or fewer days analyzed; Double red underlined indicates 1 or 2 days only
5	Number of OSVs originating at Old Faithful prior to 2006-2007 were estimated

Event Analysis:

The loudest sound events at each site were recorded and later identified. NPS snow groomer caused some of the loudest events, but mainly occurred outside the WUP day (8 am to 4 pm). Event threshold triggers were maintained above the level that prevented wind contamination from creating the majority of the events. Event analysis augments audibility analysis by distinguishing the loudest sound sources from those less loud. Table 5 lists the loudest sound sources by number of occurrences and percent of all loud sources. Madison Junction 2.3 was 100 feet (30 m) from a 35 mph zone in a travel corridor. The Madison Junction 2.3 monitor recorded several two-stroke snowmobiles. The systems at Blacktail Backcountry, Blacktail Roadside, and North Twin Lake monitoring sites were not designed to collect events. The Old Faithful Weather Station site was 230 feet (70 m) from the nearest motor route. Because of the distance and slow OSV speeds no motorized loud events were recorded there.

Table 5. The number and percentage of sound events exceeding user-defined thresholds of sound level and duration at Madison Junction 2.3 in Yellowstone National Park (8 am to 4 pm). These represent the loudest sounds recorded at this location during the 2008-2009 winter use season.

	Madison Junction 2.3[1]	
Sound Source	Number	%
Snowmobile	11	6
Snowcoach	166	94
Total	177	100

[1] Thresholds were set at 70 dBA/1 second and 60 dBA/10 seconds

Sound Levels:

Sound level analysis is not as easily understood as audibility analysis. The WUP adaptive management thresholds apply only to oversnow vehicles (snowmobiles and snowcoaches), but occasional natural sounds (wind, bird vocalizations, etc.) and other motorized sounds (aircraft, snow groomer, etc.) may be as loud as oversnow vehicle sounds during some periods and in some locations. Therefore the sound levels for oversnow vehicles should be separated from other sounds before evaluating them against sound level thresholds. Unfortunately there is yet no automated process for separating different sound sources from the sound level data and the manual separation of oversnow vehicles sound levels during the millions of seconds of data collected this past winter in this study is practically impossible. Therefore the interpretation of sound levels becomes more difficult. In the developed areas and along travel corridors the loudest sounds during 8 am-4 pm were almost always from oversnow vehicles, but as distance increased from these motorized areas natural sounds were sometimes louder than oversnow vehicle sounds. Sound levels (decibels) of some common sound sources are shown in Table 5.

The 2004 Winter Use Plan Environmental Assessment of Yellowstone (YNP) and Grand Teton National Parks and the John D. Rockefeller, Jr., Memorial Parkway (NPS 2004) set maximum sound level thresholds for oversnow vehicles as measured in three acoustic management zones. These thresholds are 70 dBA in developed areas, 50 dBA along travel corridors, and 45 dBA in backcountry areas (Table 1). To compare to other winter use plans' standards and thresholds see Appendix C.

In addition to maximum sound levels (L_{max}) other common acoustical metrics such as the energy level equivalent or energy average (L_{eq}) and the L_{50} and L_{90} sound level exceedance metrics are useful to provide a better understanding of the soundscape. See Appendix B for a glossary of acoustic terms.

L_{eq} is the level (in decibels) of a constant sound over a specific time period that has the same sound energy as the actual (unsteady) sound over the same period. L_{eq} depends heavily on the loudest periods of a time-varying sound. L_{eq} of an intruding source, though, is inadequate to fully characterize the intrusiveness of the source. The effects of intrusions in park environments depend not only upon the amplitude of the intrusion, but also upon the sound level of the "background", usually the natural ambient sound levels.

L_{50} and L_{90} are the sound levels (L), in decibels, exceeded *x* percent of the time. The L_{50} value represents the sound level exceeded 50 percent of the measurement period. L_{50} is the same as the median; the middle value where half the sound levels are above and half below. The L_{50} is also not affected by a few loud sounds as is the L_{eq} and therefore provides another useful measure of the sound environment. The L_{90} value represents the sound level exceeded 90 percent of the time during the measurement period. L_{90} is a useful measure of the natural sounds because in park situations, away from developed areas and busy travel corridors, the lowest 10 percent of sound levels are less likely to be affected by non-natural sounds. Put another way, non-natural sounds in many park areas are likely to affect the measured sound levels for less than 90 percent of the time.

Returning to the complications of evaluating these sound level results, the L_{90} is the NPS (and other organizations) standard for use as an analog to the natural ambient sound level in locations other than those most heavily impacted from non-natural sounds and when other more site specific calculations are not possible. However, using L_{90} or other L_x metrics as the natural ambient sound level is inappropriate in locations with constant non-natural sounds such as at the Old Faithful Weather Station monitoring site. In very quiet areas the L_{90} may overestimate the true natural ambient sound level because of limitations of the instrument noise floor threshold. The noise floor, the lowest level the acoustic equipment could measure, was approximately 16-20 dBA (see Table 6 for reference levels). The quietest sound levels in YNP are below this noise floor (Burson 2006) so the lowest documented measurements in this report likely overestimate the actual minimum sound levels. While there is no easy solution to these problems, the disadvantages of any one metric can be reduced by using multiple sound level metrics.

Sound levels depend on the distance from the sound source, the presence of natural sounds, as well as non-sound source variables such as atmospheric conditions, wind speed and direction, topography, snow cover, and vegetative cover. These various factors influenced day to day sound levels measured at each sound monitoring location. No two days were identical, but patterns were regularly observed and differences among monitoring locations are apparent.

Table 6. Approximate decibel levels of commonly known sound sources. Note that decibels are logarithmic and a difference of 10 decibels is perceived as a doubling or halving of loudness. The range of audible sound levels for humans is generally considered from 0 – 130 dBA. Sound sources in the table below that have no associated distance listed are at typical operational distances.

dBA	Perception	Outdoor Sounds	Indoor Sounds
130	Painful		
120	Intolerable	Jet aircraft at 50 ft	Oxygen torch
110	Uncomfortable	Turbo-prop at 200 ft	Rock Band
100		Jet flyover at 1000 ft	Human scream
90	Very noisy	Lawn mower/Nearby Thunder	Hair dryer
80		Snowcoach at 50 ft	Food blender
70	Noisy	2-stroke snowmobile 30 mph at 50 ft	Vacuum cleaner
60		4-stroke snowmobile 30 mph at 50 ft	Conversation
50	Moderate	Croaking Raven flyover at 100 ft	Office
40		Snake River at 100 ft	Living room
30	Quiet	Summer backcountry	Quiet bedroom
20	Very quiet	Winter backcountry	Recording studio
10	Barely audible	Below standard noise floor	
0	Limit of audibility	Quiet winter wilderness	

2008-2009 Sound Metrics by Monitoring Site

Table 7 summarizes the sound level metrics at the five sound monitoring sites during the winter season 2008-2009. These sites are individually discussed on the following pages.

Table 7. Sound level metrics (dBA) for five sites and three soundscape management areas in Yellowstone National Park, 8 am – 4 pm, winter 2008-2009. L_{90}, L_{50}, L_{eq} are median values from hourly calculations. The two Blacktail sites are near a plowed road with wheeled vehicles rather than OSVs.

Site	L_{min}	L_{90}	L_{50}	L_{eq}	L_{max}	Hours
Developed Area						
Old Faithful Weather Station	22.0	31.2	36.7	42.1	77.7	761
Travel Corridor						
Madison Junction 2.3	17.8	26.7	30.6	43.7	78.2	539
North Twin Lake	16.5	20.4	24.5	39.1	74.1	116
Blacktail Roadside	16.5	23.7	29.4	39.1	77.8	226
Backcountry						
Blacktail Backcountry	15.9	27.6	34.1	37.7	68.3	219

Old Faithful Weather Station

The average hourly sound levels by month from the soundscape monitoring at Old Faithful Weather Station are shown in Figures 13-16 for the winter 2008-2009. The Old Faithful monitor was 230 feet (70 m) from the entrance/exit road used by oversnow vehicles. The 2004 WUP soundscape thresholds assume a distance of 100 feet (30 m) from the sound source in developed areas. In a free-field, sound levels decrease by approximately 6 dBA for every doubling of the distance from the source to the receiver. Therefore to compensate for the additional distance from the sound monitor using the reasonable assumption that the maximum sound levels originate from oversnow vehicles traveling 230 feet (70 m) from the sound monitor, adding an additional 6 dBA to the maximum sound levels shown in the following figures would approximate the levels at 100 feet (30 m). This assumption is reasonable only for L_{max} because it is likely that lower sound levels commonly originate from areas other than the exit road such as the parking lot, the main road, the other sources near the sound monitor, and thus the source, distance and therefore the correction factors are unknown.

Because the loudest sounds have the most influence on L_{eq} values, oversnow vehicle sounds largely determined the L_{eq} value at Old Faithful. Oversnow vehicles were often used outside the period covered by the WUP measurement periods, even in the middle of the night (Fig. 4).

The lowest sound levels (about 22 dBA) and the L_{90} were largely determined by the nearly constant utility sounds (exhaust and heating fans) from the Snow Lodge and Old Faithful Ranger Station (Fig. 13-16).

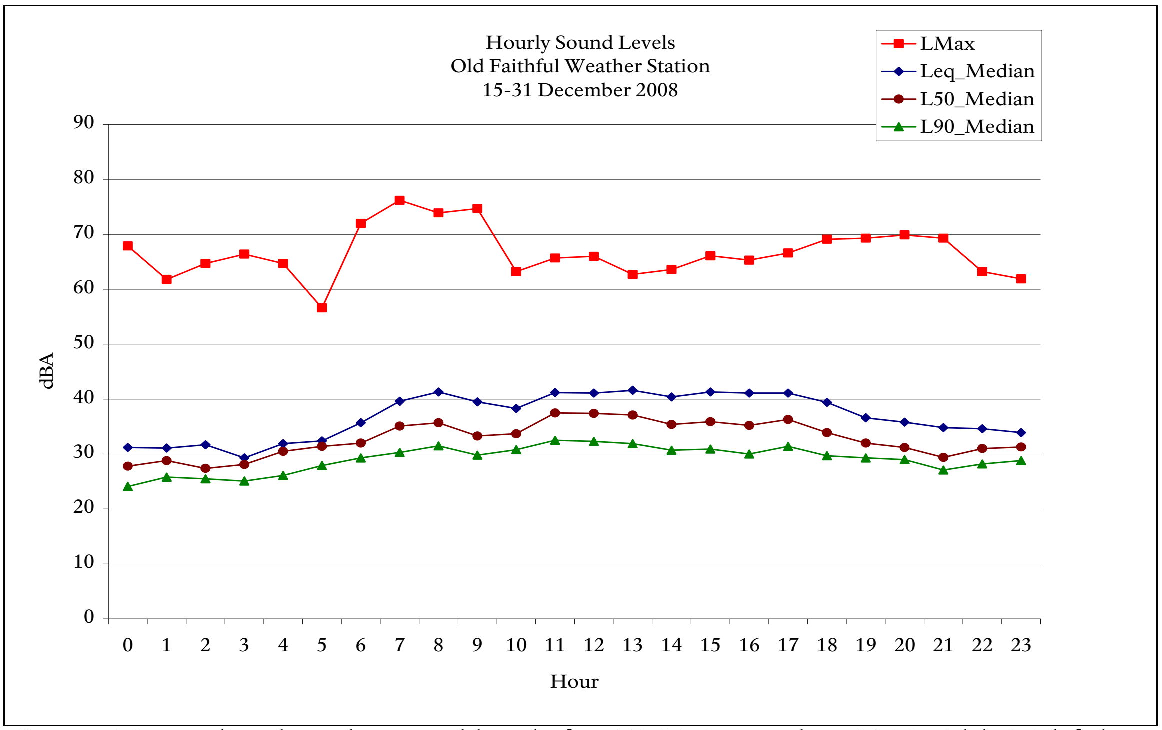


Figure 13. Median hourly sound levels for 15-31 December 2008, Old Faithful Weather Station, Yellowstone National Park. These sound levels include all natural and non-natural sounds. L_{max} is the highest sound level measured during each hour of the measurement period. (n=384 hours)

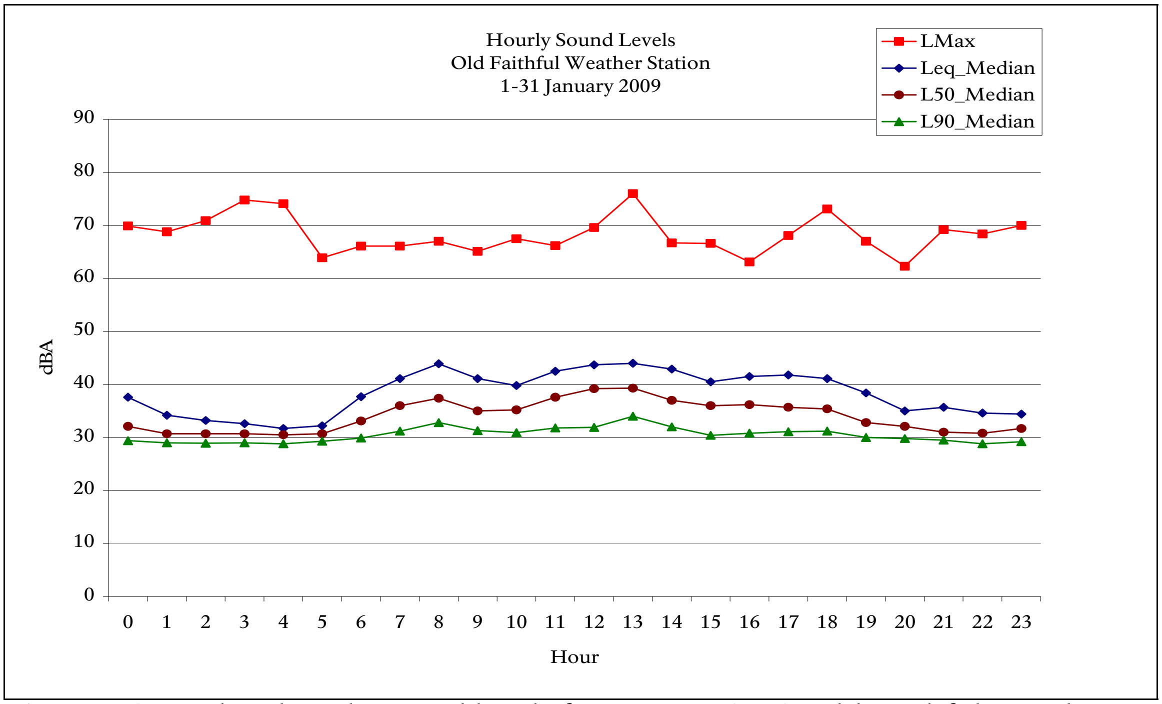


Figure 14. Median hourly sound levels for January 2009, Old Faithful Weather Station, Yellowstone National Park. See Fig. 15 caption for more details. (n=702 hours)

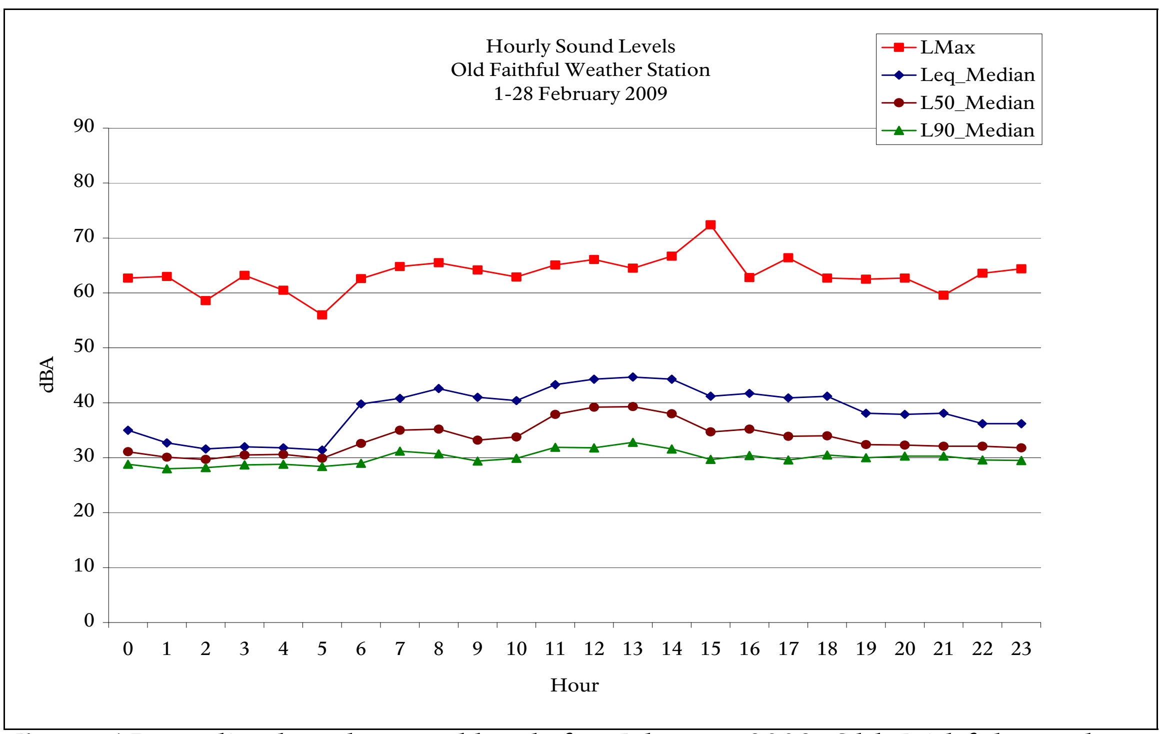


Figure 15. Median hourly sound levels for February 2009, Old Faithful Weather Station, Yellowstone National Park. See Fig. 15 caption for more details. (n=606 hours)

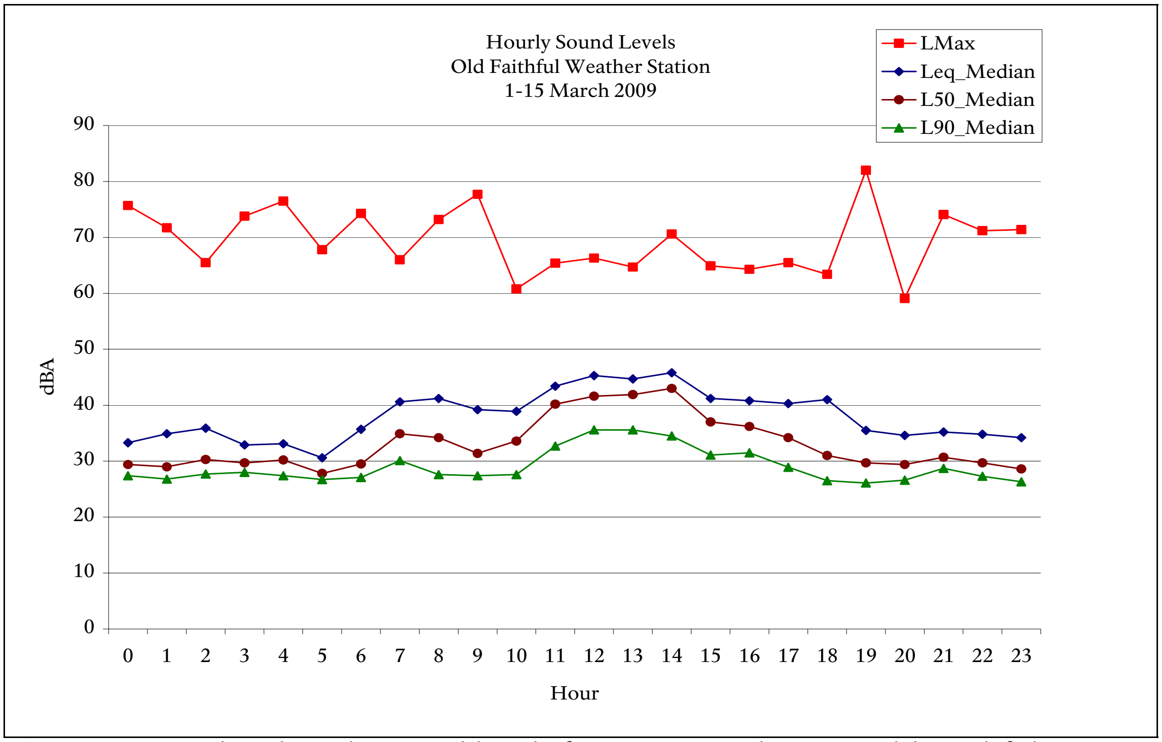


Figure 16. Median hourly sound levels for 1-15 March 2009, Old Faithful Weather Station, Yellowstone National Park. See Fig. 15 caption for more details. (n=361 hours)

Madison Junction 2.3

Consistent with previous seasons, the maximum hourly sound levels from oversnow vehicles at Madison Junction 2.3 exceeded the 2004 WUP maximum sound level threshold (70 dBA) during most of the hours of the measurement day (8 am-4 pm) in 2008-2009 (Fig. 17-20). The median hourly L_{eq} (the average sound energy) roughly follows the predictable bimodal pattern with peaks mid-morning and late afternoon consistent with OSV traffic patterns (Fig. 17-20). The maximum sound levels (L_{max}) were generally caused by snow groomers at night and snowcoaches during the day. The lowest median hourly L_{90} values are constrained by riffles of the nearby Madison River and the instrument's noise floor (Fig. 17-20). Wind generally increases during the afternoons and is reflected in the median hourly L_{50} and L_{90} values (Fig. 17-20).

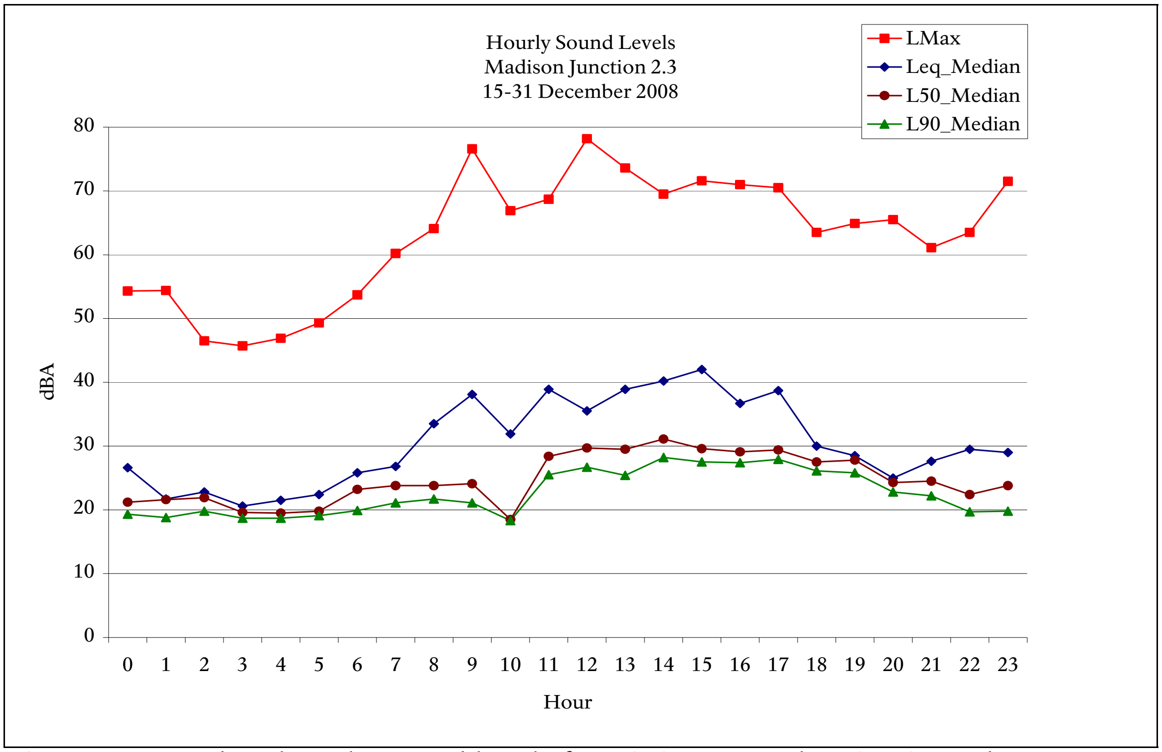


Figure 17. Median hourly sound levels for 19-31 December 2008 Madison Junction 2.3, Yellowstone National Park. See Fig. 15 caption for more details. (n=111 hours)

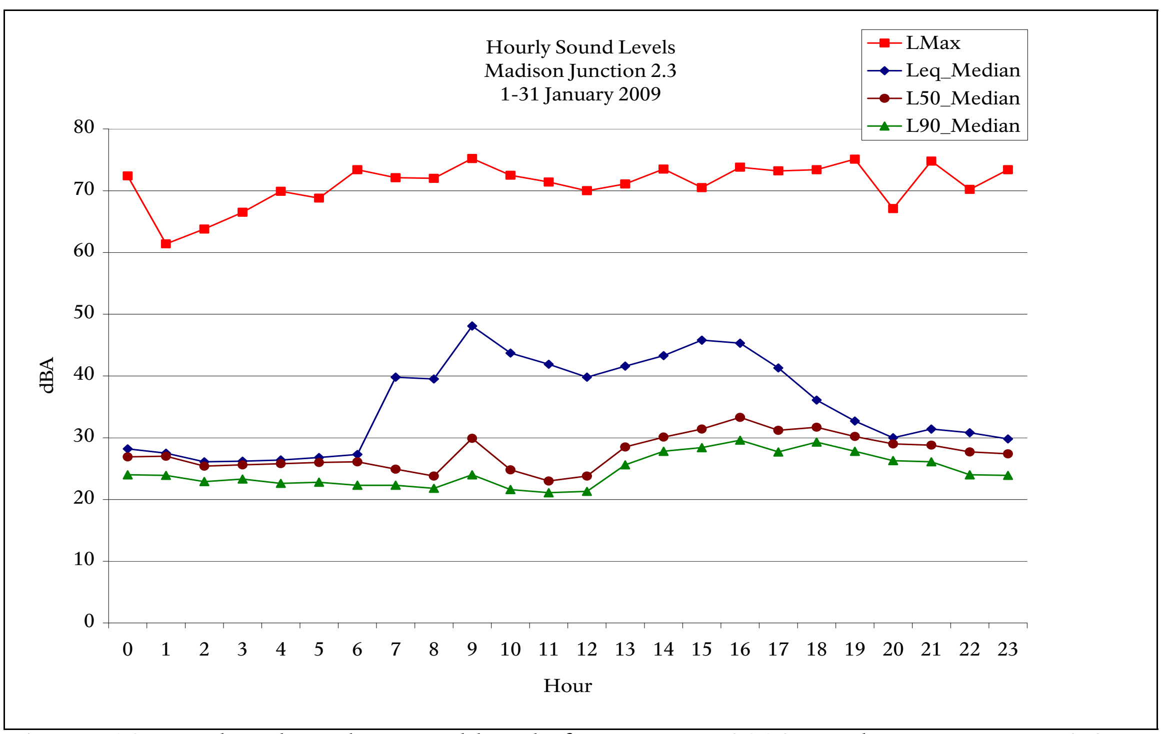


Figure 18. Median hourly sound levels for January 2009 Madison Junction 2.3, Yellowstone National Park. See Fig. 15 caption for more details. (n=507 hours)

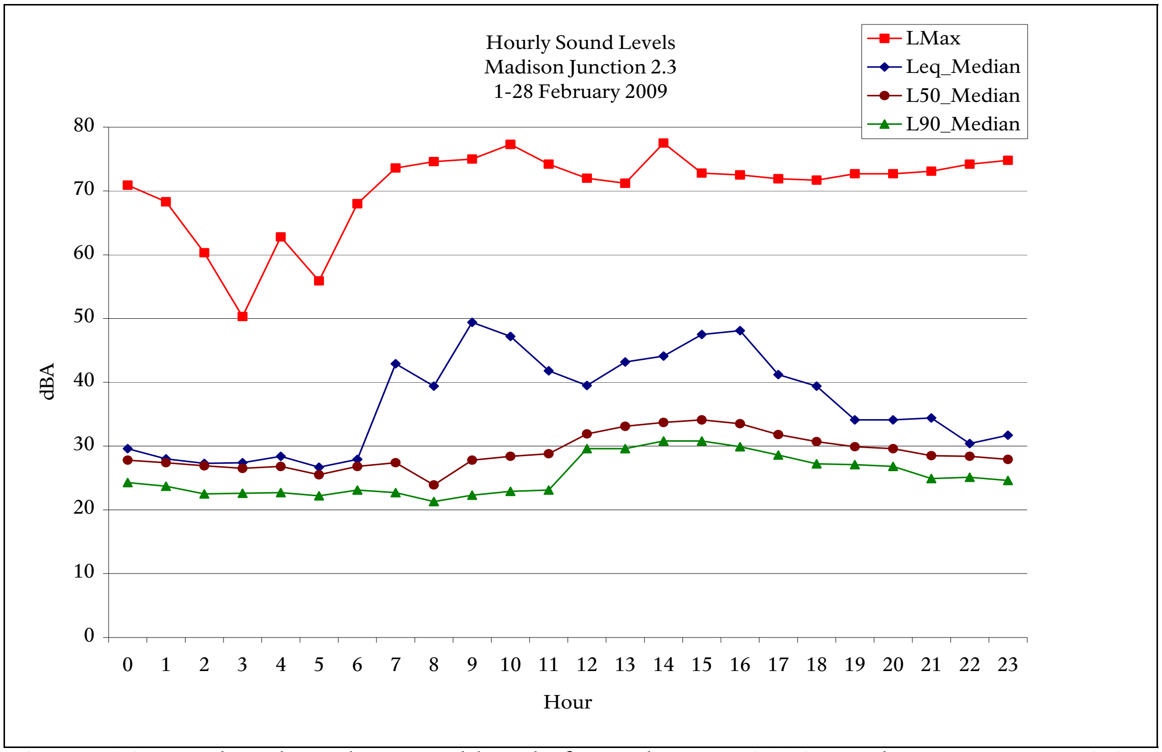


Figure 19. Median hourly sound levels for February 2009 Madison Junction 2.3, Yellowstone National Park. See Fig. 15 caption for more details. (n=663 hours)

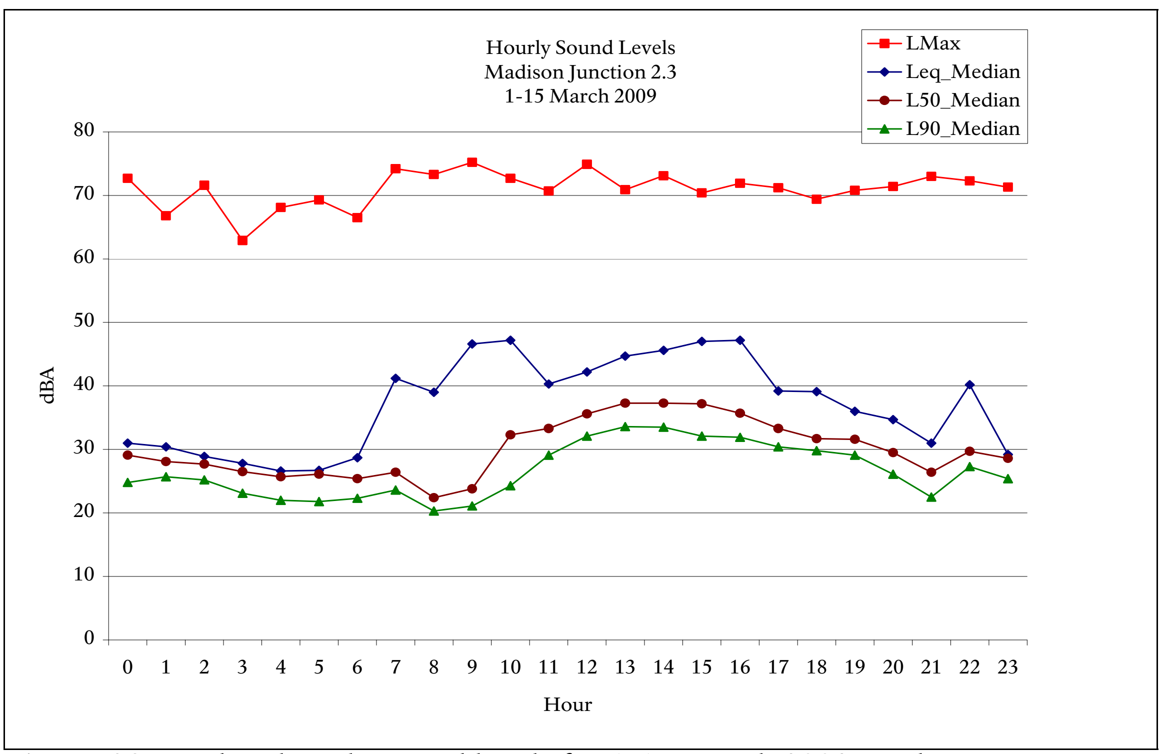


Figure 20. Median hourly sound levels for 1-15 March 2009 Madison Junction 2.3, Yellowstone National Park. See Fig. 15 caption for more details. (n=351 hours)

Blacktail Backcountry

The monitoring site was one and one half miles (2.4 km) from the plowed road between Mammoth and Tower Junction. Distant wheeled vehicles and aircraft were the non-natural sounds present at this site. Maximum sound levels from Blacktail Backcountry were consistently around 60 dBA for all hours of the day in December (Fig. 21) and slightly higher in January (Fig. 22). Wheeled vehicle sound levels were far below these maximum sound levels. The lowest sound levels (L_{min}) remained the same for both months as shown on Fig. 21 and 22. The site was in a sparse cluster of large conifers, but offered little protection from the very windy conditions on the mostly open Blacktail Deer Plateau.

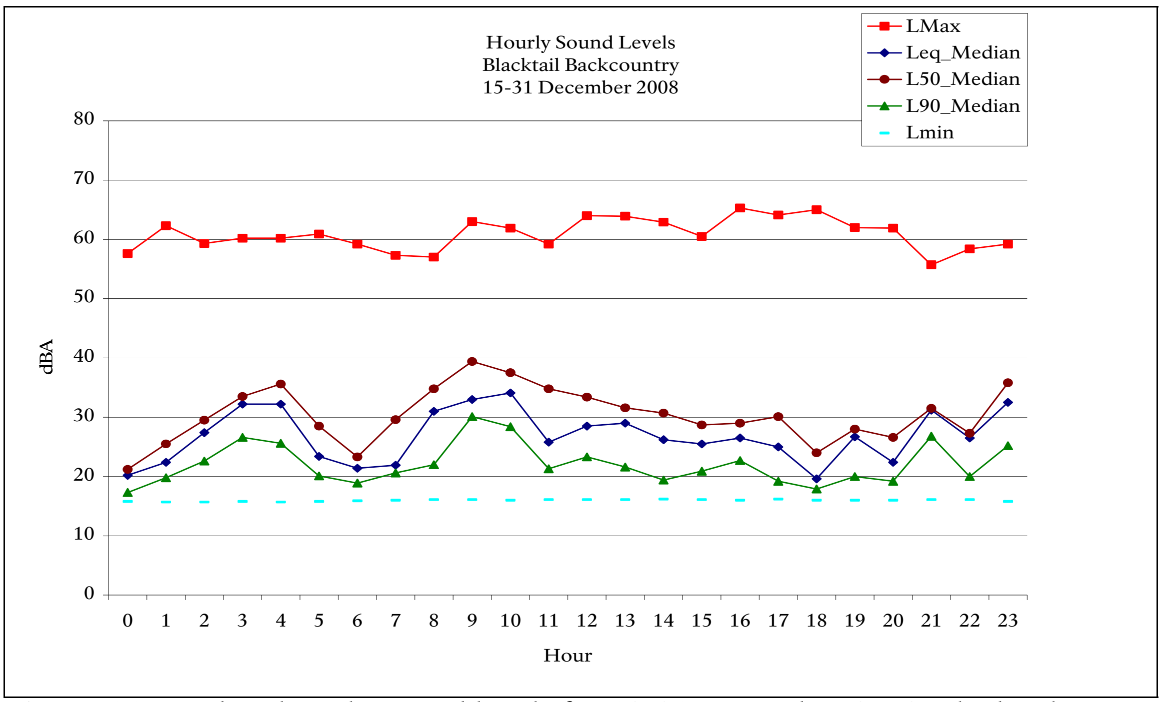


Figure 21. Median hourly sound levels for 18-31 December 2008, Blacktail Backcountry, Yellowstone National Park. See Fig. 15 caption for more details. (n=313 hours)

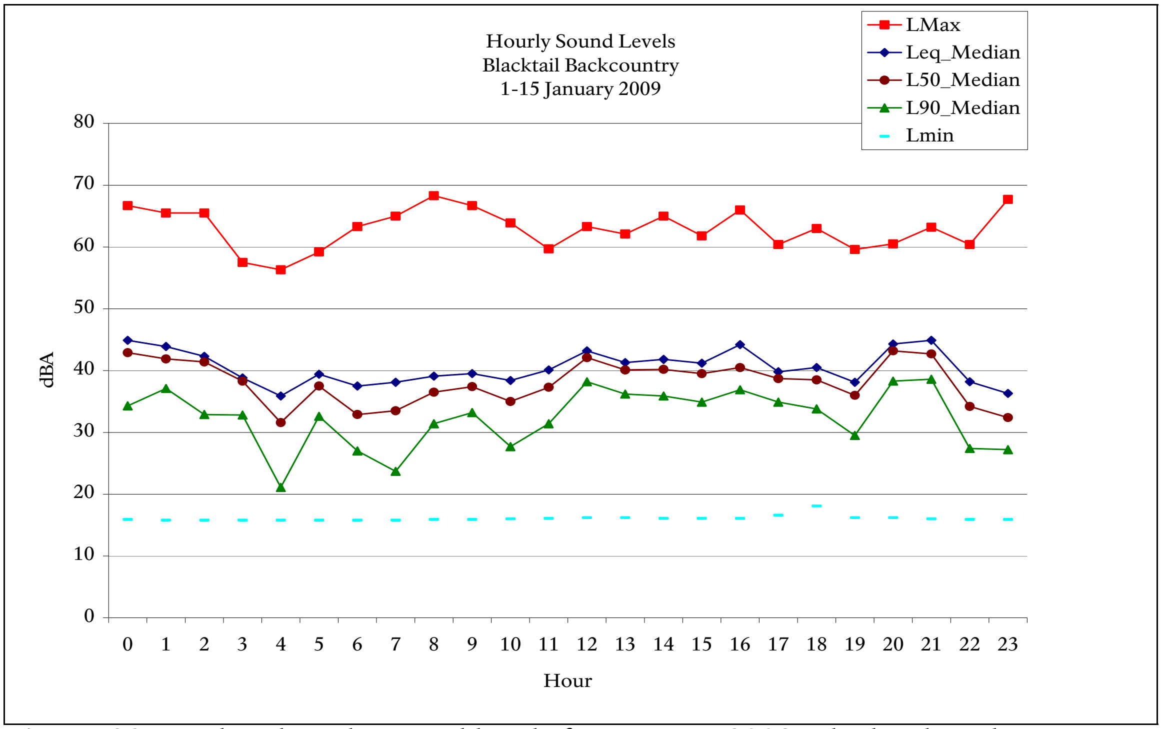


Figure 22. Median hourly sound levels for January 2009, Blacktail Backcountry, Yellowstone National Park. See Fig. 15 caption for more details. (n=354 hours)

Blacktail Roadside

This sound monitoring site was 100 feet (30 m) from the plowed road between Mammoth and Tower Junction. The loudest sounds at this site were the wheeled vehicles, especially the snow plows, traveling on the road. Aircraft sounds often were present and at levels above the natural ambient. Red squirrel chattering, bird vocalizations, and wind were nearly constant during the day and often throughout the night. January was windier than December.

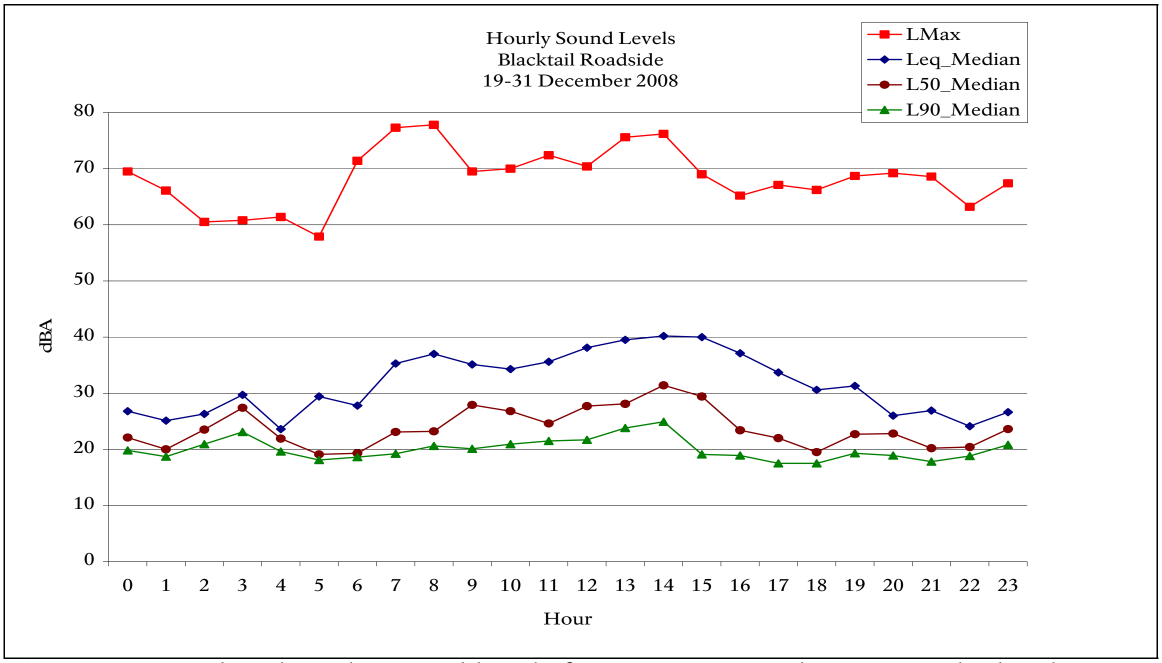


Figure 23. Median hourly sound levels for 18-31 December 2008, Blacktail Roadside, Yellowstone National Park. See Fig. 15 caption for more details. (n=311 hours)

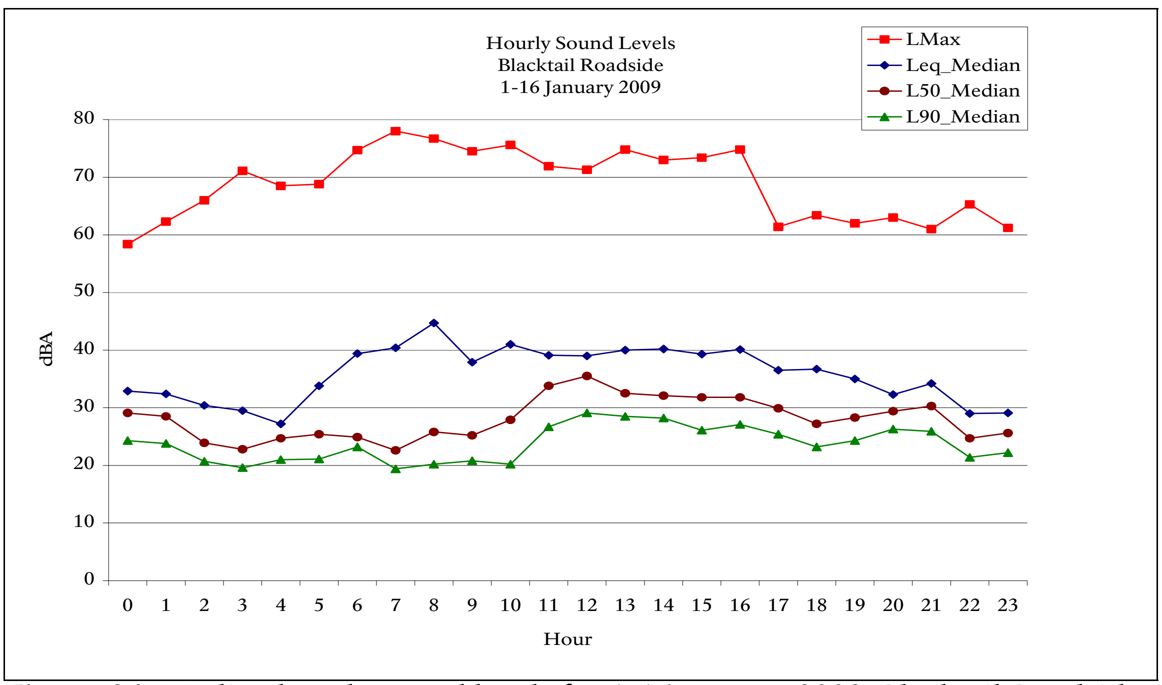


Figure 24. Median hourly sound levels for 1-16 January 2009, Blacktail Roadside, Yellowstone National Park. See Fig. 15 caption for more details. (n=370 hours)

North Twin Lake

This monitoring site was placed 100 feet (30 m) from the groomed road between Mammoth and Norris within a conifer forest adjacent to the frozen North Twin Lake. The presence of OSVs is apparent in the rapid increase in the L_{eq} and L_{max} levels starting during the 7 am hour (Fig. 25). This site shows the bimodal pattern of OVS use during the morning and again in the afternoon. Groaning trees rubbing against each other during windy periods, red squirrel chatter, bird vocalizations, and the wind in the trees were the predominant natural sounds. The early morning was generally very quiet with very few sounds above the minimum natural ambient sound levels. The snow groomer and other administrative OSVs increased the L_{eq} and L_{max} values during the evening and night until midnight.

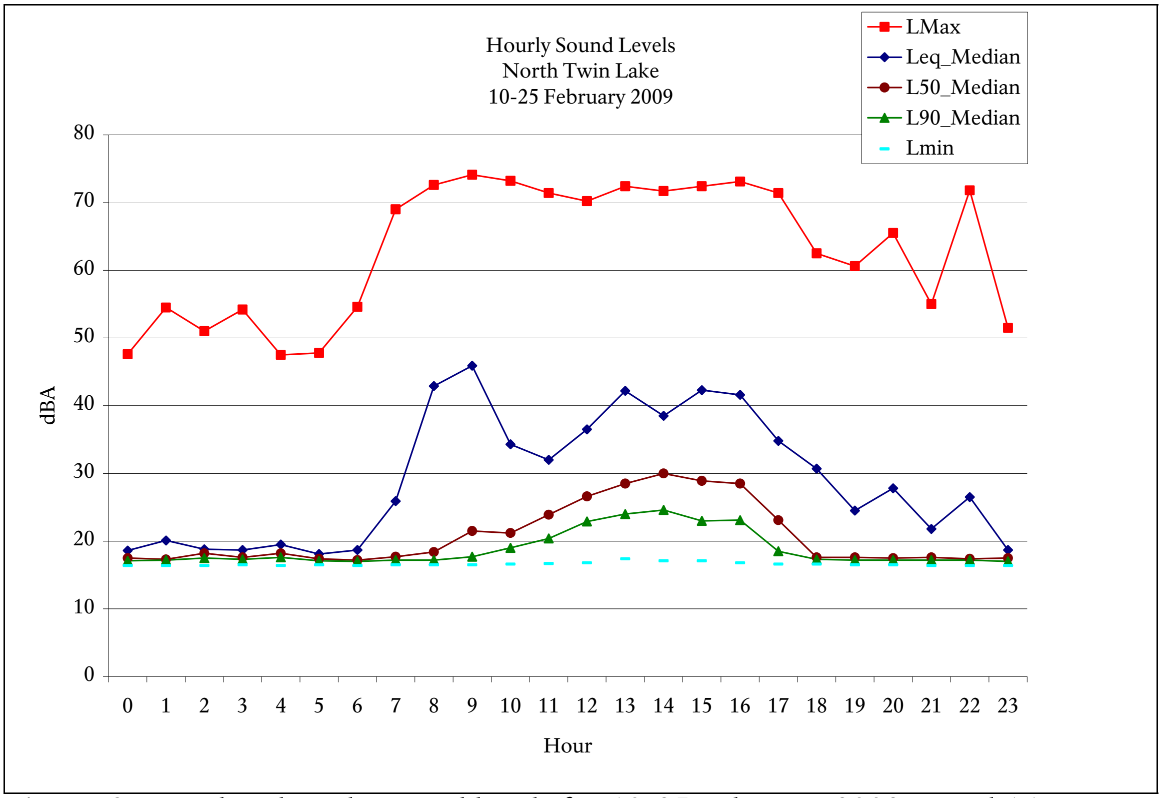


Figure 25. Median hourly sound levels for 10-25 February 2009, North Twin Lake, Yellowstone National Park. See Fig. 15 caption for more details. (n=370 hours)

Recommendations:

1- Sound levels and audibility from motorized oversnow vehicles should be reduced.

Although substantial improvements have been made by the switch from 2-stroke to 4-stroke snowmobiles and by the guiding requirement, the WUP L_{max} sound levels are still being exceeded in developed areas and travel corridors. Reduced sound levels of OSVs would also reduce their audibility. Improvements to snowcoach sound emissions should be made, especially to the older and louder Bombardier snowcoaches. Phasing out 2-stroke snowmobiles used by employees, contractors, and concessionaires would reduce the sound levels and audibility of those user groups. Minimizing administrative OSV use at all times, especially during the night, would minimize impacts to the natural soundscape.

Sound levels and audibility from motorized oversnow vehicles also can be reduced by lowering travel speeds. With reduced speed, visitors would experience lower OSV sound levels and percent time audible, especially in popular areas such as near thermal features and around Old Faithful. Decreasing the speed limit on all roads would reduce oversnow vehicle impacts on the natural soundscape and would have the added benefit of allowing sightseeing while traveling. Reducing unnecessary idling and rapid acceleration, and other driver behavior modifications would also minimize sound impacts from oversnow vehicles. Reducing the total number and reducing single OSVs operating on YNP roads would also minimize their impact to natural soundscapes. Soundscape awareness training should be developed and presented to operators of motorized oversnow vehicles. The NPS should work with manufacturers, equipment operators, and concessionaires to reduce further sound levels of oversnow vehicles.

2- Audibility and sound level metrics standards and thresholds should continue to be used for impact definitions in planning documents.

The ability to determine if the acoustic impacts of winter oversnow use are meeting the management objectives require defined quantitative acoustical standards and thresholds. Acoustical monitoring and the understanding of natural soundscapes in parks are both rapidly improving. The requirements for specific impact definitions and associated standards parallel these changes. It is essential to use easily understood, and more importantly, measurable and meaningful standards and thresholds. Additional metrics that may better address impacts from OSV sounds should be pursued.

3- Continue to monitor both audibility and sound levels.

The combination of sound level and audibility data gathered for this study provides useful acoustical information about YNP's soundscapes and the level of impact from oversnow vehicles. Collecting audibility data and identifying sources of sounds is important to characterize natural soundscapes and the non-natural acoustical impacts. Evaluating oversnow impacts on the natural soundscape requires sound source identification. In addition to information on audibility, the sound level of intruding non-natural sounds is an important aspect of soundscape monitoring. Collecting continuous 1/3 octave band frequency sound levels allows all standard acoustical metrics to be calculated. Acoustic monitoring results provide comparisons to computer acoustical modeling data.

4- Conduct acoustical experiments to fill in gaps to better understand the impacts of oversnow vehicles on the natural soundscape.

YNP can better manage the impacts of oversnow vehicles on the natural soundscape with answers to specific questions such as how group size and type of oversnow vehicle affects sound levels and audibility, what is the distance to limits of audibility in different habitat types (acoustic zones) and weather conditions, the effects of road surface on sound levels and audibility, how speed influences percent time audible and sound levels, and other currently unanswered questions. Acoustic computer modeling can begin to answer some of these questions but needs to be validated by actual field data collection. Studies are ongoing that provide information to better understand the relationship between oversnow vehicle numbers and their impact on the natural soundscape.

5- Increase the number of sampling locations and sample duration, and continue sampling beyond the winter season.

The representativeness of the acoustical dataset will improve as the number of sampling locations is increased within and among management zones. A full range of locations provides a more comprehensive evaluation of YNP's natural soundscape and the impacts from oversnow vehicles. The need for additional sites should be tempered by the disadvantages of short data collection periods. That is, because of the soundscapes inherent variability, it is usually preferable to gather multiple weeks of data at one location rather than shorter duration periods at multiple locations. Data collected during non-winter seasons allow comparisons to the winter season and provides additional information of YNP's natural and non-natural soundscapes. Year-round data collection started during the spring of 2005 and should be continued.

Acknowledgements:

Skip Ambrose (NPS Natural Sound Program-retired) developed an initial study plan that led to this project. Mike Yochim and Hilary Smith were enjoyable snowshoeing and skiing companions and helped pack the Blacktail Backcountry equipment in and out of the field. Robin Long help collect OSV logging data and in other ways in the field. The Old Faithful Ranger staff and the Old Faithful Maintenance staff, especially Roy Jenkins, provided logistical and much appreciated help on this project. Robin Long expertly coded most of the digital recordings for the fifth winter season. Her assistance continues to be invaluable. Skip Ambrose and Chris Florian provided ongoing assistance on many aspects of this project. Mike Donaldson and the NPS Natural Sound Program provided computer software. This report heavily relies on previous years' reports. John Sacklin, Denice Swanke, Mike Yochim, Linda Franklin, and Robin Long provided valuable editorial comments on previous versions.

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Appendix A: Instrument and Setup Protocol

AC Output Weighting
For digital recordings using the AC output of the SLM, the AC output weighting shall be set to Flat, with appropriate gain setting for SLM or recording device in use

Attended Data Logging
Observers will conduct attended data logging approximately 50 m (150 feet) from the sound level meter, microphone, and/or tape recorder to ensure that field personnel can move about and conduct whispered conversations without influencing the measured sound. Observations during attended logging will be recorded on a standardized NPS data sheet.

Bird Spike
Spikes made of wire or hard plastic which prevents birds from perching on microphones and windscreens shall be used.

Cables and Wiring
All cables and wiring shall be secured to prevent any sound which might be created in windy conditions (due to wiring hitting other objects).

Calibrator
A calibrator whose performance is essentially independent of off-reference atmospheric conditions (such as the B & K Model 4231) is to be used.

Instrument Clocks
All clocks associated with the sound measurement effort shall be coordinated with GPS (Global Positioning System) time. This includes sound level meters, data loggers (notebook computer, Personal Digital Assistant-PDA), and all digital watches used during data logging. For long-term measurements, all clocks will be synchronized with GPS time at the beginning of the measurement period, and time differences with GPS time will be noted at the end of the measurement period. Acoustic data collected during the measurement period will be adjusted to correspond with GPS time.

Microphone type
A Type 1 random incidence microphone is recommended for acoustic measurements in wilderness settings. Microphones can be either polarized or pre-polarized.

Monitor Location
The microphone/pre-amplifier/windscreen shall be placed in a location representative of the habitat/acoustic zone under study. The microphone diaphragm should be placed 1.1 m to 1.5 m above the ground surface and

oriented vertically (microphone grid facing the sky).

Solar Panels
All solar panels should be placed in a location with as little shading as possible and at least .3 m (12 inches) above the ground.

Sound Level Meter
Sound level meters shall be Type I or better and should perform true numeric integration and averaging in accordance with ANSI S1.4-1983.

Time Weighting
Sound level meters shall be set to fast exponential time weighting.

Windscreen
Windscreens which are effectively acoustically transparent (less than +/- 0.5 dB effect over the frequency span of interest) shall be used.

Appendix B: Glossary of Acoustic Terms

Acoustics
The science of sound.

Ambient Sound, Existing
All sounds in a given area (includes all natural and all non-natural (human-caused) sounds).

Ambient Sound, Natural
The natural sound conditions found in a given area, including all sounds of nature. The natural ambient sound level of a park is comprised of the natural sound conditions which exist in the absence of mechanical, electrical, and other non-natural sounds. Some generally unobtrusive non-natural sounds (talking quietly, walking) may be part of the natural soundscape, but not those generated by mechanical, electrical, or motorized means. Natural ambient sounds are actually composed of many natural sounds, near and far, which often are heard as a composite, not individually. In an acoustic environment subjected to high levels of non-natural sounds, natural sounds may be masked. Natural ambient sound is considered synonymous with the term "natural quiet," although "natural ambient sound is more appropriate because nature is not always quiet.

Ambient Sound, Non-natural
Ambient sounds attributable to non-natural sources (mechanical, electrical, and other non-natural sources). In a national park setting, these sounds may be associated with activities that are essential to the park's purpose, they may be a by-product of park management activities, or they may come from outside the park.

Appropriate Sounds
Sound conditions defined as appropriate for an area in national parks, such as a specific management zone. Other appropriate sounds, not natural in origin, are those types of sounds which are generated by activities directly related to the purposes of a park, including resource protection, maintenance, and visitor services. Natural sounds are not only appropriate, but are part of the park's resource base to be protected and enjoyed by the visiting public.

Appropriate Sound Level
Appropriate sound levels in a given area of a park are determined based on mandates in the Organic Act, establishment legislation, or other laws pertinent to the specific purposes and values associated with the park. This determination takes the form of management zone objectives for soundscape, as well as measurable indicators and standards for sound.

Attenuation
The reduction of sound intensity by various means (e.g., air, humidity and porous materials).

Area of Audibility
The area within which a specific sound or sounds is audible.

Audibility
Audibility is the ability of animals with normal hearing, including humans, to hear a given sound. Audibility is affected by the hearing ability of the animal, other simultaneous interfering sounds or stimuli, and by the frequency content and amplitude of the sound.

Decibel
A logarithmic measure of any measured physical quantity and commonly used in the measurement of sound. The decibel provides the possibility of representing a large span of signal levels in a simple manner as opposed to using the basic unit Pascal. The difference between the sound pressure for silence versus a loud sound is a factor of 1,000,000:1 or more, therefore it is less cumbersome to use a small range of equivalent values: 0 to 130 decibels. See also, Sound Level.

Doubling of Sound Pressure = 6 dB
Doubling of Sound Power = 3 dB
Doubling of Perceived Sound Level = 10 dB (approximately)

Doppler Effect (or Shift)
The apparent upward shift in frequency of a sound as a noise source approaches the receiver or the apparent downward shift when the noise source recedes.

Energy Equivalent Sound Level (L_{eq}**)**
The level of a constant sound over a specific time period that has the same sound energy as the actual (unsteady) sound over the same period. L_{eq} depends heavily on the loudest periods of a time-varying sound. L_{eq} of an intruding source by itself, though, is inadequate for fully characterizing the intrusiveness of the source. Research has shown that judgments of the effects of intrusions in park environments depend not only upon the amplitude of the intrusion, but also upon the sound level of the “background,” in this case, the sound level of the non-intruding sources, usually the natural ambient sound levels. L_{eq} must be used carefully in quantifying natural ambient sound levels because occasional loud sound levels (gusts of wind, birds, insects) may heavily influence (increase) its value, even though the sound levels are typically lower.

Frequency
The number of times per second that the sine wave of sound repeats itself. It can be expressed in cycles per second, or Hertz (Hz). Frequency equals Speed of Sound / Wavelength.

Hearing Range (human)
An average healthy young person can hear frequencies from approximately 20 Hz to 20000 Hz, and sound pressure levels from 0 dB to 130 dB or more (threshold of pain). The smallest perceptible change is 1 dB.

Impact
For environmental analysis, an impact is defined as a change at a receptor that is caused by a stimulus, or an action. In accordance with the CEQ regulations (40 CFR 1500-1508), direct and indirect impacts (environmental consequences) are to be described in an environmental document by assessing their type, magnitude, intensity, and duration. The significance of an impact is to be determined specifically in view of criteria provided in 40 CFR 1508.27, based on the outcome of these assessments. An assessment will take account of the short or long term nature of the impact, the extent to which it is either beneficial or adverse, whether it is irreversible or irretrievable, and, finally, its geographic and societal extent. Lastly, a resource impact is put in the context of all other past, present or reasonably foreseeable actions which affect the same resource, and its contribution to the total cumulative effect is to be disclosed. Under CEQ regulations, the term "impact" is synonymous with "effect" (40 CFR 1508.8).

Loudness
The subjective judgment of intensity of a sound by humans. Loudness depends upon the sound pressure and frequency of the stimulus. Loudness was defined by Fletcher and Munson (1933) as a physiological description of the magnitude of an auditory sensation.

Masking
The process by which the threshold of audibility for a sound is raised by the presence of another (masking) sound. A masking noise is one that renders inaudible or unintelligible another sound that is also present.

Noise
Traditionally, noise has been defined as unwanted, undesired, or unpleasant sound. This makes noise a subjective term. Sounds that may be unwanted and undesired by some may be wanted and desirable by others. Noise is sound, as defined in this document: a pressure variation, etc. In order to keep terms used in soundscape management as non-subjective as possible, sounds should be classified as either appropriate or inappropriate, rather than as "noise." or "sound." The appropriateness of any sound in a given area of a park will depend on a variety of factors, including the management objectives of that area.

Noise-free Interval
The period of elapsed time between human-caused sounds. The length of the continuous period of time during which only natural sounds are audible. Though

little research has been conducted to relate how this measure correlates with ecological functioning, visitor judgments or with common experiences in park settings, it should provide a reasonable measure of the existence and availability of periods with only natural sounds. It is also a metric that requires no acoustics knowledge to be meaningful.

Octave
The interval between two frequencies having a ration of 2 to 1. For acoustic measurements, the octaves start a 1000 Hz center frequency and go up or down from that point, at the 2:1 ratio. From 1000 Hz, the next filter's center frequency is 2000 Hz, the next is 4000 Hz, etc., or 500 Hz, 250 Hz, etc. Octave filtering is usually referred to as the class of octave filters typically 1, 3 or 12, thus creating full octaves, one-third octaves, or one-twelve octaves.

Octave Band
The segment of the frequency spectrum centered on an octave center frequency bounded by the midpoint between the next lower and higher octave.

Percent Exceedance (L_x)
These metrics are the sound levels (L), in decibels, exceeded *x* percent of the time. The L_{50} value represents the sound level exceed 50 percent of the measurement period. L_{50} is the same as the median. The L_{90} value represents the sound level exceeded 90 percent of the time during the measurement period. L_{50} and L_{90} are useful measures of the natural sounds because in park situations, away from developed areas, they are less likely to be affected by non-natural sounds. Put another way, non-natural sounds in many park areas are likely to affect the measured sound levels for less than 50% of the time, and almost certainly for less than 90% of the time. L_{50} is used when there is high probability that no non-natural sounds affect the measurements. L_{90} is used when human-produced sounds are present much of the time during measurements. Common sounds that could be present for more than 50% of the time include road traffic sounds and, in some areas, high altitude jet aircraft.

Percent Time Above Natural Ambient
The amount of time that sound levels from non-natural sound(s) are greater than sound levels of natural ambient sound levels in a given area. This measure is not specific to the hearing ability of a given animal, but a measure of when and how long non-natural sound levels exceed natural ambient sound levels.

Percent Time Audible
The amount of time that various sounds are audible to animals, including humans, with normal hearing (hearing ability varies among animals). A specific sound may be below the natural ambient sound level, but still be audible to some animals. This information is essential for measuring and monitoring non-natural sounds in national parks. These data can be collected by either a trained observer

(attended logging) or by making high-quality digital recordings (for later playback). Percent Time Audible is useful because it is a measure that is understandable without any acoustics knowledge. It is a metric that correlates well with park visitor judgments of annoyance and with visitor reports of interference from certain sound sources with the sounds of nature.

Spectrum (Frequency Spectrum)
The amplitude of sound at various frequencies. It is given by a set of numbers that describe the amplitude at each frequency or band of frequencies.

Sound
A wave motion in air, water, or other media. It is the rapid oscillatory compressional changes in a medium that propagate to distant points. It is characterized by changes in density, pressure, motion, and temperature as well as other physical properties. Not all rapid changes in the medium are sound (such as wind distortion on a microphone diaphragm).

Sound Impacts
Sound impacts are effects on a receptor caused by the physical attributes of sound emissions. In national parks, non-natural sounds cause physical changes in the soundscape that can be detected and measured. The fact that a sound can be measured does not equate immediately to whether the impact of that sound is adverse, inconsequential, or beneficial, or whether there are adverse secondary impacts on wildlife, cultural values, or visitors. Levels of impact and impact significance are policy determinations.

Soundscape
Soundscape refers to the total acoustic environment associated with a given area. In a national park setting, soundscapes can be composed of natural sounds, or it can be composed of both natural and non-natural sounds.

Soundscape, Natural
Natural soundscapes consist of sounds associated with nature: wind, water flow, rain, surf, wildlife, thermal activity, lava flows, or other sounds not generated by non-natural means.

Sound Level
The *weighted* sound pressure level obtained by frequency weighting, generally A-weighting (dBA).

Sound Level Floor (Noise Floor)
The lowest amplitude measurable by sound monitoring equipment. Most commercially available sound level meters and microphones can detect sound levels down to about 15 to 20 dBA; however, there are microphones capable of measuring sound levels below 0 dBA.

Sound Pressure Level (SPL)
The logarithmic form of sound pressure. In air, 20 times the logarithm (to the base 10) of the ratio of the actual sound pressure to a reference sound pressure (which is 20 micropascals, and by convention has been selected to be equal to the assumed threshold of human hearing). It is also expressed by attachment of the word decibel to the number.

Windscreen
A porous device used to cover the microphone of a sound level measurement system. Windscreens are designed to minimize the effects of wind disturbance on the sound levels being measured while minimizing the attenuation of the signal.

These definitions were derived from several sources, including:

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Appendix C: Acoustic standards and thresholds in previous winter use plans

Table C-1. Management zones and soundscape thresholds in 2000 Yellowstone and Grand Teton National Parks and the John D. Rockefeller, Jr. Memorial Parkway Final Environmental Impact Statement Winter Use Plan.

Zone	Management Zone	Maximum Audibility[1] of motorized sound during the hours of 8 am-4 pm
1	Destination or Support Area	Audibility: NTE 50% (anywhere within area boundary)
2	Plowed Road (within 100 feet (30 m) either side of road)	Audibility: NTE 50% at 100 feet (30 m)
3	Groomed Motorized Route Clean and Quiet (within 100 feet (30 m) either side route)	Audibility: NTE 50% at 100 feet (30 m)
4	Groomed Motorized Route (within 100 feet (30 m) either side route)	Audibility: NTE 50% at 100 feet (30 m)
5	Groomed Motorized Trail Clean and Quiet (within 100 feet (30 m) either side of trail)	Audibility: NTE 25% at 100 feet (30 m)
6	Groomed Motorized Trail (within 100 feet (30 m) either side of trail)	Audibility: NTE 25% at 100 feet (30 m)
7	Ungroomed Motorized Trail (within 100 feet (30 m) either side of trail)	Audibility: NTE 25% at 100 feet (30 m)
8	Groomed Non-motorized Trail	Audibility: NTE 10% at 500 feet (152 m)
9	Ungroomed Non-motorized Trail or Area	Audibility: NTE 10% at 500 feet (152 m)
10	Backcountry non-motor trail or area	Audibility: NTE 10% at 500 feet (152 m) Audibility: NTE 0% at 1000 feet (305 m)

[1] Audibility- the ability of a person with normal hearing to hear a given sound

Table C-2. Management zones and soundscape thresholds in 2003 Yellowstone and Grand Teton National Parks and the John D. Rockefeller, Jr. Memorial Parkway Final Supplemental Environmental Impact Statement Winter Use Plan.

Zone	Management Zone	Maximum Audibility[1], Max. dBA[2], and Hourly L_{eq}[3] of oversnow vehicle sounds during hours of 8 am-4 pm
1	Destination or Support Area (anywhere within area boundary)	Audibility: NTE[4] 50% dBA: NTE 70 dBA L_{eq}: NTE 45dBA
2	Plowed Road (within 100 feet (30 m) either side of road)	Audibility: NTE 50% dBA: NTE 70 dBA L_{eq}: NTE 45 dBA
3	Groomed Motorized Route (within 100 feet (30 m) either side route)	Audibility: NTE 50% dBA: NTE 70 dBA L_{eq}: NTE 45 dBA
4	Groomed Motorized Trail (within 100 feet (30 m) either side route)	Audibility: NTE 50% dBA: NTE 70 dBA L_{eq}: NTE 45 dBA
5	Ungroomed Motorized Trail or Area (within 100 feet (30 m) either side of trail)	Audibility: NTE 50% dBA: NTE 70 dBA L_{eq}: NTE 45 dBA
6	Groomed Non-motorized Trail (within 100 feet (30 m) either side of trail)	Audibility: NTE 25% dBA: NTE 70 dBA L_{eq}: NTE 45 dBA
7	Ungroomed Nonmotorized Trail or Area (within 100 feet (30 m) either side of trail)	Audibility: NTE 20% dBA: NTE Lnat[5] - 6 dBA L_{eq}: NTE to Lnat
8	Backcountry Nonmotorized Area (anywhere within area >1,000 feet (301 m) from motorized area)	Audibility: NTE 20% dBA: NTE Lnat - 6 dBA L_{eq}: NTE to Lnat
9	Sensitive Area (no winter use)	

[1] Audibility- the ability of a person with normal hearing to hear a given sound
[2] dBA- weighted sound level in decibels
[3] L_{eq} - The level of a constant sound over a specific time period that has the same sound energy as the actual (unsteady) sound over the same period.
[4] NTE- not to exceed
[5] Lnat- The natural sound conditions found in a given area, including only sounds of nature.

Table C-3. Management zones and adaptive management soundscape thresholds in the 2007 Winter Use Plans (WUP) Final Environmental Impact Statement and Record of Decision. Measured period is during daytime hours of park operations 8 am- 4 pm.

Management Zone	**Percent Time Audible**	**Sound Level Threshold**
Developed Area	Not to exceed 75%	Not to exceed 70 dBA
Road Corridor	Not to exceed 50%	Not to exceed 70 dBA
Transition Zone	Not to exceed 25%	Not to exceed 65 dBA
Backcountry	Not to exceed 10%	Not to exceed Natural Ambient Sound Level

Appendix D: Spectrographs of sound levels

The NPS Natural Sound Program in Ft. Collins, CO developed a technique for plotting each of the 33 one-third octave band frequency decibel levels for each second of the day (ex. Fig. D-1). The major sources of sound at each monitoring location can be "seen" in these spectrographs. Viewing the pictures in color is essential. Each figure is one day, 24 hours from midnight to midnight. Each row contains two hours starting with the first hours of the day, labeled with white two digit numbers. The site and date is the title on top. The sound frequency is plotted on a logarithmic scale as indicated in the left margin. The right margin contains the decibel range and associated colors. Brighter colors indicate higher sound levels; deep blue is the quietest. Maroon diagonal lines indicate times of sample recordings and wind is indicated by the occasional erratic white lines. Not only can specific sound sources be identified from these spectrographs, but patterns and the variability in number, timing, and sources of sounds can be seen.

Figures D-1-D-5 show example days from five monitoring sites. Determining the common sound sources signatures from the 1/3 octave band frequencies is not difficult, but takes a bit of experience. A brief introduction follows. Oversnow vehicle signatures are narrow yellow marks that extend from high to low frequency. The louder sounds are brighter yellow as shown in hour 09 and 19 is the double-twin-track Prinoth in Fig. D-1. Snow groomers are the brighter broader marks with the extended light blue trails before and after in hours 18 and 22 (Fig. D-1). During the hours 05, 06, 08, and 20 and others, a jet appears as a low frequency blob over several minutes (Fig. D-1). Starting during the early morning hours popping sounds from trees is clearly seen in the frequent vertical light blue lines.

Building utility sounds and wind create the extensive and horizontal light blue lines at Old Faithful Weather Station (Fig. D-2). The sounds of riffles on the Madison River are shown especially during the early morning and late evening hours (Fig. D-3). Aircraft and red squirrel chatter are the main "visible" sounds at Blacktail Backcountry on a rare calm day (Fig. D-4). Wheeled vehicle traffic is clearly illustrated at Blacktail Roadside (Fig. D-5). The Doppler Effect is also evident with propeller planes (double declining lines) during the 10, 12, and 14 hours at Blacktail Roadside (Fig. D-5).

Figures D-6 and D-7 compare the sound levels during Saturday of Presidents Day Weekend at Madison Junction 2.3 during 2003 (1,679 snowmobiles during Saturday and Sunday) and 2009 (681 snowmobiles during Saturday and Sunday). One can readily see the yellow spikes of OSVs passing the monitoring site beginning earlier in the day in 2003 and with shorter time intervals between OSVs. This comparison illustrates the difference in noise-free interval, sound level, distribution, and number of OSVs between years. See figure D-3 for another example of OSV activity at this site during the most recent winter season.

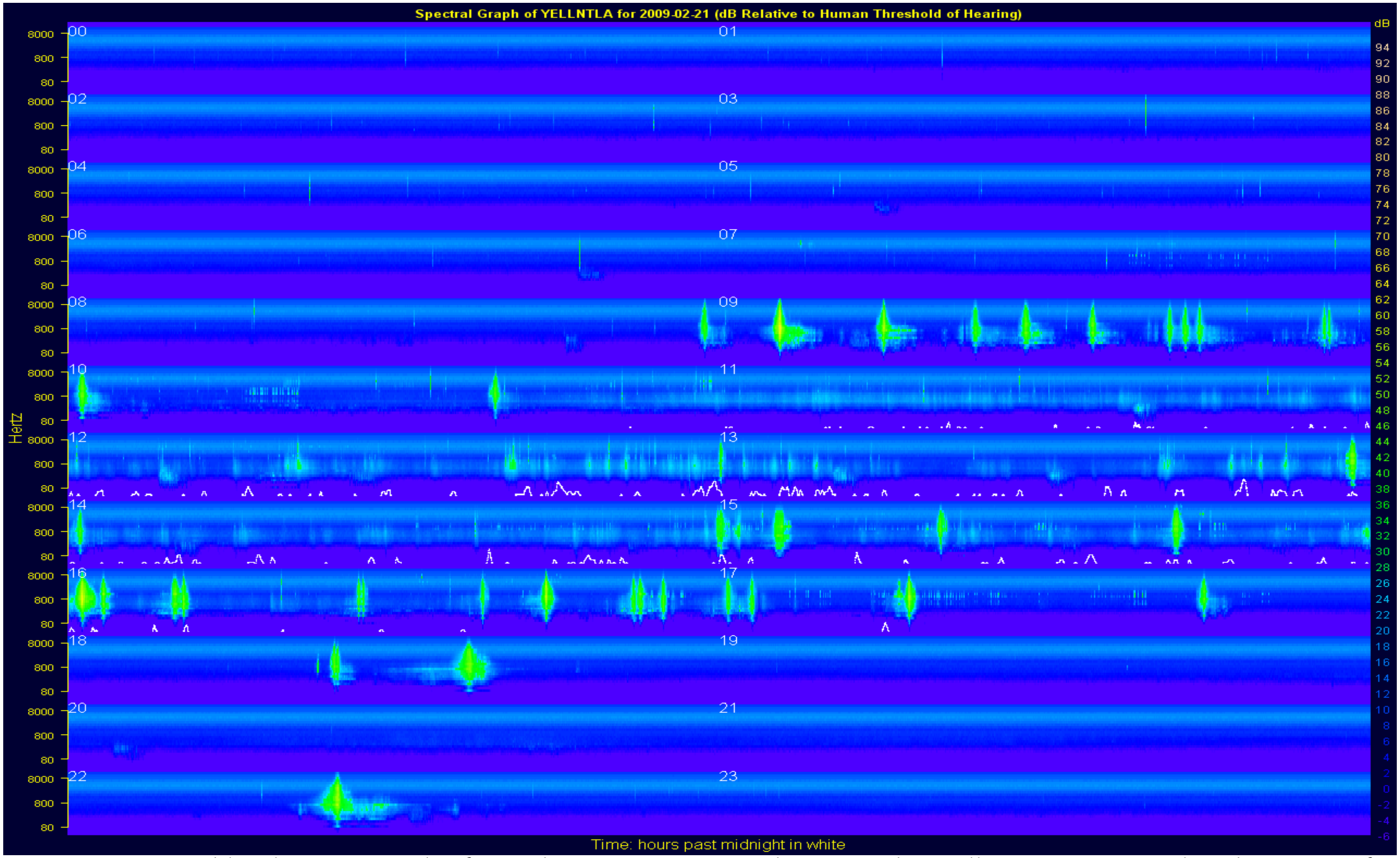

Figure D-1. Sound level spectrograph of 21 February 2009 at North Twin Lake, Yellowstone National Park. See text for explanation.

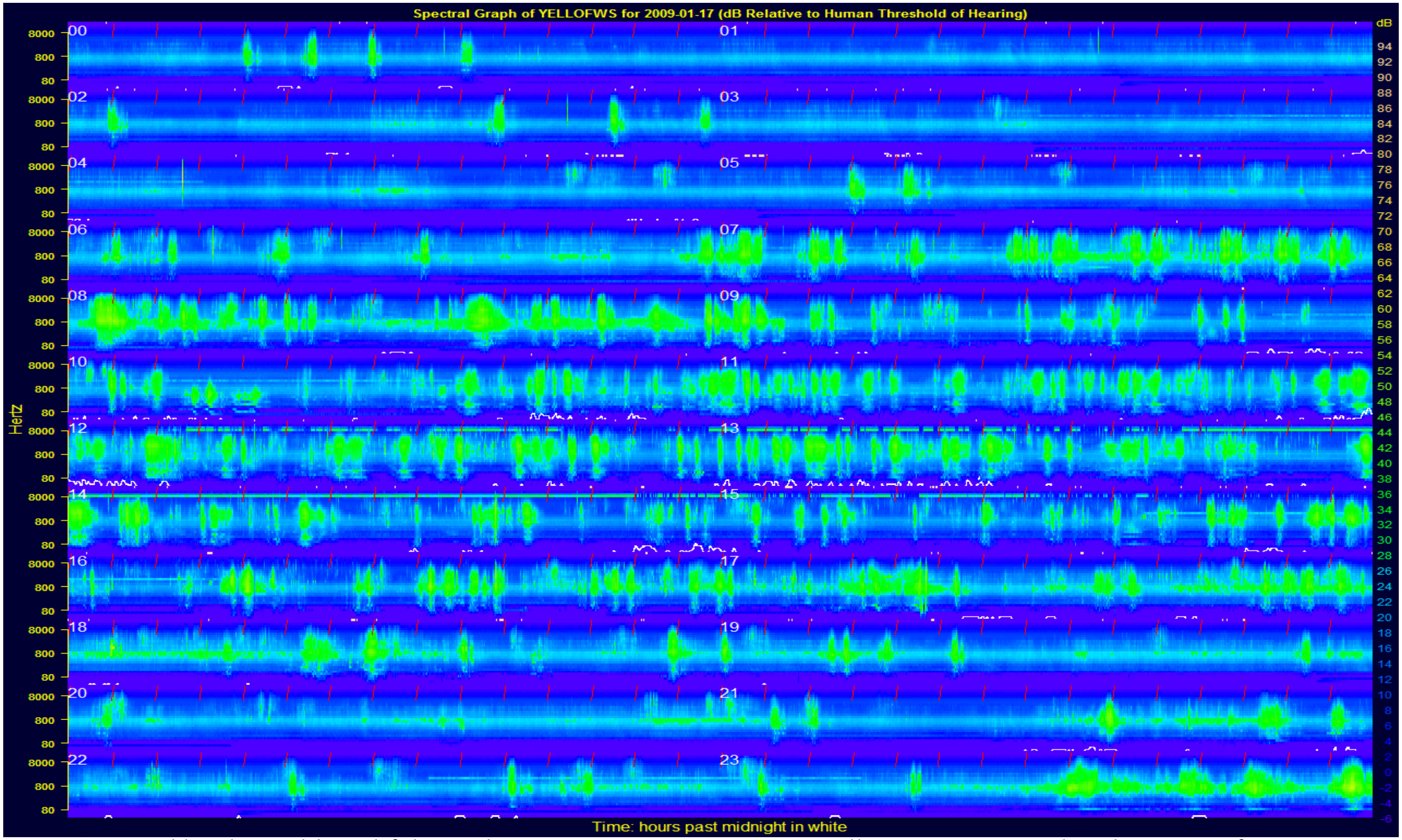

Fig D-2. Sound levels at Old Faithful Weather Station, 17 January 2009, Yellowstone National Park. See text for explanation.

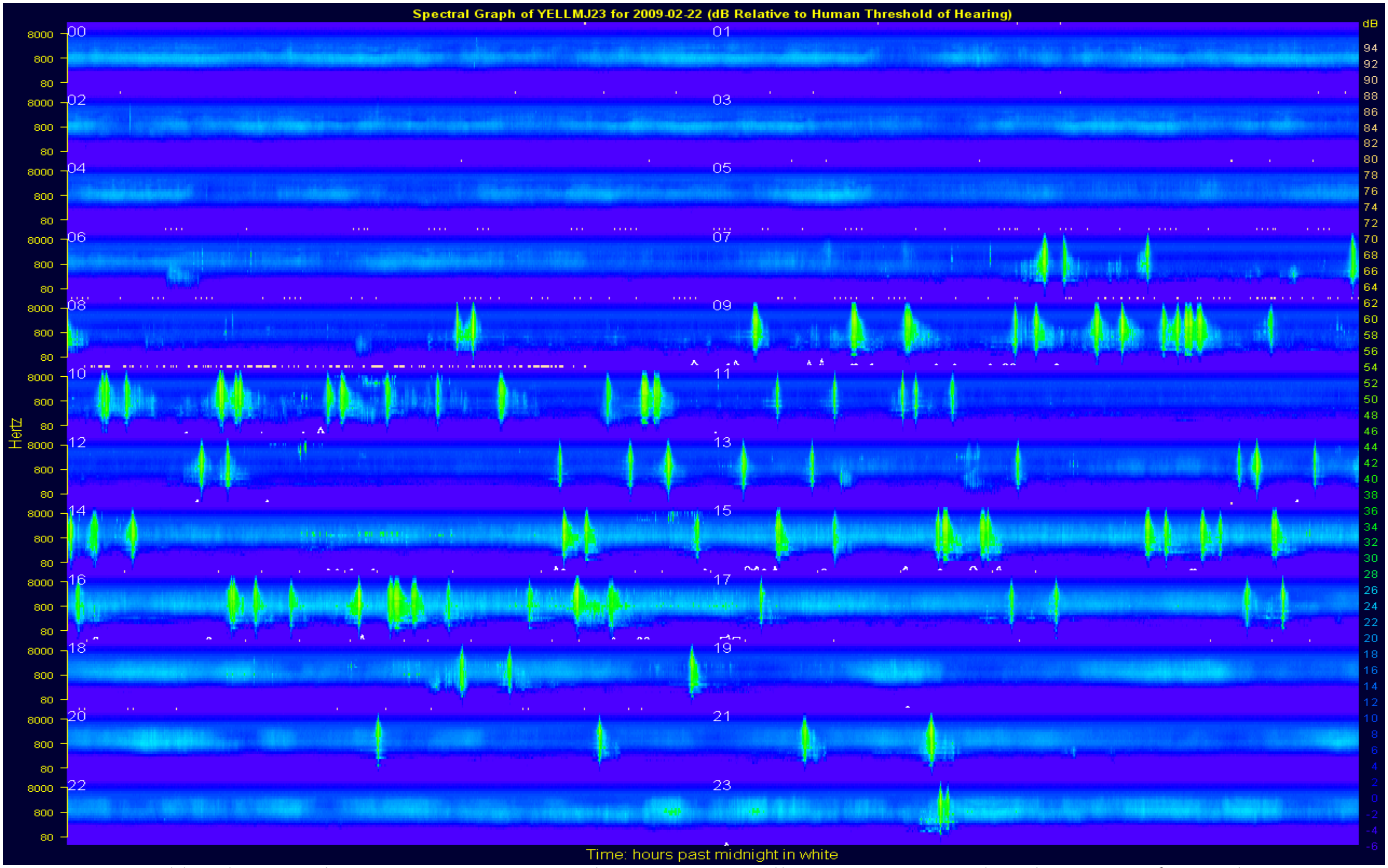

Fig D-3. Sound levels at Madison Junction 2.3, 22 February 2009, Yellowstone National Park. See text for explanation.

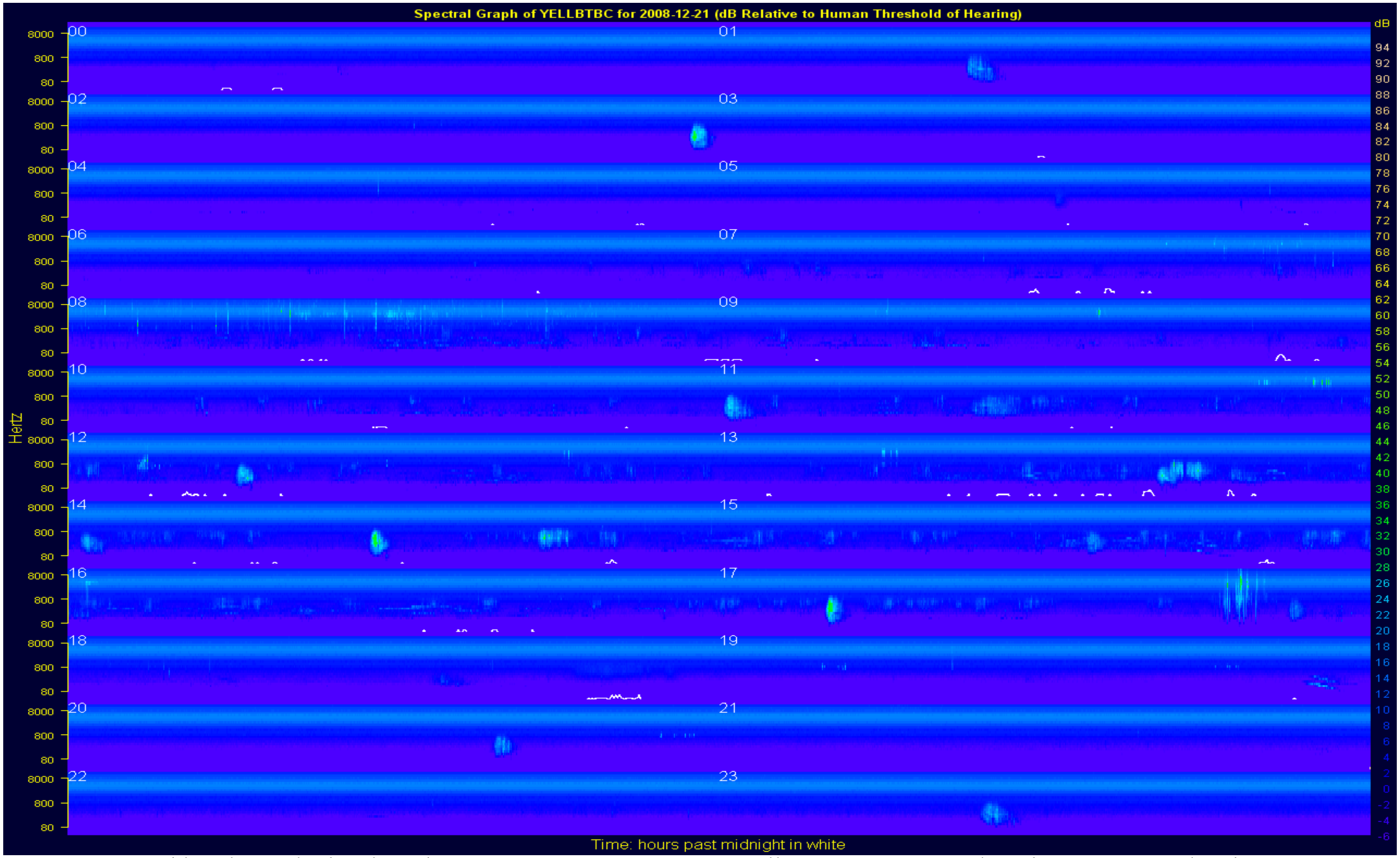

Fig D-4. Sound levels at Blacktail Backcountry, 21 January 2008, Yellowstone National Park, on a rare calm day. See text for explanation.

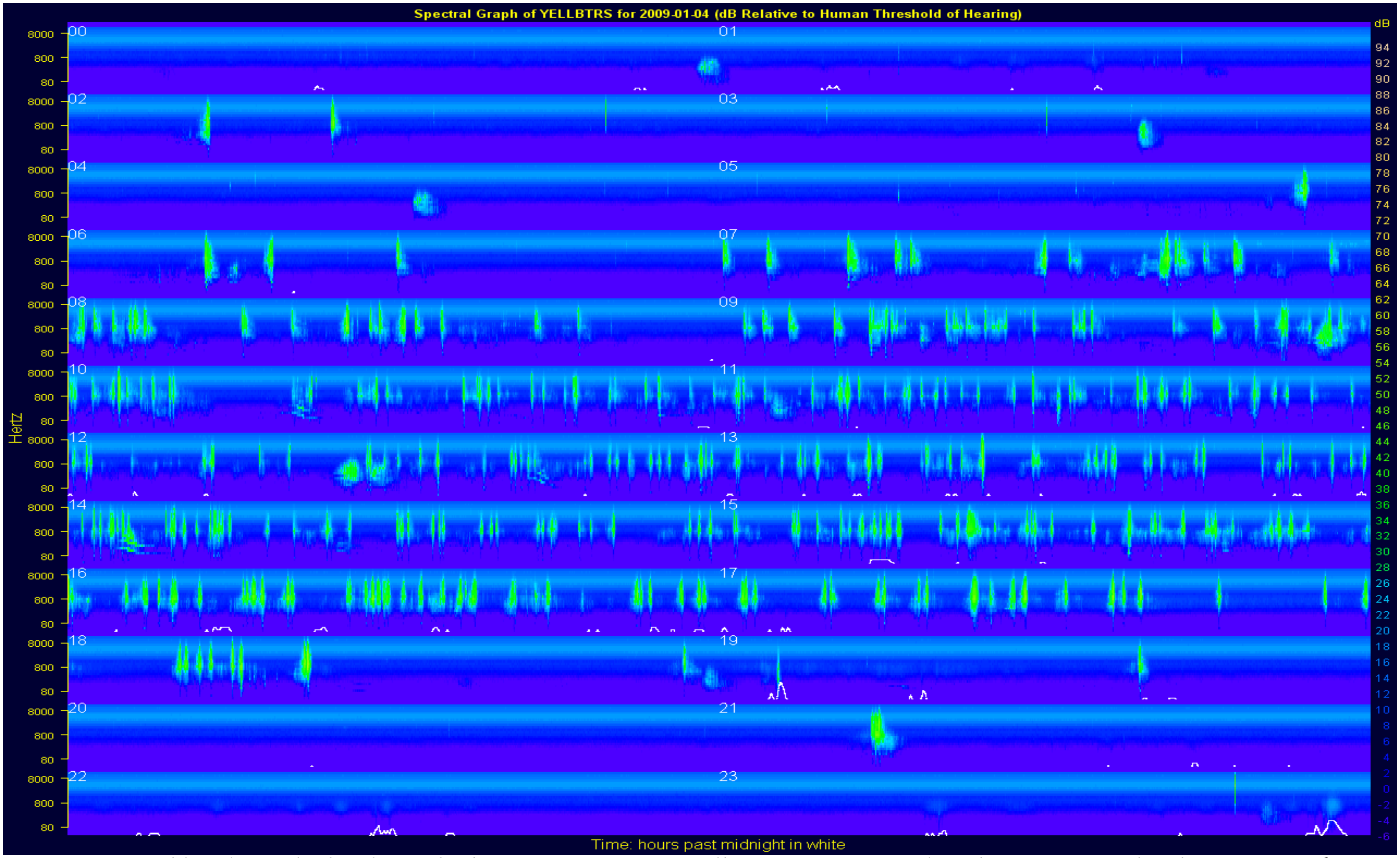

Fig D-5. Sound levels at Blacktail Roadside, 4 January 2009, Yellowstone National Park, on a rare calm day. See text for explanation.

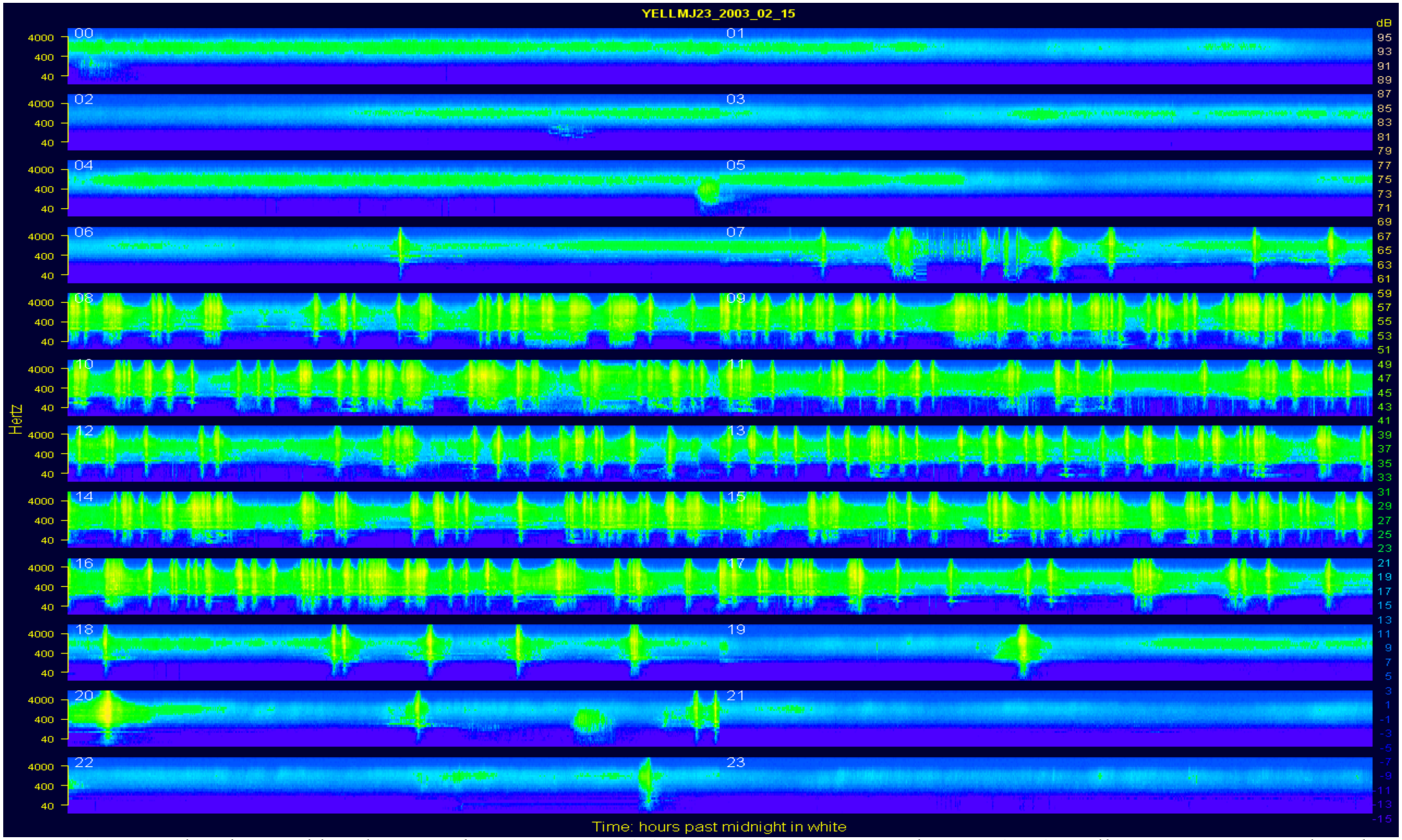

Fig D-6. A-weighted sound levels at Madison Junction 2.3 monitoring site, 15 February 2003, Yellowstone National Park. Compare to Fig. D-7 for number and timing of OSVs. See text for explanation.

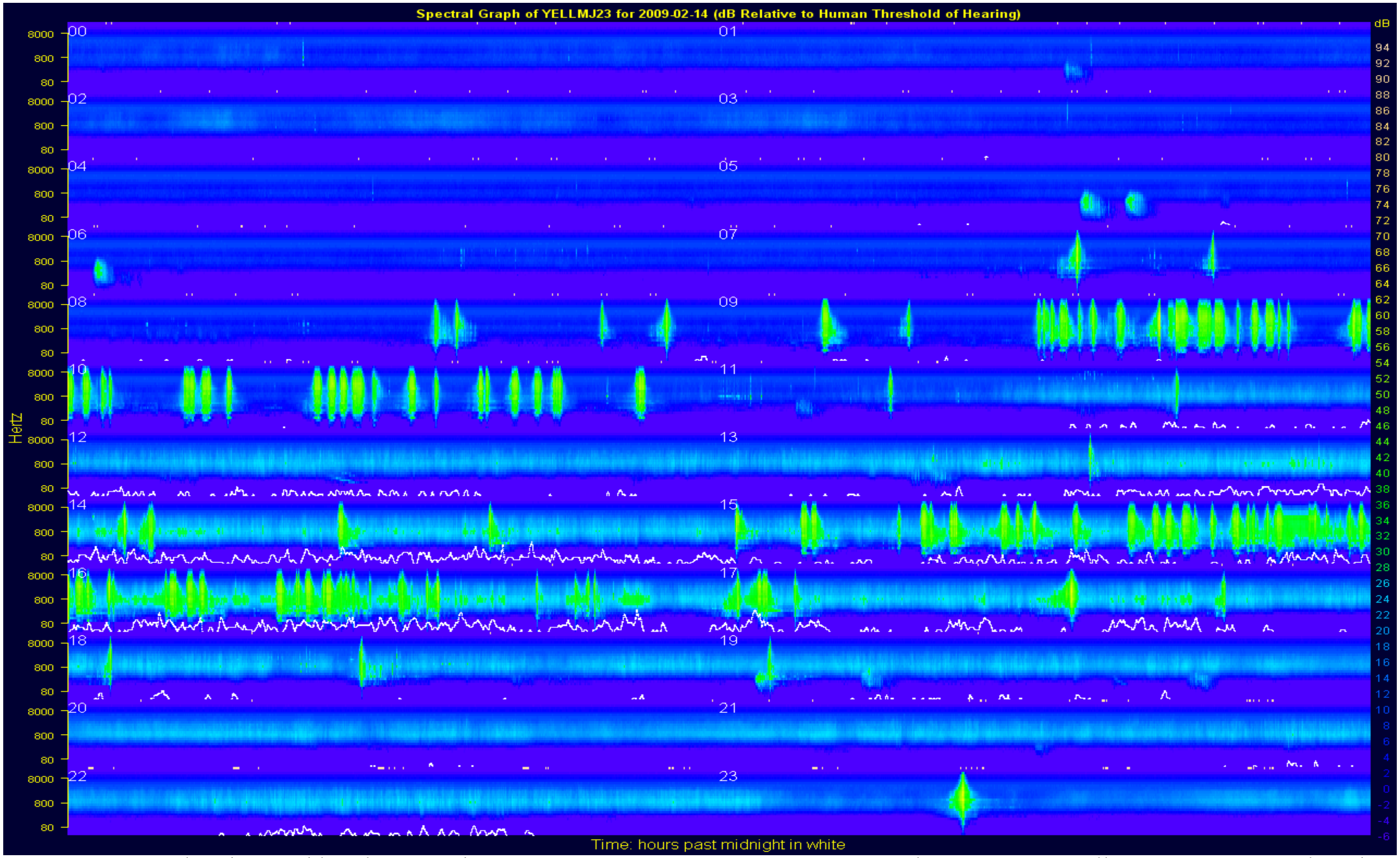

Fig D-7. A-weighted sound levels at Madison Junction 2.3 monitoring site, 14 February 2009, Yellowstone National Park. Compare to Fig. D-6 for number and timing of OSVs. See text for explanation.

Appendix E: Observational study of oversnow vehicle usage

The audibility analysis using unattended sound monitoring equipment estimated the percent time all sounds were audible at those locations. Unfortunately, that technique was not able to provide the identity of the user type of oversnow vehicles. To determine the type and proportion of oversnow vehicle usage a separate observational study was conducted during the five winters of 2005-2009. Observers were positioned within view of travel routes at key locations and documented the time audible and type of usage for each oversnow vehicle observed. The data were collected during 143 logging periods at locations within developed areas and along the travel corridors mainly between Lewis Lake and West Yellowstone and Bridge Bay and Cygnet Lake (Table E-1), 17 February-5 March 2005, 20 January-9 March 2006, 26 December 2006-5 March 2007, 8 January-5 March 2008, and 12 January-25 February 2009. The total observer logging time was 189 hr 54 min 23 sec, 7 am to 5 pm, split between morning and afternoon.

Table E-1. Locations used and percent of sampling effort for observational study of oversnow usage patterns during winters 2005-2009 in Yellowstone National Park.

Developed Area	% Sampling Time	Travel Corridor	% Sampling Time
Old Faithful Entrance Road	14.27	Kepler Cascades Pullout	2.71
Old Faithful Parking Lot	1.45	Daisy Trailhead	3.84
Old Faithful Ranger Station	0.54	Indian Creek	1.71
Old Faithful Main Road	0.57	Mallard Lake Trailhead	1.08
Canyon Junction	7.14	Midway Geyser Basin	1.62
		Mary Mountain Trailhead	8.44
		Madison Junction 2.3	12.37
		West Yellowstone 3.1	6.97
		Bridge Bay Area	5.22
		Talus Slopes	1.08
		Tuff Cliff Pullout	11.67
		Cygnet Lake Trailhead	6.61
		Grant Village Lewis Lake	5.14
		North Twin Lake	0.54
		Spring Creek	6.49

Oversnow usage types included guided visitors, NPS administrative use, contractors, and Xanterra administrative use, (see sample data sheet Table E-2). These data were then transferred to an MS Access^{TM} database for summary and analysis. Tables E-3 to E-6 present these summary analyses. Oversnow vehicles that were not seen, but only heard, were not included in these results because the user group could not be determined.

The number and proportion of snowmobiles was analyzed by group (Table E-3) and by individual machine (Table E-4). The developed area, travel corridor, and combined totals are summarized in both tables. To understand snowmobile usage patterns within Yellowstone NP it is necessary to assess both group and individual patterns. A total of 2,398 groups of oversnow vehicles were documented, including 1,547 groups of snowmobile (E-3). Guided group size ranged from 1-31 (the largest group size numbers were presumably from multiple groups that had merged together). Average size for all snowmobile groups was just over four and a quarter snowmobiles per group; seven and a quarter snowmobiles per guided group and just over one snowmobile per administrative group. A total of 7,400 individual oversnow vehicles were tallied, including 6,549 snowmobiles (E-4).

Of all individual snowmobiles observed, guided visitors (recreational use) accounted for 92% along travel corridors and 78% in developed areas (Table E-4). Guided visitors comprised 68% of all groups documented along travel corridors and 37% in developed areas (Table E-3). As would be expected, more administrative travel occurred in developed areas than along travel corridors between developed areas (Tables E-3 and E-4). Contractors working on the Old Faithful Inn and the Old Faithful Visitor Center comprised 8% of all groups of snowmobiles documented in developed areas (Table E-3). Other administrative travel totaled 55% of the total number of groups observed in developed areas (Table E-3).

The same analysis was done with snowcoach use in developed areas and travel corridors (Table E-5). Administrative travel is mostly by snowmobile but the NPS and concessions do travel by snowcoach, especially between locations in developed areas. Guided snowcoaches with park visitors comprised 93% of snowcoaches observed along travel corridors and 82% of snowcoaches within developed areas (Table E-5). Of the 851 snowcoaches observed, nearly 9 out of 10 were guided (Table E-5).

Guided snowmobiles comprised 51% of all audible snowmobiles and 57% of all audible motorized vehicles (Table E-6). Guided snowcoaches comprised 27% of all audible motorized vehicles (Table E-6). All oversnow vehicles were audible for 53% of the study period and comprised 90% of the motorized sounds audible (Table E-6). Snowmobiles were audible for 63 hours 51 minutes and 21 seconds (34%), and snowcoaches were audible for 30 hours 20 minutes and 30 seconds (16%) of the 189 hours 54 minutes and 21 second study period (Table E-6). No motorized sounds were audible for 41% of the time during the study period (Table E-6).

Table E-2. Field data sheet for logging oversnow usage type in Yellowstone National Park, during the winters of 2005-2009.

Date:	Time: Start/End	Page	of
Name, Address, Telephone:	Shan Burson Grand Teton National Park 307 739 3584		
Location Description:	Latitude:		
	Longitude:		
	Elevation (ASL, feet):		
Habitat types (up to three, include percentage) and Terrain within .5 km:			
Weather	Temperature (F):	Cloud cover (%):	
	Wind (MPH/from):	Precipitation:	

Time Start:	Source*:	Time Stopped:	Location:	Remarks:
10:41:05	4.2	10:46:08	Eastbound	Yellow Bombardier
10:45:12	4.1	10:48:50	Out headed south	8 in guided group leaving OF
24 hr. time. Include exact Obs.Time Start and End				

*Source: 0	None audible	8	People	Instructions
1.1	Aircraft, jet	10	Building sounds	Record when non-natural sounds are audible. Give priority to oversnow.
1.2	Aircraft, propeller	11	Construction	Record other non-natural sounds as possible. Note when ignoring them.
1.3	Aircraft, helicopter	19	Non-natural other	Record time in hours, minutes and seconds. Try to use GPS time (that is.
2	Vehicle (type)	20	Non-natural unk.	accurate time). Record stop time as well as start time.
3	Watercraft (type)			Record oversnow type (4.1, 4.2, 4.3, 4.4) and number making up group.
4	Oversnow Vehicle			Record type of user (contractor, Xanterra, NPS researcher, Ranger, admin,
4.1	Snowmobile			snowcoach or guided snowmobile group) in Remarks column.
4.2	Snowcoach			Note type of snowcoach (Mattrax, Red or Yellow Bomb, Yellow Bus, etc.)
4.3	Snowmobile or Snowcoach			Record type of snowmobile if not 4 stroke.
4.4	Snow Groomer			Record anything else that would improve understanding of circumstances.
6	Motors			Record direction of travel in Location column

Table E-3. Number and proportion of snowmobile groups by usage type traveling within Yellowstone National Park, winters 2005-2009.

Location	Guided Snowmobiles	Contractor	NPS Maintenance	Ranger	Research	NPS Other/Unknown	Concession Admin	Unknown Admin	Xanterra Admin	Total
Developed Area	270	56	54	82	9	85	18	29	122	725
	37%	8%	7%	11%	1%	12%	2%	4%	17%	100%
				NPS-All[a]	230					
					32%					
				Admin-All[b]	399					
					55%					
Travel Corridor	560	11	10	54	47	96	15	10	19	822
	68%	1%	1%	7%	6%	12%	2%	1%	2%	100%
				NPS-All	207					
					25%					
				Admin-All	153					
					19%					
All Areas	830	67	64	136	56	181	33	39	141	1547
	54%	4%	4%	9%	4%	12%	2%	3%	9%	100%
				NPS-All	260					
					17%					
				Admin-All	358					
					23%					

[a]NPS-All Includes maintenance, rangers, research and NPS others/unknown

[b]Admin-All Includes all but guided snowmobiles and contractors

Table E-4. Number and proportion of individual snowmobiles by usage type traveling within Yellowstone National Park, winters 2005-2009.

Location	Guided Snowmobiles	Contractor	NPS Maintenance	Ranger	NPS Research	NPS Other/Unknown	Concession Admin	Unknown Admin	Xanterra Admin	Total
Developed Area	1826	89	66	83	12	92	20	31	125	2344
	78%	4%	3%	4%	1%	4%	1%	1%	5%	100%
				NPS-All[a]	253					
					11%					
				Admin-All[b]	429					
					18%					
Travel Corridor	3873	25	14	60	62	114	24	13	20	4205
	92%	1%	0%	1%	1%	3%	1%	0%	0%	100%
				NPS-All[a]	250					
					6%					
				Admin-All[b]	307					
					7%					
All Areas	5699	114	80	143	74	206	44	44	145	6549
	87%	2%	1%	2%	1%	3%	1%	1%	2%	100%
				NPS-All[a]	503					
					8%					
				Admin-All[b]	736					
					11%					

[a]NPS-All Includes maintenance, rangers, research and NPS others/unknown

[b]Admin-All Includes all but guided snowmobiles and contractors

Table E-5. Number and proportion of individual snowcoaches by usage type traveling within Yellowstone National Park, winters 2005-2009.

Location		Guided Snowcoach	Contractor	NPS Maintenance	NPS Ranger	NPS Other/Unknown	Concession Admin	Unknown Admin	Xanterra Admin	Total
Developed Area		322	5	1	1	0	3	4	59	395
		82%	1%	0%	0%	0%	1%	1%	15%	100%
					NPS-All[a]	2				
						1%				
					Admin-All[b]	68				
						17%				
Travel Corridor		423	0	0	1	6	8	2	16	456
		93%	0%	0%	0%	1%	2%	0%	4%	100%
					NPS-All	7				
						2%				
					Admin-All	33				
						7%				
All Areas		745	5	1	2	6	11	6	75	851
		88%	1%	0%	0%	1%	1%	1%	9%	100%
					NPS-All	9				
						1%				
					Admin-All	101				
						12%				

[a]NPS-All Includes maintenance, rangers, research and NPS others/unknown

[b]Admin-All Includes all but guided snowmobiles and contractors

Table E-6. Elapsed time (hours:minutes:seconds) and percentages for motorized vehicles during an observational study, winters 2005-2009, Yellowstone National Park. Totals may not appear correct due to rounding errors.

User Group	Elapsed Time	Percentage	Combined Total
Snowmobiles Only			
Guided Snowmobile	32:20:19	51%	51%
Contractor	1:10:21	2%	2%
NPS-Maintenance	1:33:47	2%	
NPS-Ranger	3:52:48	6%	
NPS-Research	1:22:31	2%	
NPS-Other/Unknown	4:53:18	8%	18%
Admin-Concession	2:38:12	4%	
Administrative-Xanterra	2:44:57	4%	8%
Administrative-Unknown	0:43:20	1%	1%
Unknown User	12:31:48	20%	20%
	63:51:21		
Snowcoaches Only			
Guided Snowcoach	26:01:11	85%	85%
Contractor	0:04:02	0%	0%
NPS-Maintenance	0:01:41	0%	
NPS-Ranger	0:02:21	0%	
NPS-Research	0:00:00	0%	
NPS-Other/Unknown	0:16:09	1%	1%
Admin-Concession	0:17:34	1%	
Administrative-Xanterra	2:24:22	8%	9%
Administrative-Unknown	0:08:50	0%	0%
Unknown User	1:30:47	5%	5%
	30:46:57		

Table E-6 continued. Elapsed time (hours:minutes:seconds) and percentages for motorized vehicles during an observational study, winters 2005-2009, Yellowstone National Park. Totals may not appear correct due to rounding errors.

User Group	Elapsed Time	Percentage	Combined Total
All Motorized Sounds			
Jets	4:51:45	4%	
Props	2:02:55	2%	
Helicopters	0:32:43	0%	7%
Snowmobile	63:51:21	57%	
Snowcoach	30:20:30	27%	
Snowmobile or Snowcoach	2:09:02	2%	
Unknown Oversnow Vehicle	4:39:46	4%	90%
Groomer	2:19:03	2%	2%
Unknown/Other Motorized	1:18:15	1%	1%
	112:05:20		
Total Observation Time	189:54:21		
Motorized Sounds	112:05:20	59%	
Oversnow Vehicles	101:00:39	53%	
Snowmobiles	63:51:21	34%	
No Motorized Sounds	77:49:01	41%	

Appendix F: Monitoring results from the winter of 2007-2008

The following figures include monitoring results from the winter of 2007-2008. These figures are useful for comparison to the analysis presented for the 2008-2009 winter season in the body of this report.

Old Faithful Weather Station

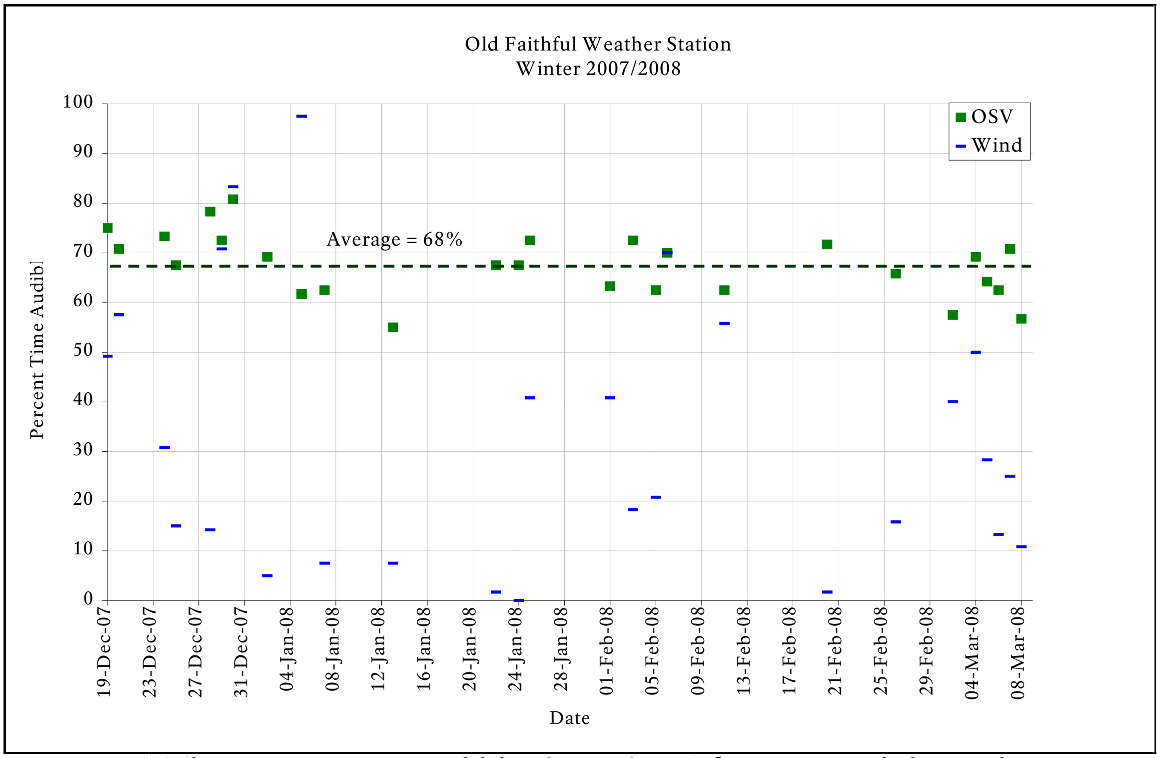

Figure F-1. The percent time audible (8 am-4 pm) for snowmobiles and snowcoaches, and wind by date at Old Faithful Weather Station, Yellowstone National Park, 19 December 2007 to 8 March 2008.

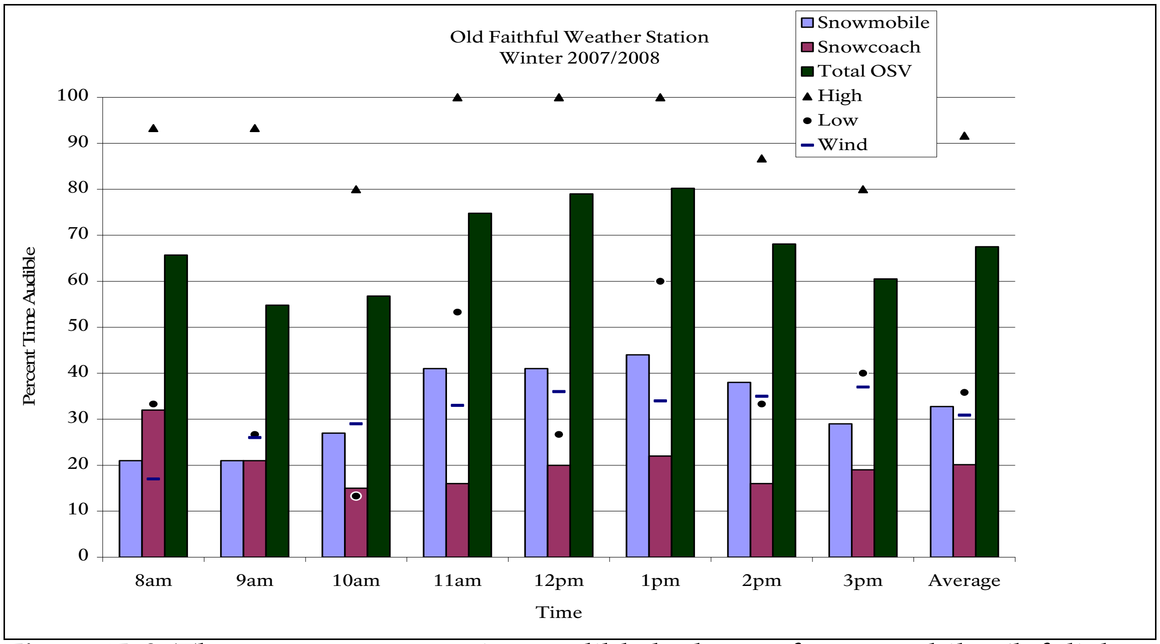

Figure F-2. The average percent time audible by hour of snowmobiles (left light blue bar), snowcoaches (middle maroon bar), and combined category (right dark green bar), and high and low OSV values at Old Faithful Weather Station, Yellowstone National Park from 8 am to 4 pm, 19 December 2007 to 8 March 2008.

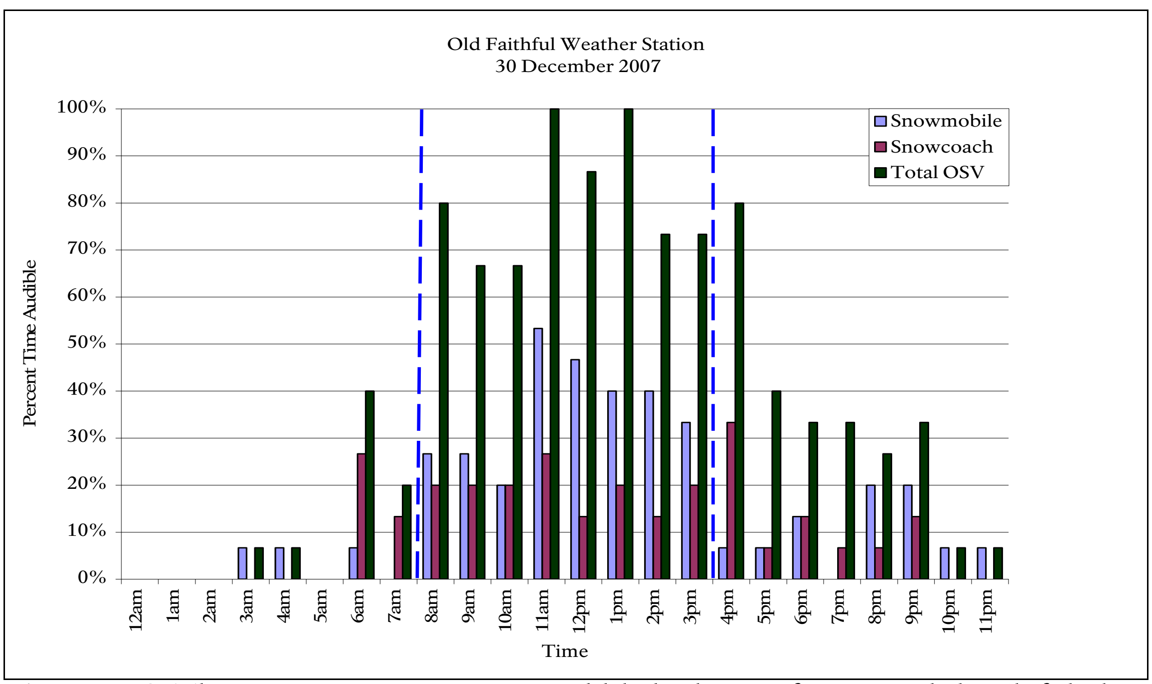

Figure F-3. The average percent time audible by hour of snowmobiles (left light blue bar), snowcoaches (middle maroon bar), and combined category (right dark green bar) at Old Faithful Weather Station, Yellowstone National Park 30 December 2007. The winter use analysis time period is between the vertical dashed lines.

Madison Junction 2.3

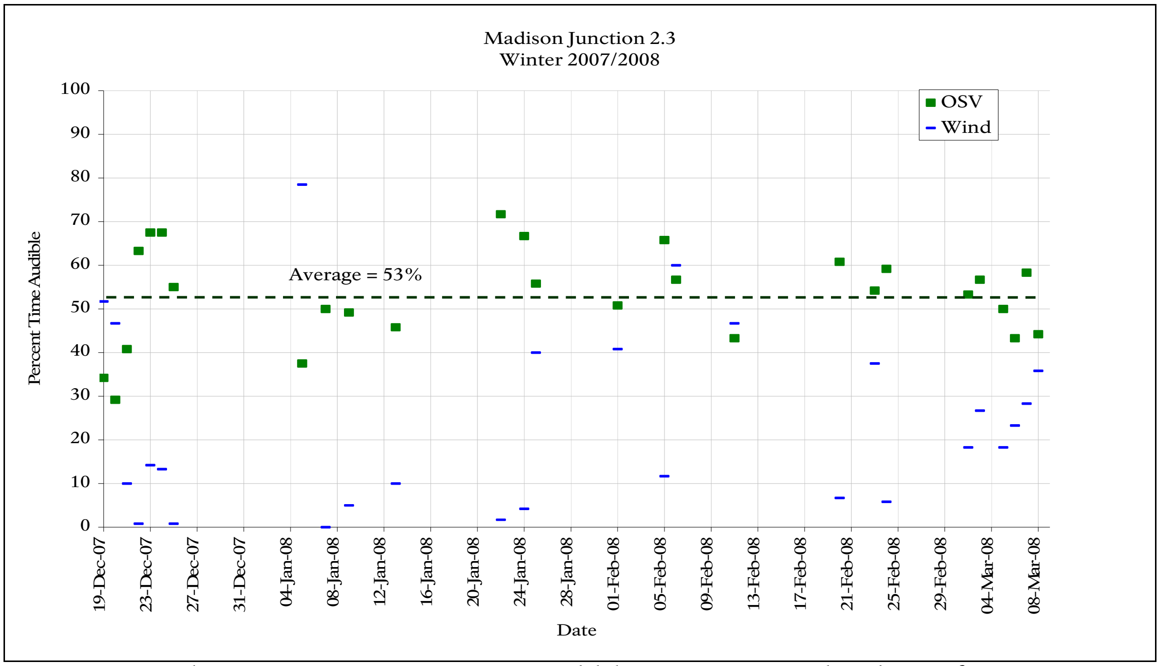

Figure F-4. The average percent time audible (8 am-4 pm) by date of snowmobiles and snowcoaches, and wind at 2.3 miles (3.7 km) west of Madison Junction along the West Entrance Road Yellowstone National Park, 19 December 2007-8 March 2008.

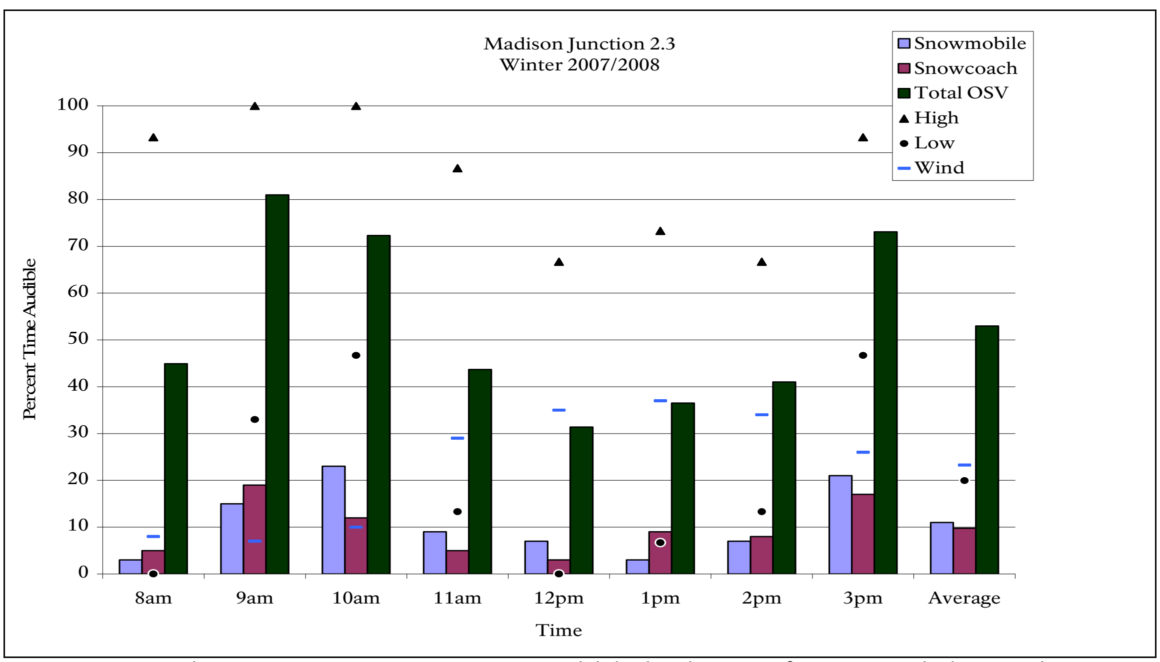

Figure F-5. The average percent time audible by hour of snowmobiles and snowcoaches, and high and low OSV values at 2.3 miles (3.7 km) west of Madison Junction along the West Entrance Road Yellowstone National Park, 19 December 2007- 8 March 2008.

Old Faithful Weather Station

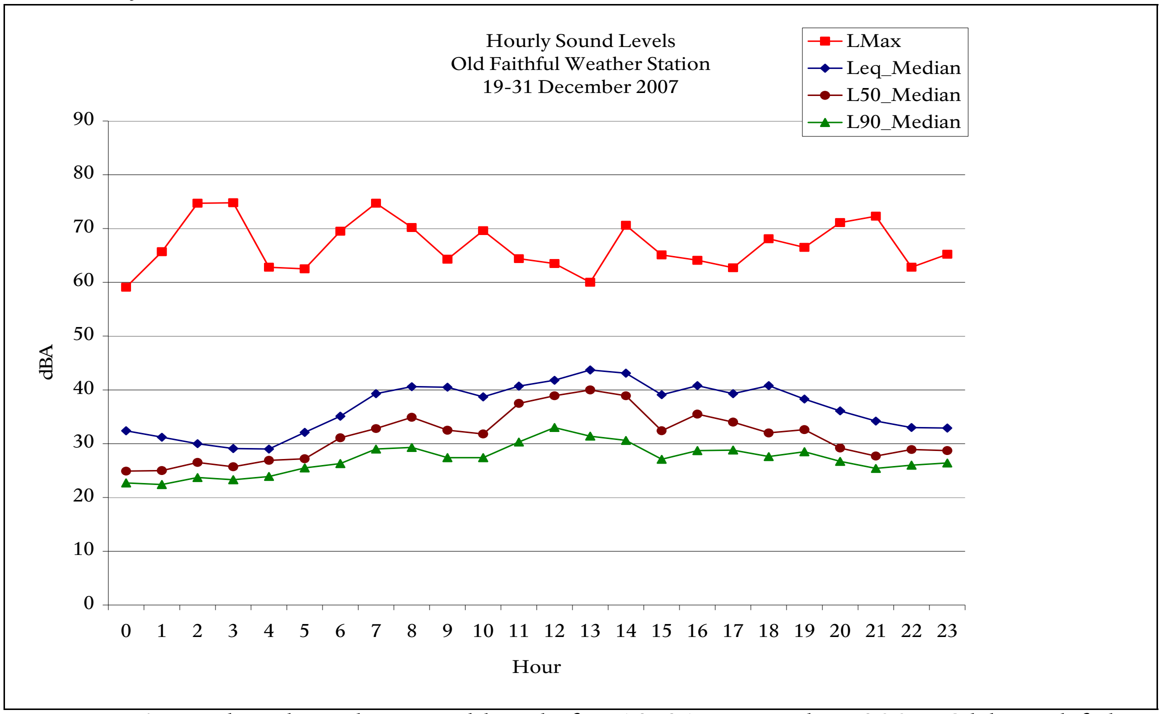

Figure F-6. Median hourly sound levels for 19-31 December 2007, Old Faithful Weather Station, Yellowstone National Park. These sound levels include all natural and non-natural sounds. Lmax is the highest sound level measured during each hour of the measurement period. (n=310 hours)

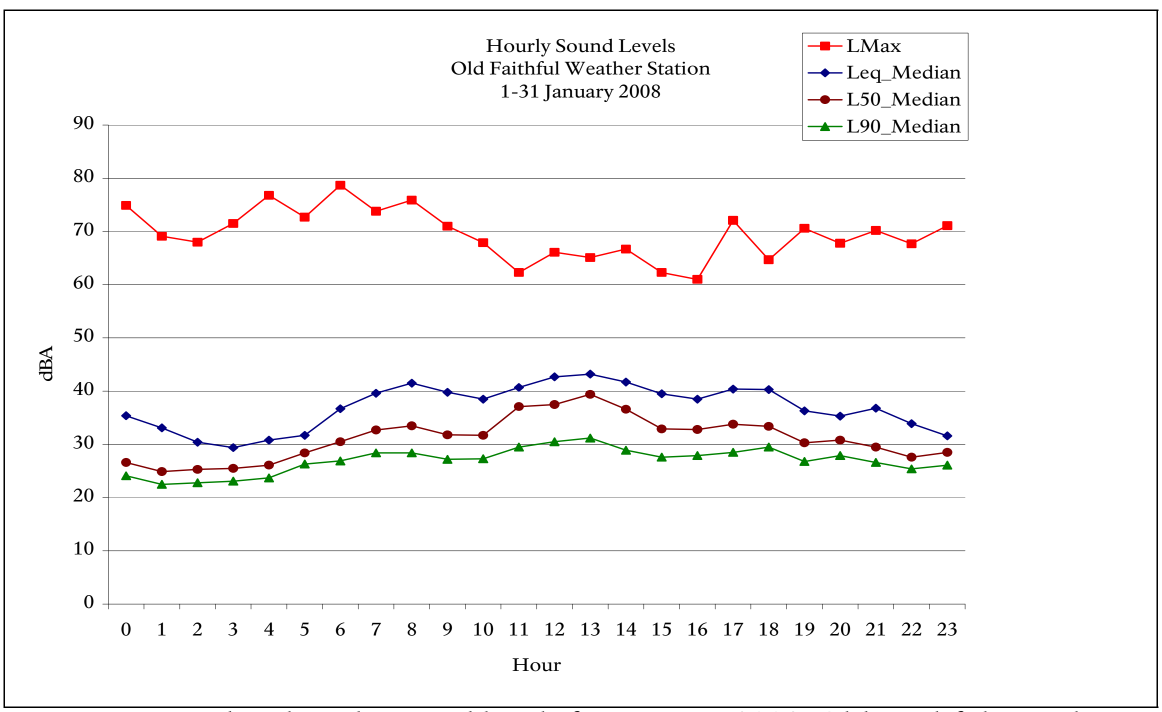

Figure F-7. Median hourly sound levels for January 2008, Old Faithful Weather Station, Yellowstone National Park. (n=730 hours)

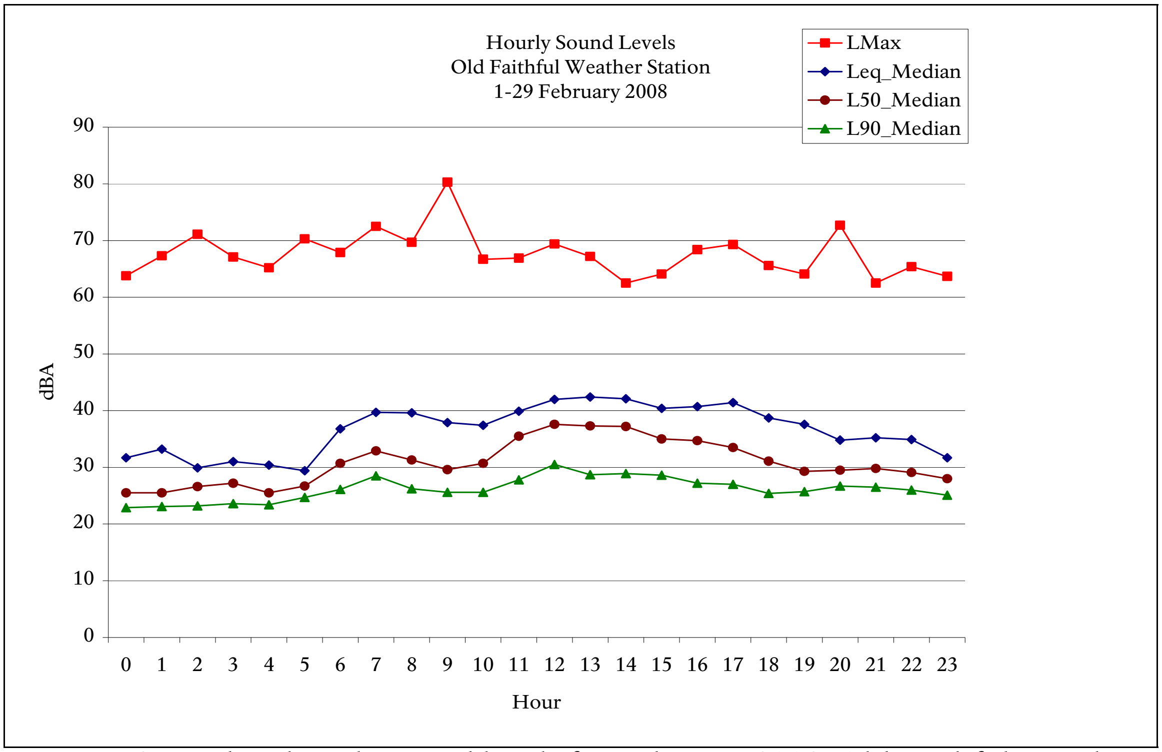

Figure F-8. Median hourly sound levels for February 2008, Old Faithful Weather Station, Yellowstone National Park. See Fig. 15 caption for more details. (n=677 hours)

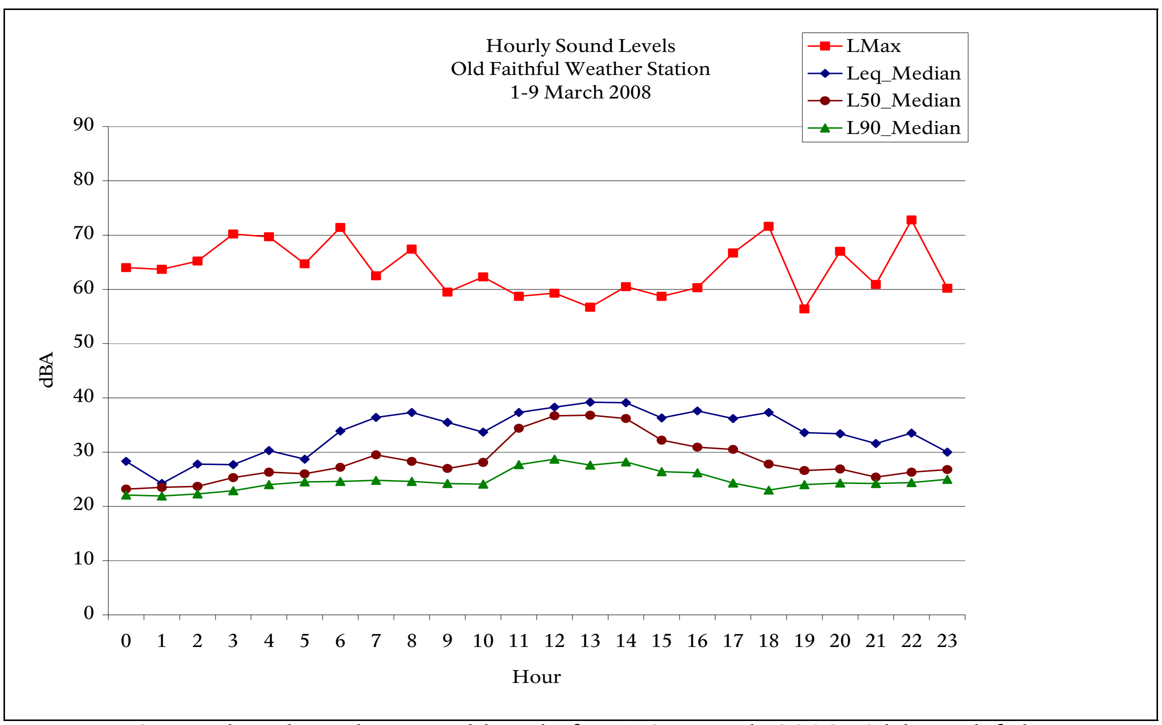

Figure F-9. Median hourly sound levels for 1-9 March 2008, Old Faithful Weather Station, Yellowstone National Park. See Fig. 15 caption for more details. (n=214 hours)

Madison Junction 2.3

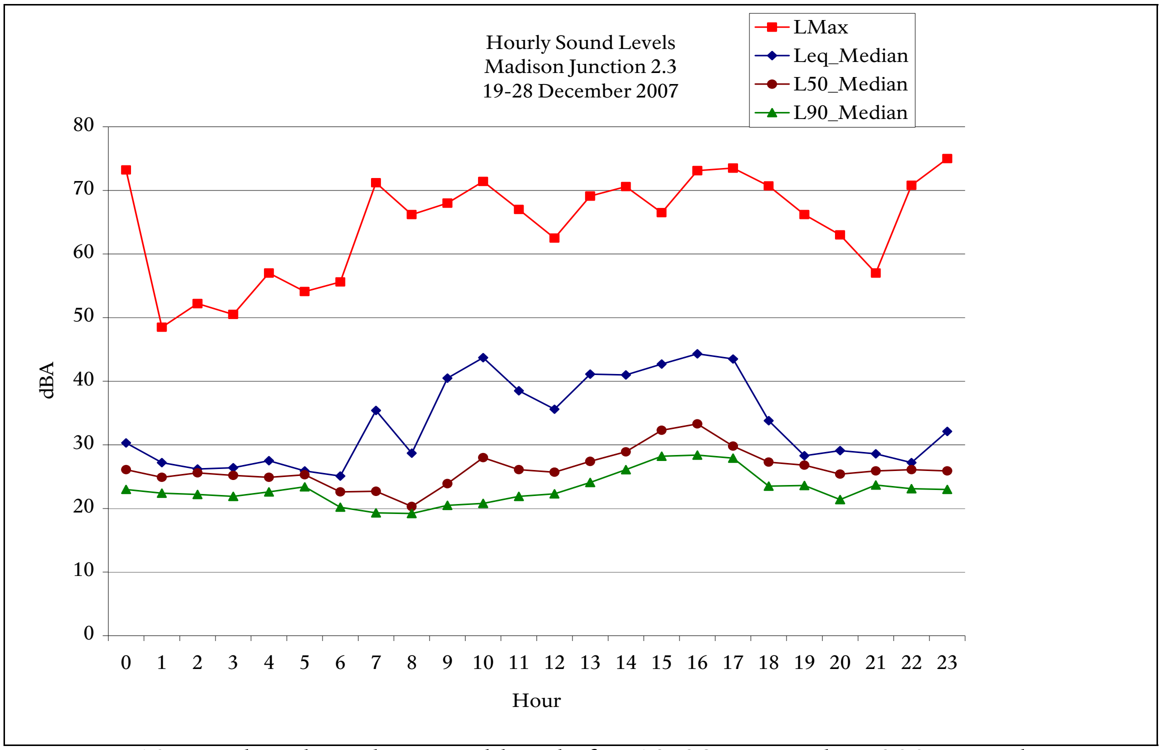

Figure F-10. Median hourly sound levels for 19-28 December 2007, Madison Junction 2.3, Yellowstone National Park. (n=222 hours)

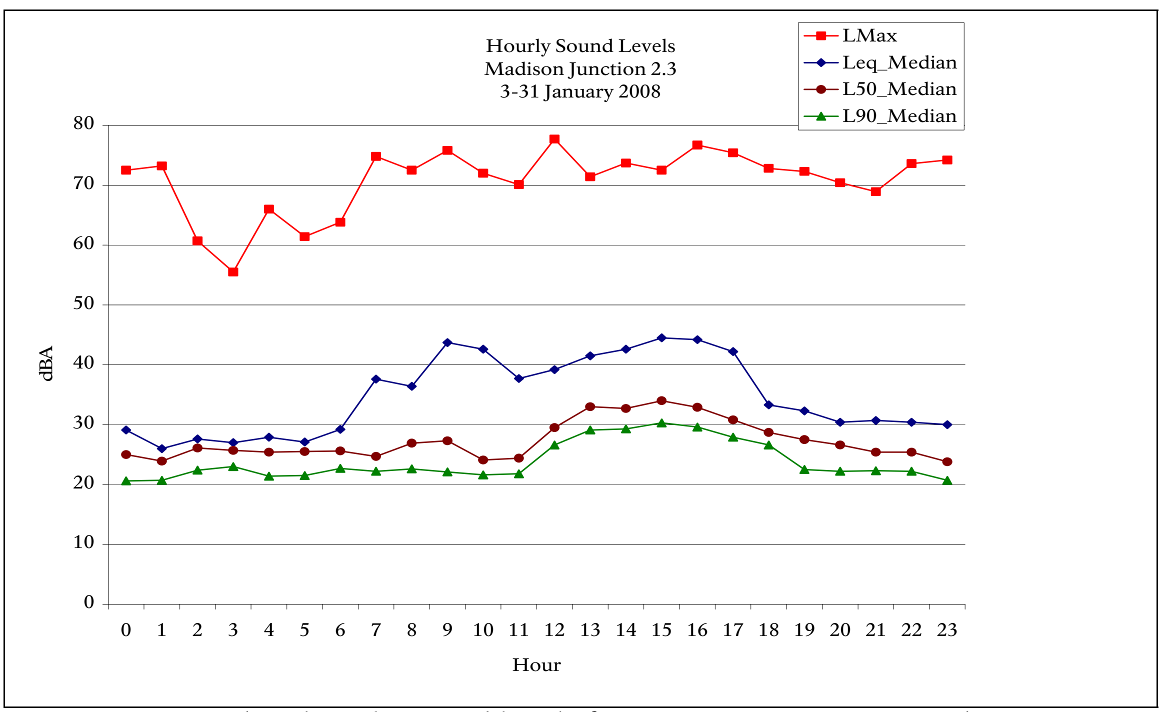

Figure F-11. Median hourly sound levels for 3-31 January 2008, Madison Junction 2.3, Yellowstone National Park. (n=678 hours)

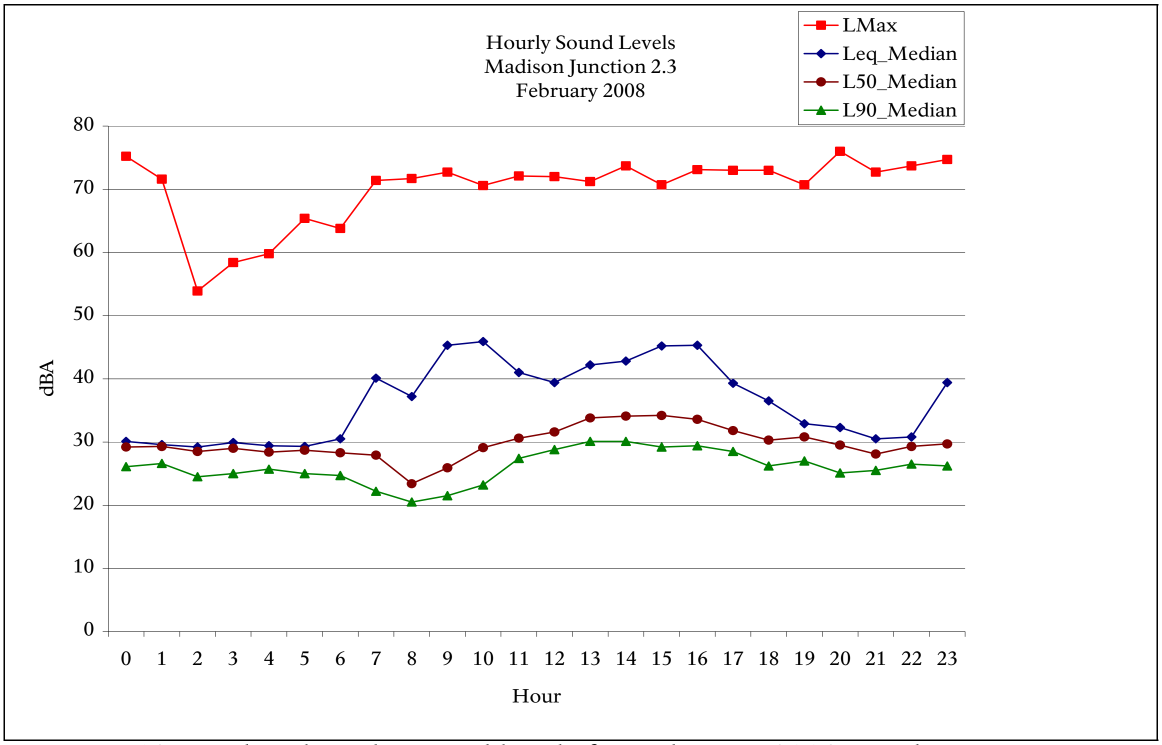

Figure F-12. Median hourly sound levels for February 2008, Madison Junction 2.3, Yellowstone National Park. (n=633 hours)

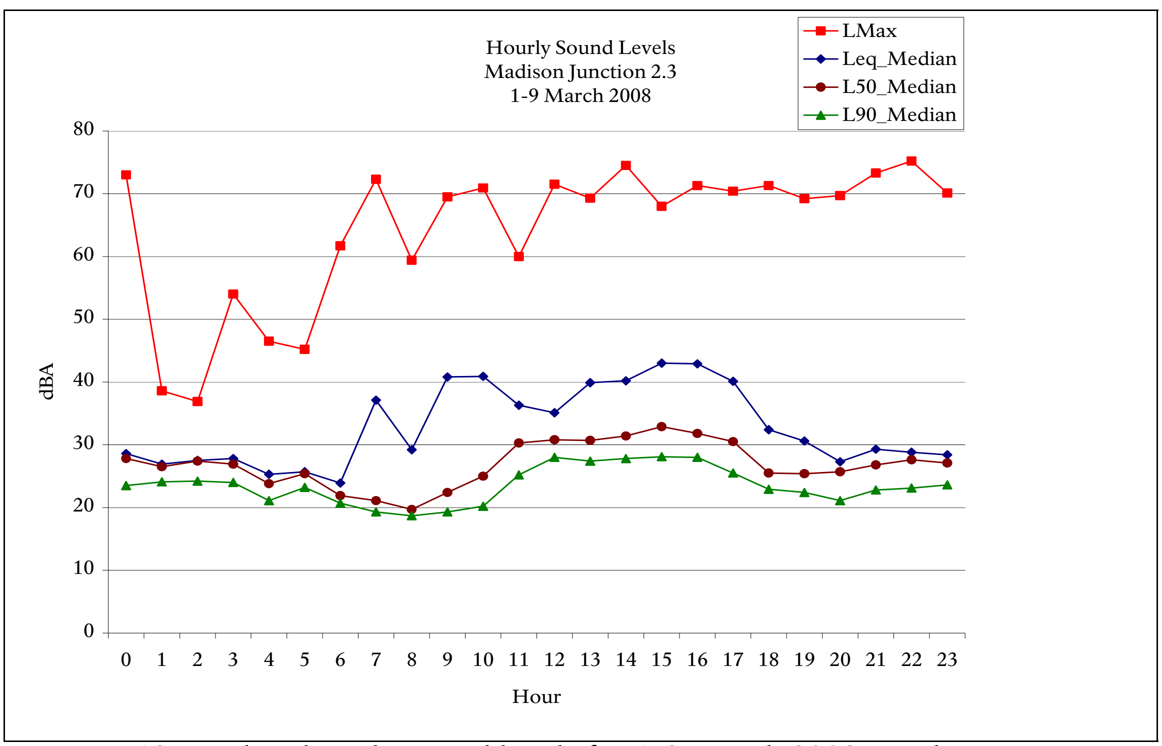

Figure F-13. Median hourly sound levels for 1-9 March 2008, Madison Junction 2.3, Yellowstone National Park. (n=204 hours)

Appendix G: Additional percent time audible considerations

As was discussed in the Results and Discussion section, the percent time OSVs were audible at any one point depended on several variables. For the last several winter use plans, audibility was measured by the percent of time between 8 am and 4 pm that OSVs were audible at a given point. The primary travel corridor monitoring site was Madison Junction on the busiest travel corridor in winter. For the winter season 2008-2009, OSVs were audible 47% of the 8-hour day. When the period of analysis is expanded to 7 am to 9 pm, the hours when the park is open to the public, OSV audibility was fell to 38%. Audibility climbed to 81% during the busiest hour of the day, 9 am to 10 am, and was 20% during the noon hour. The average OSV audibility for all days analyzed of both travel corridor monitoring sites (Madison Junction and North Twin Lake) was 42% for 8 am to 4 pm. This illustrates that the periods of analysis can greatly influence the value of percent time audible. Table G-1 illustrates the range of audibility figures depending on one's selection of monitoring site(s) and periods of analysis.

Table G-1: Audibility as a function of monitoring site and period of analysis, Yellowstone National Park, 15 December 2008-15 March 2009.

Site(s)	Period of Analysis	Audibility
Madison Junction	9 am to 10 am	81%
Madison Junction	noon to 1 pm	20%
Madison Junction	8 am to 4 pm	47%
Madison Junction	7 am to 9 pm	38%
North Twin Lake	8 am to 4 pm	24%
All travel corridor monitoring sites in Yellowstone	8 am to 4 pm	42%

In addition to the influence of time period and monitoring site, naturally occurring sounds also affect the value of percent time audible. As would be expected the percent time OSVs was audible was lower on windy days and was higher during days of higher OSV numbers.