Natural Soundscape Monitoring in Yellowstone National Park December 2009-March 2010

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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 one shorter-term site (near a plowed road used by wheeled vehicles) in Yellowstone National Park during the winter use season, 15 December 2009-15 March 2010.

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 54% of the day near Madison Junction along the corridor between Old Faithful and the West Entrance. At Madison Junction oversnow vehicles were audible over 50% for 18 (60%) of 30 days analyzed. The average noise-free interval between 8 am and 4 pm at Madison Junction was four minutes and 24 seconds. Wheeled vehicles were monitored in Lamar Valley at 140 feet (43m) from the plowed road between Tower and the Cooke City and were audible for 66% of the time between 8 am and 4 pm. The average noise-free interval between 8 am and 4 pm at Lamar Valley was 50 seconds. 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). 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. Consistent with acoustic data collected during the previous seven 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 as trends emerge with the addition of 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 and 2009 Temporary Winter Use Plans (WUP) Environmental Assessment (NPS 2004 and 2009) 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 NPS established limits on the number and group sizes of OSVs and a commercial guiding requirement. The 2009 impact definitions describing the acoustical thresholds (Table 1) can be compared to the acoustic field measurements collected in Yellowstone during the 2009-2010 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). See Burson (2004-2009) for additional information on park soundscapes during the previous winters, and the Winter Use Plans (NPS 2000, 2003, 2004, 2007, and 2009) for additional details of oversnow vehicle management. During the winter of 2009-2010, the sound level of one model of snowcoach was experimentally measured at one location in the park (Appendix G), and a six microphone array collected simultaneous OSV acoustic data along a three mile (4.8 km) transect for multiple days (Appendix H).

Table 1. Impact definitions for the natural soundscape in the 2009 Winter Use Plan (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 385 wheeled vehicles per day traveled on this plowed road between 23 December 2009 and 23 February 2010. During the winter use season, between 15 December 2009 and 15 March 2010, 16,510 snowmobiles and 2,525 snow-coaches, totaling 19,035 oversnow vehicles, entered YNP (NPS unpublished data). The majority (16,084; 97.4%) of snowmobiles entered through the West and the South entrances. Most of these winter visitors traveled to Old Faithful. Both snowmobiles (average of 7/day) and snowcoaches (average 5/day) originated from Old Faithful and were not included in the number of OSVs given above and, unless otherwise indicated, 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 and digital recordings. 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 levels were collected at the Madison Junction 2.3 and Lamar Valley Willow 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-09HR (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 sometimes lower than the noise floor (Burson 2006). Hobo™ wind speed sensors (Onset Computer Co., Pocasset, MA) collected wind speeds.

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 instrument time), and clocks were reset to GPS time. Data were downloaded to a portable hard drive, or system USB thumb drives and Secure Digital cards were swapped, 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 electrical outlets (Old Faithful) or powered by 12 or 14.4 volt batteries with or without photovoltaic charging systems. The monitors could operate continuously for weeks between site visits.

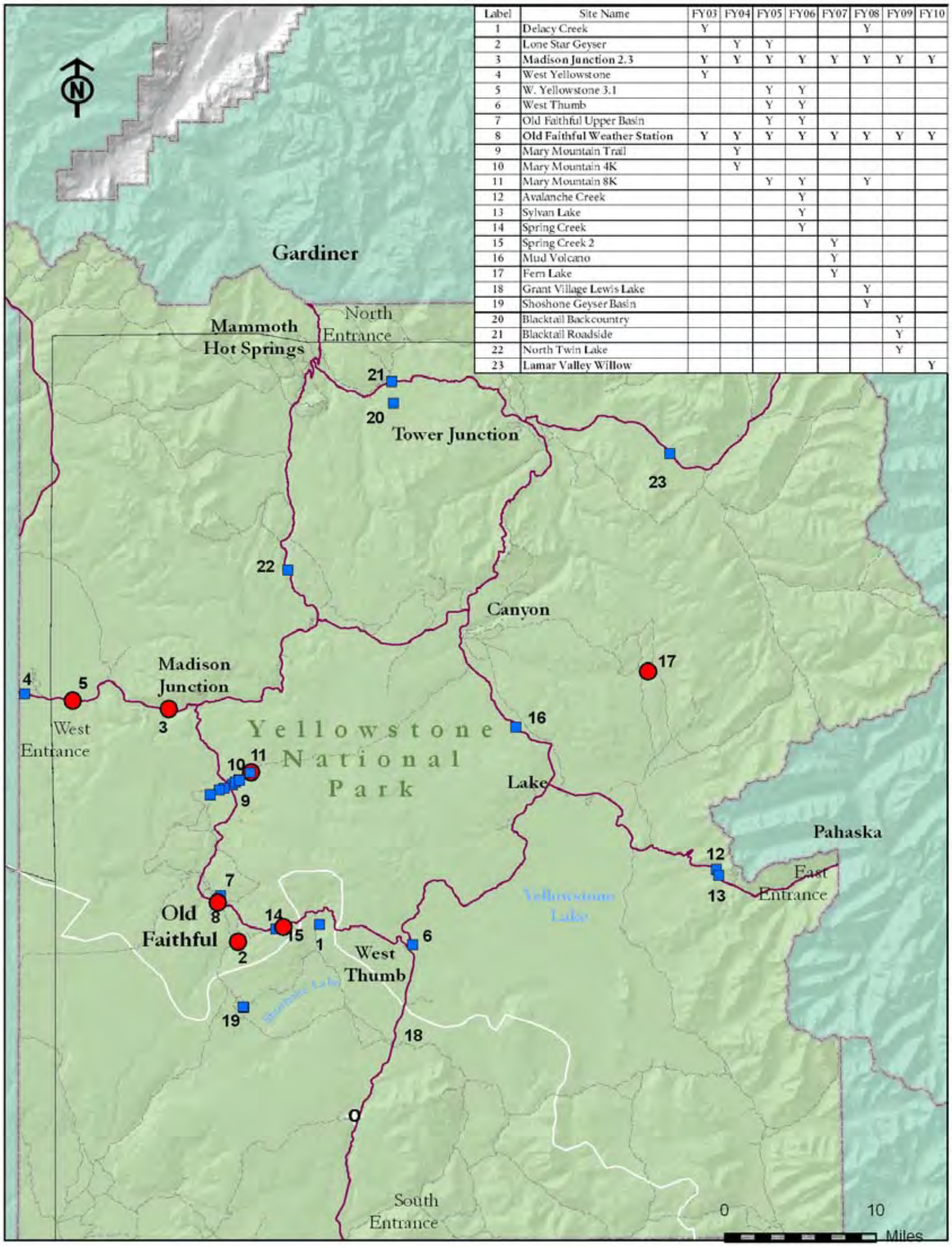
Specific methodologies (protocols) for equipment type, microphone placement, height, and other factors are summarized in Appendix A. These protocols followed guidance of Ambrose and Burson (2004) and were based on American National Standards Institute (ANSI) S12.9-1992, Part 2 (ANSI 1992), Federal Aviation 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 2009-2010 sound monitoring locations (Fig. 1) were chosen to include high OSV use and wheeled vehicle areas and represented two soundscape management zones (Developed and Travel Corridor). The specific placement relative to sound sources of interest was mainly determined by logistical constraints. These constraints included open south facing sky for solar exposure for charging systems, proximity to electrical 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 Lamar Valley site was the second to monitor soundscapes in a travel corridor for winter wheeled vehicles in Yellowstone National Park. The site was chosen along the Tower to Cooke City road segment in the general vicinity of popular winter wildlife watching area.

A six system array collected acoustic data during early February along a three mile (4.8 km) transect in the Lower Geyser Basin. The purpose of this transect was to simultaneously measure OSV sound propagation at varying distances from a travel corridor. See Appendix H for preliminary results and analyses.



Label	Site Name	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10
1	Delacy Creek	Y					Y		
2	Lone Star Geyser		Y	Y					
3	**Madison Junction 2.3**	Y	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	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	
23	Lamar Valley Willow								Y

Figure 1. Locations of sound monitoring sites (red circles- multiple seasons, and blue squares- winter-only) within Yellowstone National Park, December 2003-March 2010. See inserted table for key to year and labels. Only FY10 sampling locations are included in detail in this report (but see Burson [2004-2009] for previous winters' sampling results). Transect sampling sites are shown in blue near #s 9 and 10, but are not labeled here. See Appendix H for details.

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 by 12 volt batteries charged by solar panels. See Tables 2 and 3 for dates of operation.

Lamar Valley Willow

Latitude:	44.88406
Longitude:	110.22073
Elevation:	6600 feet (2012 m)
Habitat:	90% open (sage/meadow), 5% open (road), 5% river/stream
Management Zone:	Travel Corridor

Photo 3. Blacktail Roadside sound monitor location.

The Lamar Valley Willow monitor (in the center right of the photo above) was located 142 feet (43 m) from the road between Tower Junction and the Northeast Entrance. The microphone was in a large multi-stem willow within sage brush dominated landscape. The site was one mile (1.6 km) from the Buffalo Ranch/Lamar Ranger Station, and 750 feet (230 m) from the Lamar River. The site was at the base of a shallow bank inclined to the south which partially blocked the line-of-sight from the microphone to the road. The monitor was powered by 14 volt batteries. See Tables 2 and 3 for dates of operation.

Analyses:

Audibility

Ten seconds of every four minutes of the digital recordings were used and analyzed. These 360 10-second samples 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 2009 Yellowstone National Park Winter Use Plan Environmental Assessment (NPS 2009).

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 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, when possible, 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. Sowmobiles 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.

The noise-free interval was calculated by analyzing one full hour for each of the hours between 8 am and 4 pm at Madison Junction 2.3 and Lamar Valley Willow. Continuous recordings were analyzed for each of these 16 hours.

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. Because estimates of variability beyond the minimum and maximum values are also desirable information about the sound levels exceeding 10, 50, and 90 percent of the time is provided.

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 two months at Lamar Valley Willow, (see previous section for site details). Data collection began on 15 December 2009 and continued throughout the winter use season (15 December 2009-15 March 2010). Selected data (Tables 2-4) 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 to 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 average daily percent time audible values (see Appendix F). 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 to 4 pm.

The very low natural ambient sound levels documented near Sylvan Pass and Craig Pass (Ambrose et al. 2006, Burson 2007) were in similar habitat to 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 can result in higher vehicle percent time audible. At some monitoring locations the lowest minimum sound levels can be 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, and other factors, 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 eight winter seasons, although the first winter consisted of only short-term data collection. This dataset provides information on trends, similarities among years and variability in time and location (Table 5). 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 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 data collection and analyses than is used in this study. 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 collected and 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 additional considerations of OSV percent time audible summaries. See Appendix G for results of standardized noise measurements of a Glaval snowcoach and Appendix H for preliminary results from the six microphone array.

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 three locations in Yellowstone National Park, December 2009-March 2010. Daily average number of guided snowmobiles was 181/day for the 91-day winter use season, excluding OSVs originating from Old Faithful. Daily average number of wheeled vehicles was 385/day during 22 December 2009-23 February 2010[1]. Total number of days analyzed, 84. See Appendix H for additional sites analyzed.

Old Faithful Weather Station	Madison Junction 2.3	Lamar Valley Willow
30 days	30 days	23 days
15 Dec 09	15 Dec 09	23 Dec 09
16 Dec 09	16 Dec 09	24 Dec 09
18 Dec 09	18 Dec 09	25 Dec 09
24 Dec 09	24 Dec 09	26 Dec 09
26 Dec 09	26 Dec 09	27 Dec 09
27 Dec 09	27 Dec 09	28 Dec 09
28 Dec 09	28 Dec 09	29 Dec 09
1 Jan 10	1 Jan 10	1 Jan 10
4 Jan 10	4 Jan 10	4 Jan 10
5 Jan 10	5 Jan 10	5 Jan 10
7 Jan 10	7 Jan 10	7 Jan 10
10 Jan 10	10 Jan 10	10 Jan 10
13 Jan 10	13 Jan 10	13 Jan 10
19 Jan 10	19 Jan 10	19 Jan 10
25 Jan 10	25 Jan 10	25 Jan 10
30 Jan 10	30 Jan 10	30 Jan 10
5 Feb 10	5 Feb 10	5 Feb 10
10 Feb 10	10 Feb 10	10 Feb 10
11 Feb 10	11 Feb 10	11 Feb 10
15 Feb 10	15 Feb 10	15 Feb 10
20 Feb 10	20 Feb 10	16 Feb 10
23 Feb 10	23 Feb 10	20 Feb 10
28 Feb 10	28 Feb 10	
4 Mar 10	4 Mar 10	
5 Mar 10	5 Mar 10	
6 Mar 10	6 Mar 10	
7 Mar 10	7 Mar 10	
9 Mar 10	9 Mar 10	
10 Mar 10	10 Mar 10	
15 Mar 10	15 Mar 10	
Daily # of guided snowmobiles or wheeled vehicles entering Yellowstone NP during sampling days.[1]		
168/day	168/day	389*/day

[1]Listed at bottom of table are daily guided snowmobile averages for the days included in the analysis in the first two columns. Average number of snowmobiles was calculated using all snowmobiles entering Yellowstone. Not all snowmobiles would pass by each site. Administrative use was also not included. Average daily number of snowcoaches for the winter use season was 28/day. See text for further details. * Wheeled vehicle averages listed in the last column as collected by a traffic counter (#2702) just beyond Mammoth on road to Tower.

Table 3. Hours and dates used for analysis of noise-free intervals at Madison Junction 2.3 and Lamar Valley Willow. Total number of days and hours analyzed, 16.

Site	Hour	Date	Site	Hour	Date
Madison Junction 2.3	**8 am**	**24 Dec 09**	**Lamar Valley Willow**	**8 am**	**24 Dec 09**
	9 am	**4 Jan 10**		**9 am**	**4 Jan 10**
	10 am	**10 Jan 10**		**10 am**	**10 Jan 10**
	11 am	**16 Jan`10**		**11 am**	**16 Jan`10**
	12 pm	**30 Jan 10**		**12 pm**	**30 Jan 10**
	1 pm	**5 Feb 10**		**1 pm**	**5 Feb 10**
	2 pm	**10 Feb 10**		**2 pm**	**10 Feb 10**
	3 pm	**20 Feb 10**		**3 pm**	**15 Feb 10**

Table 4. Dates used for sound level analyses at three locations in Yellowstone National Park, December 2009-March 2010. Total hours 5,815. See Appendix H for details on an additional six Transect site measurements.

Old Faithful (2,171 hours) 15 December 2009-15 March 2010	Madison Junction 2.3 (2,168 hours) 15 December 2009-15 March 2010
Lamar Valley Willow (1,476 hours) 23 December 2009-23 February 2010	

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. Often multiple snowmobiles or snowmobiles and snowcoaches were audible simultaneously, but at other times one masked the sound of the other. 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 28/day (range 7-54) with an additional daily average of five snowcoaches originating from Old Faithful. The average number of snowmobiles entering YNP during the winter season was 181/day (range 60-284) with an additional daily average of seven 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.

For the second winter, acoustic data were collected along the plowed road between Mammoth and Silver Gate at the Northeast Entrance. A sound monitor was placed along the plowed road in Lamar Valley. Vehicle traffic along the road was highest during the monitoring period around the Christmas holidays and in February. The daily average number of vehicles was 336/day for 15-31 December, 332/day in January, and 434/day in February. Acoustic data were collected during December, January, and February. 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 winters. Several factors, though, complicate the relationship. First, not all snowmobiles are part of guided groups; there are many NPS and concession snowmobiles and snowcoaches used within the park, especially in destination areas such as Old Faithful (see Appendix E for information about the relative contribution of guided versus administrative OSV use). Second, not all OSVs that enter the park travel along the same route. Therefore the number of OSVs 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 snowcoaches and OSV percent time audible.

A related audibility issue involves an acoustical metric called the noise-free interval (NFI). NFIs measure the uninterrupted periods of time when only silence or natural sounds are audible. For the purposes of this report, NFIs were the times when no oversnow vehicles or wheeled vehicles were audible. Using logic and common sense, the number and distribution of vehicles largely determine the NFI. Given the same number of vehicles, NFIs measured near travel corridors would be longer with larger rather than smaller groups (however as group size increases they 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-4 and D-5).

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 full 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 55% last winter and 67-69% during the previous five winter use seasons (Table 4). The lower percent time audible value of the past two winters is likely due to a decrease in the daily average of about 100 snowmobiles/day. Figure 2 also shows a marked seasonal decline in OSV audibility as the road conditions deteriorated from snow melt in late February and March. No (0%) of the 30 days analyzed exceeded the 2009 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). During 8 am and 9 am oversnow vehicles were audible for more time than during the mid-morning lull, but then increased as visitors arrived closer to mid-day. On average, snowmobiles were audible for 29% of the day versus 16% 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 throughout most of the day (Fig. 3) on the day with the season's second highest number of visitor OSVs.

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.

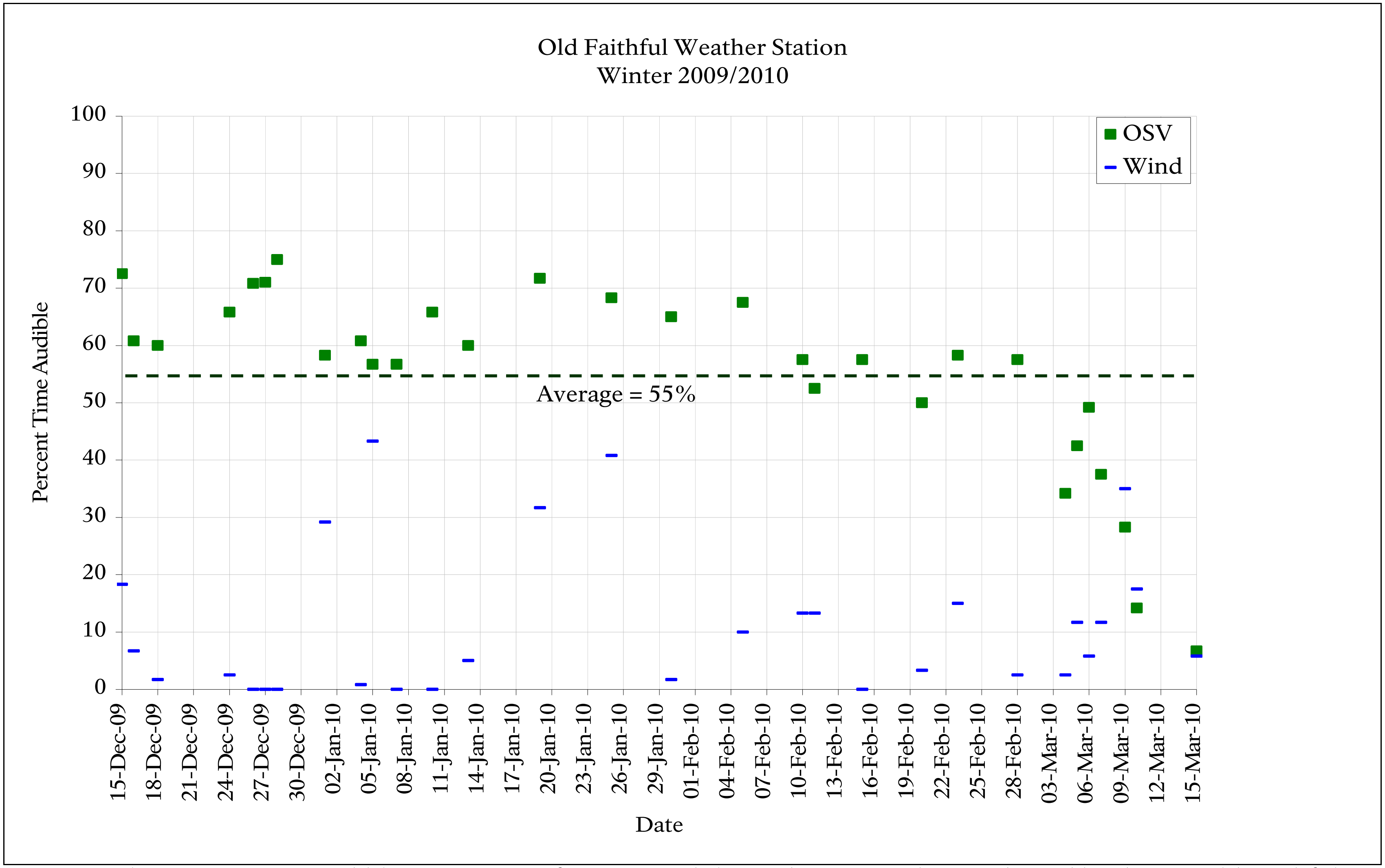


Figure 2. The percent time audible (8 am-4 pm) for snowmobiles and snowcoaches, and wind by date at Old Faithful Weather Station, Yellowstone National Park, 15 December 2009-15 March 2010.

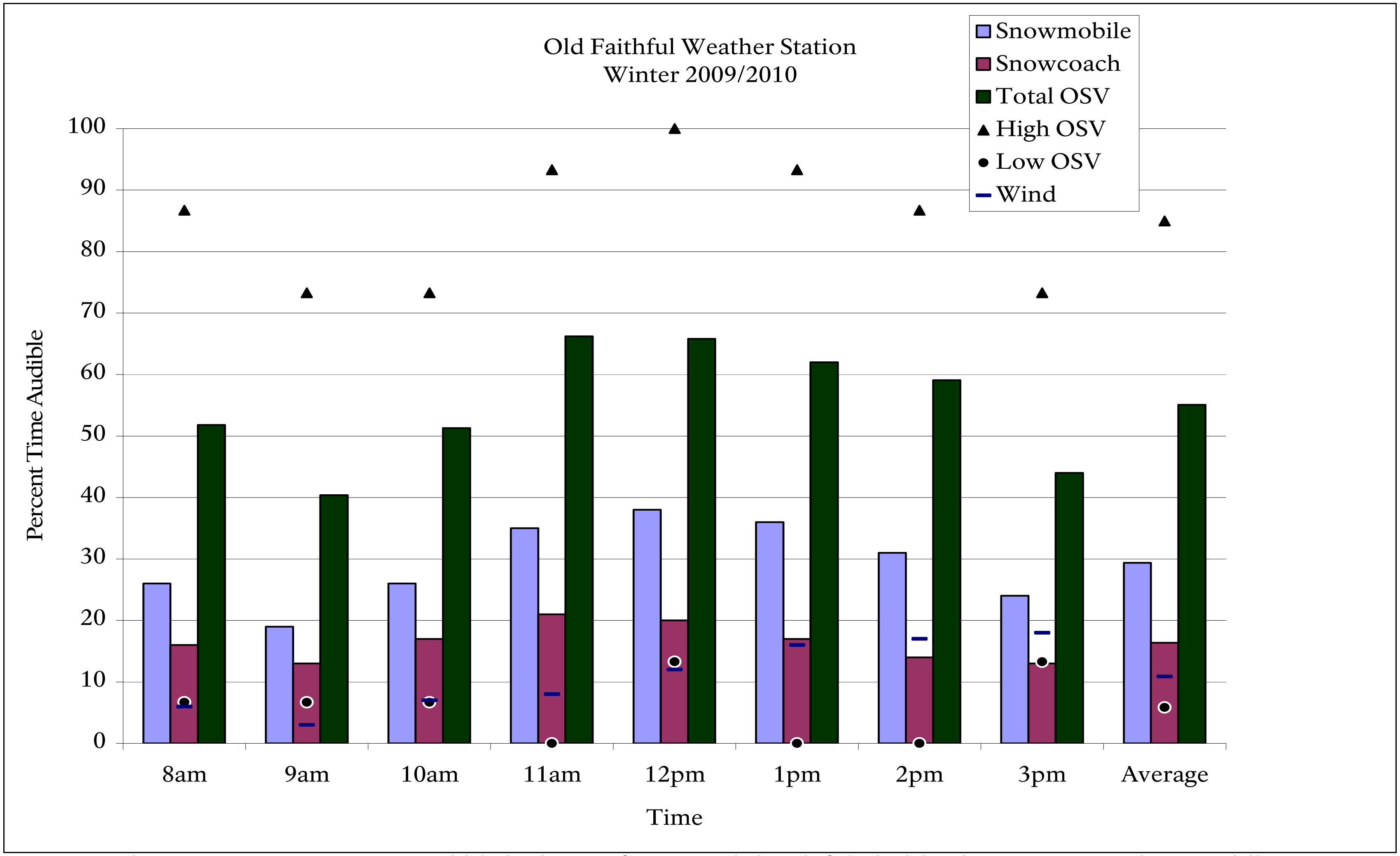


Figure 3. The average percent time audible by hour of snowmobiles (left light blue bar), snowcoaches (middle maroon bar), and combined category (right dark green bar), and high and low OSV values at Old Faithful Weather Station, Yellowstone National Park from 8 am-4 pm, 15 December 2009-15 March 2010.

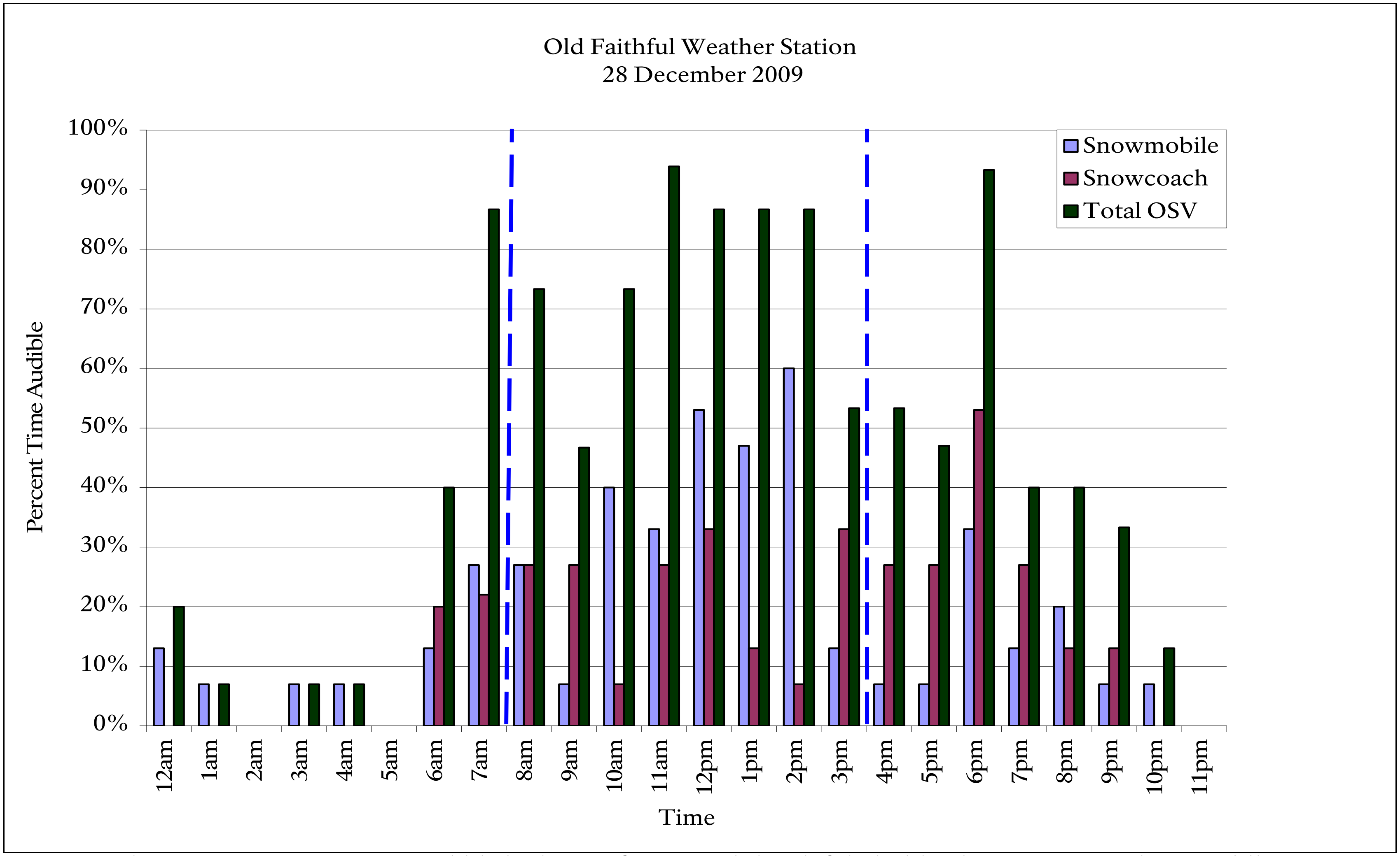


Figure 4. The average percent time audible by hour of snowmobiles (left light blue bar), snowcoaches (middle maroon bar), and combined category (right dark green bar) at Old Faithful Weather Station, Yellowstone National Park, 28 December 2009. The winter use analysis time period is between the vertical 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 have been collected for all or parts of eight winter use seasons (Table 4) at this location. Riffles of the Madison River were audible when not masked by the sounds of wind, swans, coyotes, wolves, ducks, geese, ravens, aircraft, or oversnow vehicles. Snowmobiles and snowcoaches were audible for an average of 54% of the time during the entire winter use season (Fig. 5). This compares to 47% during the winter of 2007-2008 and 53%-59% for the previous three full seasons. The past two winter seasons had about 100 snowmobiles/day lower daily average compared to the previous season. Figure 5 also shows the lower percent time audible towards the end of the winter use season when the road conditions deteriorated due to poor snow conditions. The OSV percent time audible exceeded 50% for 18 (60%) of 30 days analyzed during the winter 2009-2010 (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. However, the average percent time that wind was audible was almost half that of the previous year 15% vs. 27% and explains, in part, why OSVs were audible more this past winter than the previous winter.

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 8am, 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 specifically identity many distant faint OSVs.

The average noise-free interval at Madison Junction 2.3 was four minutes and 15 seconds (Figure 7). Midday has the longest average noise-free interval (over 28 minutes) and 11 am had continuous sounds of OSVs (0 noise-free minutes) during the winter use day. Only one hour was analyzed for each of these eight hours and additional samples would give a better representation of typical noise-free conditions, however, this limited noise-free interval analysis again reflects the pulse of OSVs traveling by the site during the morning and afternoon hours (Figure 7). The results during the 11 am hour are likely higher than would occur given additional sampling.

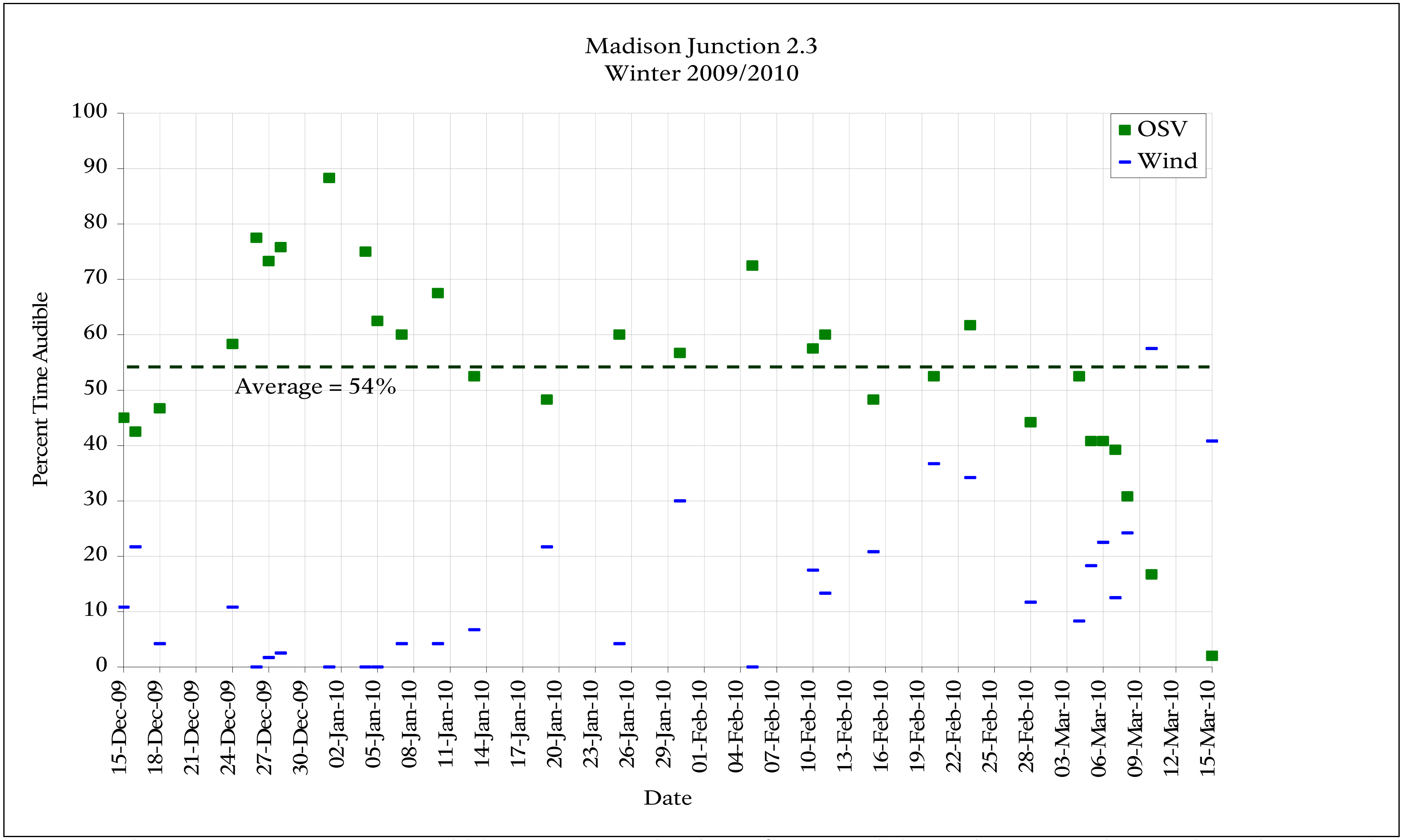


Figure 5. The average percent time audible (8 am-4 pm) by date of snowmobiles and snowcoaches, and wind at 2.3 miles (3.7 km) west of Madison Junction along the West Entrance Road Yellowstone National Park, 15 December 2009-15 March 2010.

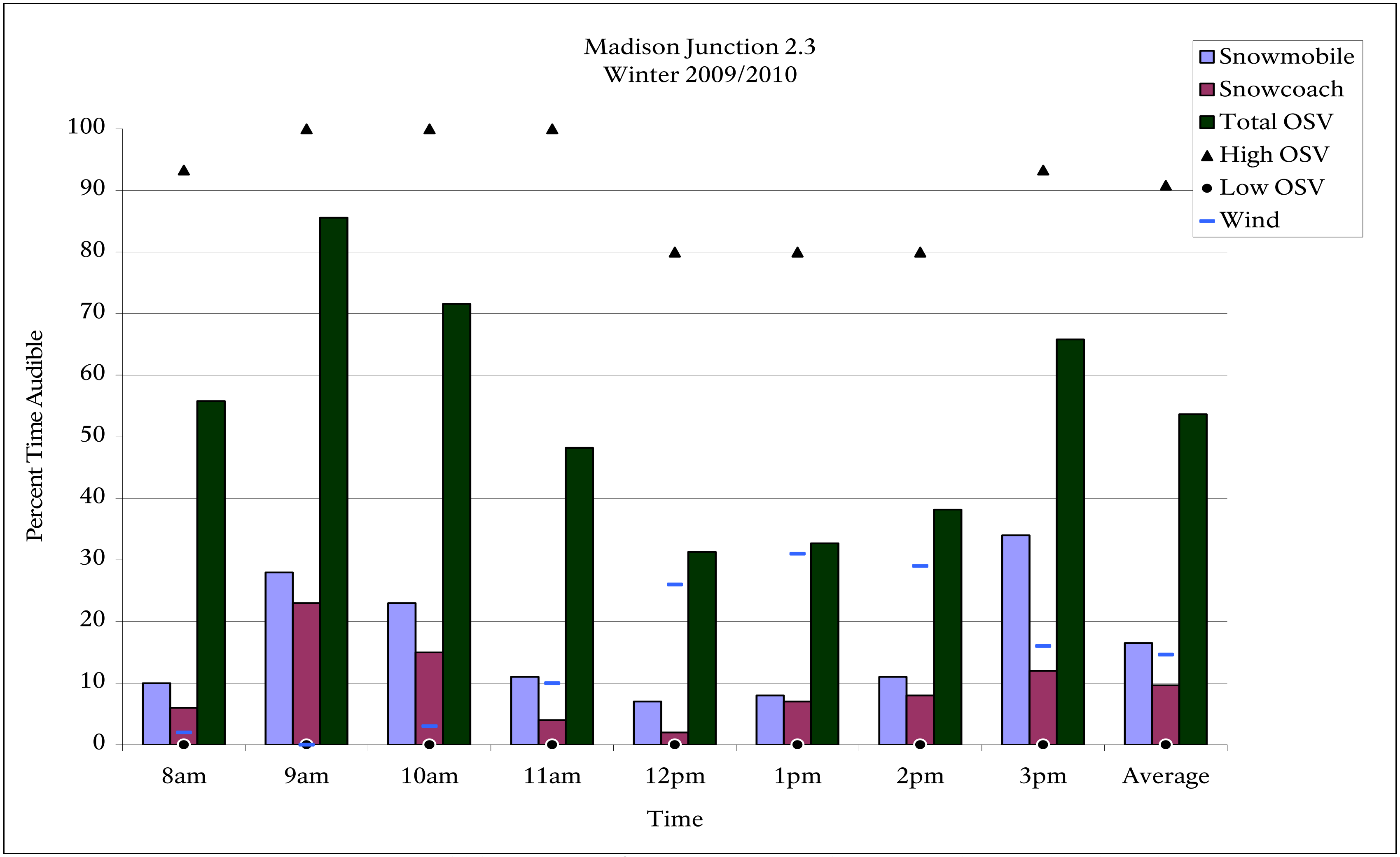


Figure 6. The average percent time audible by hour of snowmobiles and snowcoaches, and high and low OSV percent time audible at 2.3 miles (3.7 km) west of Madison Junction along the West Entrance Road, Yellowstone National Park, 15 December 2009-15 March 2010.

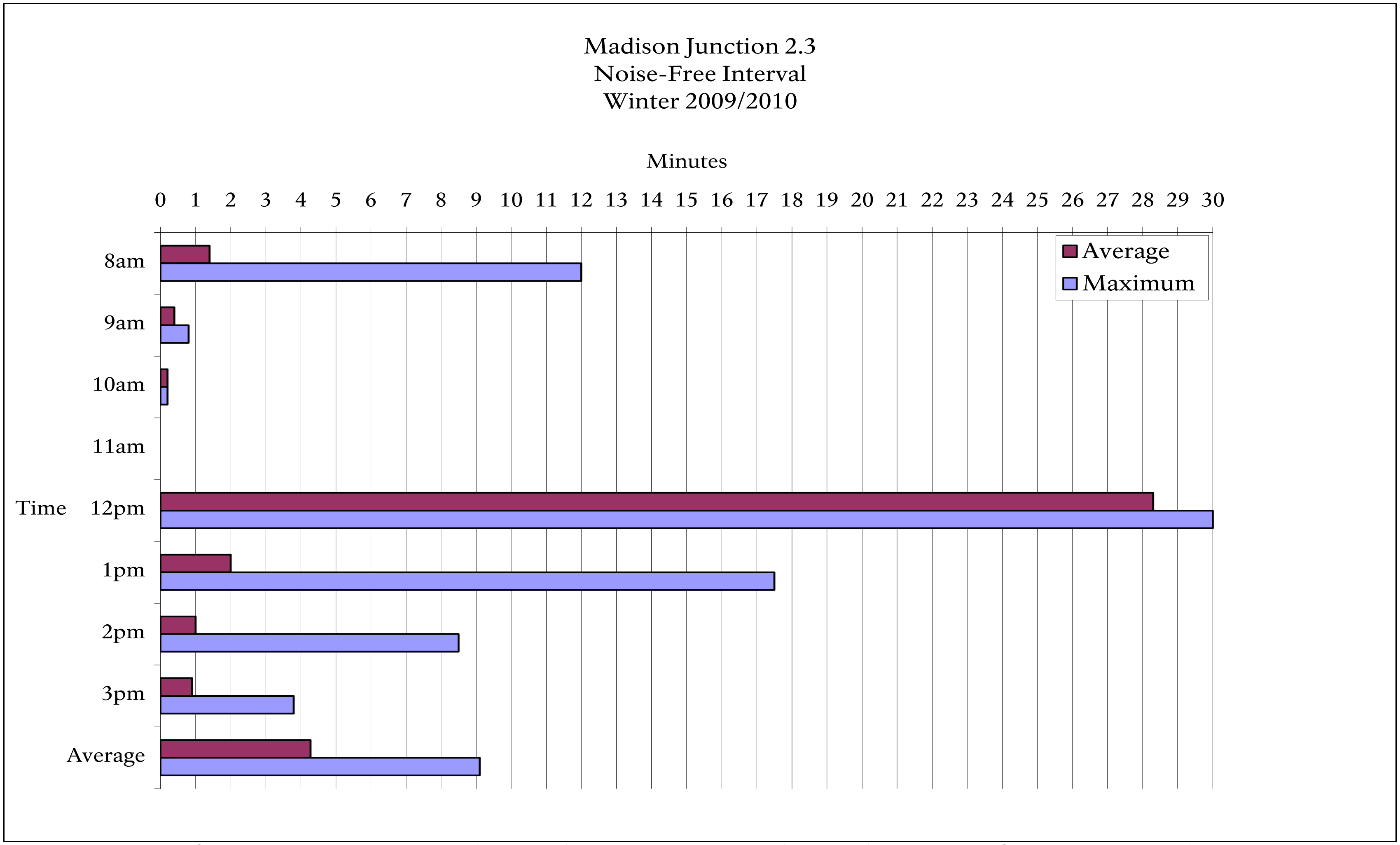


Figure 7. Noise-free interval as measured at Madison Junction 2.3 during the winter of 2009-2010, Yellowstone National Park. See Table 3 for dates used and text for more details.

Lamar Valley Willow

Acoustic monitoring data were collected in Lamar Valley for the first time this winter season. This location was one mile (1.6 km) east of the Lamar Ranger Station at the Buffalo Ranch along the plowed road between Tower Junction and the Northeast Entrance. The closest oversnow vehicle use was over sixteen miles away on the groomed road at Canyon Village. Wheeled vehicles (Fig. 8), aircraft, and a Buffalo Ranch generator were the only motorized sounds audible at Lamar Valley Willow.

Wheeled vehicles were audible an average of 66% of the time between 8 am and 4 pm during the 21 days analyzed in December, January, and February (Fig. 8). Wind was audible on many days. Wind masked the low sound levels of distant vehicle sounds on a few days (see 23 December 09; Fig. 8).

Each hour of the 8-hour day had average wheeled vehicle audibility between 60% and 70% (Fig. 9). Five of eight hours had a maximum wheeled vehicle audibility of 100% on at least one day that was analyzed (Fig. 9). Aircraft were audible an average of 3% from 8 am to 4 pm.

The average noise-free interval at Lamar Valley Willow was 50 seconds (Figure 10). This startling low noise-free interval demonstrates two conditions of this site. The first is there are many wheeled vehicle traffic on this section of road and the other is that it is a very quiet site so vehicles are audible for long distances. 10 am had continuous sounds of motorized (0 noise-free minutes). There was no obvious pattern of noise-free interval by hour in the hours analyzed. Additional samples would give a better representation of typical noise-free conditions because only one hour was analyzed for each of these eight hours (Figure 10).

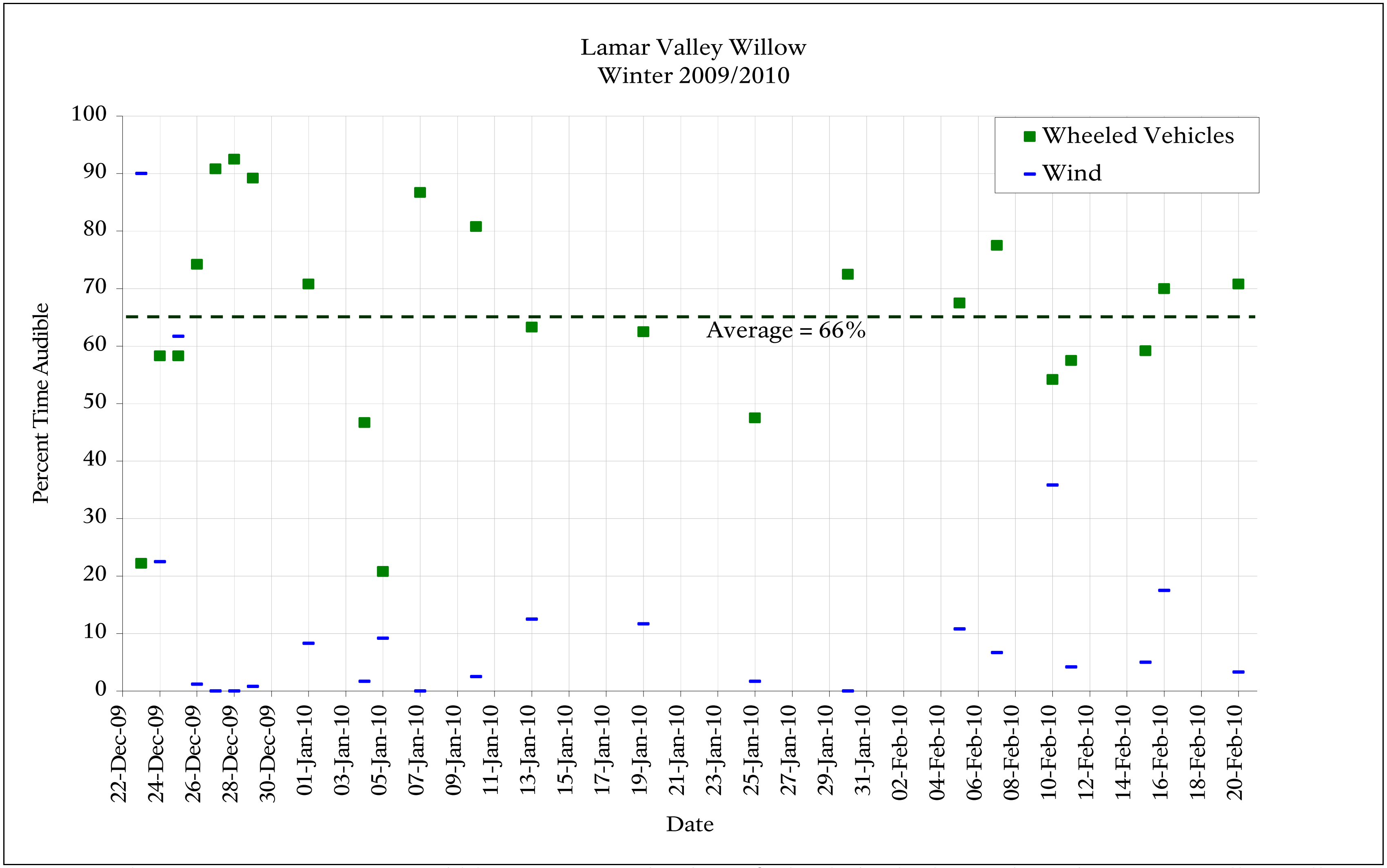


Figure 8. The average percent time audible (8 am-4 pm) by date of wheeled vehicles, and wind at Lamar Valley Willow, Yellowstone National Park, 23 December 2009-23 February 2010.

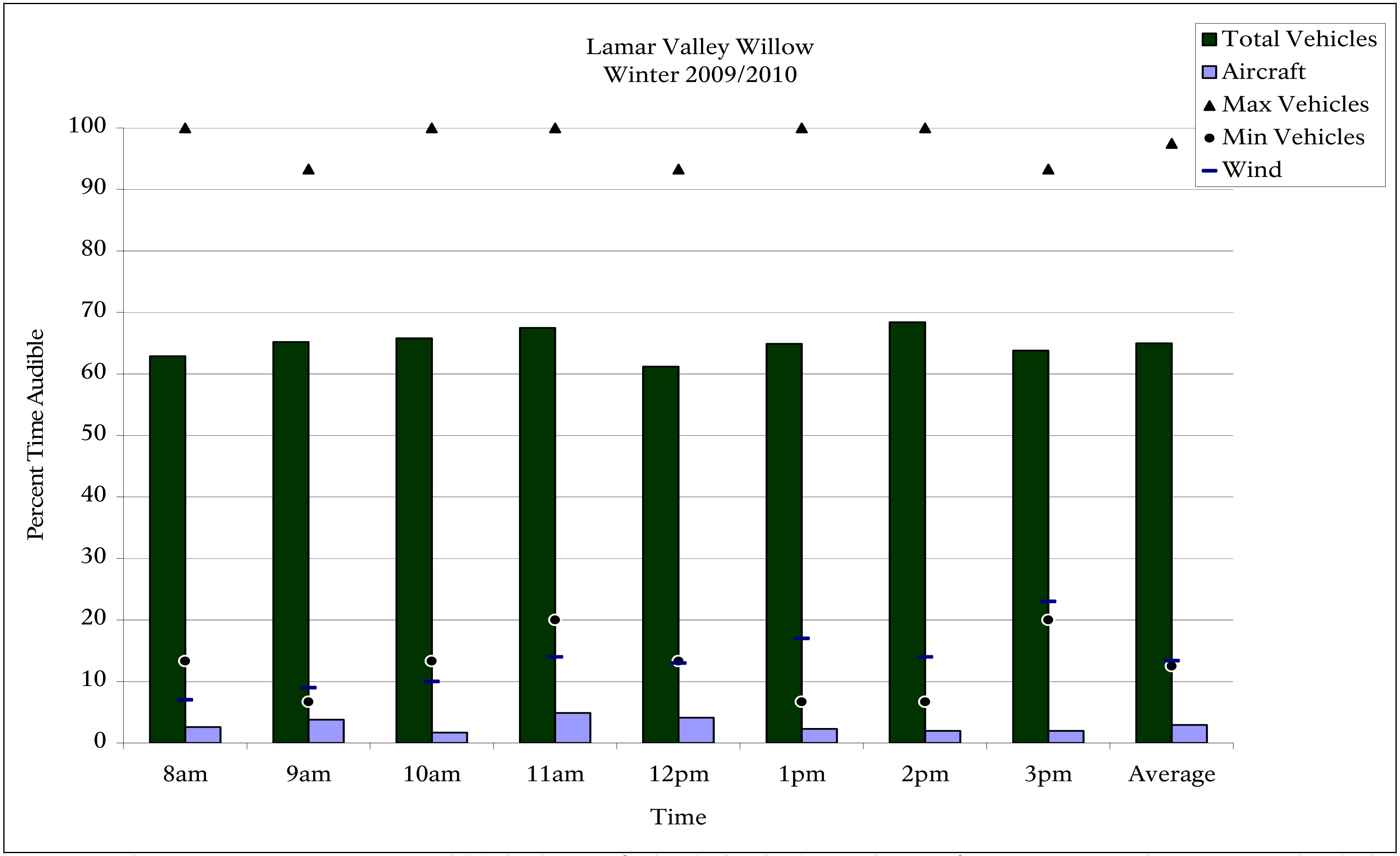


Figure 9. The average percent time audible by hour of wheeled vehicles and aircraft, maximum and minimum wheeled vehicle percent time audible, and wind at Lamar Valley Willow, Yellowstone National Park, 23 December 2009-23 February 2010.

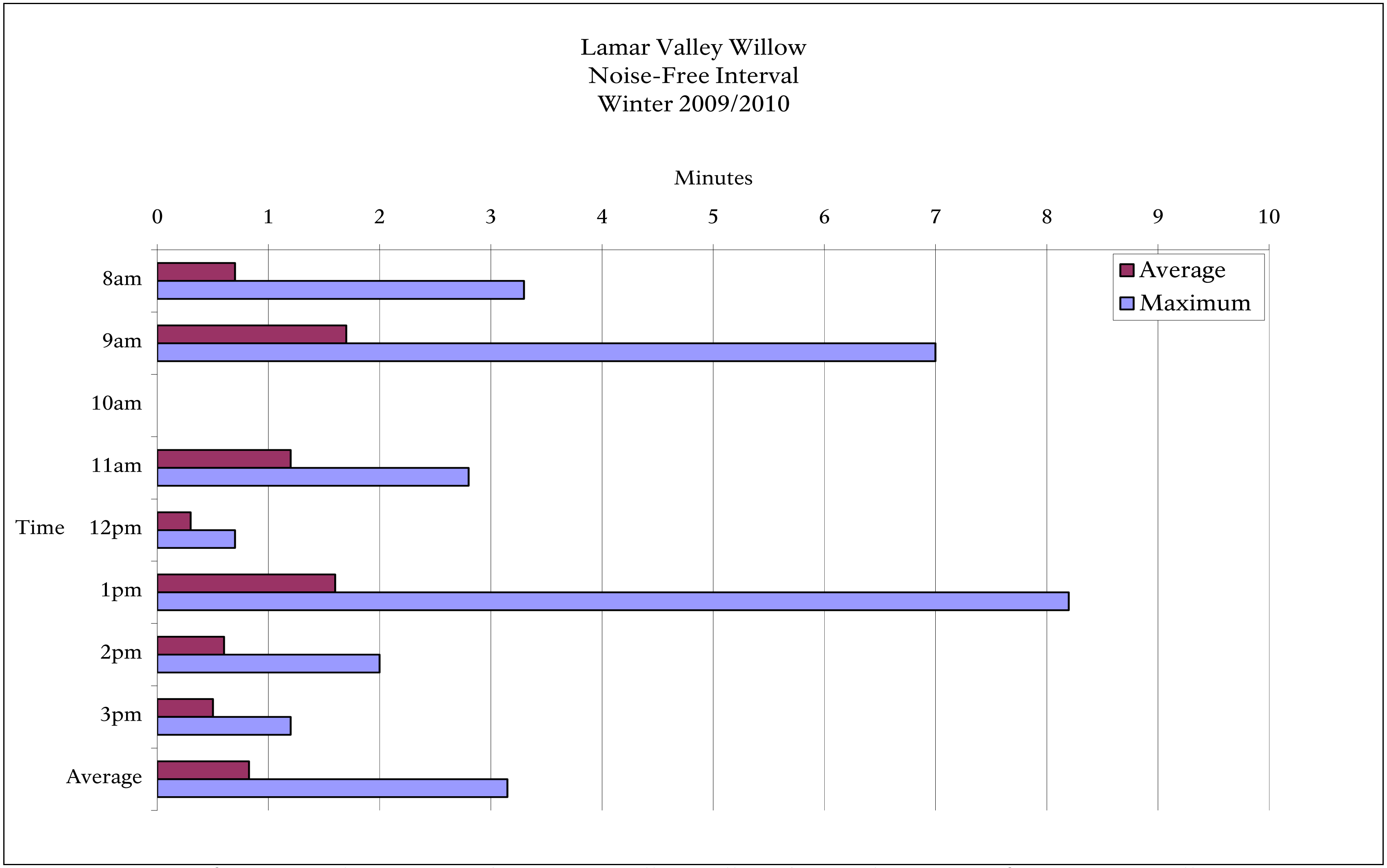


Figure 10. Noise-free interval as measured at Lamar Valley Willow during the winter of 2009-2010, Yellowstone National Park. See Table 3 for dates used and text for more details.

Audibility Trends:

Oversnow audibility is summarized for 18 locations in Yellowstone National Park during the past seven winters (Table 5). These locations include the four winter use plan management zones (developed, travel corridors, transition and backcountry). The monitoring sites in Table 5 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 may 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 59% 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 relatively 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 5. Percent time audible (8 am-4 pm) of oversnow vehicle sounds at monitoring sites by management zone during seven winters (2003-2010), Yellowstone National Park.

	Management Zone: Sites[1]																
	Developed[2]		Road 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%								
2009-2010	55%		54%														
Site Average	63%	55%	55%	55%	34%	44%	37%	26%	24%	32%	32%	13%	20%	4%	26%	18%	0%
Management Zone Average		59%							39%					20%			15%

	# of Oversnow Vehicles (OSVs) /day		
	Snowmobile	Snowcoach	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
2009-2010	181	28	221
Average	242	28	278

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

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 6.

The 2009 Winter Use Plan (NPS 2009) defined major adverse maximum sound level thresholds for oversnow vehicles as measured in three acoustic management zones. These thresholds are 70 dBA in developed areas and 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 (L_{max}) and minimum (L_{min}) sound levels, other common acoustical metrics such as the energy level equivalent or energy average (L_{eq}) and the L_{10}, 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 these and other 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".

L_{10}, L_{50} , and L_{90} are the sound levels (L), in decibels, exceeded *x* percent of the time. The L_{10} value represents the sound level exceeded 10 percent of the time and the L_{50} 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 estimate of the natural ambient sound level 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 14-20 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 to be 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	

2009-2010 Sound Metrics by Monitoring Site

A number of sound level metrics at the three sound monitoring sites during the winter season 2009-2010 are compared in Table 7. These sites are individually discussed on the following pages.

Table 7. Sound level metrics (dBA) for three sites and two soundscape management areas in Yellowstone National Park, 8 am-4 pm, winter 2009-2010. L_{90}, L_{50}, L_{eq} are median values from hourly calculations. The Lamar Valley site is 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	23.7	30.0	35.2	41.9	74.5	719
Travel Corridor						
Madison Junction 2.3	15.3	22.0	28.2	42.2	79.5	721
Lamar Valley Willow	14.4	16.4	21.9	33.0	82.8	491

Old Faithful Weather Station

The average hourly sound levels by month from the soundscape monitoring at Old Faithful Weather Station are shown in Figures 10-13 for the winter 2009-2010. The Old Faithful monitor was 230 feet (70 m) from the entrance/exit road used by oversnow vehicles. The 2009 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 a point 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 24 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. 10-13).

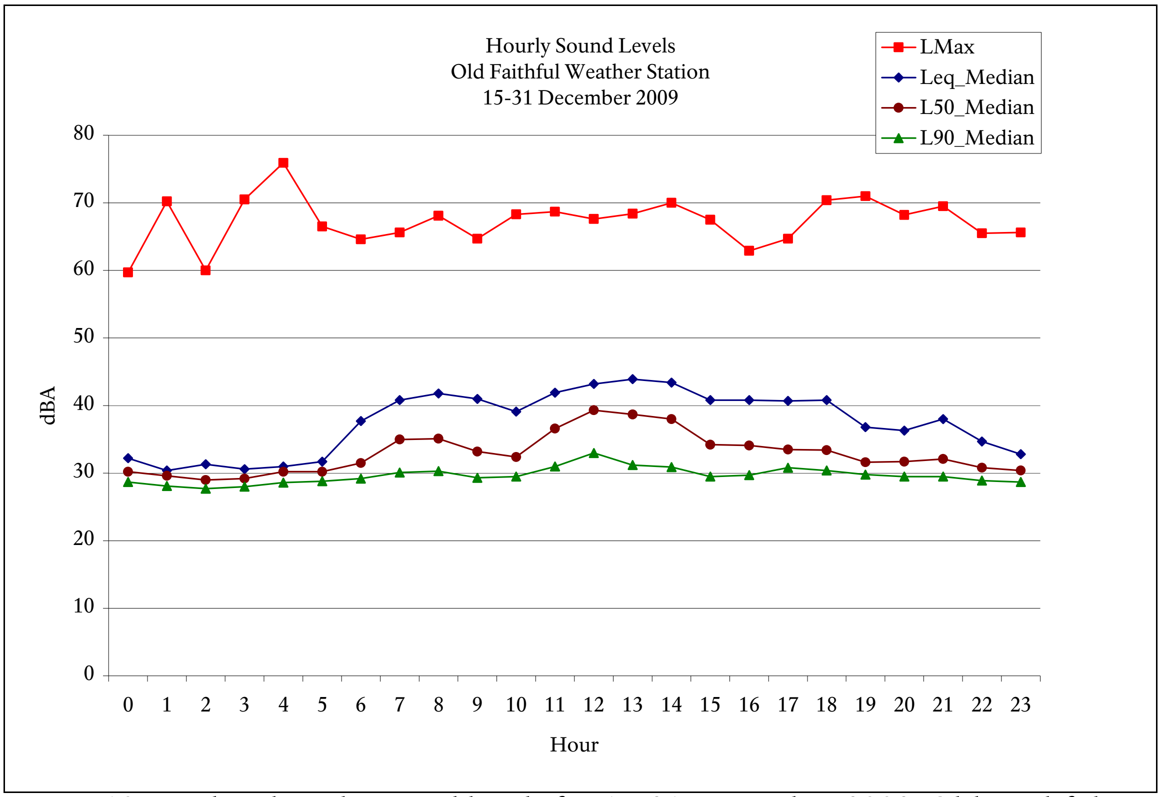


Figure 10. Median hourly sound levels for 15-31 December 2009, Old Faithful Weather Station, Yellowstone National Park. These sound levels include all natural and non-natural sounds. L_{max} is the highest sound level measured during each hour of the measurement period. (n=406 hours)

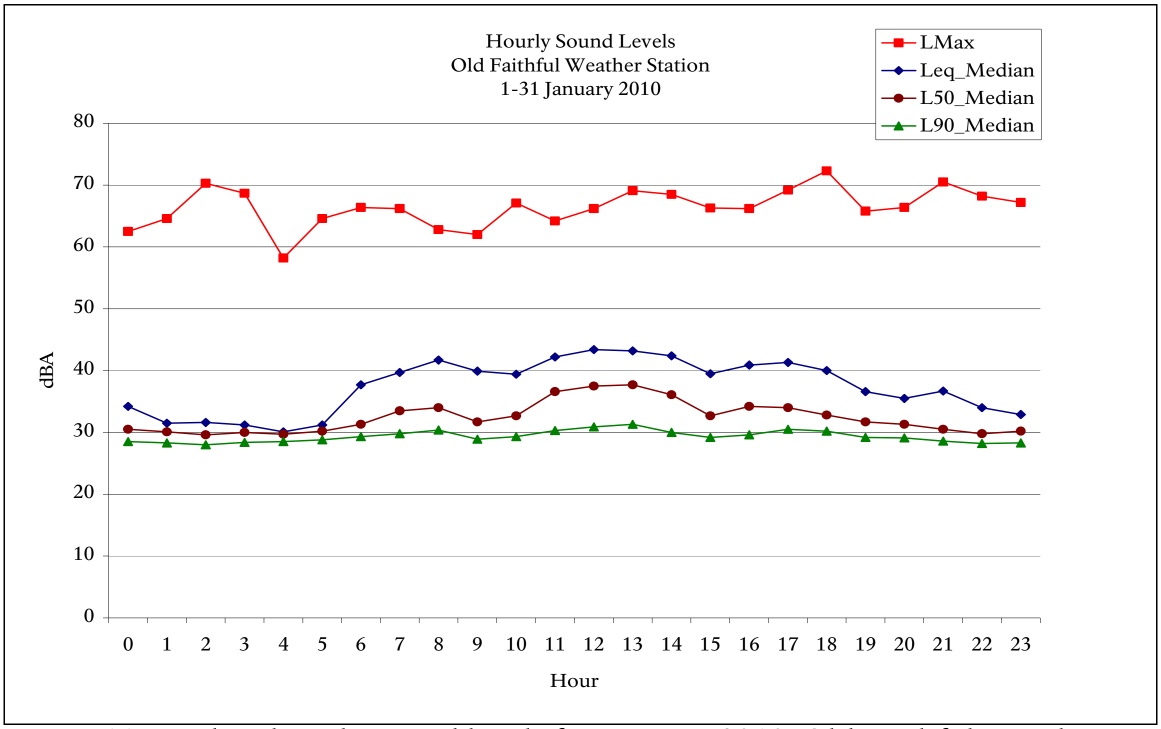


Figure 11. Median hourly sound levels for January 2010, Old Faithful Weather Station, Yellowstone National Park. See Fig. 10 caption for more details. (n=739 hours)

Figure 12. Median hourly sound levels for February 2010, Old Faithful Weather Station, Yellowstone National Park. See Fig. 10 caption for more details. (n=668 hours)

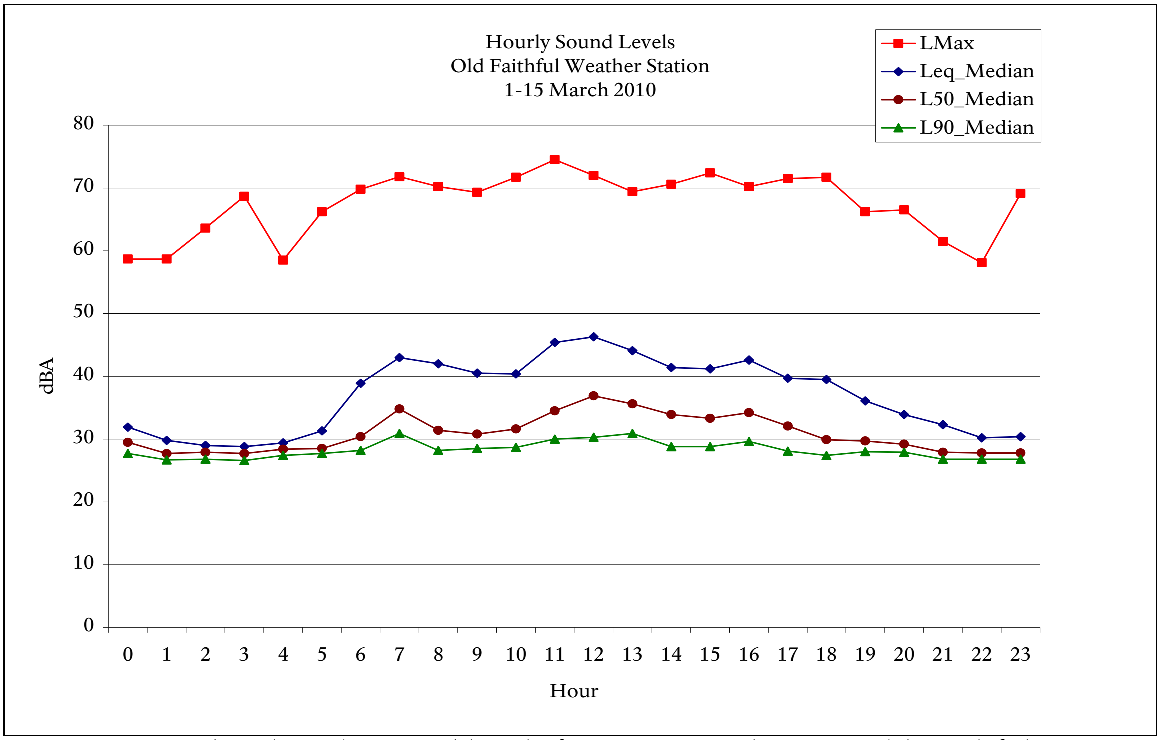


Figure 13. Median hourly sound levels for 1-15 March 2010, Old Faithful Weather Station, Yellowstone National Park. See Fig. 10 caption for more details. (n=358 hours)

In addition to displaying sound levels by month (Figures 10-13), winter-long acoustic metric summaries are shown in Figures 14 and 15. Figure 14 shows the metrics, including L_{10} (the highest 10% of sound levels), for the 24 hour day.

Figure 15 illustrates the daytime and nighttime one-third octave band frequency distribution for the 8-hour day of the winter use season. Included in this frequency plot figure are the frequencies that are audible to humans (area without gray shading in the figure). The sounds contained within the shaded area were present but inaudible to humans.

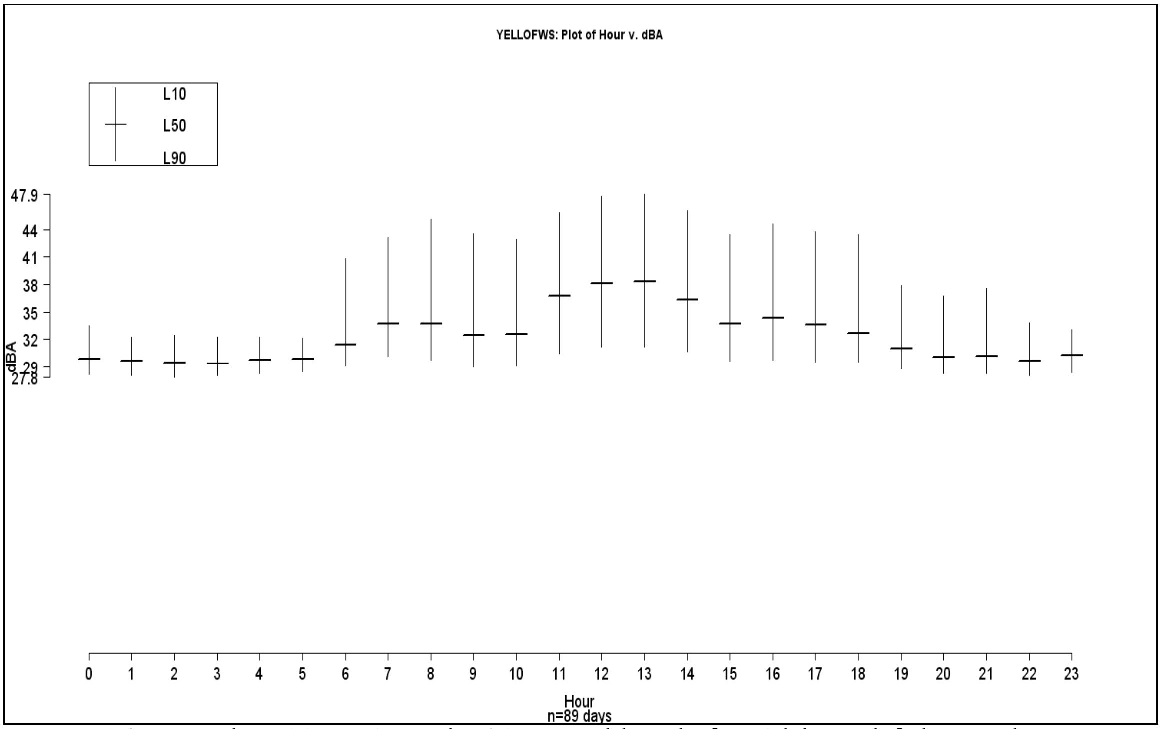


Figure 14. Hourly L10, L50, and L90 sound levels for Old Faithful Weather Station, Yellowstone National Park, winter 2009-2010. (n=89 days)

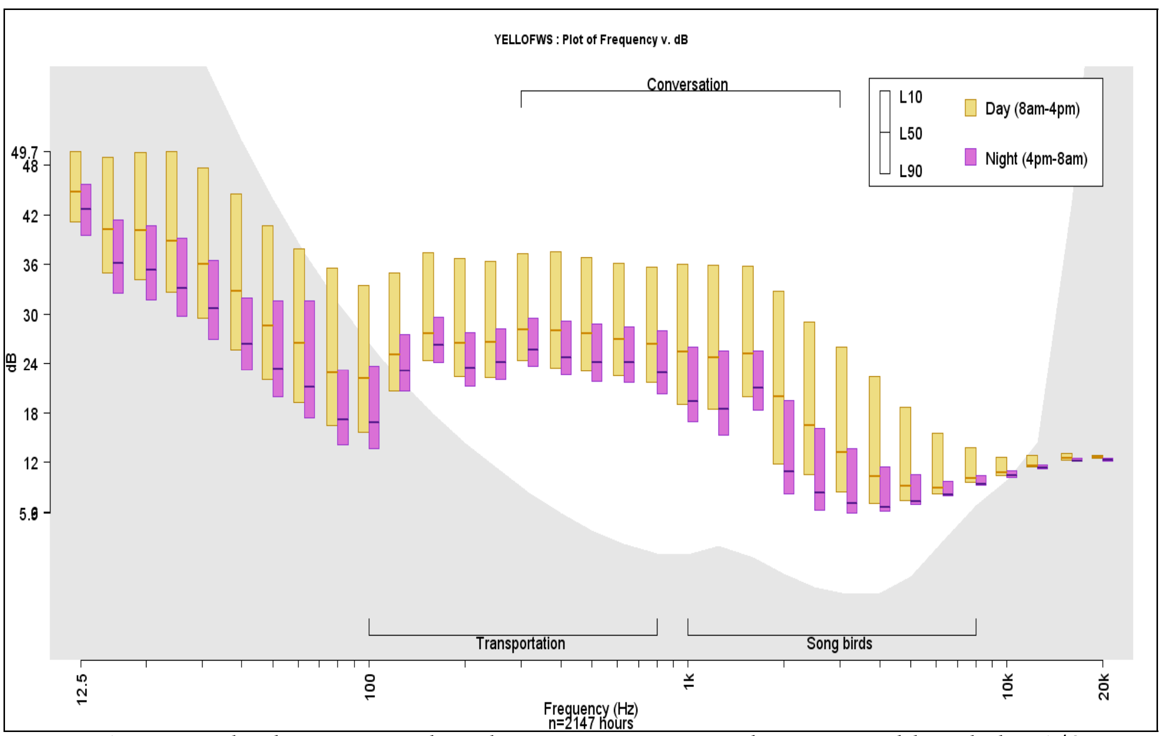


Figure 15. Hourly daytime and nighttime L_{10}, L_{50}, and L_{90} sound levels by 1/3 octave band frequency, Old Faithful Weather Station, Yellowstone National Park, winter 2009-2010. Shaded area denotes region inaudible to humans. (n=2147 hours)

Madison Junction 2.3

Consistent with previous seasons, the maximum hourly sound levels from oversnow vehicles at Madison Junction 2.3 sometimes exceeded the 2009 WUP maximum sound level threshold (70 dBA) during many of the hours of the measurement day (8 am-4 pm) in 2009-2010 (Fig. 16-19). 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. 16-19). 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. 16-19). Wind generally increases during the afternoons and is reflected in the median hourly L_{50} and L_{90} values (Fig. 16-19).

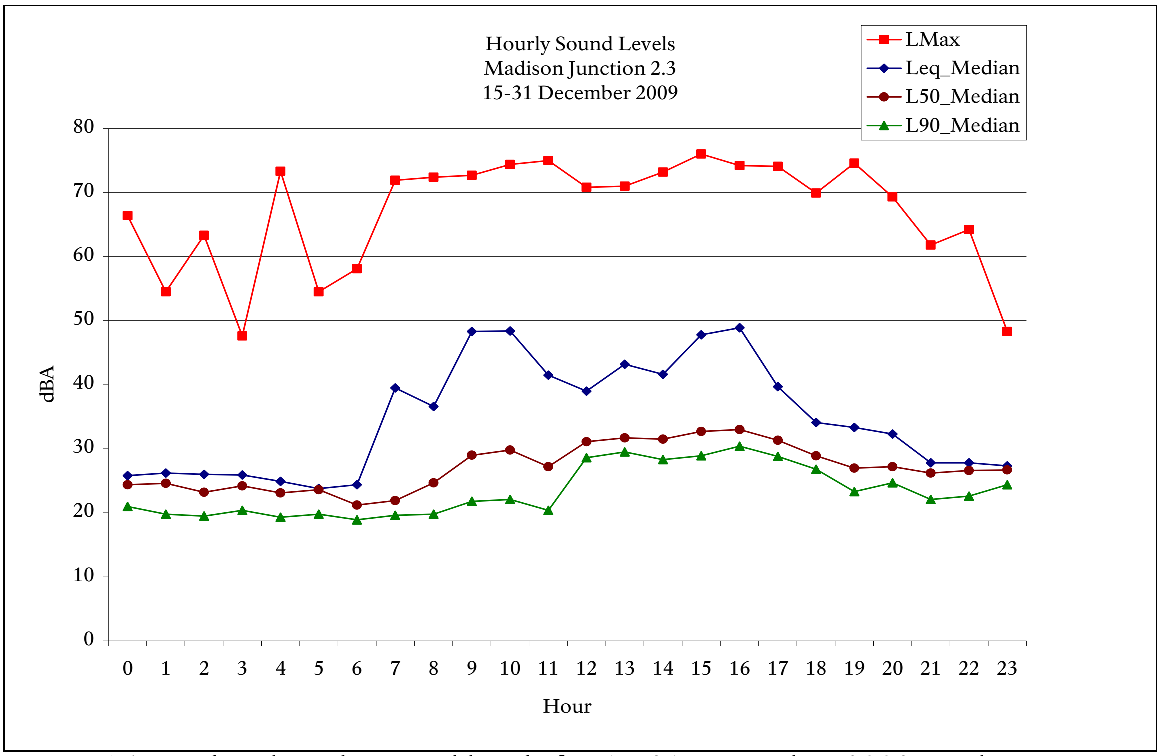


Figure 16. Median hourly sound levels for 15-31 December 2009 Madison Junction 2.3, Yellowstone National Park. See Fig. 10 caption for more details. (n=399 hours)

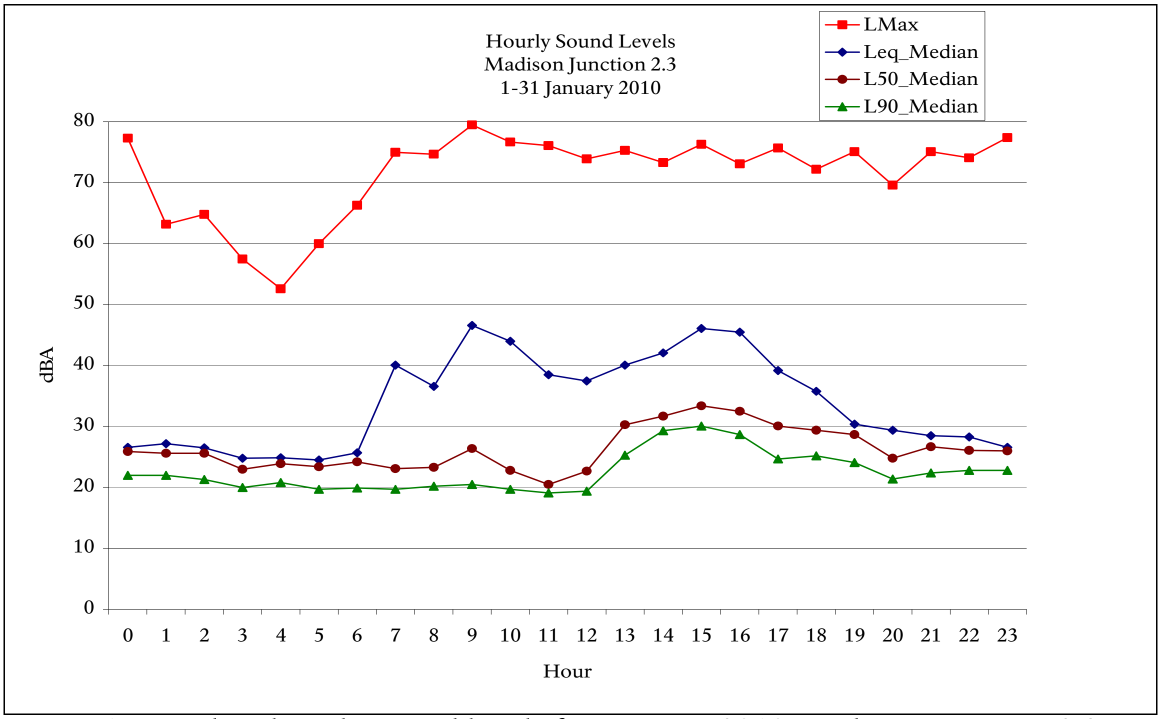


Figure 17. Median hourly sound levels for January 2010 Madison Junction 2.3, Yellowstone National Park. See Fig. 10 caption for more details. (n=742 hours)

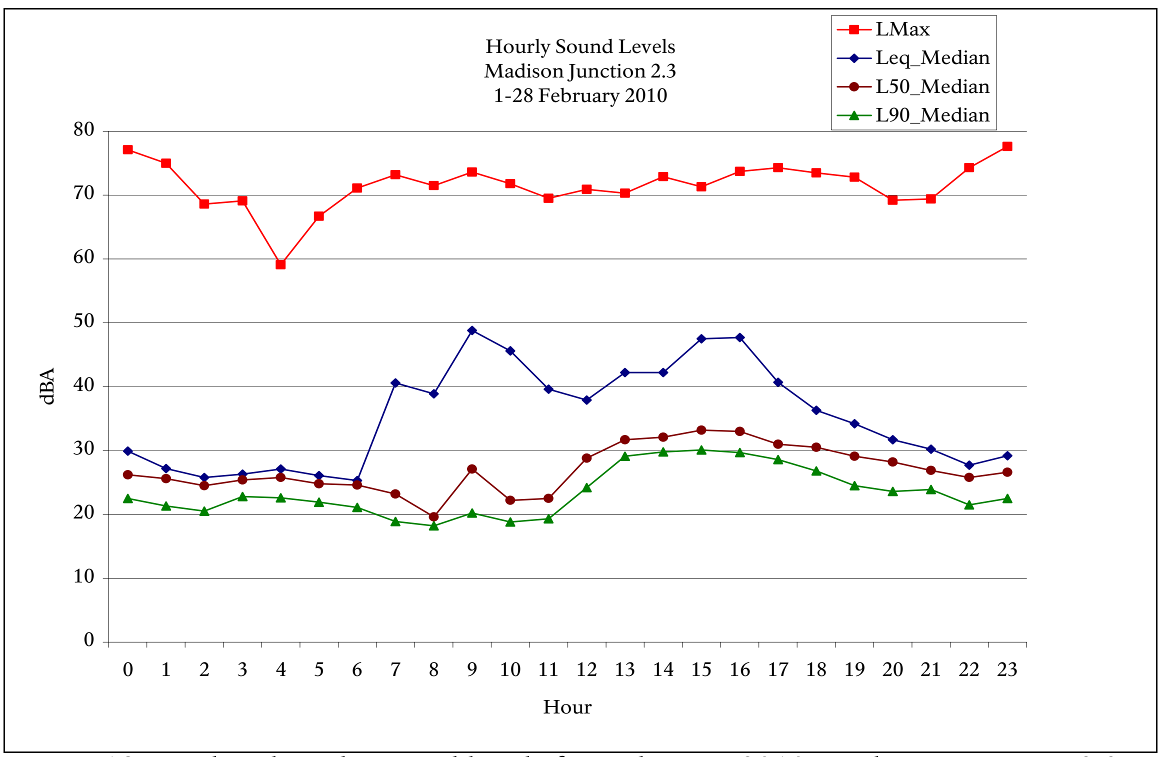


Figure 18. Median hourly sound levels for February 2010 Madison Junction 2.3, Yellowstone National Park. See Fig. 10 caption for more details. (n=669 hours)

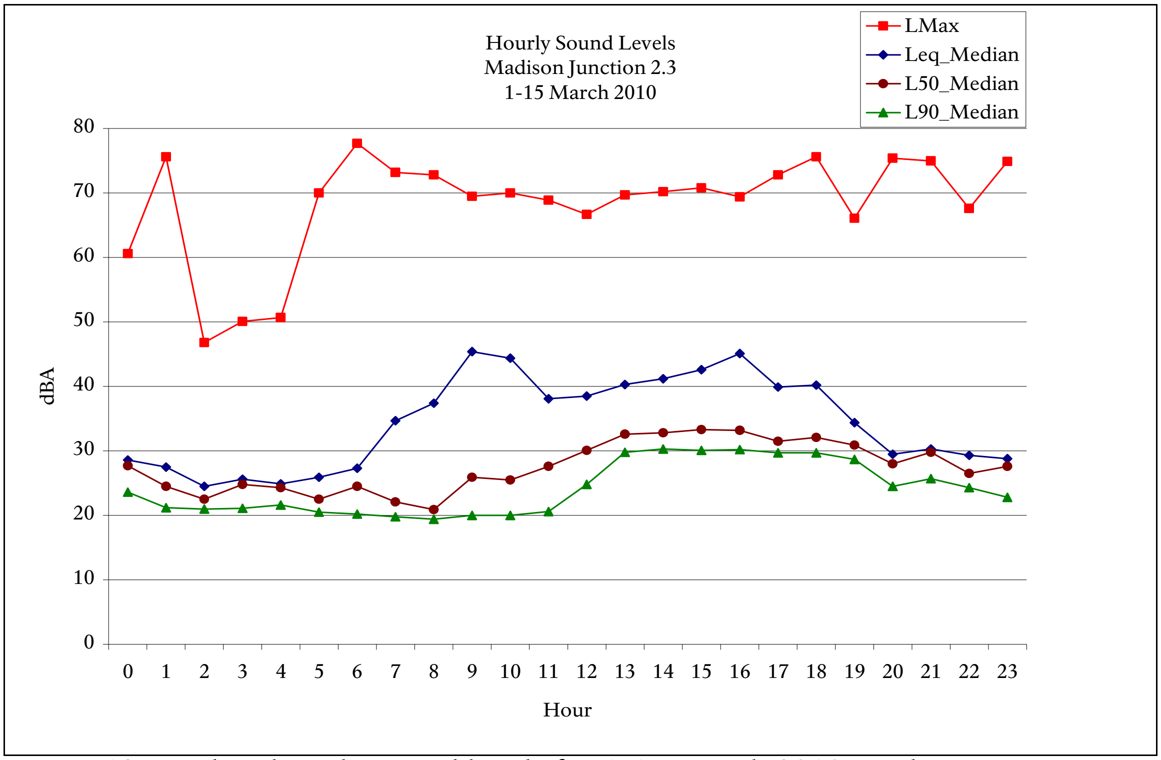


Figure 19. Median hourly sound levels for 1-15 March 2010 Madison Junction 2.3, Yellowstone National Park. **See Fig. 10 caption for more details. (n=358 hours)**

In addition to displaying sound levels by month (Figures 16-19), winter-long acoustic metric summaries are shown in Figures 20 and 21. Figure 20 shows the metrics, including L_{10} (the highest 10% of sound levels), for the 24 hour day.

Figure 21 illustrates the daytime and nighttime one-third octave band frequency distribution for the 8-hour day of the winter use season. Included in this frequency plot figure are the frequencies that are audible to humans (area without gray shading in the figure).

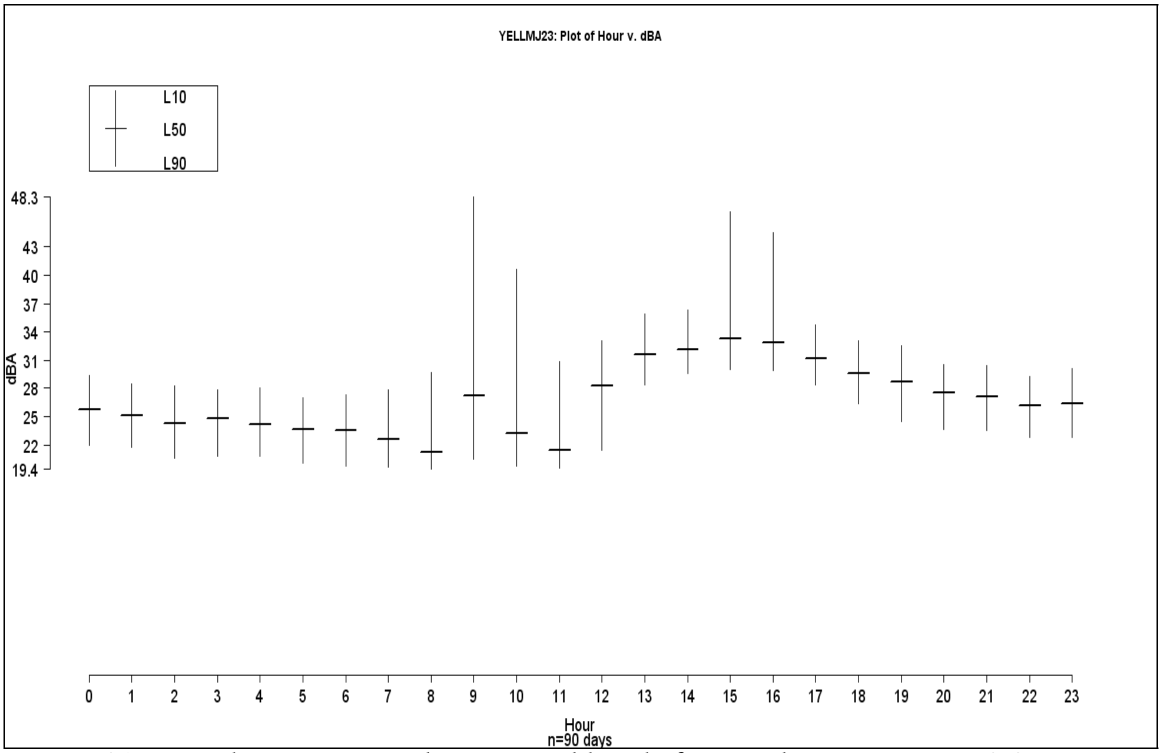


Figure 20. Hourly L_{10}, L_{50}, and L_{90} sound levels for Madison Junction 2.3, Yellowstone National Park, winter 2009-2010. (n=90 days)

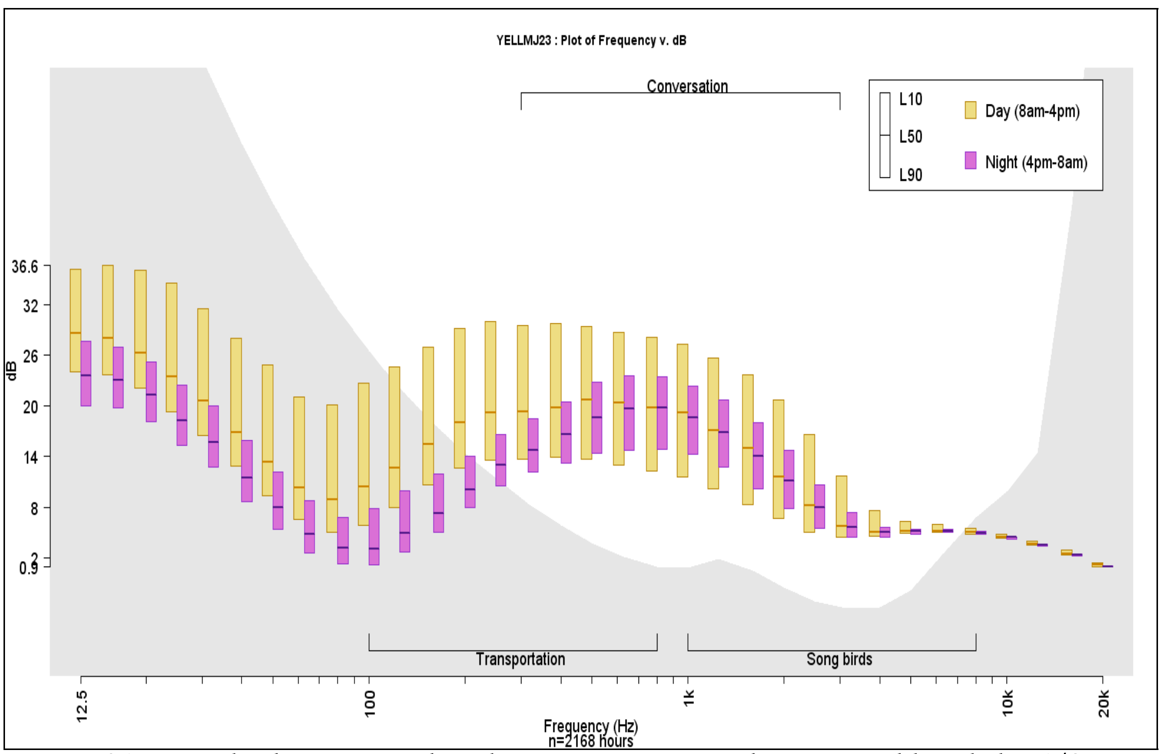


Figure 21. Hourly daytime and nighttime L_{10}, L_{50}, and L_{90} sound levels by 1/3 octave band frequency, Madison Junction 2.3, Yellowstone National Park, winter 2009-2010. Shaded area denotes region inaudible to humans. (n=2168 hours)

Lamar Valley Willow

This sound monitoring site was 142 feet (43 m) from the plowed road between Tower Junction and the Northeast Entrance. This site, though near a plowed road, was very quiet between vehicles (Figures 22-24) The loudest sounds at this site were the wheeled vehicles traveling on the road. Aircraft sounds were sometimes present and at levels above the natural ambient. The generator at the Buffalo Ranch Ranger Station, one mile (1.6 km) away, was also audible during quiet periods. Trickling water, bird vocalizations, and wind were often audible during the day and throughout the night.

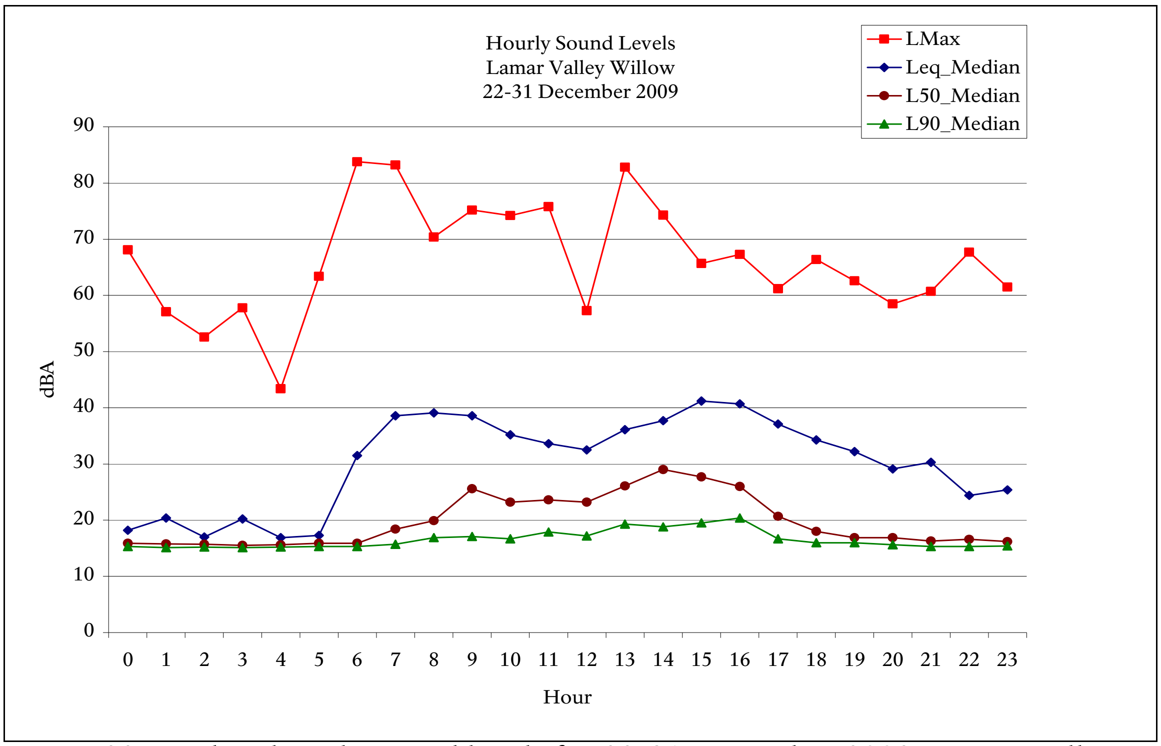


Figure 22. Median hourly sound levels for 22-31 December 2009, Lamar Valley Willow, Yellowstone National Park. See Fig. 10 caption for more details. (n=216 hours)

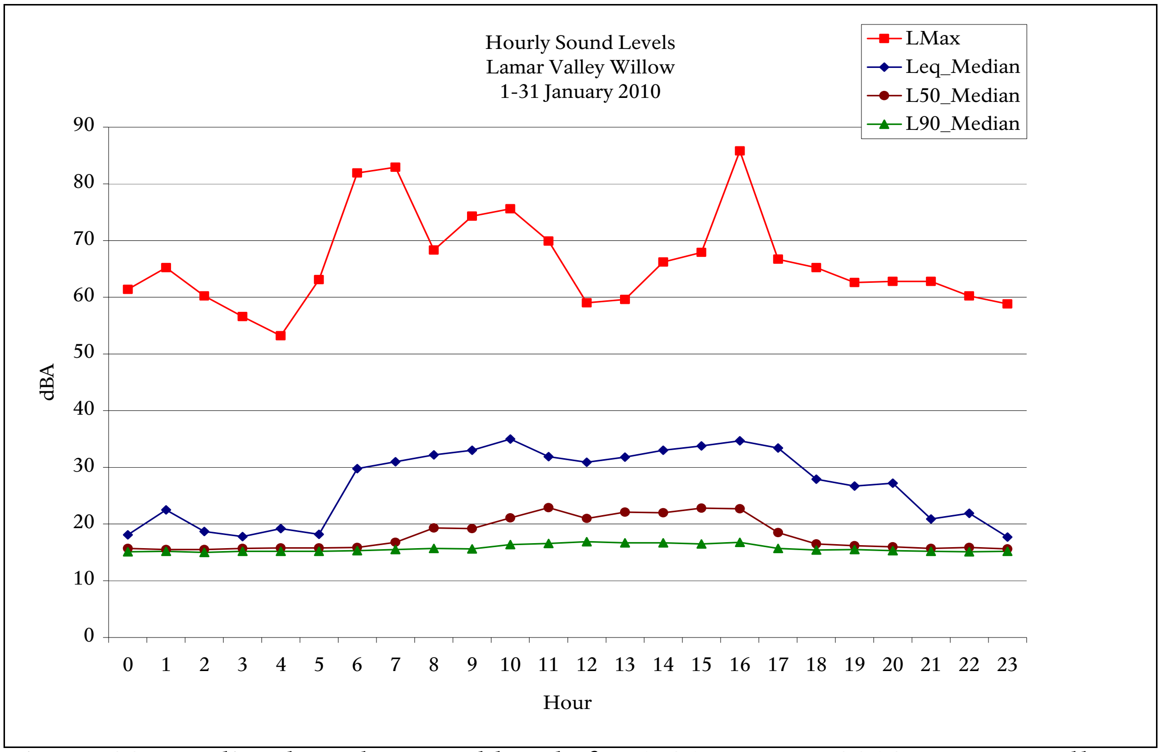


Figure 23. Median hourly sound levels for 1-31 January 2010, Lamar Valley Willow, Yellowstone National Park. See Fig. 10 caption for more details. (n=728 hours)

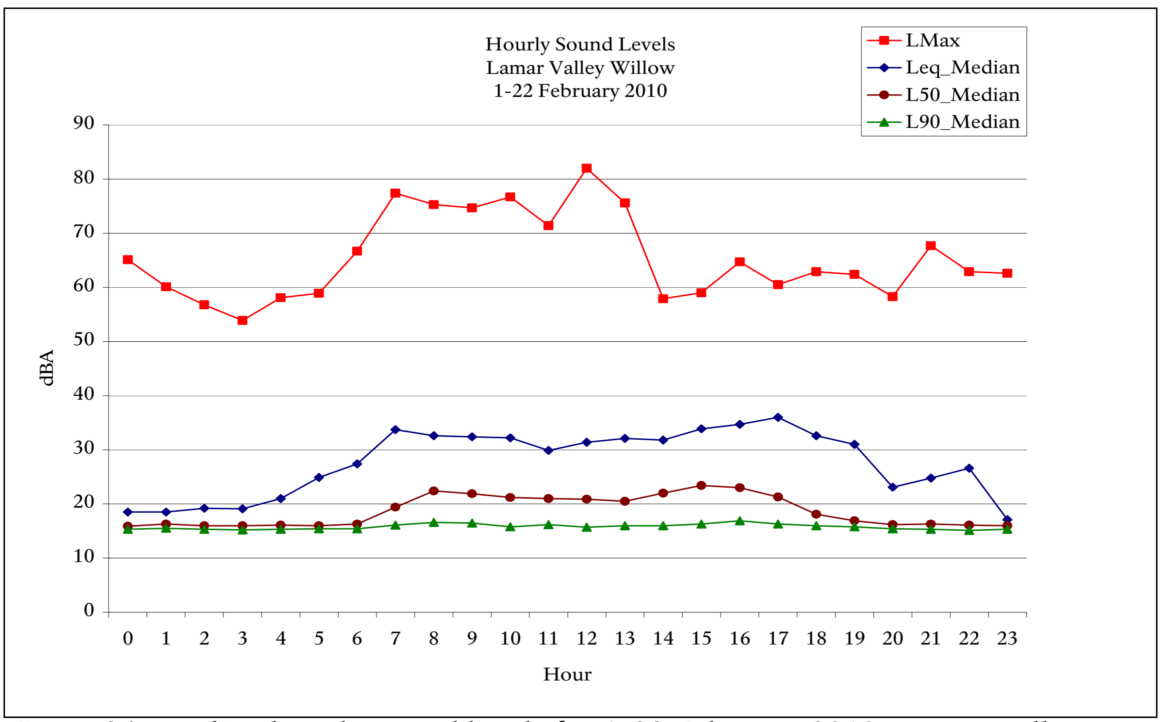


Figure 24. Median hourly sound levels for 1-22 February 2010, Lamar Valley Willow, Yellowstone National Park. **See Fig. 10 caption for more details. (n=515 hours)**

In addition to displaying sound levels by month (Figures 22-24), winter-long acoustic metric summaries are shown in Figures 25 and 26. Figure 25 shows the metrics, including L_{10} (the highest 10% of sound levels), for the 24 hour day.

Figure 26 illustrates the daytime and nighttime one-third octave band frequency distribution for the 8-hour day of the winter use season. Included in this frequency plot figure are the frequencies that are audible to humans (area without gray shading in the figure).

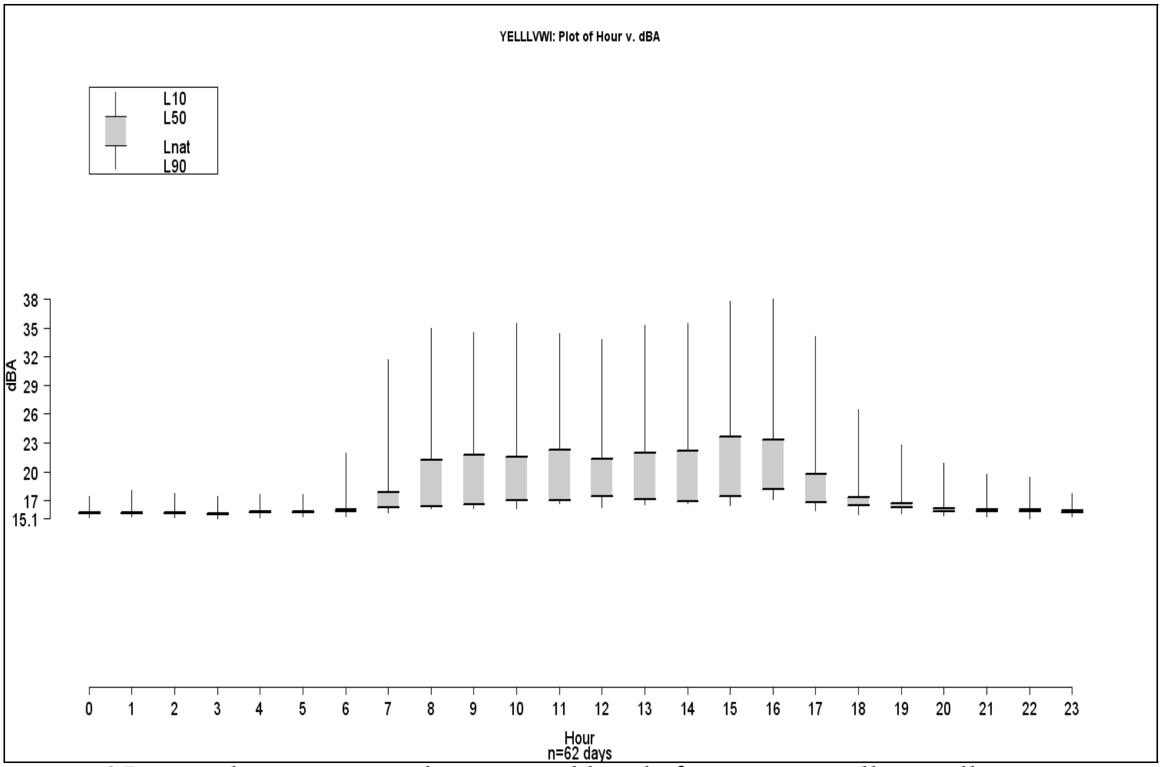


Figure 25. Hourly L_{10}, L_{50}, and L_{90} sound levels for Lamar Valley Willow, Yellowstone National Park, winter 2009-2010. (n=62 days)

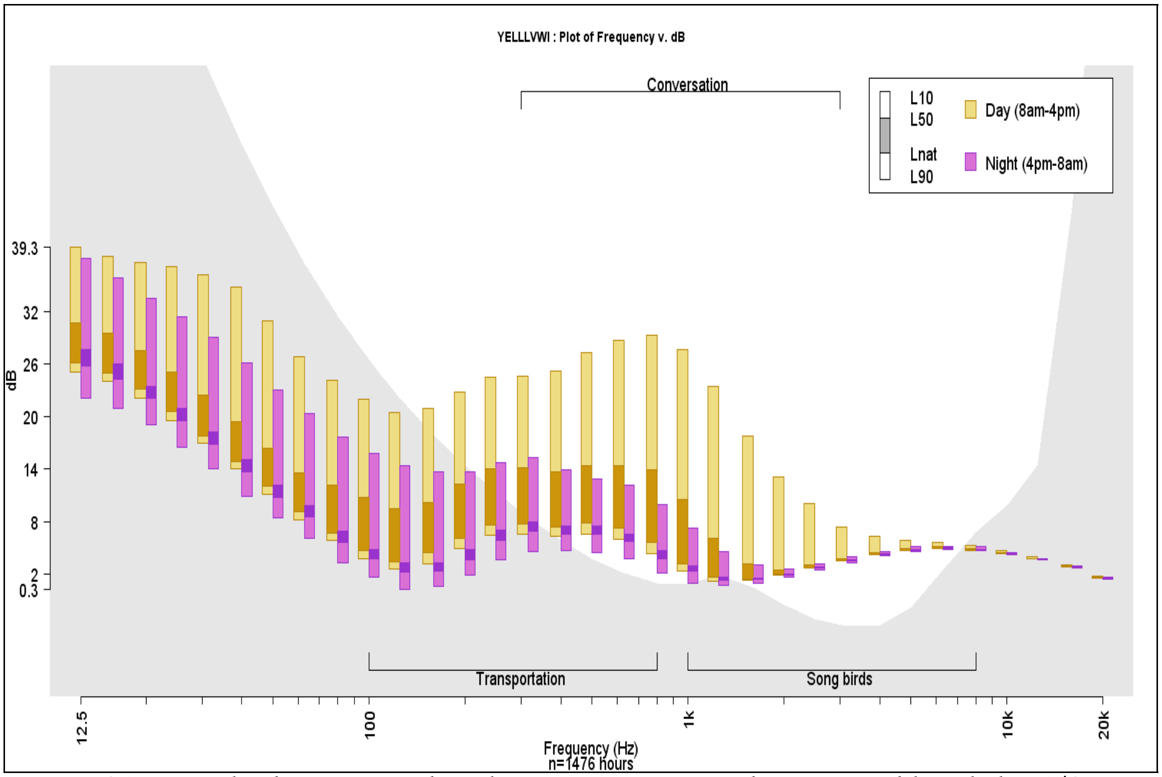


Figure 21. Hourly daytime and nighttime L_{10}, L_{50}, and L_{90} sound levels by 1/3 octave band frequency, Lamar Valley Willow, Yellowstone National Park, winter 2009-2010. (n=1476 hours)

Recommendations:

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

Although substantial reductions to the impacts on the natural soundscape were 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 along 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 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 and include measurement and reporting of noise-free intervals.

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. Newly implemented monitoring measurements including continuous recordings now provide the data to measure and report noise-free intervals. These data are an important complement to audibility analyses for describing OSV impacts on the park's natural soundscape and on visitor experience.

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 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- Continue to augment 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 soundscape's 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. Mary Ann Donovan and Brian Teets collected sixty-seven additional hours of OSV logging data over the course of the winter- no small feat. The Old Faithful Maintenance staff, especially Roy Jenkins, provided logistical and much appreciated help on this project. Robin Long, through the Sandhill Company, expertly coded most of the digital recordings for the sixth winter season. Her assistance continues to be invaluable. 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, Skip Ambrose, 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_{10} value represents the sound level exceeding 10 percent of the time; the loudest sounds. 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. . Impact definitions for the natural soundscape in the 2004 Winter Use Plans (WUP) Environmental Assessment.

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)].

Table C-4. 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 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 preferable. 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 with high frequencies at the top and low frequencies at the bottom of each row. The right, or bottom margin contains the decibel range and associated colors. Brighter colors indicate higher sound levels; deep blue is the quietest. Maroon diagonal lines, when plotted, indicate times of sample recordings, and wind, when plotted, 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 three 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 or wheeled vehicle signatures are narrow orange-yellow marks that extend from high to low frequency. The louder sounds are brighter yellow as shown in hour 01 and 23 (snow groomer) in Fig. D-1. At 0450, a jet appears as a low frequency blob (Fig. D-1). A propeller plane is visible at 2150 (Fig. D-1) The sounds of riffles on the Madison River are shown especially during the early morning and late evening hours (Fig. D-1).

Building utility sounds and wind create the extensive and horizontal light yellow lines at Old Faithful Weather Station (Fig. D-2). Aircraft and wheeled vehicles are the main "visible" sounds at Lamar Valley Willow on a calm day (Fig. D-3). A snowplow at 1450 and returning 1—15 minutes later is the loudest event of the day (Fig. D-3).

Figures D-4 and D-5 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 2010 (499 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-1 for another example of OSV activity at this site during the most recent winter season.

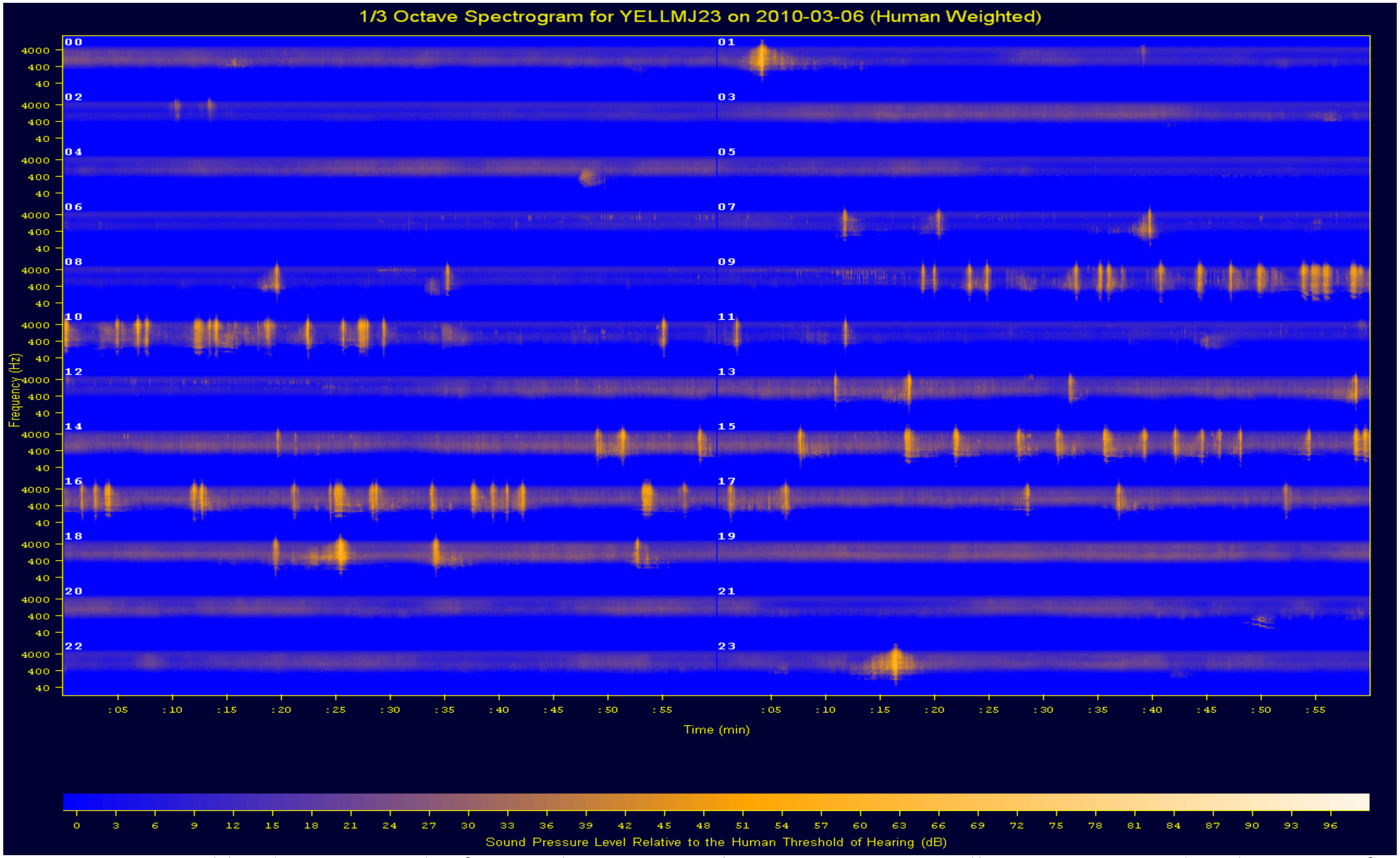

Figure D-1. Sound level spectrograph of 6 March 2010 at Madison Junction 2.3, Yellowstone National Park. See text for explanation.

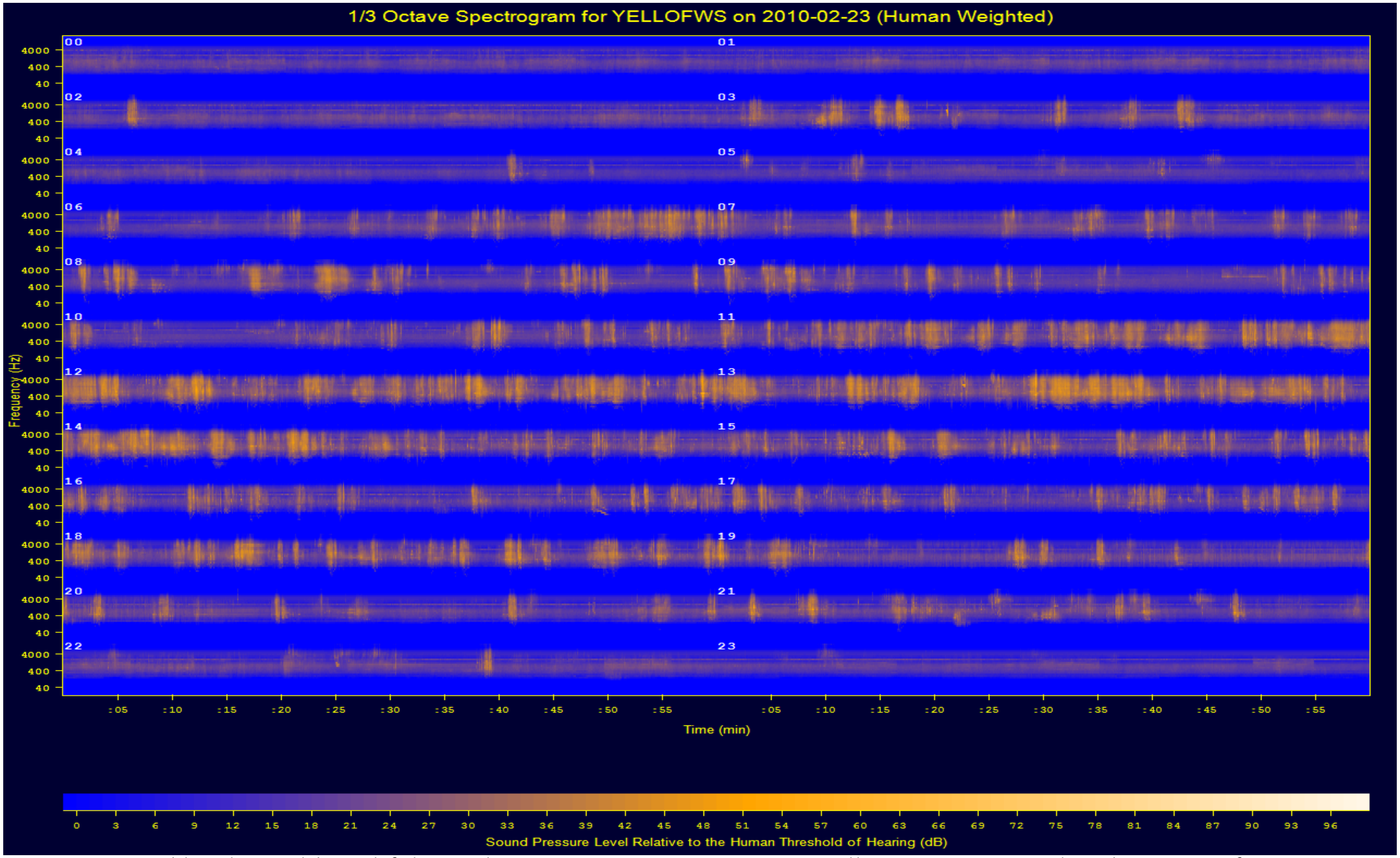

Fig D-2. Sound levels at Old Faithful Weather Station, 23 January 2010, Yellowstone National Park. See text for explanation.

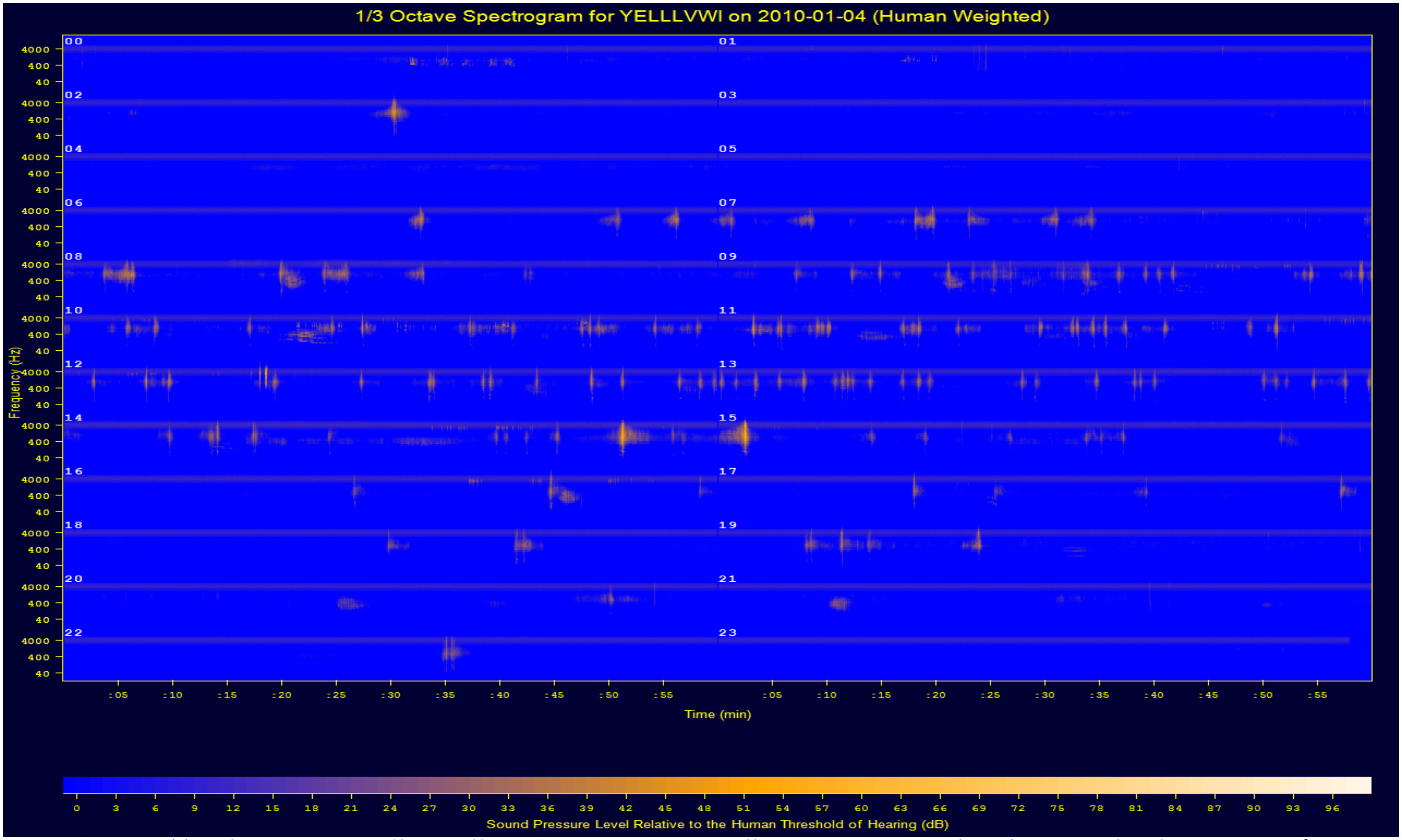

Fig D-3. Sound levels at Lamar Valley Willow, 4 January 2010, Yellowstone National Park, on a calm day. See text for explanation. Motorized sounds were audible for long distances at this very quiet site. The audible events were of longer duration than is indicated by the gold marks here.

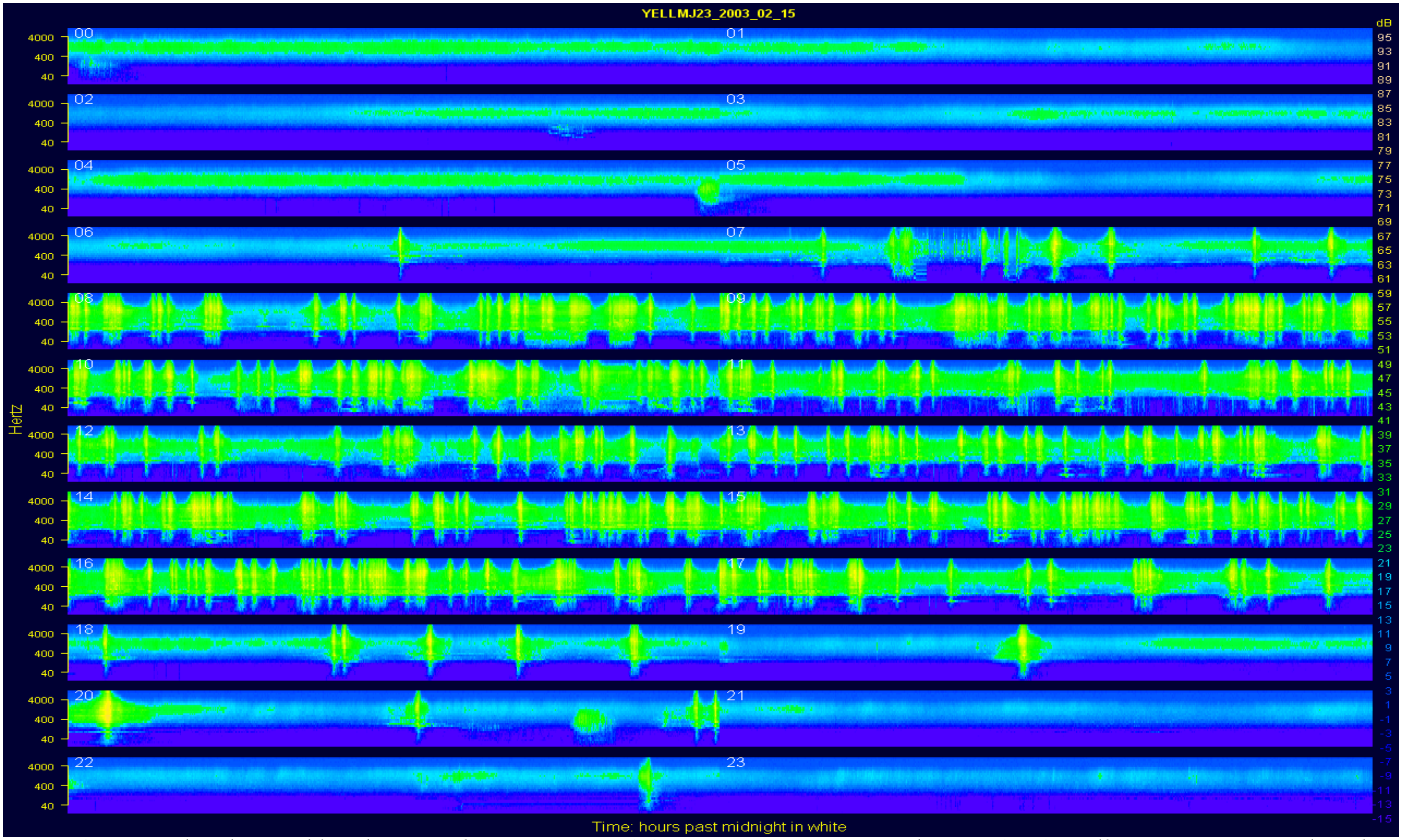

Fig D-4. A-weighted sound levels at Madison Junction 2.3 monitoring site, 15 February 2003, Yellowstone National Park. Compare to Fig. D-5 for number and timing of OSVs. See text for explanation.

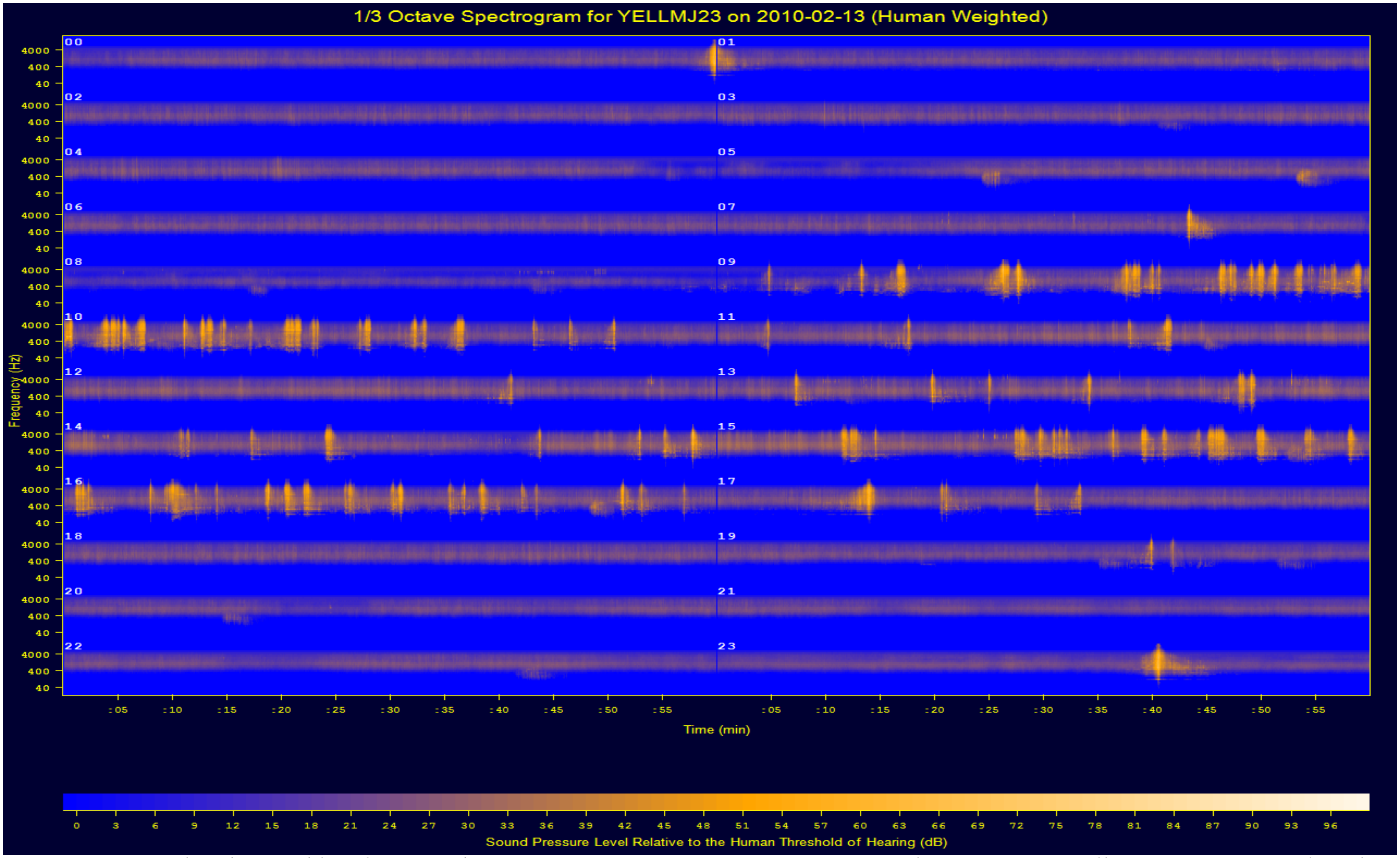

Fig D-5. A-weighted sound levels at Madison Junction 2.3 monitoring site, 13 February 2010, Yellowstone National Park. Compare to Fig. D-4 for number and timing of OSVs. See text for explanation.

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 six winters of 2005-2010. 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 182 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, 12 January-25 February 2009, and 22 December 2009-11 March 2010. The total observer logging time was 251 hr 51 min 27 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 2005-2010 in Yellowstone National Park.

Developed Area	% Sampling Time	Travel Corridor	% Sampling Time
Old Faithful Entrance Road	13.26	Kepler Cascades Pullout	1.99
Old Faithful Parking Lot	1.06	Daisy Trailhead	2.86
Old Faithful Ranger Station	0.40	Indian Creek	1.26
Old Faithful Main Road	0.42	Mallard Lake Trailhead	0.79
Canyon Junction	7.10	Midway Geyser Basin	1.19
		Mary Mountain Trailhead	6.20
		Madison Junction 2.3	11.95
		West Yellowstone 3.1	5.12
		Bridge Bay Area	6.67
		Talus Slopes	0.79
		Tuff Cliff Pullout	11.14
		Cygnet Lake Trailhead	7.49
		Hayden Valley	3.10
		Grant Village Lewis Lake	6.87
		North Twin Lake	1.44
		Spring Creek	8.73

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™ 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 2,847 groups of oversnow vehicles were documented, including 1,814 groups of snowmobile (Table E-3). Guided group size ranged from 1-31 (the largest group sizes were presumably from multiple groups that had merged together). Average size for all snowmobile groups was just under four and a quarter snowmobiles per group; just under seven snowmobiles per guided group and just over one snowmobile per administrative group. A total of 8,724 individual oversnow vehicles were tallied, including 7,691 snowmobiles (Tables E-4 and E-5).

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 67% 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 56% 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 94% of snowcoaches observed along travel corridors and 85% of snowcoaches within developed areas (Table E-5). Of the 1,033 snowcoaches observed, nearly 9 out of 10 were guided (Table E-5).

Guided snowmobiles comprised 53% of all audible snowmobiles and 56% of all audible motorized vehicles were snowmobiles (Table E-6). Guided snowcoaches comprised 23% of all audible motorized vehicles (Table E-6). All oversnow vehicles were audible for 51% of the study period and comprised 91% of the motorized sounds audible (Table E-6). Visitor and administrative snowmobiles were audible for 80 hours 6 minutes and 35 seconds (31%), and snowcoaches were audible for 40 hours 4 minutes and 3 seconds (16%) of the 255 hours 51 minutes and 27 second study period (Table E-6). No motorized sounds were audible for 44% 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 2005-2010.

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

Table E-3. Number and proportion of snowmobile groups by usage type traveling within Yellowstone National Park, winters 2005-2010.

Location	Guided Snowmobiles	Contractor	NPS Maintenance	Ranger	Research	NPS Other/Unknown	Concession Admin	Unknown Admin	Xanterra Admin	Total
Developed Area	308	63	60	96	9	92	18	46	143	835
	37%	8%	7%	11%	1%	11%	2%	6%	17%	100%
				NPS-All[a]	257					
					31%					
				Admin-All[b]	464					
					56%					
Travel Corridor	659	17	19	62	52	112	17	22	19	979
	67%	2%	2%	6%	5%	11%	2%	2%	2%	100%
				NPS-All	245					
					25%					
				Admin-All	303					
					31%					
All Areas	967	80	79	158	61	204	35	68	162	1814
	53%	4%	4%	9%	3%	11%	2%	4%	9%	100%
				NPS-All	502					
					28%					
				Admin-All	767					
					42%					

[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 2005-2010.

Location	Guided Snowmobiles	Contractor	NPS Maintenance	Ranger	NPS Research	NPS Other/Unknown	Concession Admin	Unknown Admin	Xanterra Admin	Total
Developed Area	2108	96	72	97	12	102	20	48	148	2703
	78%	4%	3%	4%	0%	4%	1%	2%	5%	100%
				NPS-All[a]	283					
					10%					
				Admin-All[b]	499					
					18%					
Travel Corridor	4592	31	23	69	68	133	26	26	20	4988
	92%	1%	0%	1%	1%	3%	1%	1%	0%	100%
				NPS-All[a]	293					
					6%					
				Admin-All[b]	365					
					7%					
All Areas	6700	127	95	166	80	235	46	74	168	7691
	87%	2%	1%	2%	1%	3%	1%	1%	2%	100%
				NPS-All[a]	576					
					7%					
				Admin-All[b]	864					
					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 2005-2010.

Location	Guided Snowcoach	Contractor	NPS Maintenance	NPS Ranger	NPS Other/Unknown	Concession Admin	Unknown Admin	Xanterra Admin	Total
Developed Area	415	5	2	1	0	3	4	60	490
	85%	1%	0%	0%	0%	1%	1%	12%	100%
				NPS-All[a]	3				
					1%				
				Admin-All[b]	70				
					14%				
Travel Corridor	508	0	0	1	6	8	2	18	543
	94%	0%	0%	0%	1%	1%	0%	3%	100%
				NPS-All	7				
					1%				
				Admin-All	35				
					6%				
All Areas	923	5	2	2	6	11	6	78	1033
	89%	0%	0%	0%	1%	1%	1%	8%	100%
				NPS-All	10				
					1%				
				Admin-All	105				
					10%				

[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 2005-2010, Yellowstone National Park. Totals may not appear correct due to rounding errors.

User Group	Elapsed Time	Percentage	Combined Total
Snowmobiles Only			
Guided Snowmobile	42:24:25	53%	53%
Contractor	1:27:04	2%	2%
NPS-Maintenance	2:25:05	3%	
NPS-Ranger	4:36:12	6%	
NPS-Research	1:43:37	2%	
NPS-Other/Unknown	6:29:17	8%	19%
Admin-Concession	2:40:15	3%	
Administrative-Xanterra	3:12:44	4%	
Administrative-Unknown	1:32:58	2%	9%
Unknown User	13:34:58	17%	17%
	80:06:35		
Snowcoaches Only			
Guided Snowcoach	33:17:07	83%	83%
Contractor	0:04:02	0%	0%
NPS-Maintenance	0:02:31	0%	
NPS-Ranger	0:02:31	0%	
NPS-Research	0:00:00	0%	
NPS-Other/Unknown	0:16:09	1%	1%
Admin-Concession	0:17:34	1%	
Administrative-Xanterra	3:12:44	8%	
Administrative-Unknown	0:08:50	0%	9%
Unknown Overnow User	2:42:35	7%	7%
	40:04:03		

Table E-6 continued. Elapsed time (hours:minutes:seconds) and percentages for motorized vehicles during an observational study, winters 2005-2010, Yellowstone National Park. Totals may not appear correct due to rounding errors.

User Group	Elapsed Time	Percentage	Combined Total
All Motorized Sounds			
Jets	6:30:41	5%	
Props	2:39:10	2%	
Helicopters	0:32:43	0%	7%
Snowmobile	80:06:35	56%	
Snowcoach	40:04:03	28%	
Snowmobile or Snowcoach	3:49:08	3%	
Unknown Oversnow Vehicle	6:21:08	4%	91%
Groomer	2:19:03	2%	2%
Unknown/Other Motorized	1:36:30	1%	1%
	143:59:01		
Total Observation Time	255:51:27		
Motorized Sounds	143:59:01	56%	
Oversnow Vehicles	130:20:54	51%	
Snowmobiles	80:06:35	31%	
Snowcoaches	40:04:03	16%	
No Motorized Sounds	111:52:26	44%	

Appendix F: 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 has been Madison Junction 2.3 along the busiest travel corridor in winter. For the winter season 2009-2010, OSVs were audible 54% 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 visitor OSV use, audibility fell to 44%. Audibility climbed to 86% during the busiest hour of the day, 9 am to 10 am, and was 31% during the noon hour. The average OSV audibility for all days analyzed of all travel corridor monitoring sites was 39% for 8 am to 4 pm. The periods and locations of data collection and analysis can greatly influence the value of percent time audible (Table F-1).

Table F-1: Oversnow audibility as a function of monitoring site and period of analysis, Yellowstone National Park, 15 December 2009-15 March 2010.

Site(s)	Period of Analysis	Audibility
Madison Junction	9 am to 10 am	86%
Madison Junction	noon to 1 pm	31%
Madison Junction	8 am to 4 pm	54%
Madison Junction	7 am to 9 pm	44%
All travel corridor monitoring sites in Yellowstone all years	8 am to 4 pm	39%

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 were audible was lower on windy days and was higher during days of higher OSV numbers.

Appendix G: Pass-by sound level measurements of a Glaval Snowcoach

One management approach to reduce the sound levels of oversnow vehicles (OSVs) in Yellowstone is the use of Best Available Technology (BAT). BAT for sound is defined for snowmobiles, but not snowcoaches. The NPS is acquiring a standardized acoustic database of snowcoaches that operate in Yellowstone. It is with this information that BAT sound requirements, and procedures to evaluate snowcoach compliance with those BAT requirements, will be developed.

To supplement previous snowcoach acoustic measurements performed by the John A. Volpe National Transportation Systems Center's Environmental Measurement and Modeling Division (Volpe Center), acoustic measurements were collected during the winter of 2009-2010 on a Glaval snowcoach operated by Xanterra. This Glaval snowcoach represented one of three snowcoaches of this type that were operating in Yellowstone National Park. Their sound levels had not been previously measured using standardized pass-by methodology.

The Society of American Engineers (SAE) J1161 specifies a methodology for the measurement of exterior operational sound levels for OSVs. The pass-by protocol of the Volpe Center (2010) and these Glaval measurements closely followed those methodologies. Details can be found in the Volpe Center's report (2010). The course set-up is shown in Figure G-1.

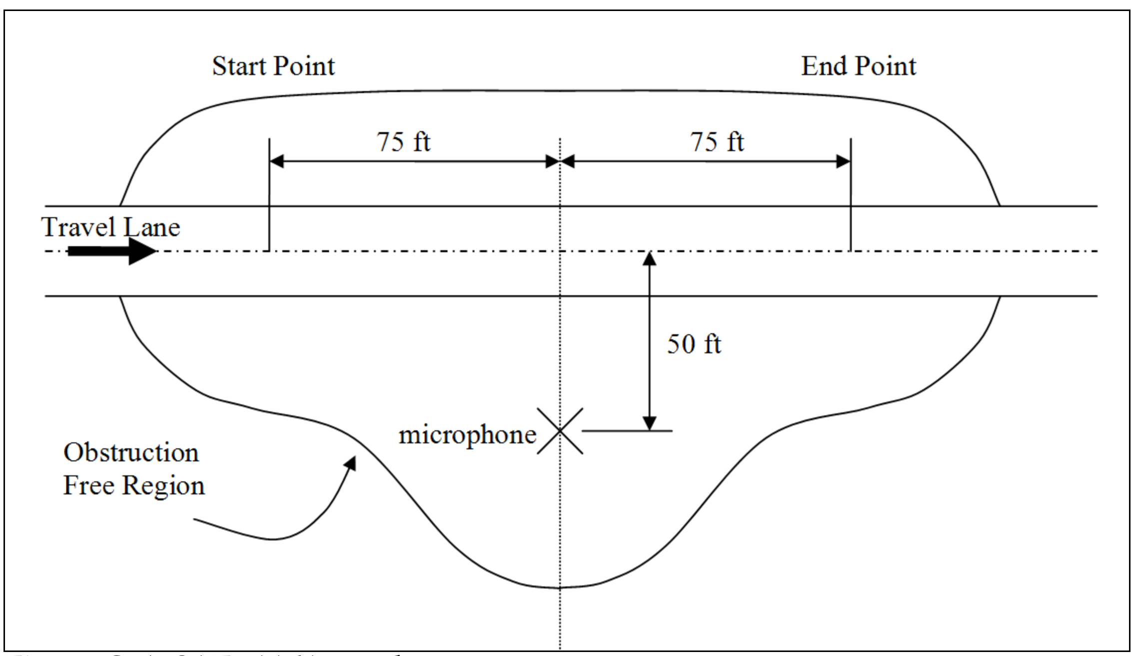

Figure G-1. SAE J1161 area layout.

The Glaval snowcoach measurements were conducted on 3 March 2010 at the Indian Creek Pass-by measurement site. Table G-1 contains the details of the measurement instruments, weather conditions, and Glaval specifications.

Table G-1. Datasheet containing instrument, weather, and vehicle specifications.

Shan Burson			
PO Drawer 170, Grand Teton National Park, Moose, WY 83012			
307 739 3584			
Date	03-Mar-10		
Snowcoach Type	Glaval #524	VIN:	1GB965A63A1105697
Track Type	Mattrax	Year:	2010
Location: Indian Creek Pass-by Location, Yellowstone NP	Latitude: 44.881942	Longitude: 110.732869	
	Type	Serial #	
SLM microphone	GRAS40AE	36931	
SLM preamp	LDPRM902	2681	
Sound Level Meter	LD 824	824A2650	+20 Gain
Digital Recorder	Edirol R09HR	AW94897	
Elevation	7250 ft	2210 m	
Weather	Cloudy bright		
Temperature	34F	1C	
Wind speed/direction	0-11mph/S	0-18kmh	
Cloud cover	100%		
Precipitation	Light snow		
Humidity	75-90%		
Barometric pressure	22.87in	775.5mb	calculated from Weatherunderground.com data
Snow conditions	Depth		
On road	7+ in	18+ cm	
Between road and microphone	20"	51 cm	
Ambient sound level	30-35 dBA		
GPS time at start of recording/data logging	1013		
Pass-bys- until 3 within 2 dB			
3 measurement conditions	Idle	15 mph	Cruising speed
		24 kph	

Table G-2 presents the actual field measurements. The standard pass-by speeds of 15 mph and cruising speed were augmented by a fast and slow idle measurement and pass-bys at the maximum safe speed (as determined by the snowcoach driver). Following SAE J1161 protocol the standard pass-bys were continued until three sound level readings from each side of the vehicle were within 2 dBA. Those three values were then arithmetically averaged and the side with the highest average level is reported. Table G-3 shows these test result values.

Table G-2. Field measurement of a Glaval snowcoach, Yellowstone National Park, 3 March 2010. Lmax is the maximum sound level. SEL is sound exposure level.

Trial #	Speed (mph)	Time (hh:mm:ss) Start	End	Vehicle Side Driver	Passenger	Lmax (dBA)	SEL (dBA)	Comments
1	21	101630	nd	x		72.0	nd	crusing speed
2	21.5	1020	nd		x	73.9	80.0	crusing speed
3	21.5	1022	nd	x		73.6	79.4	crusing speed
4	21	1026	nd		x	73.2	79.3	crusing speed
5	21	1029	nd	x		73.4	79.2	crusing speed
6	21	1033	nd		x	73.1	79.4	crusing speed
7	28	1036	nd	x		76.9	82.1	maximum safe speed
8	28	1039	nd		x	77.1	82.5	maximum safe speed
9	15	104245	nd	x		70.1	77.4	SAE J1161
10	15	104829	nd		x	70.3	77.6	SAE J1161
11	15	105044	nd	x		70.2	77.2	SAE J1161
12	15	105424	nd		x	71.2	78.6	SAE J1161
13	15	105645	nd	x		70.5	77.4	SAE J1161
14	15	110026	nd		x	70.0	77.7	SAE J1161
						1min Leq		
15	Idle	110330	110430	x		43.5	60.8	slow idle- 600 rpm
16	Idle	110515	110615	x		48.4	66.0	fast idle- 1200 rpm
17	Idle	111055	111155		x	43.4	60.6	slow idle- 600 rpm
18	Idle	111220	111320		x	49.4	66.4	fast idle- 1200 rpm

Table G-3. Sound levels for the pass-by test of a Glaval snowcoach, Yellowstone National Park, 3 March 2010.

Speed	dBA
Cruising	73
15 mph	71
Maximum*	77
Slow Idle*	44
Fast Idle*	49

*No replicates measured at these speeds.

Tables G-4 and G-5 show the Glaval sound measurements compared to other snowcoaches measured by the Volpe Center (2010). Out of 17 snowcoaches, the Glaval was tied for second loudest at 15 mph (Table G-4). Out of 19 snowcoaches, the Glaval was ranked 10th in speed and was sixth loudest at its maximum speed, and 17th in speed and 12th loudest at its cruising speed.

Tables G-4 and G-5 include snowcoach measurements collected at the north test site (Indian Creek) and at two other test sites in Yellowstone. These sites can be considered interchangeable for comparing these results. For complete details of the Volpe Center's snowcoaches see Volpe Center (2010).

Table G-4 Maximum sound level for the loudest side of the snowcoach at low speed. From Volpe Center (2010).

Vehicle	Entrance	Vehicle Side[#]	Average L_{max} (dBA)	Average Speed of Runs (mph)
See Yellowstone Tours #9	West	Right	76	15
73 DBA BAT Limit				
Xanterra 537	North	Right**	71	10.7[!!]
GLAVAL XANTERRA 524	**North**	**Right**	**71**	**15**
See Yellowstone Tours #6	West	Right	69	16
Xanterra 709	South	Left**	68	15
Xanterra 707	North	Right	68	15
Buffalo Bus Touring #3	West	Right**	67	15
Buffalo Bus Touring T2	West	Left	67	16
Yellowstone Snowcoach - SNOVAN5	North	Left	66	16
Buffalo Bus Touring #4	West	Left	65	16
Xanterra 430	North	Left	65	17
Yellowstone Expedition - Eleanor	West	Left	65	15
Xanterra 713	North	Right	65	15
Xanterra 710	West	Left	64	15
Yellowstone Snowcoach - SNOVAN4	North	Left	63	15
Yellowstone Expedition - Hayden	North	Left	60	15
Alpen Guide - Kitty	North	Left**	59	15

[#] "Left/Right" indicates left/right side of vehicle from the driver's perspective.
** Indicates that data was only available for one side of the vehicle.
[!!] The Xanterra 537 has a top speed of approximately 16 mph.

Table G-5. Maximum sound level for the loudest side of the snowcoach at high or cruising speed. From Volpe Center (2010).

Vehicle	Entrance	Vehicle Side#	Average L_{max} (dBA)	Average Speed of Runs (mph)
Xanterra 707	North	Left	80	29
Xanterra 709	South	Left	80	28
See Yellowstone Tours #9	West	Left	78	36
See Yellowstone Tours #6	West	Right	78	35
Yellowstone Snowcoach - SNOVAN5	North	Right	77	34
GLAVAL XANTERRA 524	**North**	**Right**	**77**	**28**
Xanterra 537	North	Left	77	16
Xanterra 710	West	Right	76	32
Yellowstone Snowcoach - SNOVAN4	North	Right	76	33
Xanterra 713	North	Right	76	26
Buffalo Bus Touring #3	West	Left	75	27
73 DBA BAT Limit				
GLAVAL XANTERRA 524	**North**	**Right**	**73**	**21**
Buffalo Bus Touring T2	West	Left	72	24
See Yellowstone Tours #4	West	Right	72	33
Buffalo Bus Touring #4	West	Left	72	24
Xanterra 430	North	Left	71	23
Yellowstone Expedition - Eleanor	West	Left	69	25
Alpen Guide - Kitty	North	Right	67	29
Yellowstone Expedition - Hayden	North	Left	64	20

"Left/Right" indicates left/right side of vehicle from the driver's perspective.

!! The Xanterra 537 has a top speed of approximately 16 mph.

Appendix H: Initial Transect Array Results and Analysis

Introduction

Vast amounts of acoustic data have been collected during the winter in Yellowstone National Park. Many questions can be answered with this dataset. Up until last winter, how oversnow vehicle sounds propagate across the landscape had been modeled, but had not been explicitly measured in the field. A technical assistance request to remedy this gap in knowledge was submitted and approved in December 2009 by the NPS's Natural Sounds Program, Ft. Collins, CO. This appendix describes the measurements designed to address this question and the preliminary results of the oversnow vehicle propagation data. The Natural Sounds Program has the primary responsibility to further analyze these data including developing propagation models.

Study Area and Methodology

During the winter of 2009-2010 six microphones were aligned in a three mile (4.8 km) transect in the Lower Geyser Basin. The groomed road between Old Faithful and Madison Junction ran perpendicular to and split the transect into an eastern and western halves. The eastern half of the transect ran roughly along the Mary Mountain Trail. The western portion of the transect extended just beyond the ungroomed Freight Road.

The acoustic systems were installed on 4 February 2010 at each of the six locations. The most distant system in each direction was 1 ½ (2.4 km) miles from the OSV travel route. The other two systems on each segment were placed half the distance to the road from the next most distant system. So three systems were approximately 1 ½ miles (2.4 km), ¾ miles (1.2 km), and 3/8 miles (0.6 km) from the main road in each direction.

Each system collected 1-second L_{eq} (wideband and 1/3 octave bands), and continuous mp3 recordings (same systems as described in the body of this report). Each system used one 40 amp-hour 14.4 volt battery.

Audibility analyses were conducted for a subset of the days for each of the West segment systems following the protocol outlined in the body of this report.

Results

A total of 1,262 hours of acoustic data were collected at the six systems. The systems operated continuously from four to eleven days (Table H-1) before running out of battery power.

Table H-1. Dates (hours) of data collected at six locations in Yellowstone National Park, December 2009-March 2010. (n=1,262 hours)

Transect 1 West 1 (274 hours)	Transect 1 East 1 (267 hours)
4-16 February 2010	5-16 February 2010
Transect 1 West 2 (166 hours)	Transect 1 East 2 (242 hours)
4-11 February 2010	4-14 February 2010
Transect 1 West 3 (206 hours)	Transect 1 East 3 (107 hours)
5-13 February 2010	4-8 February 2010

Standard acoustic metrics were calculated for each of the six transect systems (Table H-2). The minimum sound levels ranged from 15.2 to 20.3 dBA, and the maximum sound levels measured at these sites ranged from 61.0 to 73.0 dBA. Even these low minimum sound levels were constrained by the noise floor (inherent noise) of the instruments. Sounds from all sources are included in these results.

Table H-2. Sound level metrics (dBA) for six sites of the Mary Mountain Transect and in Yellowstone National Park, 8 am-4 pm, February 2010. L_{90}, L_{50}, L_{eq} are median values from hourly calculations. The Old Faithful to Madison Junction groomed road is perpendicular to the transect and between Transect 1 East 1 and West 1.

Site	L_{min}	L_{90}	L_{50}	L_{eq}	L_{max}	Hours
Travel Corridor						
Transect 1 East 3	16.4	18.6	20.0	26.0	73.0	35
Transect 1 East 2	20.3	24.4	26.0	29.6	72.4	82
Transect 1 East 1	16.1	19.9	22.5	28.1	67.6	88
---Old Faithful to Madison Junction Road bisects transect here---						
Transect 1 West 1	15.0	20.9	25.2	30.7	65.8	72
Transect 1 West 2	15.2	19.2	23.3	28.5	64.9	56
Transect 1 West 3	17.7	22.6	27.2	30.5	61.0	70

Audibility analyses were conducted for data from three systems on the west side of the groomed road from 5-11 February 2010 (Table H-3). Audibility decreased as distance from the groomed road increased (Figure H-1).

Table H-3. Dates used for audibility analyses at three locations in Yellowstone National Park, February 2010. Daily average number of guided snowmobiles was 181/day for the 91-day winter use season, excluding OSVs originating from Old Faithful. (n=20 days)

Transect 1 West 1[2] 7 days	Transect 1 West 2[2] 6 days	Transect 1 West 3[2] 7 days
5 Feb 10	5 Feb 10	5 Feb 10
6 Feb 10	6 Feb 10	6 Feb 10
7 Feb 10		7 Feb 10
8 Feb 10	8 Feb 10	8 Feb 10
9 Feb 10	9 Feb 10	9 Feb 10
10 Feb 10	10 Feb 10	10 Feb 10
11 Feb 10	11 Feb 10	11 Feb 10
Daily # of guided snowmobiles or wheeled vehicles entering Yellowstone NP during sampling days.[1]		
212/day	212/day	212/day

[1]Listed at bottom of table are daily guided snowmobile averages for the days included in the analysis in the first two columns. Average number of guided snowmobiles was calculated using all guided snowmobiles entering Yellowstone. Not all snowmobiles would pass by each site. Daily average number of snowcoaches for the winter use season was 28/day. See text for further details.

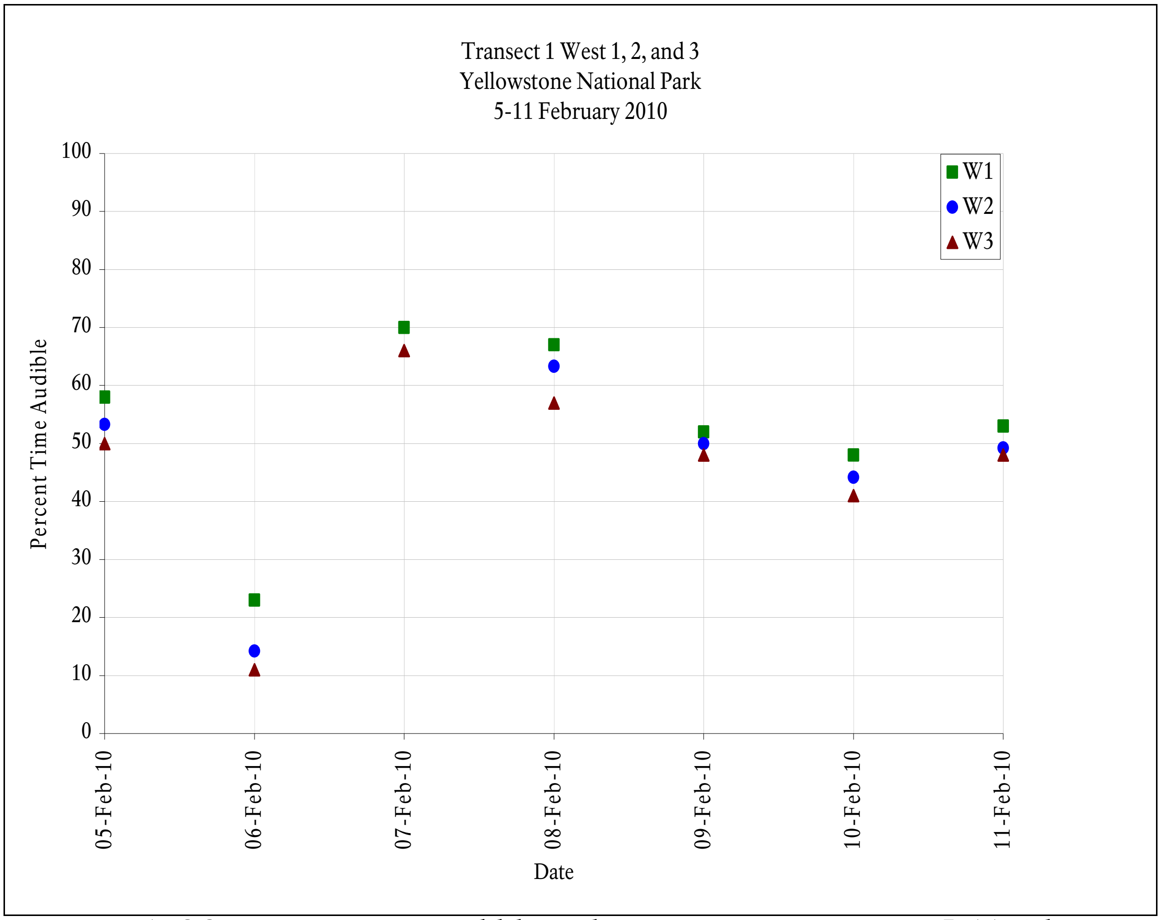

Figure H-1. OSV percent time audible at three West transect sites, 5-11 February 2010, Yellowstone National Park. (n=20 days)