Natural Soundscape Monitoring in Yellowstone National Park December 2007-March 2008

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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. These data were then compared to the adaptive management thresholds in the 2007 Yellowstone and Grand Teton National Park Winter Use Plans Environmental Impact Statement. Acoustical data were collected at three winter-long sites and three short-term sites in Yellowstone National Park during the winter use season, 19 December 2007- 9 March 2008.

Oversnow vehicles were audible in the most heavily used developed area, Old Faithful, an average of 68% of the day between 8 am and 4 pm. At Old Faithful, oversnow vehicles were audible over 75% for 2 (7%) of 27 days analyzed. Oversnow vehicles were audible for an average of 45% of the day at the two travel corridor monitoring sites. Oversnow vehicles were audible for 53% of the day near Madison Junction along the busiest corridor between Old Faithful and the West Entrance, and for 37% adjacent to the road between Grant Village and Lewis Lake along the route to the South Entrance. At Madison Junction oversnow vehicles were audible over 50% for 15 (56%) of 27 days analyzed and 3 (14%) of 22 days analyzed at Grant Village/Lewis Lake site. Oversnow vehicles were audible at one transition zone and two backcountry short-term monitoring sites; 20% at Delacy Creek Trail (one mile [1.6 km] from the groomed road), 26% at Mary Mountain 8K (one and one half mile [2.4 km] from the groomed road), and 18% at Shoshone Geyser Basin (five miles [8 km] from the groomed road). The maximum sound levels of oversnow vehicles exceeded 70 A-weighted decibels (dBA) along the groomed travel corridor between Madison Junction and the West Yellowstone entrance (Madison Junction 2.3) and between West Thumb and the South Entrance (Grant Village/Lewis Lake). The majority of these higher sound levels were caused by old technology snowcoaches. Sounds from both visitor and administrative oversnow vehicles were included in this study.

Although on average snowmobiles were audible for more time than snowcoaches, snowcoaches in general had higher sound levels, especially at higher speeds. The overall impact on the natural soundscape from oversnow vehicles was similar to the past four seasons, although there was a slight decrease in oversnow vehicle audibility at Madison Junction 2.3. The daily average number of oversnow vehicles that entered the park decreased about 2% from last season. Consistent with acoustic data collected during the previous four winter seasons, the sound level and the percent time oversnow vehicles were audible remained substantially lower than during the 2002-2003 winter use season. The reduced sound and audibility levels were largely explained by fewer snowmobiles, the change from two to four-stroke engine technology, and the guided group requirements. The value of this monitoring study increases with each additional year because trends can begin to emerge in addition to detailed information about specific winters and locations.

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Introduction:

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

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

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. During the winter use season, between 19 December 2007 and 9 March 2008, 23,814 snowmobiles and 2,653 snowcoaches, totaling 26,467 oversnow vehicles, entered YNP (NPS unpublished data). The majority (25,509; 96.4%) of these oversnow vehicles entered through the West and the South entrances. Most of these winter visitors traveled to Old Faithful. A total of approximately 879 snowmobiles (10.7/day) and about 343 snowcoaches (4.2/day) originated from Old Faithful and may not be included in the number of OSVs given elsewhere in this report.

Instrumentation and Methods:

Automated acoustic monitors (developed by Skip Ambrose, Sandhill Company, Castle Valley, UT and Mike Donaldson, Far North Aquatics, Fairbanks, AK) collected continuous one-second sound levels, digital recordings using a systematic sampling scheme (10 seconds every four minutes for a daily total of 360 samples), and 20-second recordings of sound events exceeding user-defined thresholds of sound level (decibel) and duration (seconds). These two event threshold triggers were set at 70 dBA and 1 second (fast) and 60 dBA and 10 seconds (slow). Calibrated Type 1 Larson Davis (Provo, Utah) 824 sound level meters, PRM902 microphone preamplifiers, and G.R.A.S. (North Olmsted, Ohio) 40AE microphones with windscreens were used to collect A-weighted wideband and 33 unweighted one-third octave band frequency (12.5-20,000 Hz) sound pressure levels each second during the sampling period. SoundMonitor051210™ (Far North Aquatics, Fairbanks, Alaska) software running on a Windows™-based Panasonic™ laptop computer controlled and stored the acoustical data. Sound level data were collected at the Shoshone Geyser Basin and Delacy Creek Trail monitoring sites using a calibrated Type 1 Larson Davis (Provo, Utah) 831 sound level meter, PCB PRM831 preamplifier, PCB 377802 microphone (Provo, UT) with windscreen. Digital recordings were made at Delacy Creek Trail and Mary Mountain 8K with an iAudio X5 (Irvine, CA) or Edirol R-09 (Bellingham, WA) mp3 digital recorders. Each system collected high quality digital recordings (44.1 KHz, 16-bit). B&K (Naerum, Demark) Model 4231 and Larson Davis LD200 calibrators were used for field calibration. The sound level meters, microphone preamplifiers, microphones, and calibrators were tested and calibrated at a laboratory that conforms to and operates under the requirements of ANSI/NCSL Z540-1. During the initial deployment, the sound level meter noise floor was measured using a Larson Davis ADP005 dummy microphone. The actual system noise floor (3-7 dBA above the level measured with a dummy microphone) is the lowest sound level that the system can measure. During quiet periods the actual ambient sound level was often lower than the noise floor (Burson 2006). Hobo™ wind speed sensors (Onset Computer Co., Pocasset, MA) and CV3F ultrasonic wind sensors (LCJ Capteurs, France) collected continuous wind speed data.

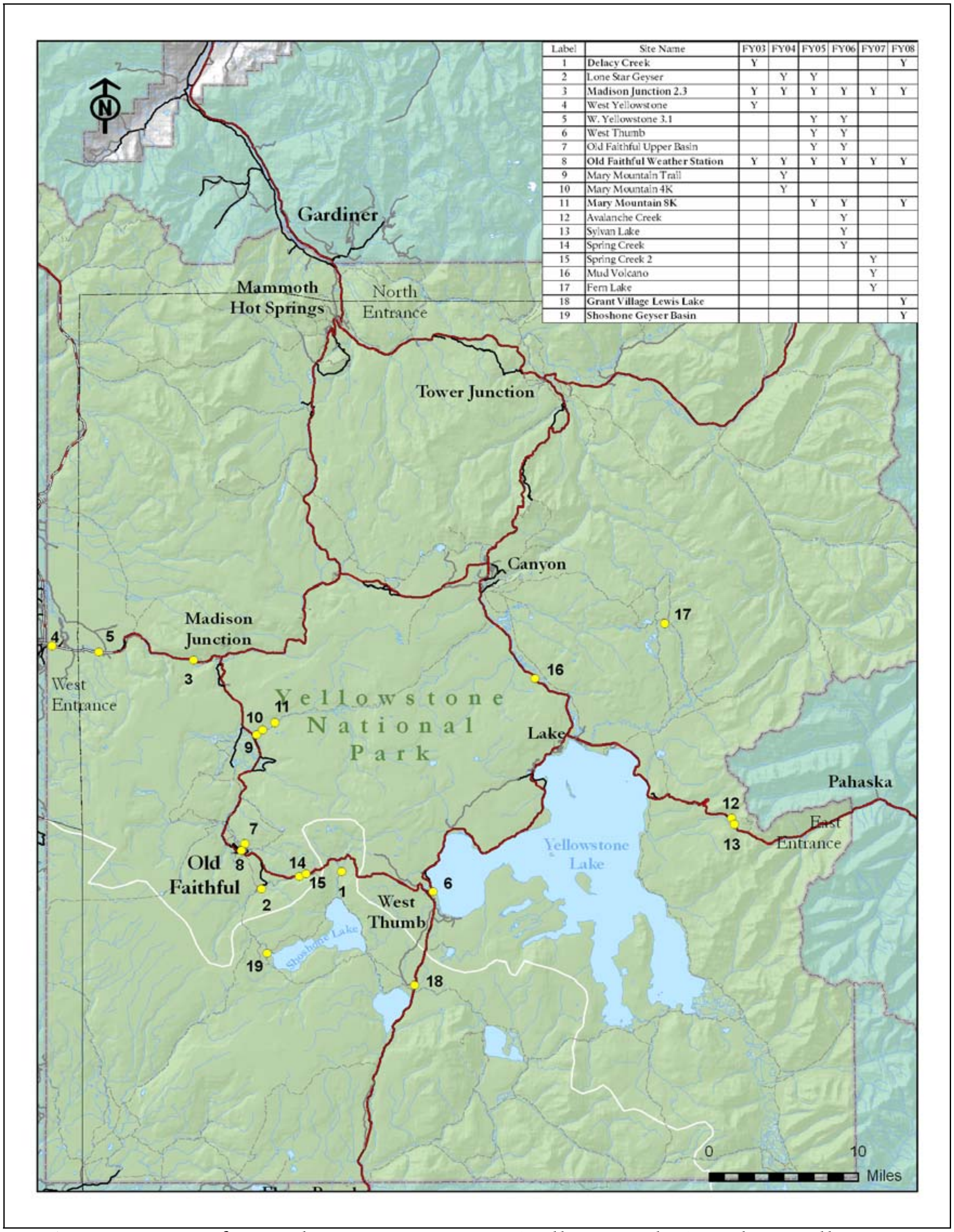
After the initial deployment, each monitor was visited at least biweekly. A field data sheet was completed during each visit. Basic site information, time arrive/time depart, latitude and longitude, habitat/vegetation types, equipment type and serial numbers, and software settings were documented. During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

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

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

Acoustic Measurement Locations:

The 2007-2008 sound monitoring locations (Fig. 1) were chosen to include high, medium and no OSV use areas and represented four soundscape management zones (Developed, Travel Corridor, Transition, and Backcountry). Locations that facilitated comparisons to acoustic data collected during previous winters were preferred. The specific placement relative to sound sources of interest was mainly determined by staffing and logistical constraints. The logistical constraints included open south facing sky for solar exposure for charging systems, proximity to electricity outlets, and placement of instrumentation in locations protected from large mammals. Habitat



Label	Site Name	FY03	FY04	FY05	FY06	FY07	FY08
1	**Delacy Creek**	Y					Y
2	Lone Star Geyser		Y	Y			
3	**Madison Junction 2.3**	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
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

Figure 1. Locations of sound monitoring sites (yellow circles) within Yellowstone National Park, December 2003-March 2008. See inserted table for key to year and map label. FY03 monitoring sites were sampled during the winter of 2002-2003 during an initial pilot study. Only FY08 sampling locations are included in detail in this report (but see Appendix F and Burson [2004, 2005, 2006, and 2007] for previous winters' sampling results).

cover percentages listed below were measured in a 500 meter radius of the sound monitor.

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.

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 Firehole River. The site and nearby motorized route were in a long mostly flat valley, one mile (1.6 km) wide, bounded on both sides by steep bluffs. The Madison Junction 2.3 monitor was powered from 12 volt batteries charged by solar panels.

Grant Village/Lewis Lake

Latitude:	44.32449
Longitude:	110.59624
Elevation:	7900 feet (2408 m)
Habitat:	80% forested (burned, regenerating pine), 20% open (road, meadow)
Management Zone:	Travel Corridor

Photo 3. Grant Village Lewis Lake sound monitor location.

The Grant Village Lewis Lake monitor (in the center left of the photo above) was located 100 feet (30 m) from the South Entrance Road within a forest of burned large and 4-8 feet (1-2 m) regenerating lodgepole pines at the south edge of a small south-facing open area about 3/4 of a mile (1.2 km) east of the north end of Lewis Lake and 4 3/4 miles (7.6 km) southwest of the road entrance to Grant Village. The site and nearby motorized route was on a slight incline to the north. The monitor was powered from 12 volt batteries charged by solar panels.

Shoshone Geyser Basin: Short-term measurements

Latitude:	44.35712
Longitude:	110.79757
Elevation:	7800 feet (2377 m)
Habitat:	55% open (wetlands, thermal area, meadow, lake), 45% forested (lodgepole pine)
Management Zone:	Backcountry

Photo 4. Shoshone Geyser Basin sound monitor location.

The Shoshone Geyser Basin monitor was placed within a cluster of lodgepole pines within an extensive thermal area. The microphone was located 5 1/4 miles (8.5 km) from the nearest motorized route (between Old Faithful to West Thumb), 7 1/4 miles (11.7 km) from the Old Faithful developed area, 100 feet (30 m) from the closest thermal activity, and 400 yards (366 m) from the west shore of Shoshone Lake. The monitor was powered by 12 volt batteries.

Delacy Creek Trail: Short-term measurements
Latitude: 44.43573
Longitude: 110.69513
Elevation: 7900 feet (2408 m)
Habitat: 15% open (meadow), 85% forested (lodgepole pine)
Management Zone: Transition

Photo 5. Delacy Creek Trail sound monitor location.

The Delacy Creek Trail monitor (in center of the photo above) was located 1 mile (1.6 km) from the nearest groomed roads (Grand Loop Road between Old Faithful and West Thumb) within a mature forest of lodgepole pines and 100 feet (30 m) from the edge of a long narrow meadow. The site was within an extensive area of rolling hills that gently sloped to Shoshone Lake. The monitor was powered by 12 volt batteries.

Mary Mountain 8K: Short-term measurements

Latitude: 44.58153
Longitude: 110.78603
Elevation: 7200 feet (2195 m)
Habitat: 60% open (grassland), 10% open (river), 30% forested (lodgepole pine)
Management Zone: Backcountry

Photo 6. Mary Mountain 8K sound monitor location.

The Mary Mountain 8K monitor was located adjacent to a downed tree on the edge of a meadow 8000 feet (1.5 miles, 2.4 km) from the groomed Old Faithful-Madison Junction Road, 200 feet (61 m) from the Nez Pierce River and 500 feet (152 m) from the Mary Mountain Trail. The terrain was mostly open with pockets of lodgepole forests and two isolated hills between the monitor and the road. The monitor was powered by 12 volt batteries.

Analyses:

Audibility
The daily 360 10-second digital recordings were calibrated, combined, and replayed using Adobe's Audition™ software, Sound Devices USBPre™ acoustical interface, and professional grade headphones. The Soundscape Database software (Ric Hupulo, formerly of the Natural Sounds Program, Ft. Collins, CO) was used to analyze the audibility data. The entire 24 hour period was analyzed but the time period 8 am to 4 pm (120 samples totaling 20 minutes per day) is reported here as prescribed in the 2007 Yellowstone and Grand Teton National Park Winter Use Plans Environmental Impact Statement (NPS 2007).

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

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

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

Event Analysis

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

Sound levels

Sound pressure levels (decibels) were compiled and common acoustic metrics were calculated using HourlyMetrics™ software (Ric Hupalo, formerly of the NPS Natural Sound Program, Ft. Collins, CO). Wind contamination (distortion) causes false sound levels when wind speeds exceed 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 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 masked when only medians are displayed. A disadvantage of using only medians is that knowledge of these other values is often valuable for interpretation, therefore minimum and maximum values are also given. Although estimates of variability beyond the minimum and maximum values are also desirable no simple, yet informative, methods have been developed.

Results from this sound monitoring project can be compared to the soundscape adaptive management thresholds in the 2007 Final Winter Use Plans Environmental Impact Statement and Record of Decision (Table 1). The 2000, 2003, and 2004 WUP acoustic thresholds (Appendix C) contain previous standards and thresholds for further comparison.

Table 1. 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. Also see Appendix C.

Management Zone	Percent Time Audible[1]	Sound Level Threshold
Developed Area[2]	NTE[3] 75%	NTE 70 dBA
Road Corridor[2]	NTE 50%	NTE 70 dBA
Transition Zone	NTE 25%	NTE 65 dBA
Backcountry	NTE 10%	NTE Natural Ambient Sound Level[4]

[1] Audibility is the ability of a person with normal hearing to hear a given sound
[2] Acoustic data measured at 100 feet (30 m) from main travel areas
[3] NTE = Not to exceed
[4]The natural sound conditions found in a given area, including only sounds of nature

Results and Discussion:

Winter-long acoustical measurements were collected at Old Faithful Weather Station, Madison Junction 2.3 and Grant Village Lewis Lake. Additional acoustic data were collected for shorter time periods at Mary Mountain 8K, Shoshone Geyser Basin and Delacy Creek Trail (see previous section for site details). Data collection began on 19 December 2007 and continued throughout the winter use season (19 December 2007- 9 March 2008). Selected data (Tables 2 and 3) of those available were chosen for analysis based on random sampling stratified by day of the week and month. The 2007 WUP impact thresholds applied only to motorized oversnow vehicle sounds from 8 am-4 pm so for the audibility analyses generally only those periods are presented in this report. Because the majority of OSV use was during 8 am to 4 pm, using the full 14-hour period of the day when OSV use was permitted would lower the resulting percent time audible values (see Appendix G). A wealth of biological data, as well as sound level data, is contained within this study's acoustic dataset. These additional data, substantially not yet analyzed, are available for future study. For comparative value the sound levels are presented for the 24 hour day although the WUP thresholds applied only to 8 am-4 pm.

A related, short-term study using specialized low noise instrumentation documented very low sound levels (as low as 0.7 dBA) near Craig Pass at Spring Creek 2 during February 2007. This second winter of low noise measurements reinforced the conclusions from Ambrose et al. (2006). The findings have implications for winter use monitoring. The very low natural ambient sound levels documented at these two Yellowstone National Park sites were not unlike some of the other locations used in this current study. Audibility of oversnow vehicles is determined, in part, by the natural ambient sound levels. Lower natural ambient sound levels result in higher OSV percent time audible. At several monitoring locations the lowest minimum sound levels were below the range (noise floor) of the instrumentation for many hours of the day. The actual minimum levels are therefore unknown. Because of this uncertainty, at the lowest sound levels the association between the number of OSVs, the natural ambient sound levels, and the distances OSVs are audible remains ambiguous (see pg. 19-20 for more discussion).

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

See Appendix C for acoustical standards and thresholds of the 2000, 2003, and 2004 Winter Use Plans (WUP) of Yellowstone (YNP) 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 an observational study designed to determine the proportion of several usage categories for oversnow vehicles (e.g., percent of total snowmobiles driven by park visitors).

See Appendix F for related sound monitoring data from previous winter seasons.

Table 2. Dates used for audibility analyses at five locations in Yellowstone National Park, December 2007-March 2008. Daily average number of snowmobiles was 290/day for the winter use season. Total number of days analyzed, 94.

Old Faithful Weather Station	Madison Jnct. 2.3	Grant Village Lewis Lake	Shoshone Geyser Basin	Mary Mountain 8K	Delacy Creek Trail
27 days	27 days	22 days	7 days	7 days	4 days
19-Dec-07	19-Dec-07	20-Dec-07	11-Feb-08	4-Feb-08	4_Jan-08
20-Dec-07	20-Dec-07	24-Dec-07	12-Feb-08	5-Feb-08	5-Jan-08
24-Dec-07	21-Dec-07	25-Dec-07	13-Feb-08	6-Feb-08	6-Jan-08
25-Dec-07	22-Dec-07	26-Dec-07	14-Feb-08	7-Feb-08	7-Jan-08
28-Dec-07	23-Dec-07	27-Dec-07	15-Feb-08	16-Feb-08	
29-Dec-07	24-Dec-07	28-Dec-07	16-Feb-08	17-Feb-08	
30-Dec-07	25-Dec-07	29-Dec-07	17-Feb-08	18-Feb-08	
2-Jan-08	5-Jan-08	5-Jan-08			
5-Jan-08	7-Jan-08	7-Jan-08			
7-Jan-08	13-Jan-08	9-Jan-08			
13-Jan-08	20-Jan-08	13-Jan-08			
22-Jan-08	22-Jan-08	22-Jan-08			
23-Jan-08	24-Jan-08	24-Jan-08			
25-Jan-08	25-Jan-08	25-Jan-08			
1-Feb-08	1-Feb-08	1-Feb-08			
3-Feb-08	5-Feb-08	3-Feb-08			
5-Feb-08	6-Feb-08	11-Feb-08			
6-Feb-08	11-Feb-08	13-Feb-08			
11-Feb-08	20-Feb-08	20-Feb-08			
20-Feb-08	23-Feb-08	26-Feb-08			
26-Feb-08	24-Feb-08	1-Mar-08			
2-Mar-08	2-Mar-08	2-Mar-08			
4-Mar-08	3-Mar-08				
5-Mar-08	5-Mar-08				
6-Mar-08	6-Mar-08				
7-Mar-08	7-Mar-08				
8-Mar-08	8-Mar-08				
Daily # of snowmobiles entering Yellowstone NP during sampling days.[1]					
285/day	247/day	299/day	271/day	341/day	341/day

[1]Listed at bottom of table are daily snowmobile averages for the days included in the analysis. Average number of snowmobiles was calculated using all snowmobiles entering Yellowstone. Not all snowmobiles would pass by each site. Daily average number of snowcoaches for the winter use season was 32/day. See text for further details.

Table 3. Dates used for sound level analyses at five locations in Yellowstone National Park, December 2007-March 2008. Total hours, 5,957.

Old Faithful (1,931 hours) 19 December 2007-9 March 2008	Madison Jct 2.3 (1,737 hours) 19-28 December 2007 3 January- 9 March 2008
Grant Village Lewis Lake (1,869 hours) 21 December 2007-4 February 2008 7 February- 9 March 2008	Delacy Creek Trail (187 hours) 3-11 January 2008
Mary Mountain 8K (233 hours) 13 January-23 January 2008	

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.

Audibility:

The source of each sound (snowmobile, animal, aircraft, wind, thermal activity, etc.) that was audible was identified from the 120 10-second digital recording samples each day during 8 am-4 pm. The proportion of each sound source sample out of the possible 120 was used to calculate the percent time audible for each sound source; however, only the snowmobile, snowcoach and wind percent time audible is presented. Oversnow vehicles were often audible outside the 8 am- 4 pm time period, but these data are generally not presented, but see Appendix G. Often multiple snowmobiles or snowmobiles and snowcoaches were audible simultaneously, but other times one masked the sound of the other so all percent time audible statistics should be considered minimum values. Audibility of OSVs were calculated using existing ambient conditions, that is, other non-natural sound sources could have been present and may have masked OSV sounds. The average number of snowcoaches entering YNP during the winter season was 32/day (range 18-56). The average number of snowmobiles entering YNP during the winter season was 290/day (range 119-543). See Table 2 for further details. The percent time audible calculations were based on days throughout the entire winter use season.

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 some of the acoustic data collected during the past five winters. Several factors, though, complicate the relationship. First, not all snowmobiles are part of guided groups; there are NPS and concession snowmobiles and snowcoaches used within the park, especially in destination areas such as Old Faithful (see Appendix E). Second, not all OSVs that enter the park travel along the same route. Therefore the number of snowmobiles entering the park is not directly related to the number passing any particular section of the road and hence their impact on the natural soundscape of that area. Third, as the numbers of visitors entering the park increases, additional snowmobiles are often added to existing groups enlarging group size, but not creating additional groups. The percent time that snowmobiles are audible is more closely associated with the number and distribution of groups rather than the number of individual snowmobiles. Fourth, audibility also depends on environmental conditions, such as temperature, wind conditions, inversions, the natural ambient sound level and other factors (as discussed in the next paragraph) that vary spatially and temporally, further complicating the relationship between the number of visitor snowmobiles and their percent time audible.

A related issue involves an acoustical metric called the noise-free interval (NFI). NFIs measure the uninterrupted periods of time when only natural sounds are audible. For the purposes of this report, NFIs were the times when no oversnow vehicles were audible. Using logic and common sense, the number and distribution of oversnow vehicles largely determine the NFI. Given the same number of oversnow vehicles, NFIs measured near travel corridors would be longer with larger rather than smaller groups (however as group size increases OSVs would likely be heard at increasing distances). A particular percent time audible can have varying NFIs. For example, if oversnow vehicles were audible for 50% of an hour, depending on the distribution of these vehicles they could all be audible in the first 30 minutes and not audible the remaining 30 minutes. Or oversnow vehicles could be audible every other 10 minute period during the hour. The NFI of the first scenario would be 30 minutes but only 10 minutes for the second. Groups of guided snowmobiles have increased the NFIs at YNP compared to unguided snowmobiles (personal observation, and Appendix D; Fig. D-7 and D-8).

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 sixth winter. Even though this site is Yellowstone's busiest developed area 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 68% within the developed area at Old Faithful, (Fig. 2). This compares to 68% during the previous winter use season and 67% during 2005-2006 (Table 4 and Appendix F). The average daily percent time audible of OSVs during the last four winter use seasons was essentially the same. During the winter of 2007-2008 the daily OSV percent time audible was consistently between 60% and 80% on all but four days (Fig. 2). Two (7%) of the 27 days analyzed exceeded the 2007 WUP audibility threshold of 75% for developed areas. There were fewer days with OSV audibility greater than 75% compared to last year, but there were also more days at slightly higher percent time audible compared to the winter of 2006-2007 (Fig. 2 and Appendix F-1).

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 the distance sounds are audible or mask other sounds. However, with all else equal OSVs are heard at greater distances during calm wind conditions, and there appears to be no strong association between wind and oversnow vehicle percent time audible at Old Faithful (Fig. 2). This is logical because the higher ambient sound levels at Old Faithful mask distant OSV sounds.

Percent time audible can be calculated by hour to understand the pattern of oversnow vehicle use between 8 am and 4 pm (Fig. 3). Early in the day (8 am and 9 am) snowcoaches were audible for more time than snowmobiles. On average, however, snowmobiles were audible for 33% of the day versus 20% for snowcoaches (Fig. 3). Oversnow vehicles were audible on average at least 75% of the time during each of the three mid-day hours (11 am, 12 pm and 1 pm). Oversnow vehicles were audible over 90% of the hour during 8 am, 9 am, 11 am, 12 pm and 1 pm during some days of the winter season (Fig. 3).

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

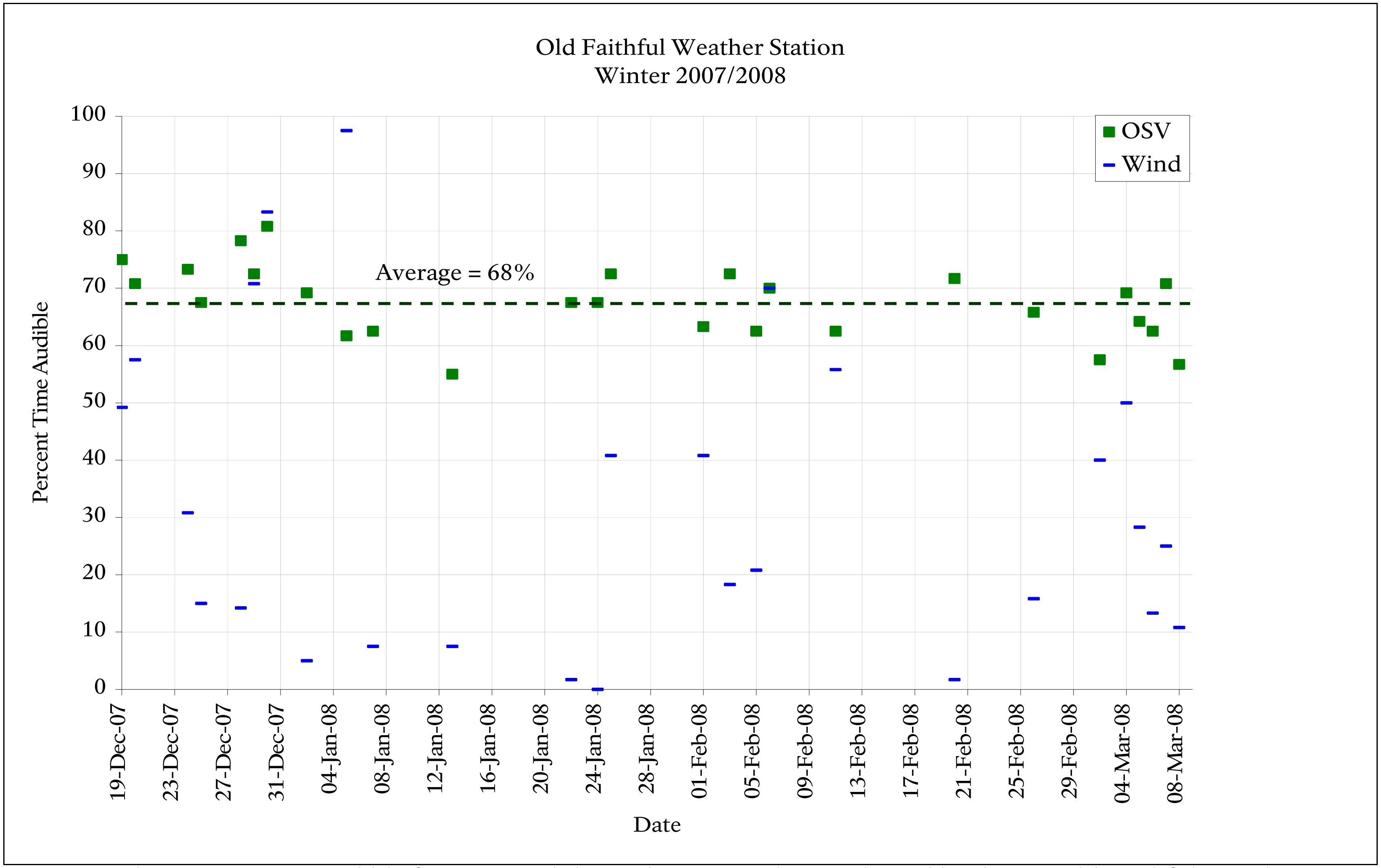


Figure 2. The percent time audible for snowmobiles and snowcoaches, and wind by date at Old Faithful Weather Station, Yellowstone National Park from 8 a.m. to 4 p.m., 19 December 2007 to 8 March 2008.

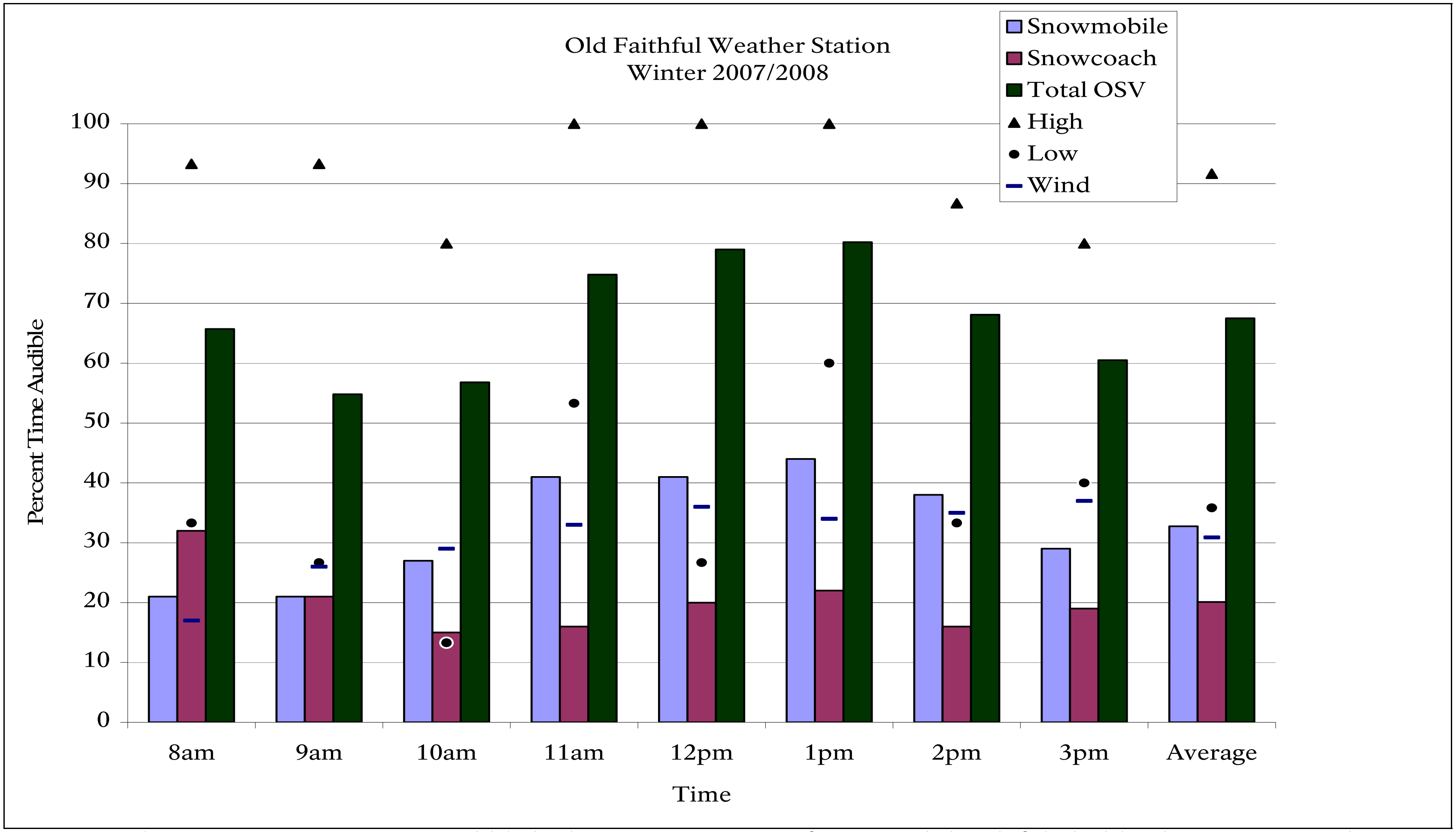


Figure 3. The average percent time audible by hour (8 am-4 pm) of snowmobiles (left light blue bar), snowcoaches (middle maroon bar), and combined category (right dark green bar), and high and low OSV values at Old Faithful Weather Station, Yellowstone National Park from 8 a.m. to 4 p.m., 19 December 2007 to 8 March 2008.

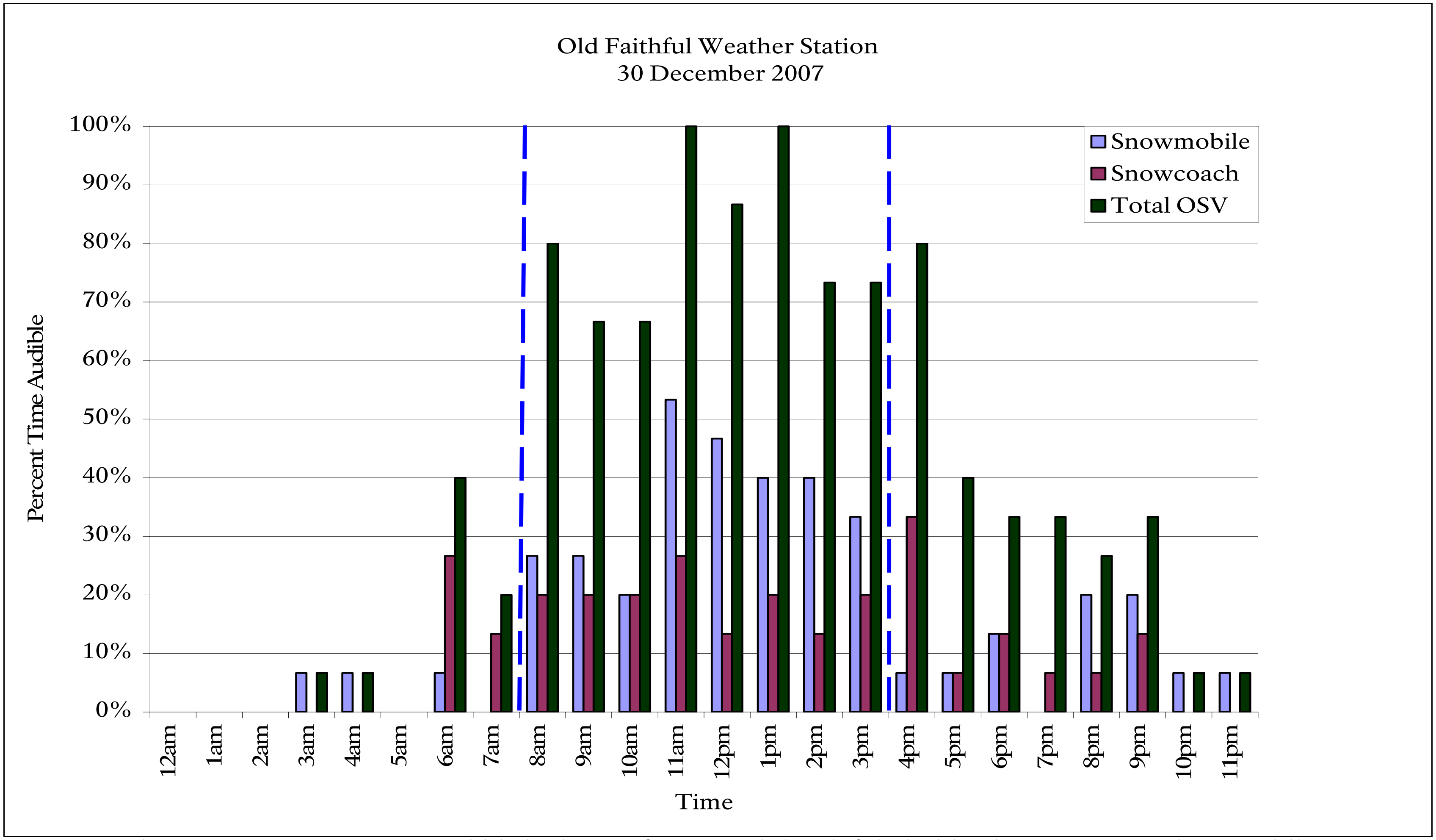


Figure 4. The average percent time audible by hour of snowmobiles (left light blue bar), snowcoaches (middle maroon bar), and combined category (right dark green bar) at Old Faithful Weather Station, Yellowstone National Park 30 December 2007. The winter use analysis time period is between the vertical 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 travel corridor. Acoustic data were collected over the entire winter use seasons of 2007-2008 (Fig. 5), 2006-2007 and 2005-2006, and during the Presidents Day Weekends of 2005, 2004, and 2003 (Appendix F). Quiet riffles of the Madison River were audible when not masked by the sounds of wind, swans, coyotes, wolves, ducks, geese, ravens, and oversnow vehicles. Snowmobiles and snowcoaches were audible for an average of 53% of the time during the entire winter use season (Fig. 5). This compares to 59% last winter and 55% the winter before. The season's average audibility of OSVs during the last three winters exceeded the WUP audibility threshold of 50% for travel corridors (Table 1), but see Grant Village/Lewis Lake, the other travel corridor monitoring site. The OSV percent time audible exceeded 50% for 15 (56%) of 27 days analyzed during the winter 2007-2008 (Fig. 5). Wind speed was associated with the audibility of OSVs at this site. OSVs were less audible on days with more wind due to the masking effect of wind on the distant and faint OSV sounds.

The hourly pattern follows a bimodal distribution (Fig. 6) documenting the pulse of OSVs passing by the site in the morning on the way into the park and in the afternoon on the way back to West Yellowstone. Figure 6 also shows that many of the OSVs cannot be distinguished as a snowmobile or a snowcoach. This indicates that many OSVs were audible over long distances because nearby OSVs can usually be identified.

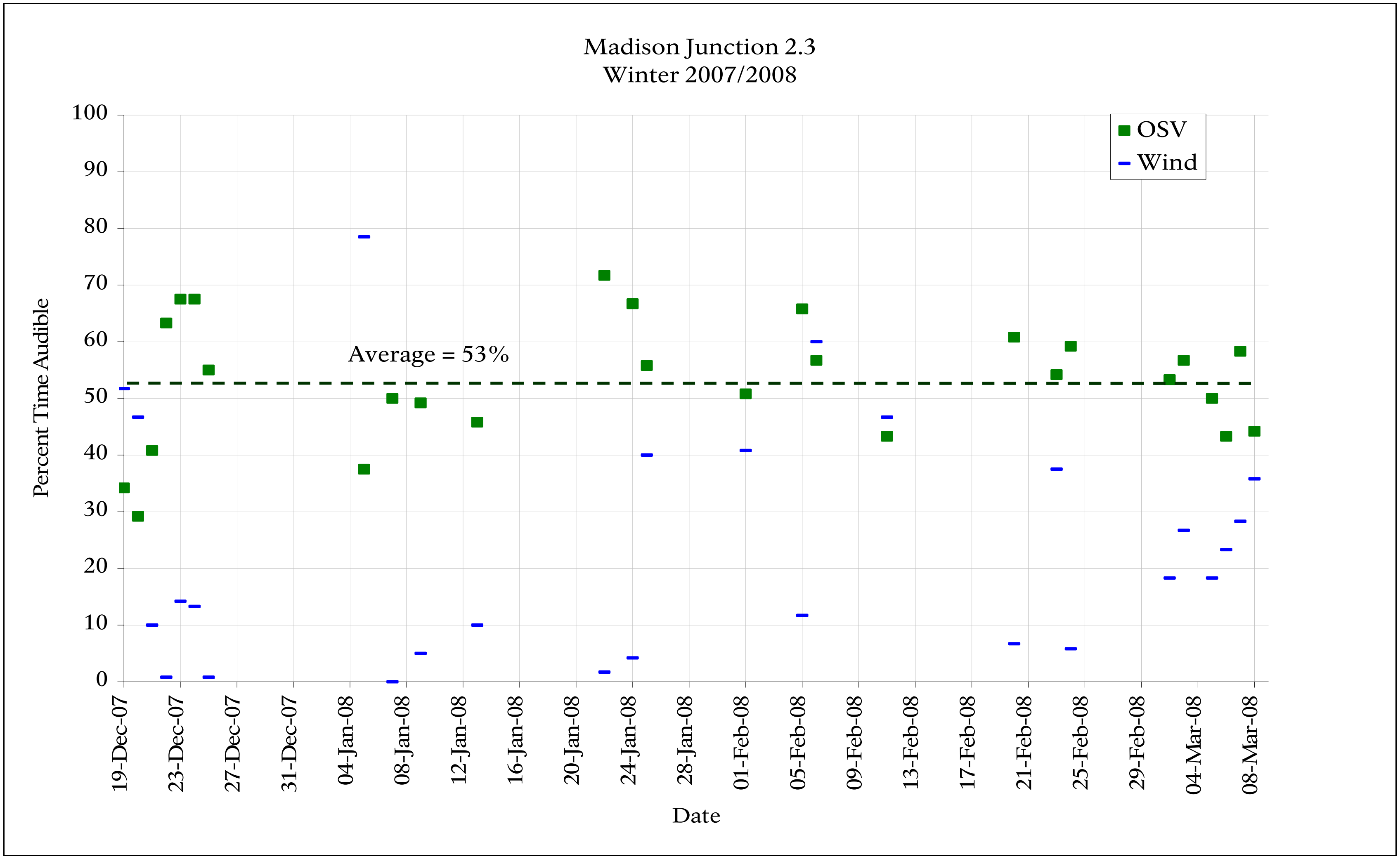


Figure 5. The average percent time audible by date of snowmobiles and snowcoaches, and wind at 2.3 miles (3.7 km) west of Madison Junction along the West Entrance Road Yellowstone National Park, 19 December 2007-8 March 2008.

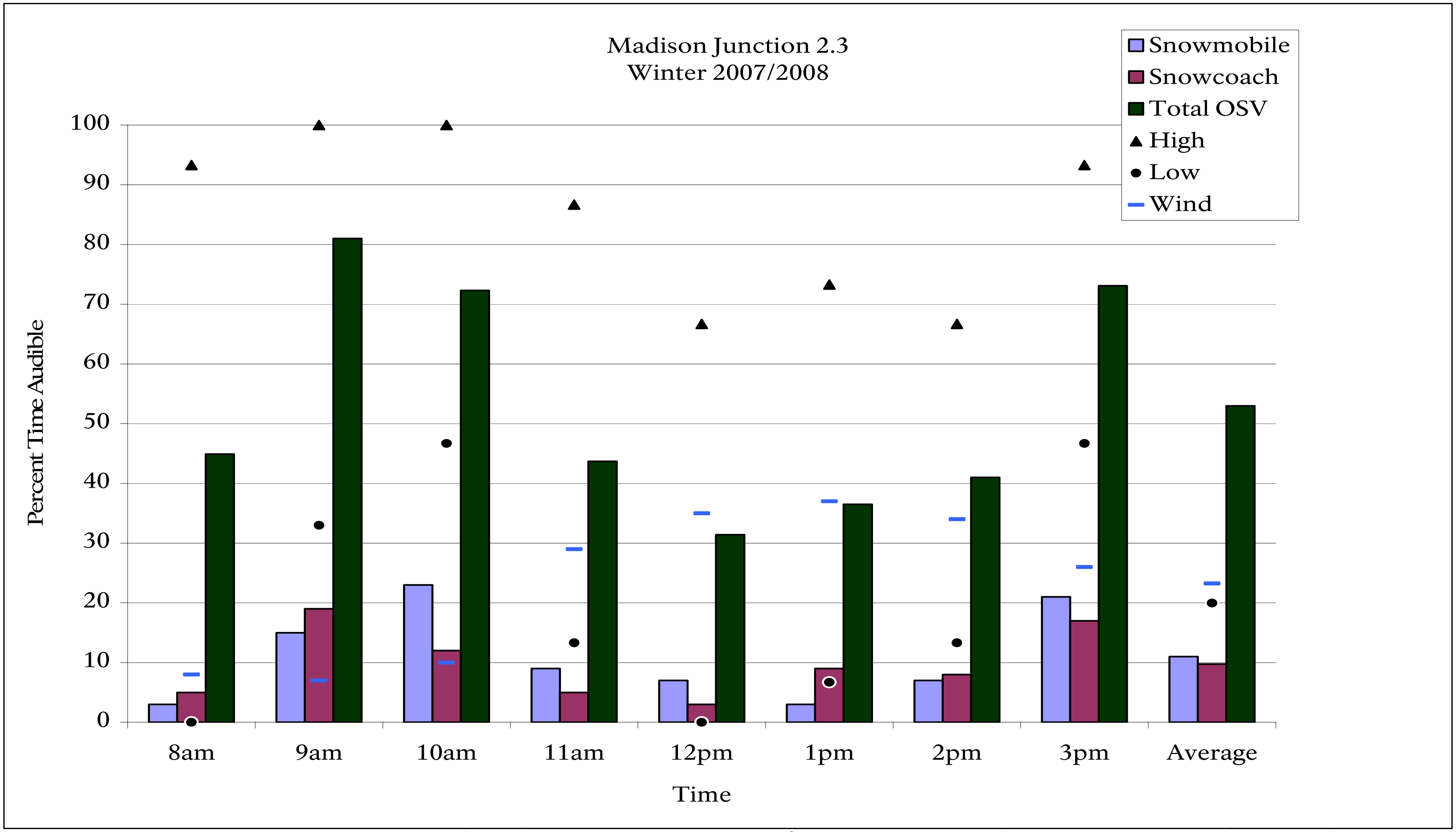


Figure 6. The average percent time audible by hour (8 am-4 pm) of snowmobiles and snowcoaches, and high and low OSV values at 2.3 miles (3.7 km) west of Madison Junction along the West Entrance Road Yellowstone National Park, 19 December 2007- 8 March 2008.

Grant Village Lewis Lake

The Grant Village Lewis Lake monitoring site was chosen to represent the busy travel corridor between the South Entrance and West Thumb. This site was one mile (1.6 km) north of the Heart Lake trailhead. Popping trees, birds, wind, and snowfall were audible along with oversnow vehicles. The average percent time audible for all OSVs was 37% (Fig. 7). There was a high variability among days at this site mainly a result of a strong association with wind. Days with little wind had high OSV audibility and days with considerable wind masked distant, but otherwise audible OSVs. This site experienced stronger wind during a higher proportion of days than the other two winter-long monitoring sites (Fig. 7). The average percent time audible adaptive management threshold of 50% for OSVs for travel corridors was exceeded on three (14%) of the 22 days that were analyzed (Fig. 7).

The expected travel corridor strongly bimodal pattern is again shown by the hourly percent time audible (Fig. 8). This pattern is weaker at locations farther from the park's entrances and stronger nearer the park entrances. The site also demonstrates that many OSVs were audible for long distances as shown by the large proportion of OSVs that could not be specifically identified due to their low sound levels. OSVs are generally audible at greater distances at sites with the lowest ambient sound levels. The average percent time audible adaptive management threshold of 50% for OSVs for travel corridors was exceeded during hours of 10, 2 and 3 (Fig. 8).

See Appendix D for additional information about the soundscape at this and other sites.

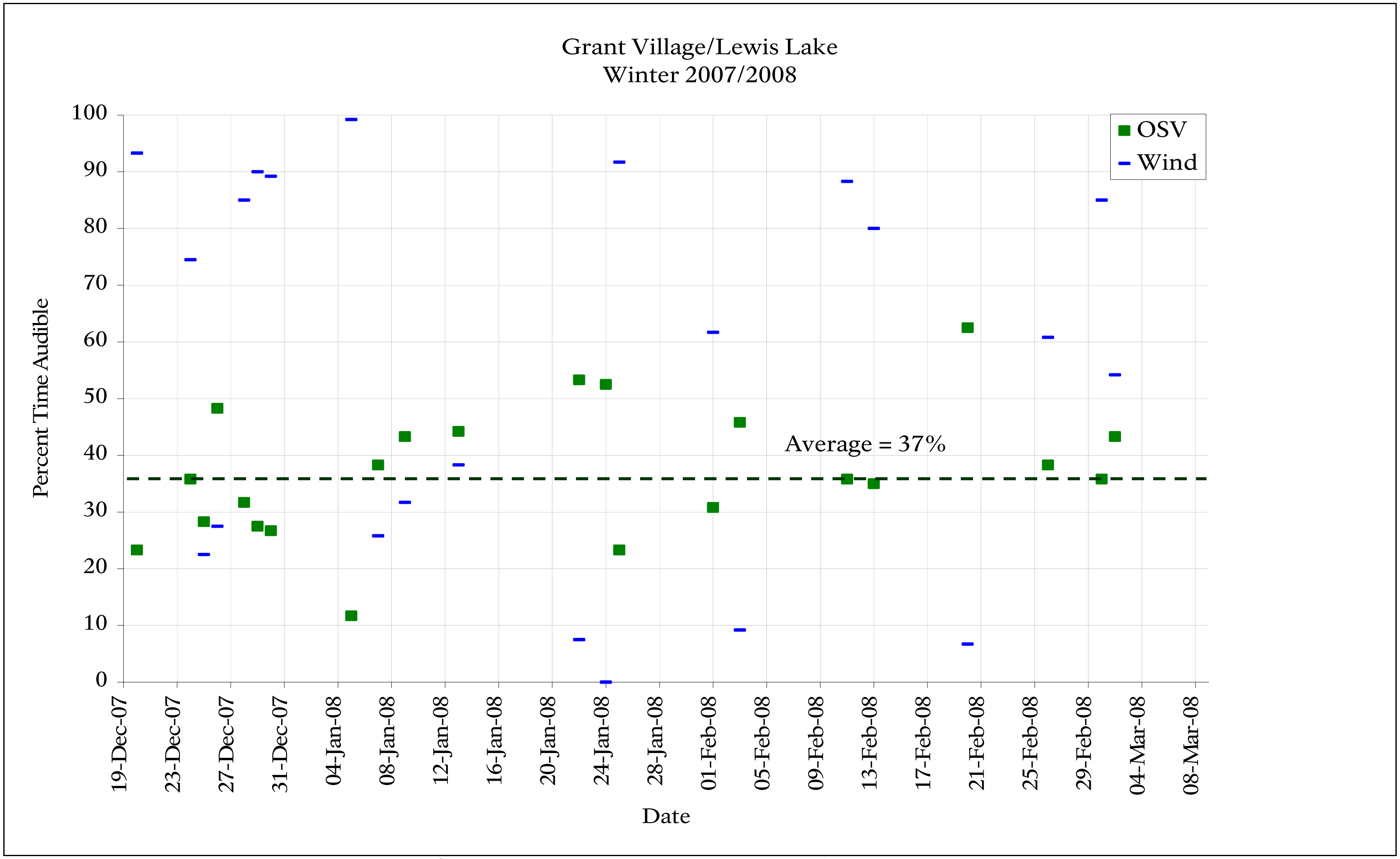


Figure 7. The percent time audible of snowmobiles, snowcoaches, and wind by date at Grant Village Lewis Lake, Yellowstone National Park, (8 am-4 pm), 20 December 2007-2 March 2008.

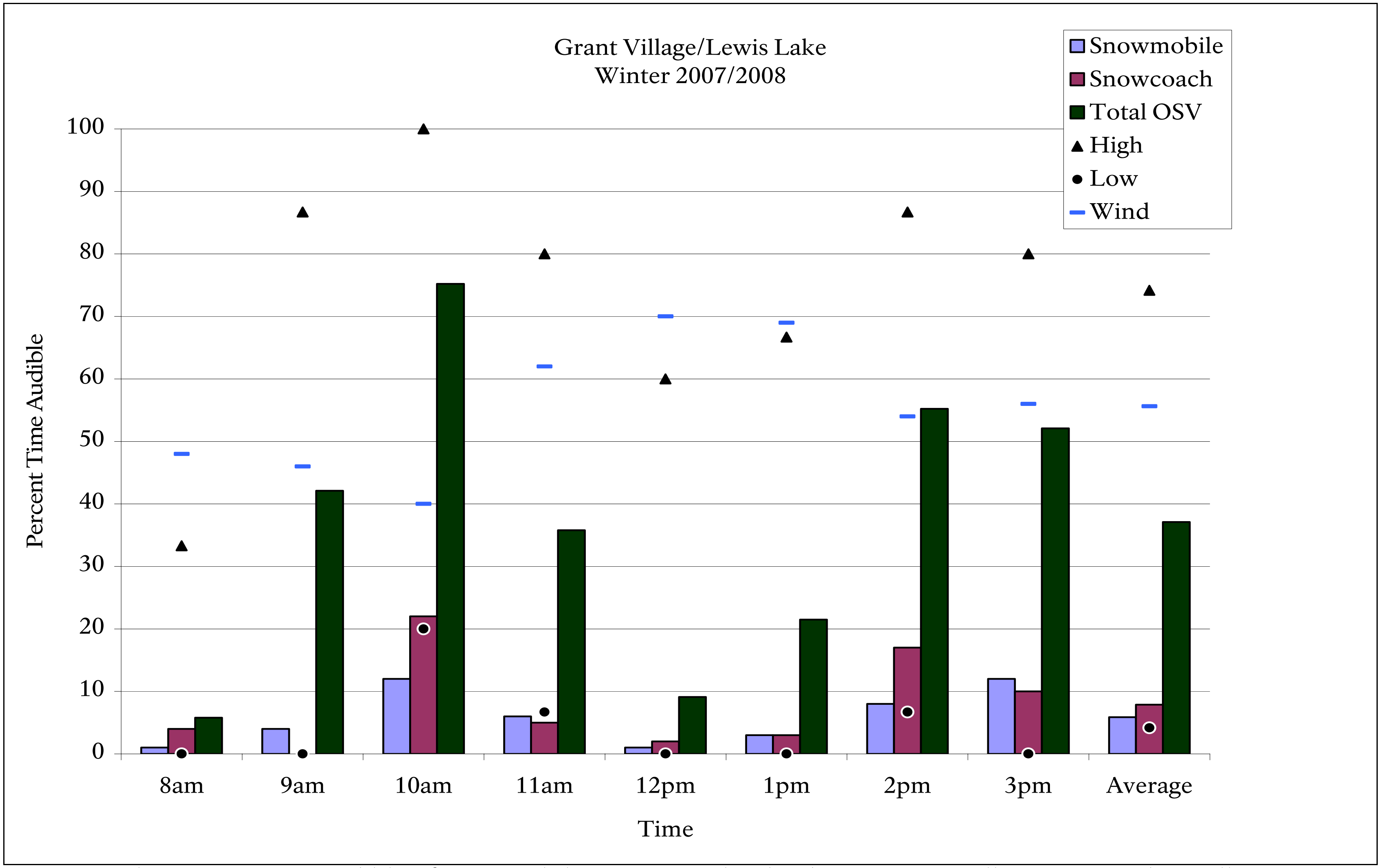


Figure 8. The percent time audible of snowmobiles, snowcoaches by date at Grant Village Lewis Lake, Yellowstone National Park, (8 am-4 pm), 20 December 2007-2 March 2008.

Shoshone Geyser Basin: Short-term measurements

Seven days of acoustic data were collected at this backcountry site (Fig. 1, #19). Although this site was located over five miles (8 km) from the groomed road between West Thumb and Old Faithful, distant OSV sounds were faintly audible along with the more prominent wind and geothermal sounds. Geothermal activity was often audible unless masked by frequent and strong wind. Oversnow vehicles were audible for an average of 18% of the time between 8 am and 4 pm (Fig. 9).

The percent time audible by hour had a weak bimodal distribution near the noon hour (Fig. 10). This is consistent with locations far from a park entrance and close to a major destination such as Old Faithful. OSVs were more audible in the morning than afternoon, likely because wind increased in the afternoon and masked faint sounds.

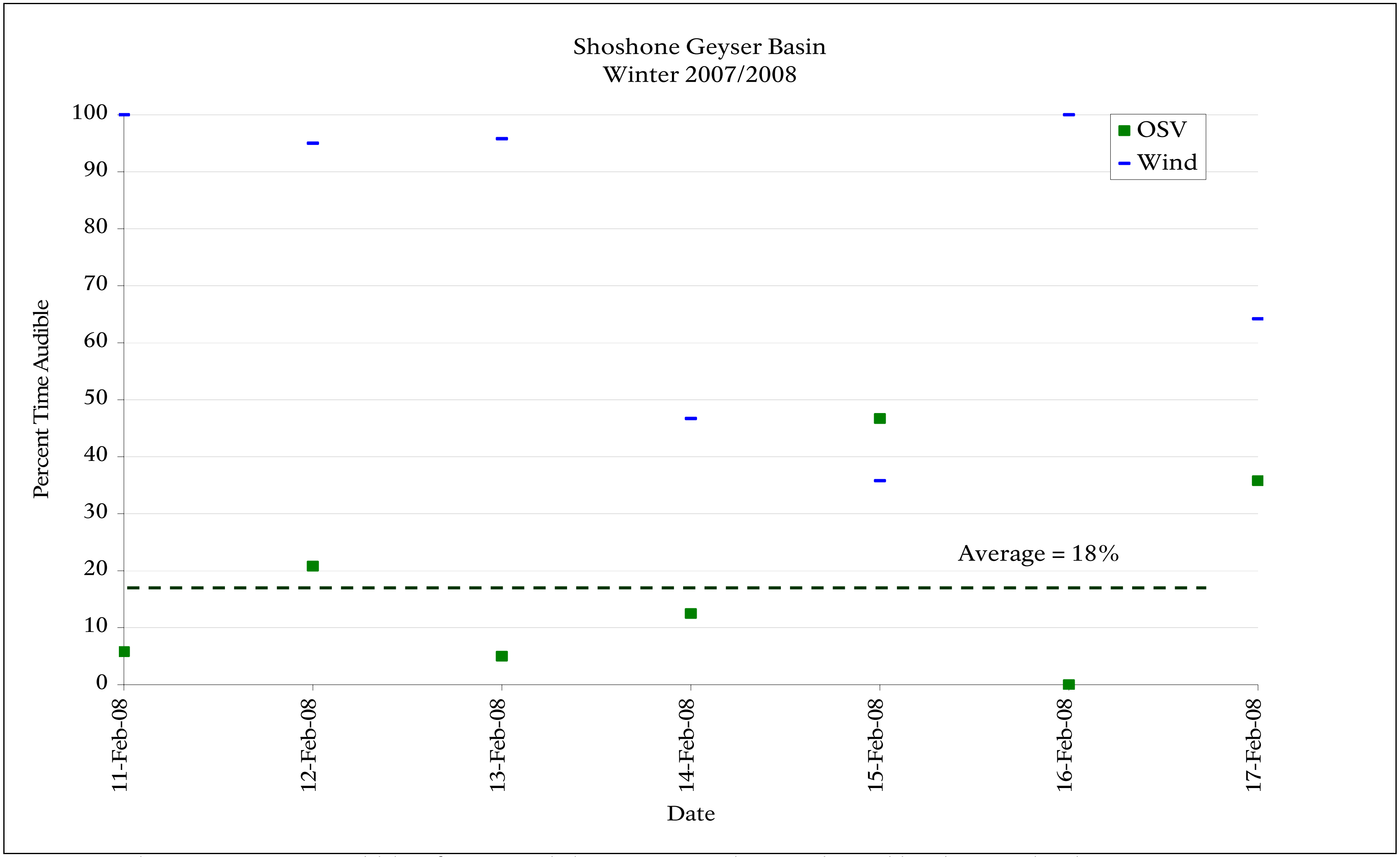


Figure 9. The percent time audible of snowmobiles, snowcoaches, and wind by date at Shoshone Geyser Basin, Yellowstone National Park, (8 am-4 pm), 11-17 February 2008.

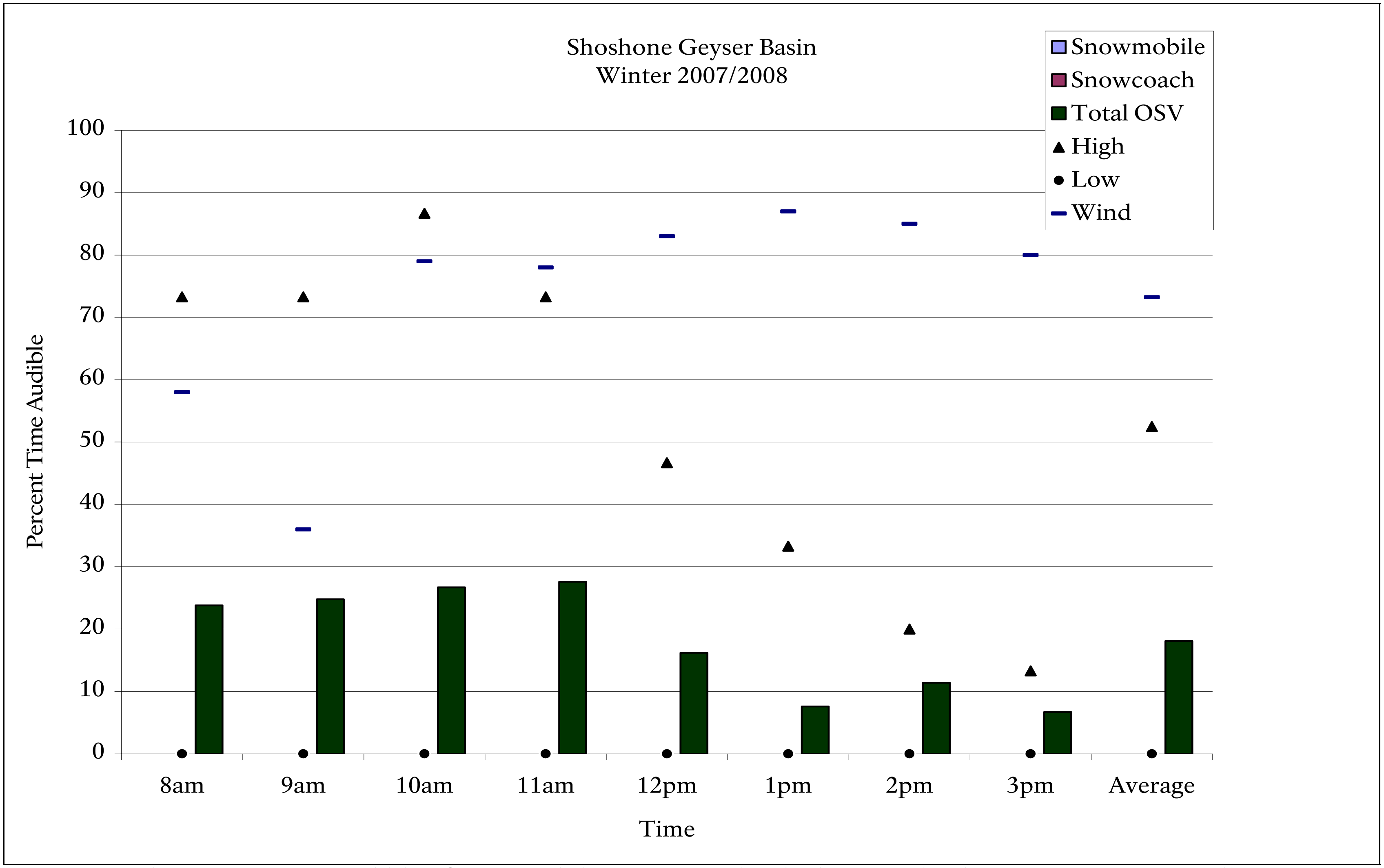


Figure 10. The percent time audible of snowmobiles, snowcoaches by hour at Shoshone Geyser Basin, Yellowstone National Park, (8 am-4 pm), 11-17 February 2008.

Delacy Creek Trail: Short-term measurements

The sound monitor at Delacy Creek Trail was in the transition management zone one mile (1.6 km) from the nearest OSV corridor (the road between West Thumb and Old Faithful) (Fig 1, #1). This site was along the travel corridor nearest Shoshone Geyser Basin site. The same OSVs that were audible at Shoshone Geyser Basin would pass by this Delacy Creek Trail monitor. Four days of acoustic data were analyzed for OSV audibility at this site. Wind, bird vocalizations, and distant OSV sounds defined the soundscape at this location during these four days. Oversnow vehicles were audible for an average of 20% of the time between 8 am and 4 pm (Fig. 11).

The percent time audible by hour had a weak bimodal distribution near the noon hour (Fig. 12). This is consistent with locations far from a park entrance and closer to a major destination such as Old Faithful.

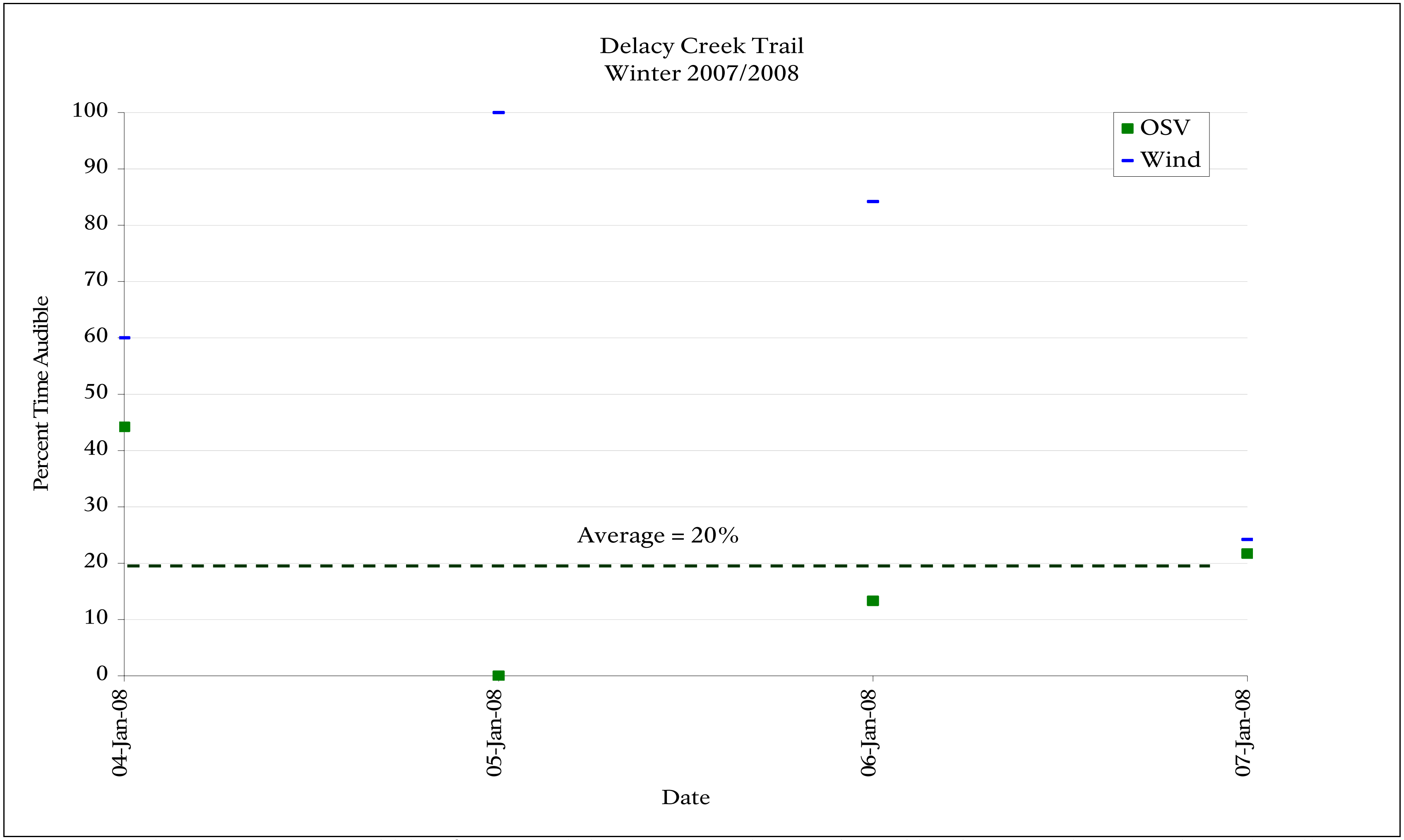


Figure 11. The percent time audible of snowmobiles, snowcoaches, and wind by date at Delacy Creek Trail, Yellowstone National Park, (8 am-4 pm), 4-7 January 2008.

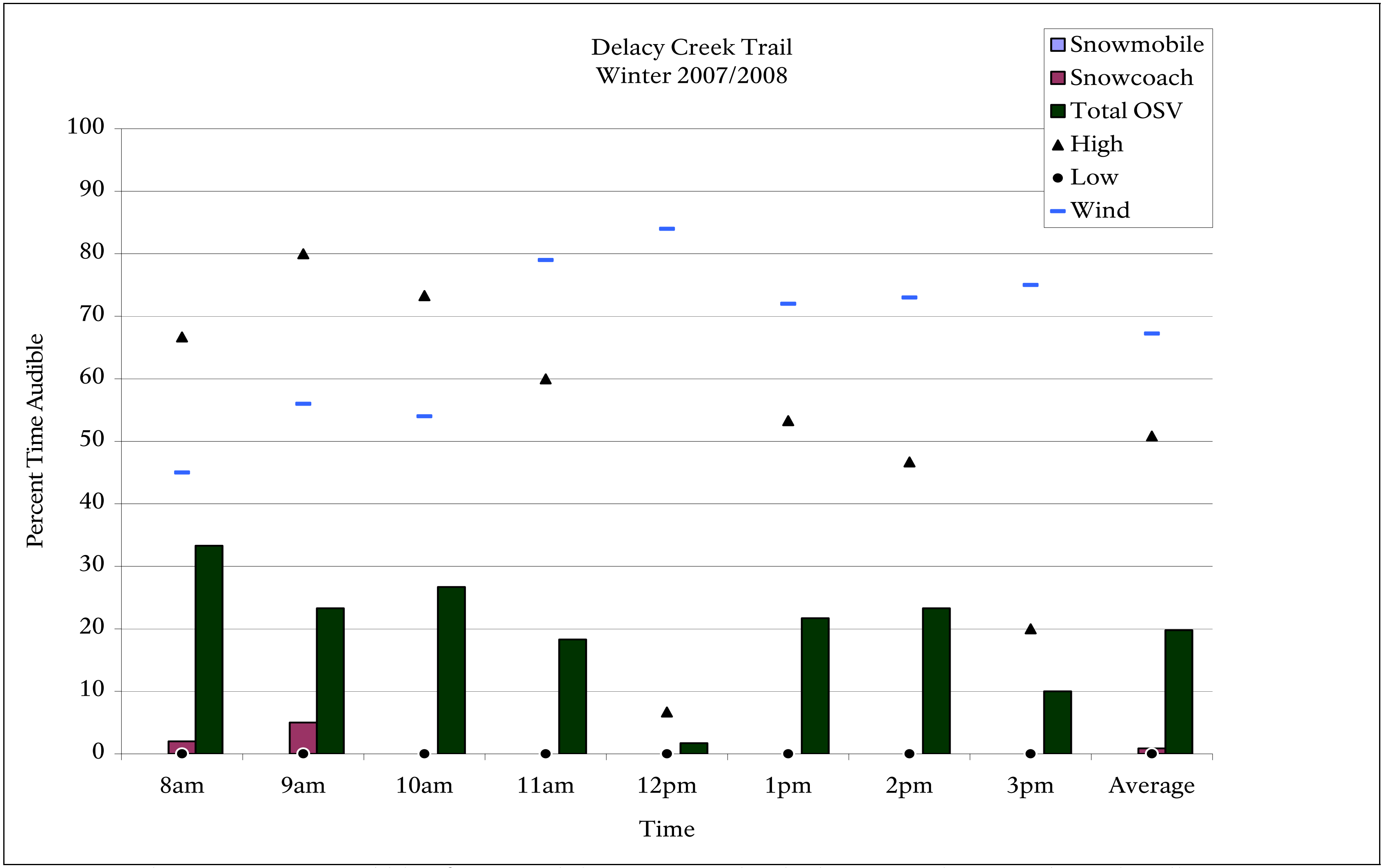


Figure 12. The percent time audible of snowmobiles, snowcoaches by hour at Delacy Creek Trail, Yellowstone National Park, (8 am-4 pm), 4-7 January 2008.

Mary Mountain 8K: Short-term measurements

The sound monitor at Mary Mountain was in the backcountry about 1.6 miles (2.6 km) from the nearest OSV corridor (the busy travel corridor between Madison Junction and Old Faithful) (Fig 1, #11). Seven days of acoustic data were analyzed for OSV audibility at this site. OSV sounds were audible for 26% of the day (8 am to 4 pm), along with frequent wind (Fig. 13) and birds. Several coyotes and wolves were also recorded. The OSV percent time audible was also 26% during a previous winter's long-term measurement period during January-February 2005 (Burson, 2005).

The audibility of OSV sounds by hour appears closely related to the percent time that wind is present at the site (Fig. 14). Wind would be expected to mask low sound level OSV sounds at this location 1.6 miles from the OSV corridor. OSVs became less audible as wind became more audible and increased in speed as the day progressed. A weak bimodal distribution may also be present following the general daily pattern of OSV travel to and from Old Faithful.

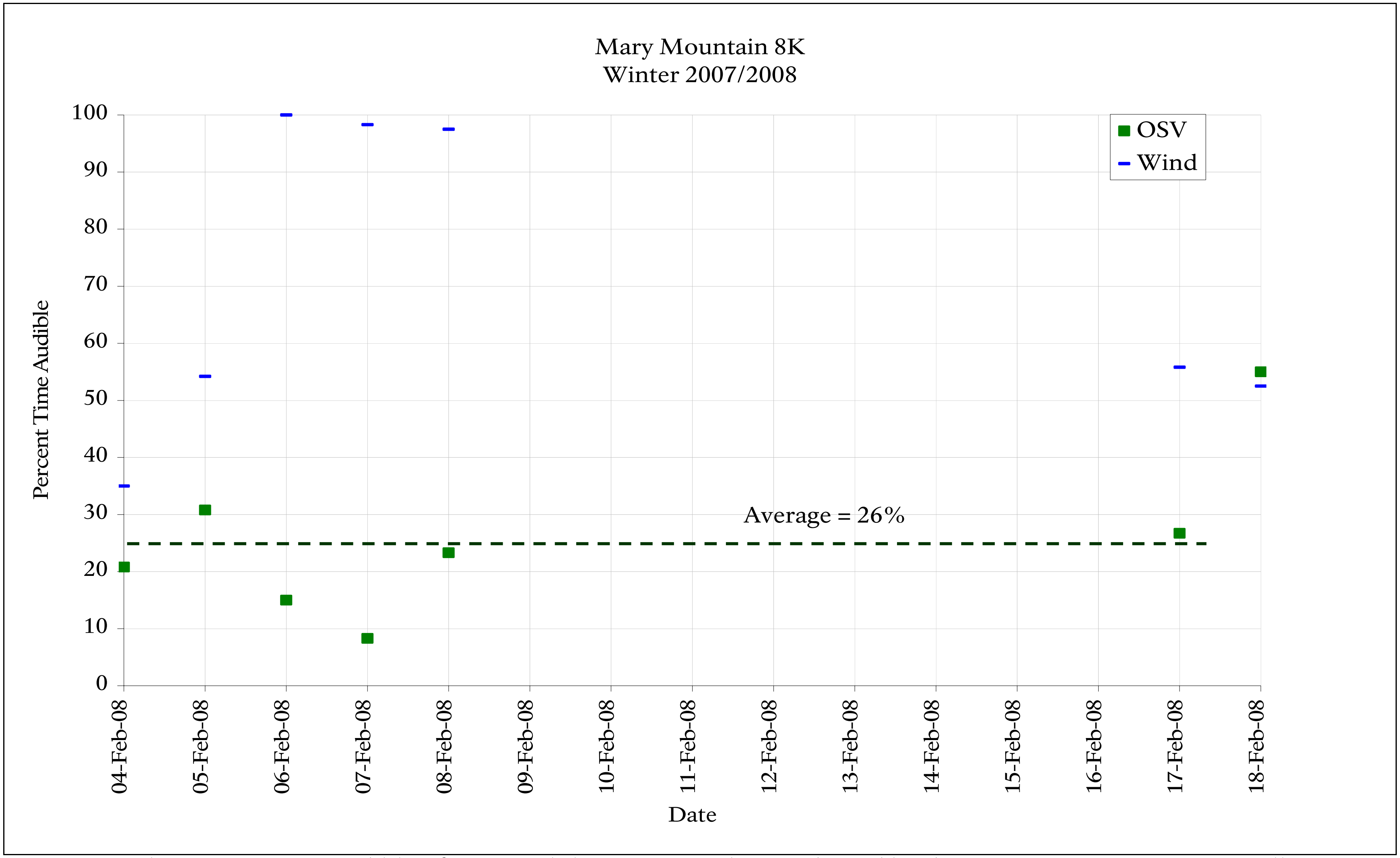


Figure 13. The percent time audible of snowmobiles, snowcoaches, and wind by date at Mary Mountain 8K, Yellowstone National Park, (8 am-4 pm), 4-18 February 2008.

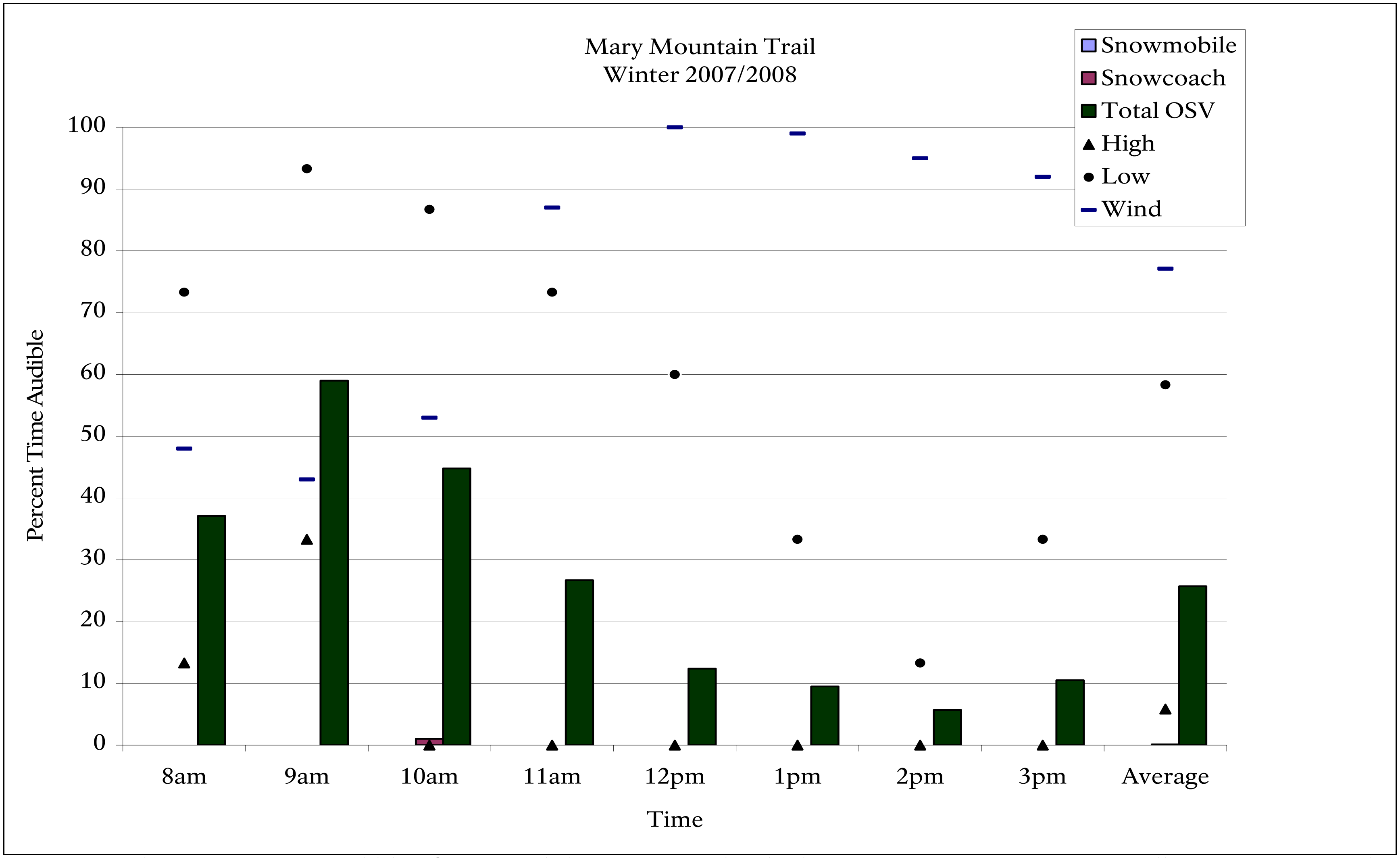


Figure 14. The percent time audible of snowmobiles, snowcoaches by hour at Mary Mountain 8K, Yellowstone National Park, (8 am-4 pm), 4-18 February 2008.

Audibility Trends

Oversnow audibility is summarized for 16 locations in Yellowstone National Park during the past five winters (Table 4). These locations include the four acoustic management zones (developed, travel corridors, transition and backcountry). The monitoring sites in Table 4 are ordered left to right from most busy (closer to OSV activity or busier road corridor) to most distant to OSV activity. Interpret sites with small sample sizes, those with seven or fewer days of data, with caution. Acoustic conditions vary widely due to wind and other atmospheric conditions, and depend on the daily number of OSVs; therefore small sample sizes often do not represent typical or average acoustic conditions.

The percent time audible values illustrate the expected pattern that sites farthest from OSV activity have the lowest OSV audibility. Based on all monitoring data, the average percent time audible was 61% for developed areas, 42% for travel corridors, 20% for transition zone, and 15% for backcountry areas. Sites that had more than seven days of analysis had consistent audibility values when monitored in multiple years. Sites along the same segment of road (WY31 and MJ12) 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. The Shoshone Geyser Basin (SHGB) monitoring site was five miles from the busy Old Faithful to West Thumb road. The two Spring Creek sites (SPCR and SPC2) were 100 feet from this same road. The monitor at Lone Star Geyser (LSGY) was also along this route one mile from the road. Topography and frequent prolonged geyser activity were likely the reasons that OSVs were less audible at Lone Star Geyser than at Shoshone Geyser Basin more than four miles farther from the road.

Table 4. Percent time audible of oversnow vehicle sounds at monitoring sites by management zone during five winters (2003-2007), 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	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%	
Site Average	67%	55%	57%	55%	34%	44%	37%	26%	32%	32%	13%	20%	4%	26%	18%	0%
Management Zone Average		61%						42%					20%			15%

	# of Oversnow Vehicles (OSVs) /day		
	Snowmobile	Snowcoach	All OSVs incl. OF[5]
2003-2004	254	23	281
2004-2005	206	25	236
2005-2006	267	30	302
2006-2007	299	30	336
2007-2008	290	32	338
Average	263.2	28	298.6

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; MMTR-Mary Mountain Trail; OFUB- Old Faithful Upper Basin; MM4K-Mary Mountain 4K; DLCR-Delacy Creek Trail; LSGY-Lone Star Geyser Basin; MM8K-Mary Mountain 8K; SHGB-Shoshone Geyser Basin; FLBC-Fern Lake Backcountry
2	Sites ordered from left to right, busiest to less busy
3	Sites ordered from left to right, closest to motorized route to most distant
4	Red underlined indicates 7 or fewer days analyzed; Double red underlined indicates 1 or 2 days only
5	Number of OSVs originating at Old Faithful prior to 2006-2007 were estimated

Event Analysis:

The loudest sound events at each site were recorded and later identified. NPS snow groomer events were often one of the louder events, but mainly occurred outside the WUP day (8 am to 4 pm). Event threshold triggers were maintained just above the level that prevented wind contamination from creating the majority of the events. Event analysis augments audibility analysis by distinguishing the loudest sound sources from those less loud. Table 5 lists the loudest sound sources by number of occurrences and percent of all loud sources. Madison Junction 2.3 was 100 feet (30 m) from a 35 mph zone and Grant Village Lewis Lake a 45 mph zone; both in travel corridors. The Grant Village Lewis Lake monitoring site recorded many loud Bombardier snowcoaches at cruising speed. The Madison Junction 2.3 monitor recorded several two-stroke snowmobiles. No loud motorized events occurred at the backcountry Delacy Creek, Mary Mountain 8K or the Shoshone Geyser Basin monitoring sites and therefore are not included here. The Old Faithful Weather Station site was 230 feet (70 m) from the nearest motor route. The distance and slow OSV speeds caused few loud events to be recorded there.

Table 5. The number and percentage of sound events exceeding user-defined thresholds of sound level and duration at two locations in Yellowstone National Park (8 am to 4 pm). These represent the loudest sounds recorded at these locations during the 2007-2008 winter use season.

	Grant Village Lewis Lake[1]		Madison Junction 2.3[1]	
Sound Source	Number	%	Number	%
Snowmobile	15	6	4	4
Snowcoach	216	93	94	92
Snow Groomer	2	1	4	4
Total	233	100	102	100

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

Sound Levels:

Sound level analysis is not as easily understood as audibility analysis. The WUP adaptive management thresholds apply only to oversnow vehicles (snowmobiles and snowcoaches), but occasional natural sounds (wind, bird vocalizations, etc.) and other motorized sounds (aircraft, snow groomer, etc.) may be as loud as oversnow vehicle sounds during some periods and in some locations. Therefore the sound levels for oversnow vehicles should be separated from other sounds before evaluating them against sound level thresholds. Unfortunately there is yet no automated process for separating different sound sources from the sound level data and the manual separation of oversnow vehicles sound levels during the nearly 21 million seconds of data collected this past winter in this study is practically impossible. Therefore the interpretation of sound levels becomes more difficult. In the developed areas and along travel corridors the loudest sounds during 8 am-4 pm were almost always from oversnow vehicles, but as distance increased from these motorized areas natural sounds were sometimes louder than oversnow vehicle sounds. Sound levels (decibels) of some common sound sources are shown in Table 5.

The adaptive management plan within the 2007 Winter Use Plan Environmental Impact Statement of Yellowstone (YNP) and Grand Teton National Parks and the John D. Rockefeller, Jr., Memorial Parkway (NPS 2007) set maximum sound level thresholds for oversnow vehicles as measured in the four acoustic management zones. These thresholds are 70 dBA in developed areas and travel corridors, 65 dBA in the transition zone, and the natural ambient sound level in backcountry areas (Table 1). To compare to previous winter use plans' standards and thresholds see Appendix C.

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

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

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

Returning to the complications of evaluating these sound level results, the L_{90} is the NPS (and other organizations) standard for use as an analog to the natural ambient sound level in locations other than those most heavily impacted from non-natural sounds and when other more site specific calculations are not possible. However, using L_{90} or other L_x metrics as the natural ambient sound level is inappropriate in locations with constant non-natural sounds such as at the Old Faithful Weather Station monitoring site. In very quiet areas the L_{90} may overestimate the true natural ambient sound level because of limitations of the instrument noise floor threshold. The noise floor, the lowest level the acoustic equipment could measure, was approximately 19-20 dBA (see Table 6 for reference levels). The quietest sound levels in YNP are below this noise floor (Burson 2006) so the lowest documented measurements in this report likely overestimate the actual minimum sound levels. While there is no easy solution to these problems, the disadvantages of any one metric can be reduced by using multiple sound level metrics.

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

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

dBA	Perception	Outdoor Sounds	Indoor Sounds
130	Painful		
120	Intolerable	Jet aircraft at 50 ft	Oxygen torch
110	Uncomfortable	Turbo-prop at 200 ft	Rock Band
100		Jet flyover at 1000 ft	Blood-curdling scream
90	Very noisy	Lawn mower/Nearby Thunder	Hair dryer
80		Diesel truck 50 mph 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	

Old Faithful Weather Station

The average hourly sound levels by month from the soundscape monitoring at Old Faithful Weather Station are shown in Figures 15-18 for the winter 2007-2008. The Old Faithful monitor was 230 feet (70 m) from the entrance/exit road used by oversnow vehicles. The 2007 WUP adaptive management thresholds assume a distance of 100 feet (30 m) from the sound source in developed areas. In a free-field, sound levels decrease by approximately 6 dBA for every doubling of the distance from the source to the receiver. Therefore to compensate for the additional distance from the sound monitor using the reasonable assumption that the maximum sound levels originate from oversnow vehicles traveling 230 feet (70 m) from the sound monitor, adding an additional 6 dBA to the maximum sound levels shown in the following figures would approximate the levels at 100 feet (30 m). This assumption is reasonable only for L_{max} because it is likely that lower sound levels commonly originate from areas other than the exit road such as the parking lot, the main road, the other sources near the sound monitor, and thus the source, distance and therefore the correction factors are unknown.

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

The lowest sound levels (about 22 dBA) were determined by the nearly constant utility sounds (exhaust and heating fans) from the Snow Lodge and Old Faithful Ranger Station (Fig. 15-18).

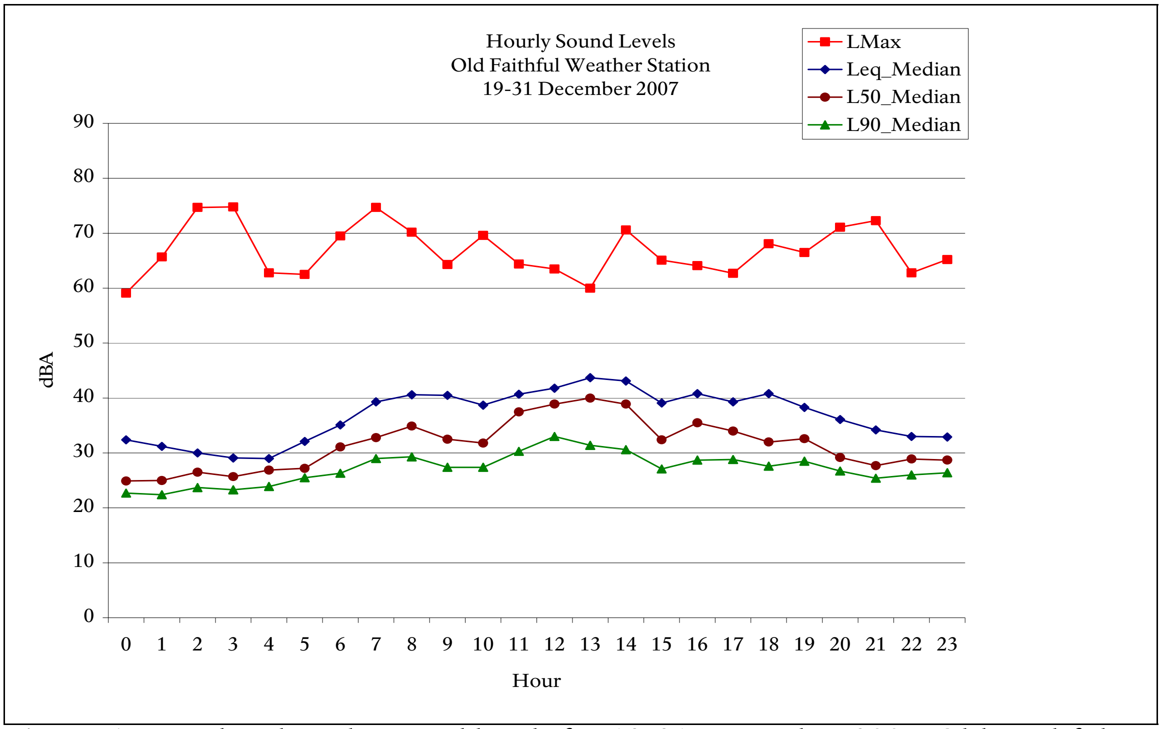


Figure 15. Median hourly sound levels for 19-31 December 2007, Old Faithful Weather Station, Yellowstone National Park. These sound levels include all natural and non-natural sounds. L_{max} is the highest sound level measured during each hour of the measurement period. (n=310 hours)

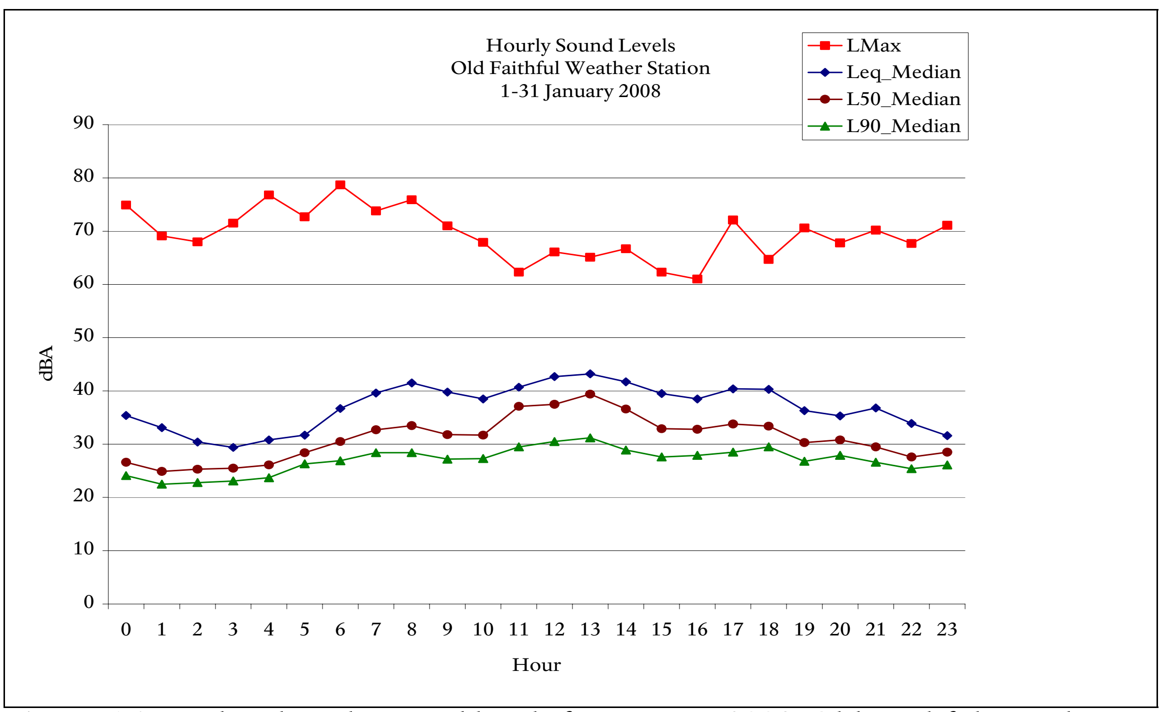


Figure 16. Median hourly sound levels for January 2008, Old Faithful Weather Station, Yellowstone National Park. See Fig. 15 caption for more details. (n=730 hours)

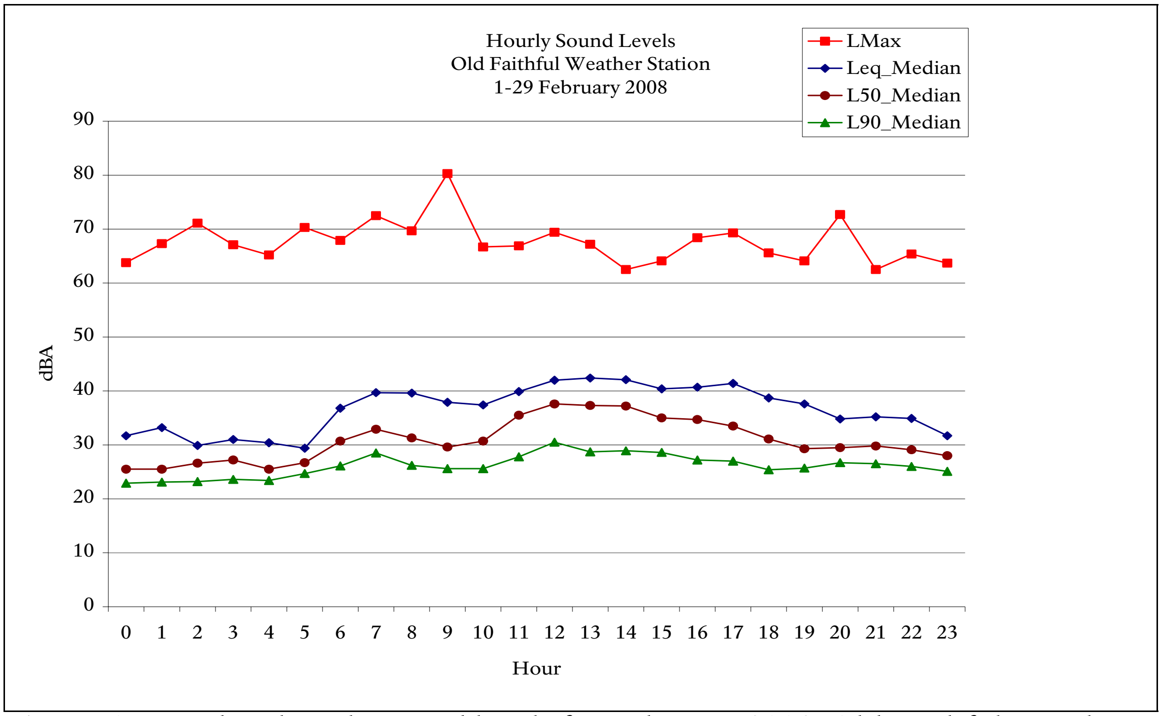


Figure 17. Median hourly sound levels for February 2008, Old Faithful Weather Station, Yellowstone National Park. See Fig. 15 caption for more details. (n=677 hours)

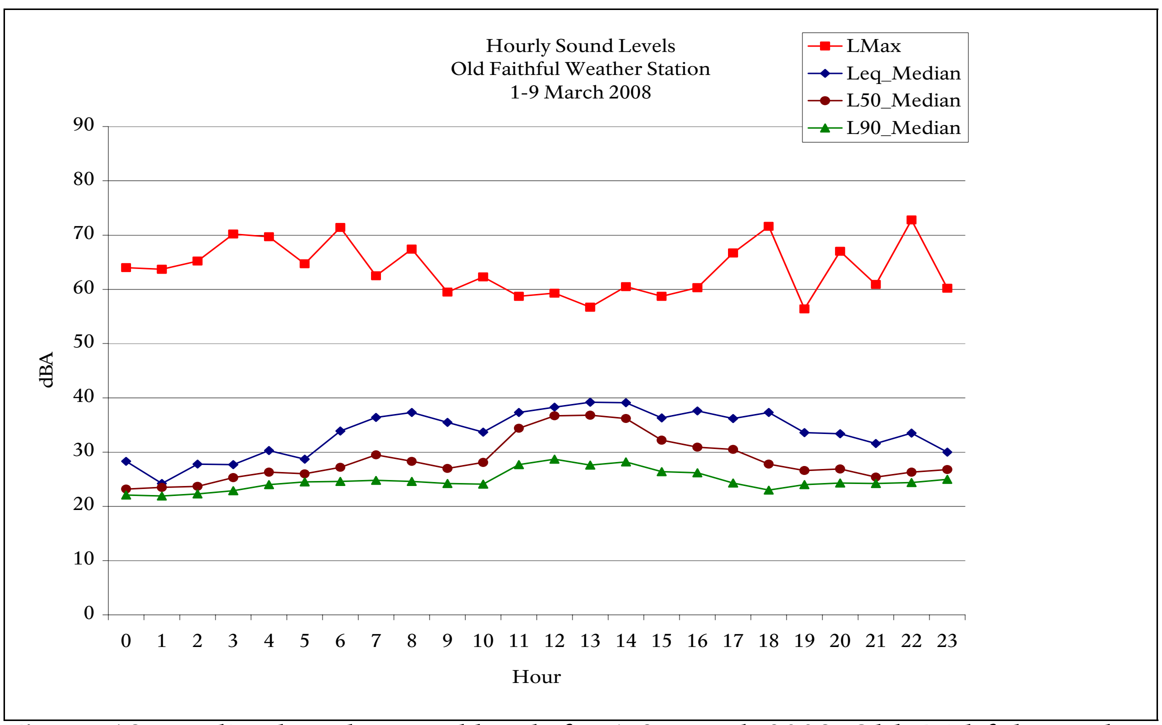


Figure 18. Median hourly sound levels for 1-9 March 2008, Old Faithful Weather Station, Yellowstone National Park. See Fig. 15 caption for more details. (n=214 hours)

Madison Junction 2.3

Consistent with previous seasons, the maximum hourly sound levels from oversnow vehicles at Madison Junction 2.3 exceeded the 2007 WUP maximum sound level adaptive management threshold (70 dBA) during most of the hours of the measurement day (8 am-4 pm) in 2007-2008 (Fig. 19-22). 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. 19-22). 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 (Fig. 19-22). Wind generally increases during the afternoons and is reflected in the median hourly L_{50} and L_{90} values (Fig. 19-22).

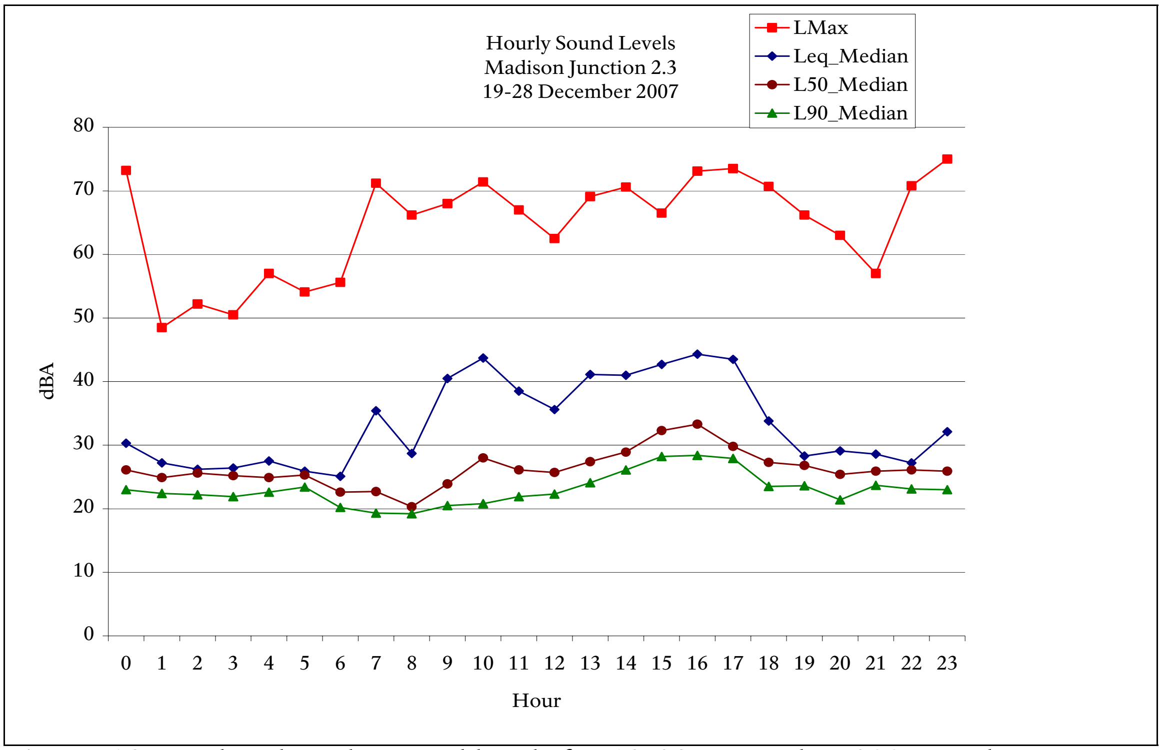


Figure 19. Median hourly sound levels for 19-28 December 2007 Madison Junction 2.3, Yellowstone National Park. See Fig. 15 caption for more details. (n=222 hours)

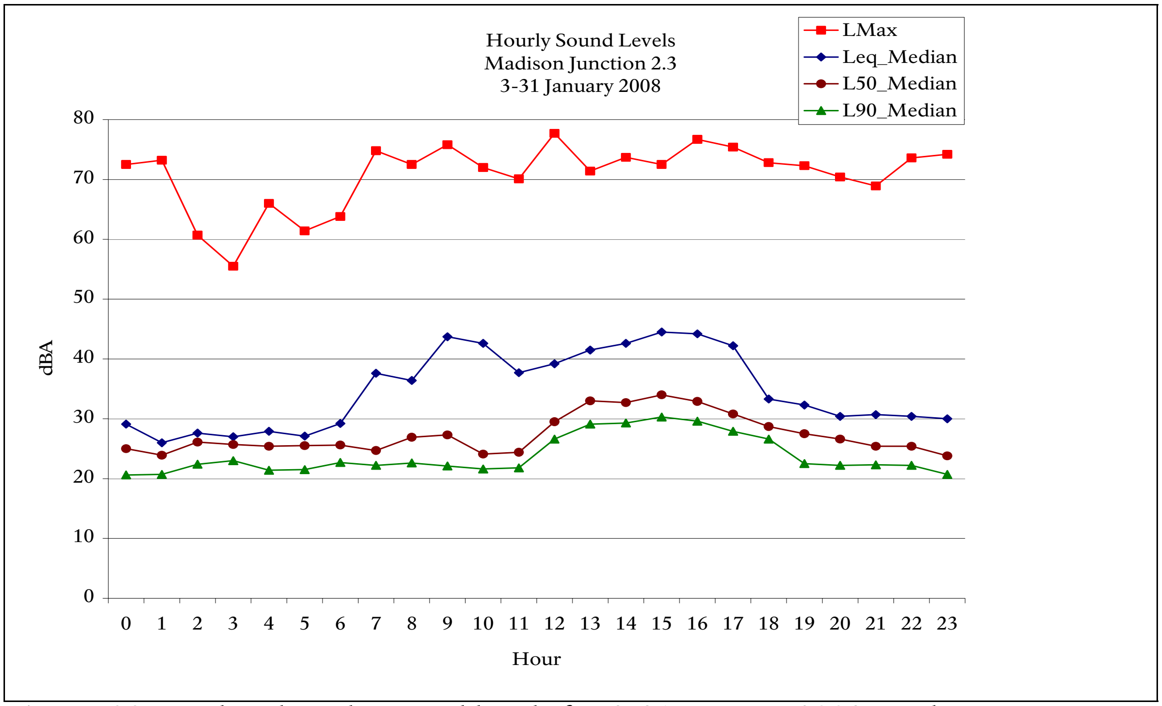


Figure 20. Median hourly sound levels for 3-31 January 2008 Madison Junction 2.3, Yellowstone National Park. See Fig. 15 caption for more details. (n=678 hours)

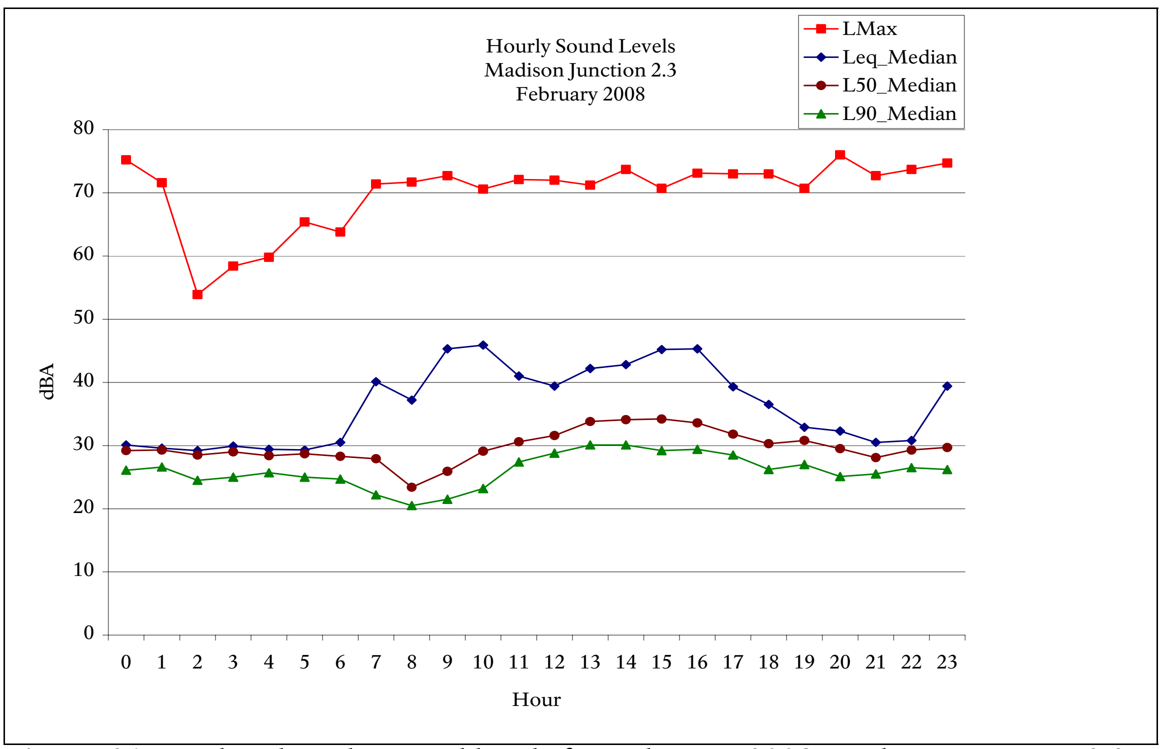


Figure 21. Median hourly sound levels for February 2008 Madison Junction 2.3, Yellowstone National Park. See Fig. 15 caption for more details. (n=633 hours)

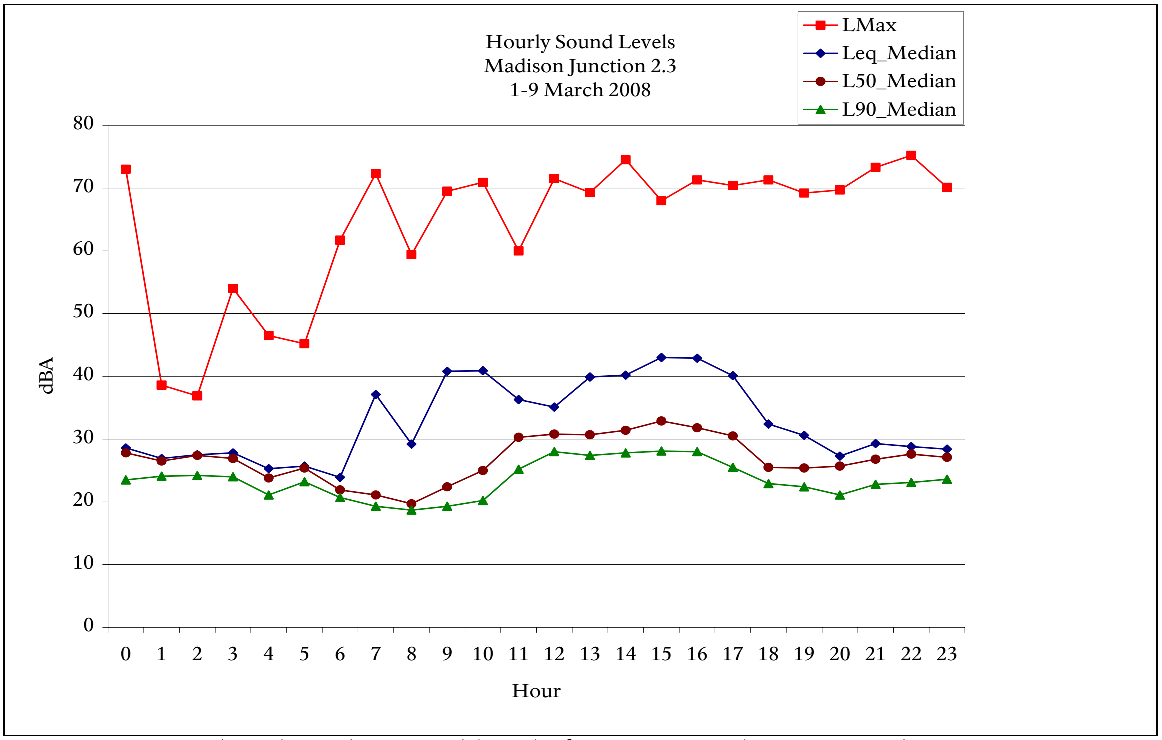


Figure 22. Median hourly sound levels for 1-9 March 2008 Madison Junction 2.3, Yellowstone National Park. See Fig. 15 caption for more details. (n=204 hours)

Grant Village Lewis Lake

The Grant Village Lewis Lake monitoring site was along a travel corridor just north of Lewis Lake between the South Entrance and Grant Village. The maximum sound levels (L_{max}) from oversnow vehicles at Madison Junction 2.3 exceeded the 2007 WUP maximum sound level adaptive management threshold (70 dBA) during most of the hours of the measurement day (8 am-4 pm) in 2007-2008 (Fig. 19-22). The tight clustering of L_{90}, L_{50}, and L_{eq} during the night indicates that this area was consistently very quiet with few loud events (Fig. 23-26). Wind and oversnow vehicles increased the sound levels during the day (Fig. 23-26). The OSV travel pattern created the familiar L_{eq} bimodal pattern. High exhaust Bombardier snowcoaches and conversion van snowcoaches traveled at cruising speeds past this monitoring site. Consistent with other similar travel corridor monitoring sites the Bombardiers were generally loudest, but most snowcoaches had higher sound levels than snowmobiles. Overall, snowcoaches were the loudest non-natural sources of sound during the day and snow groomers were the loudest non-natural source of sound outside the WUP period, 8 am – 4 pm.

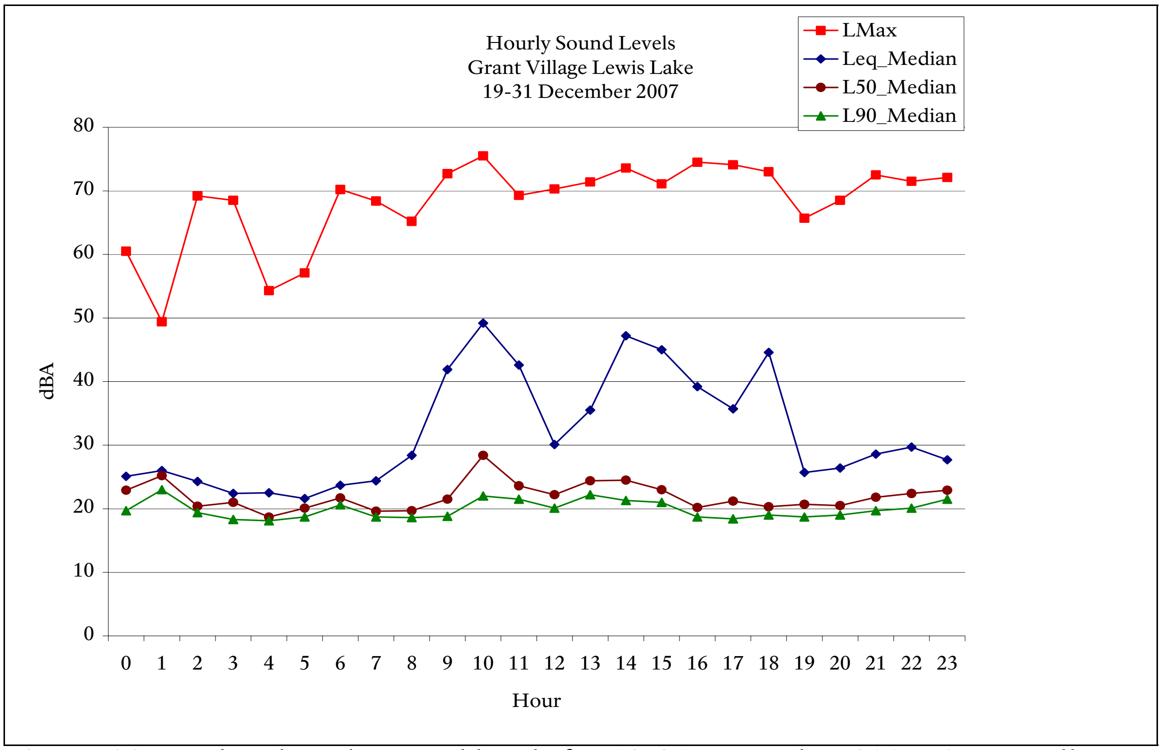


Figure 23. Median hourly sound levels for 19-31 December 2007, Grant Village Lewis Lake, Yellowstone National Park. See Fig. 15 caption for more details. (n=296 hours)

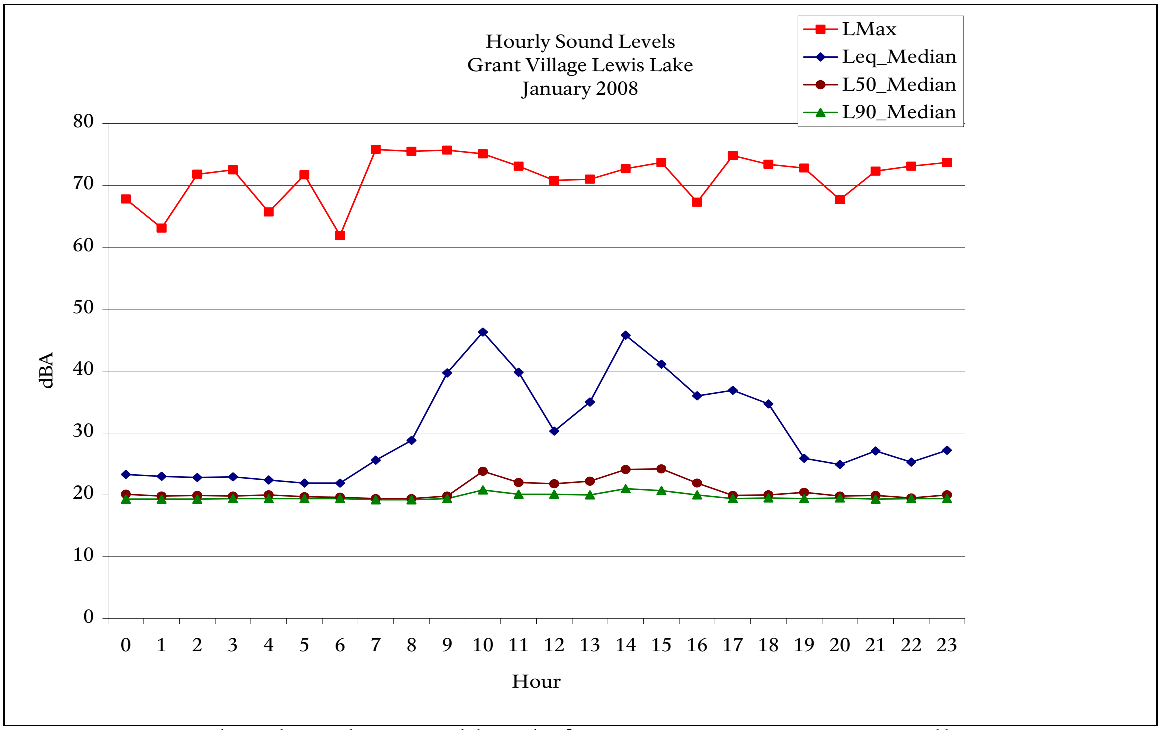


Figure 24. Median hourly sound levels for January 2008, Grant Village Lewis Lake, Yellowstone National Park. See Fig. 15 caption for more details. (n=739 hours)

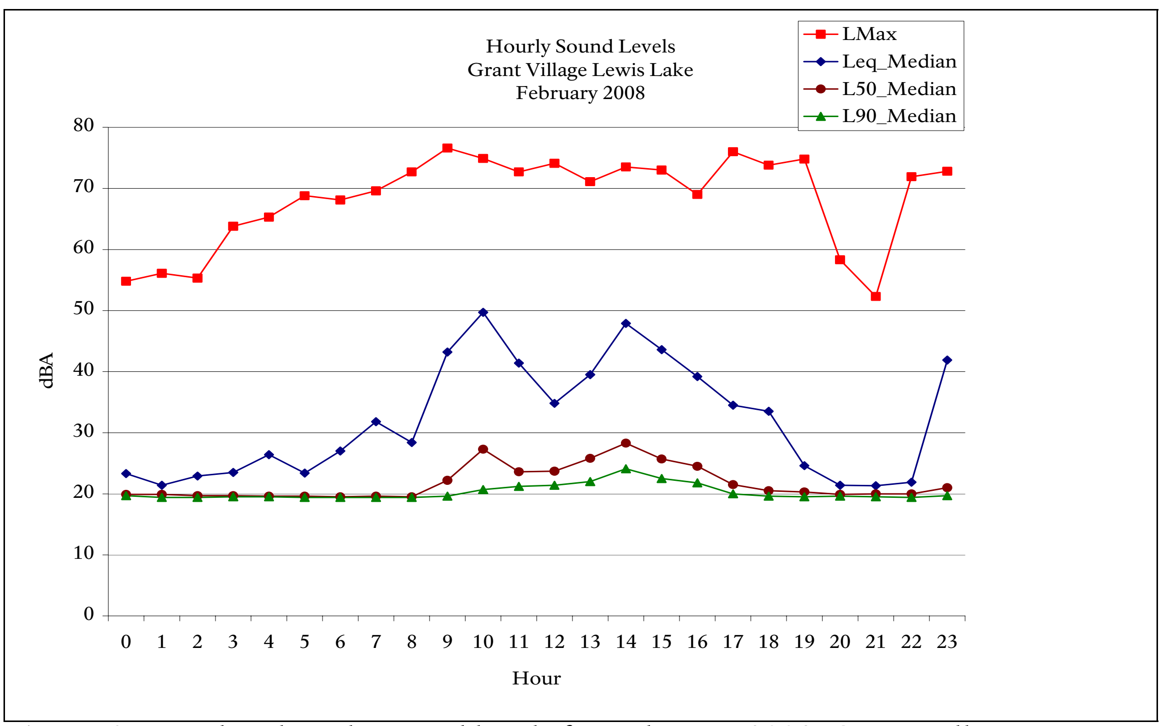


Figure 25. Median hourly sound levels for February 2008, Grant Village Lewis Lake, Yellowstone National Park. See Fig. 15 caption for more details. (n=621 hours)

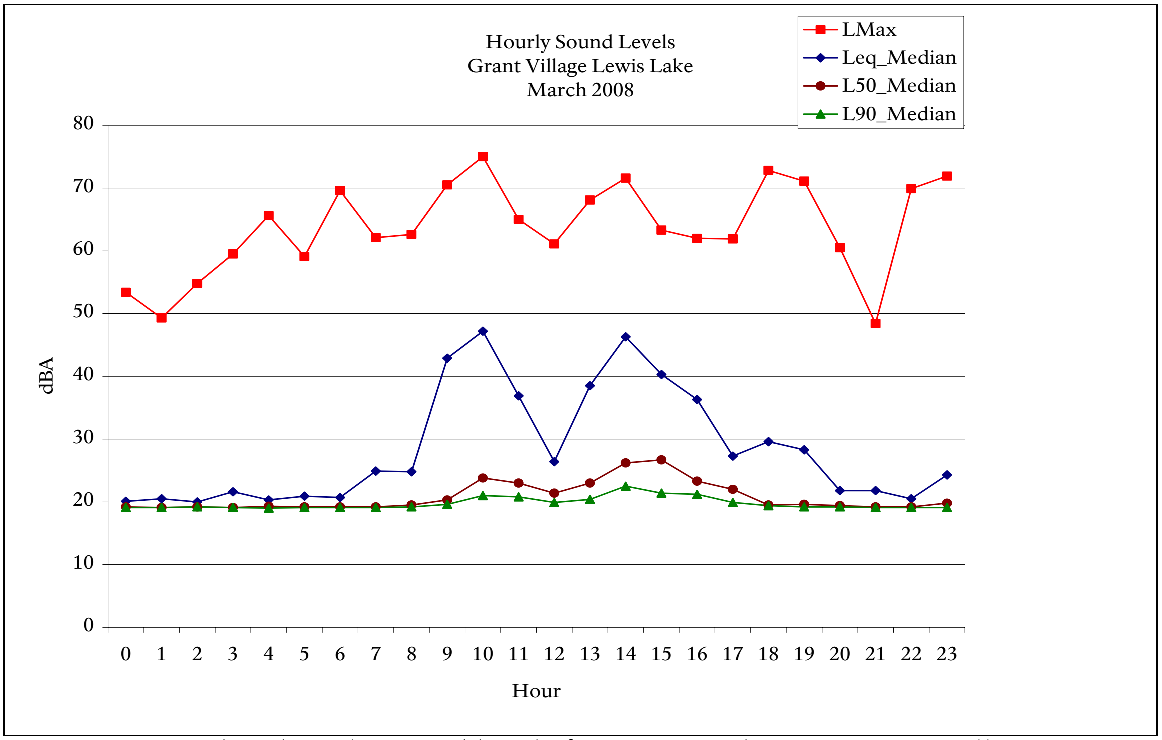


Figure 26. Median hourly sound levels for 1-9 March 2008, Grant Village Lewis Lake, Yellowstone National Park. See Fig. 15 caption for more details. (n=213 hours)

Delacy Creek Trail: Short-term measurements

The temporary sound monitor at Delacy Creek Trail was one mile (1.6 km) south of the nearest OSV corridor (the road between Old Faithful and West Thumb) (Fig 1, #1). OSVs traveling along the road corridor were frequently audible, but at low levels. The L_{90}, L_{50}, and L_{eq} were relatively spread out during most of the day indicating that this area consistently had quiet periods, but also regular louder sounds (Fig. 27). OSVs, wind, bird vocalizations, and aircraft increased the sound levels during the day, with mainly wind at night (Fig. 27).

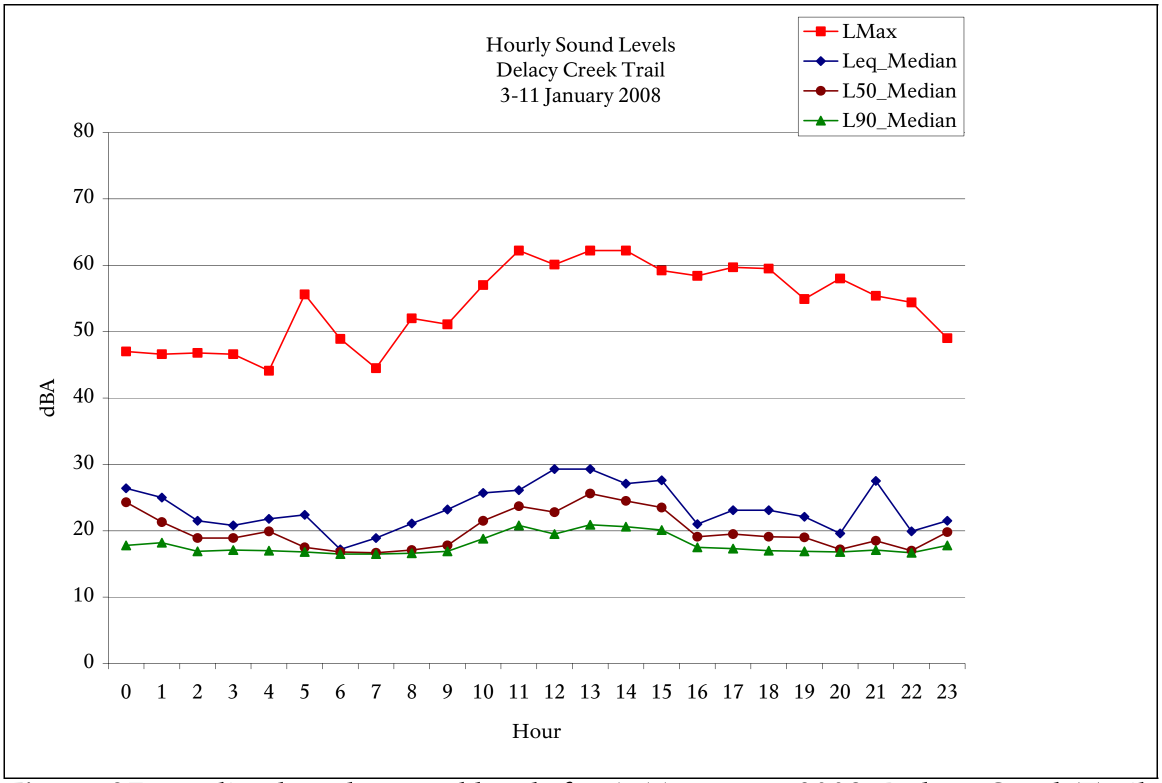


Figure 27. Median hourly sound levels for 1-11 January 2008, Delacy Creek Trail, Yellowstone National Park. See Fig. 15 caption for more details. (n=187 hours)

Mary Mountain 8K: Short-term measurements

Figure 28 shows the hourly sound levels for Mary Mountain 8K during ten days in January. The snowmobiles and snowcoaches traveling along the corridor between Old Faithful and Madison Junction (at least 1.5 miles (2.4 km) from the measurement location) were audible at this site at sound levels near the natural ambient sound level.

Similar to other backcountry sites, Mary Mountain 8K had a consistently low sound level with occasional louder sounds. The loudest sounds at Mary Mountain 8K were aircraft and wind in the trees. The nearby Nez Perce Creek constrained the lowest sound levels measured. The increase in the median hourly sound levels during the day reflects the increased afternoon wind speed.

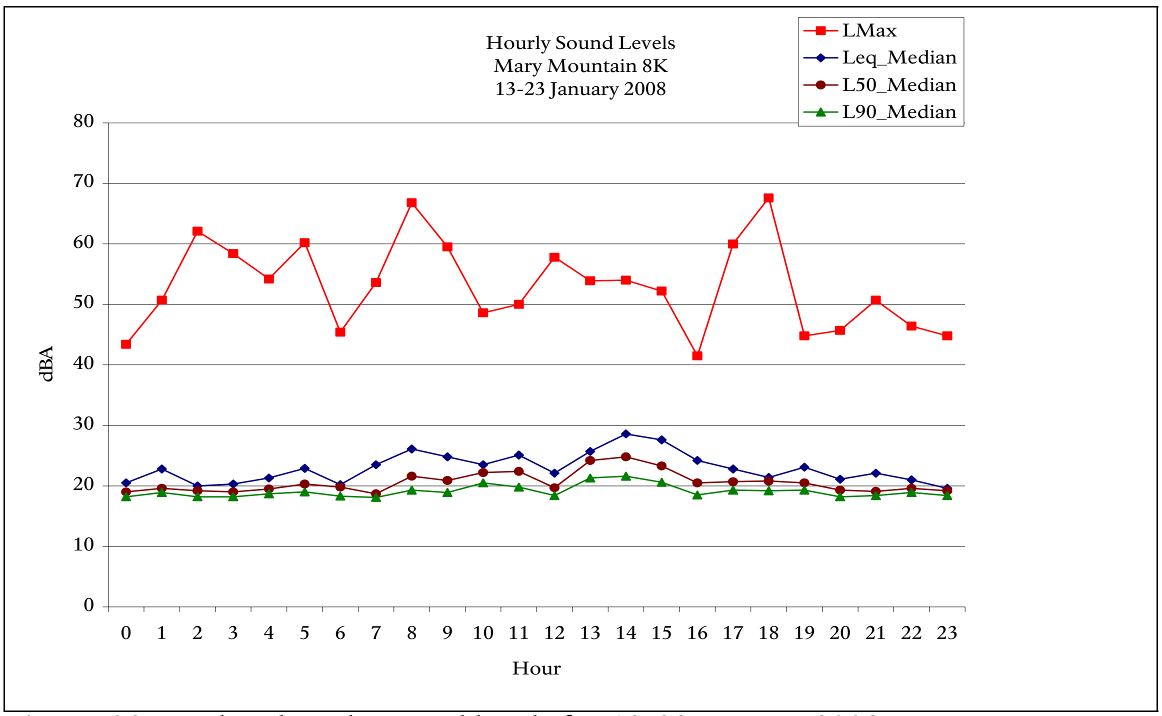


Figure 28. Median hourly sound levels for 13-23 January 2008, Mary Mountain 8K, Yellowstone National Park. See Fig. 15 caption for more details. (n=233 hours)