Natural Soundscape Monitoring in Yellowstone National Park December 2005-March 2006

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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 impact definition thresholds in the 2004 Yellowstone and Grand Teton National Park Temporary Winter Use Plans Environmental Assessment. Acoustical data were collected at five primary sites in Yellowstone National Park during the winter use season, 21 December 2005-12 March 2006.

Oversnow vehicles were audible in the Old Faithful developed area an average of 67% of the day between 8 am and 4 pm. Oversnow vehicles were audible 35% (Old Faithful Upper Basin) and 62% (West Thumb Geyser Basin) of the day within geyser basins adjacent to developed areas. Along travel corridors the percent time audible was 34% (Spring Creek) and 55% (Madison Junction 2.3). The maximum sound levels for oversnow vehicles exceeded 70 dBA at Old Faithful, along the groomed travel corridor between Madison Junction and the West Yellowstone entrance (Madison Junction 2.3) and between West Thumb and Old Faithful (Spring Creek). Sounds from both visitor and administrative oversnow vehicles were included in this study. Acoustic data from previous years is included for comparison.

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 two seasons, although there was increased audibility at two locations. The number of oversnow vehicles that entered the park increased slightly. Consistent with acoustic data collected during the previous three 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 2001 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 parts of its 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 other human activity and facility utilities in destination and support areas.

The 2000 and 2003 Winter Use Plans Environmental Impact Statement of Yellowstone (YNP) and Grand Teton National Parks and the John D. Rockefeller, Jr., Memorial Parkway concluded that historical oversnow vehicle use created unacceptable adverse impacts on natural soundscapes (and other resources). To continue to minimize the impact of sounds from oversnow vehicles (OSV) on the natural soundscape and other resources, the 2004 Temporary Winter Use Plans (WUP) Environmental Assessment established acoustical impact definition thresholds within three soundscape management areas. This Temporary WUP was in effect during the winters of 2004-2005 and 2005-2006. The impact definitions describing the acoustical thresholds of adverse major effects (Table 1) are compared to the acoustic field measurements collected in Yellowstone during the 2005-2006 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. In general, sounds from both guided visitor and primarily unguided administrative oversnow vehicles were included in the study (but see Appendix E). For comparative purposes, this report also includes similar acoustical data collected during the winters of 2002-2003, 2003-2004, and 2004-2005. See Burson (2004 and 2005) for additional information on park soundscapes during the previous winters, and the 2000 and 2003 Winter Use Plans 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 highways 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 21 December 2005 and 12 March 2006, 21,916 snowmobiles and 2,463 snowcoaches, totaling 24,379 oversnow vehicles, entered YNP (NPS unpublished data). The majority (21,851; 93.7%) of these oversnow vehicles entered through the West and the South entrances. Most of these winter visitors traveled to Old Faithful. A total of 154 snowmobiles and about 400 snowcoaches originated from Old Faithful and are not included in the numbers 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. 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 (see Appendix F). Hobo™ wind speed sensors (Onset Computer Co., Pocasset, MA) 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.

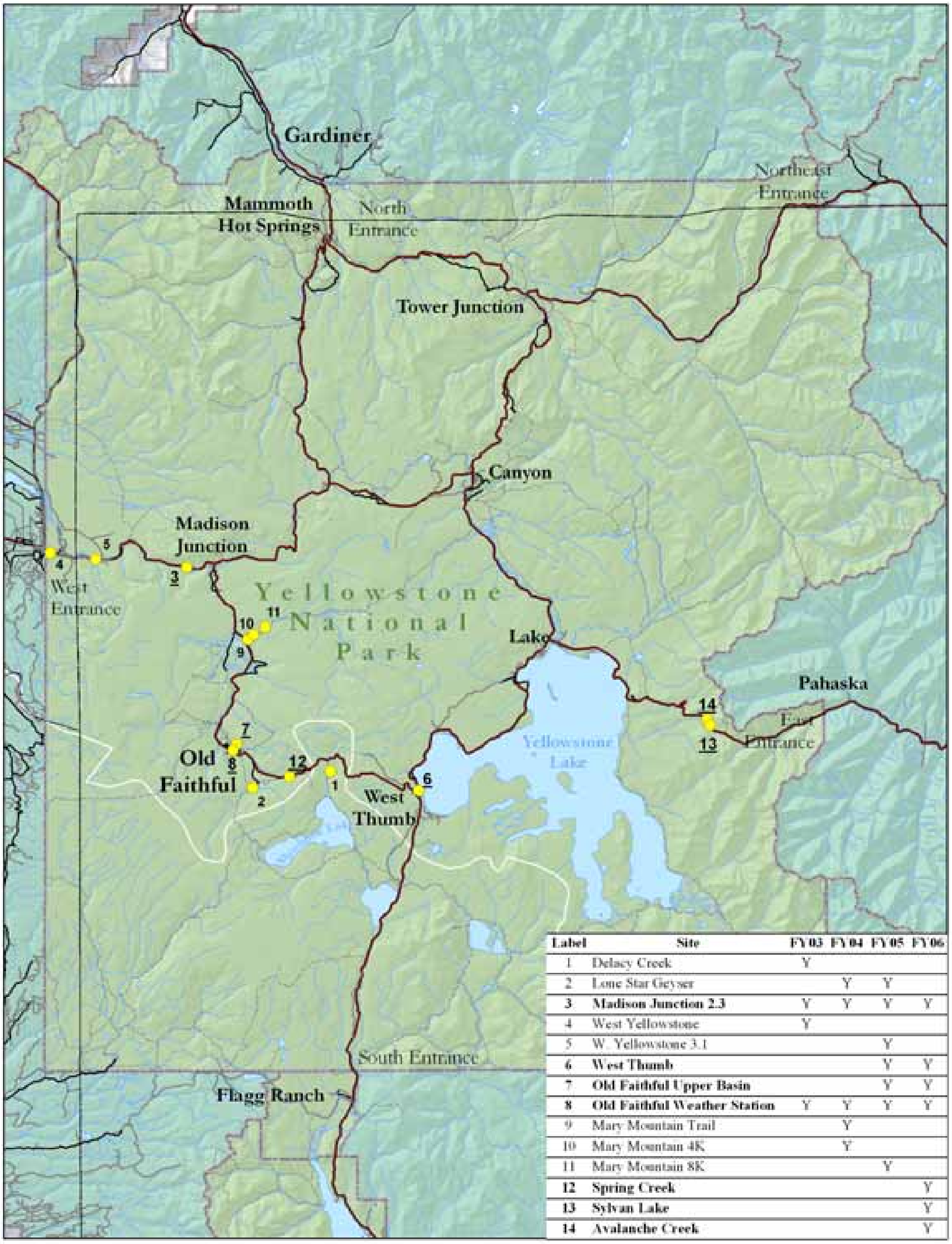
Specific methodologies (protocols) for equipment type, microphone placement, height, and other factors are summarized in Appendix A. These protocols followed guidance of Ambrose and Burson (2004) and were based on American National Standards Institute (ANSI) S12.9-1992, Part 2 (ANSI 1992), Federal Aviation 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 2005-2006 sound monitoring locations (Fig. 1) were chosen to include high use areas and represented two soundscape management zones (Developed Area and Travel Corridor). 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 logistical constraints. These constraints included open south facing sky for solar exposure for charging systems, proximity to electricity outlets, and placement of instrumentation in locations protected from large mammals. Habitat cover percentages listed below were measured in a 500 m radius of the sound monitor.

Old Faithful Weather Station

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



Label	Site	FY03	FY04	FY05	FY06
1	Delacy Creek	Y			
2	Lone Star Geyser		Y	Y	
3	**Madison Junction 2.3**	Y	Y	Y	Y
4	West Yellowstone	Y			
5	W. Yellowstone 3.1			Y	
6	**West Thumb**			Y	Y
7	**Old Faithful Upper Basin**			Y	Y
8	**Old Faithful Weather Station**	Y	Y	Y	Y
9	Mary Mountain Trail		Y		
10	Mary Mountain 4K		Y		
11	Mary Mountain 8K			Y	
12	**Spring Creek**				Y
13	**Sylvan Lake**				Y
14	**Avalanche Creek**				Y

Figure 1. Locations of sound monitoring sites (yellow circles) within Yellowstone National Park, December 2003-March 2006. See inserted table for key to year and label. Only FY06 sampling locations are included in this report (#13 and #14 in Appendix F). See Burson (2005 and 2006) for previous winters' sampling results.

The Old Faithful Weather Station monitor was located within the fenced area of the weather station adjacent to the Ranger Station. The microphones were located 40 feet from a walking/ski trail, 200 feet from the Ranger Station, 230 feet from the entrance road used by oversnow traffic, 300 feet from the large parking lot between the Ranger Station and the Visitors Center, 600 feet from the Old Faithful Inn, and 700 feet from the Snow Lodge. The monitor was powered by AC electricity.

Old Faithful Upper Basin

Latitude:	44.46325
Longitude:	110.82740
Elevation:	7400 feet
Habitat:	60% open (wetlands, thermal area, boardwalk), 10% open (river), 30% forested (lodgepole pine),
Management Area:	Developed Area

The Old Faithful Upper Basin monitor was in a small group of lodgepole pines within the thermal area directly adjacent to a boardwalk. The microphone was located 15 feet off the boardwalk on Geyser Hill, 1050 feet from Old Faithful Geyser, 1650 feet from the Visitor Center, and 1800 feet from the nearest motorized route (parking area). The monitor was powered directly from 12 volt batteries without solar panels.

Madison Junction 2.3

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

The Madison Junction 2.3 monitor was located 2.3 miles west of Madison Junction, 100 feet from the West Entrance-Madison Junction Road within a large area of small (4 to 8 feet) lodgepole pines, and 275 feet from the Firehole River. The Madison Junction 2.3 monitor was powered from 12 volt batteries charged by solar panels.

West Thumb

Latitude:	44.41589
Longitude:	110.57093
Elevation:	7900 feet
Habitat:	15% open (parking lot, road, boardwalk, buildings), 60% open (wetlands, thermal area, lake), 25% forested (lodgepole pine)

Management Area: Developed Area

The West Thumb monitor was located 15 feet from the most easterly boardwalk loop within the West Thumb geyser basin under a large single lodgepole pine 425 feet from the warming hut, 650 feet from Yellowstone Lake, 850 from the West Thumb to Lake groomed road, and 1800 feet from the South Entrance to West Thumb groomed road. The West Thumb monitor was powered directly from 12 volt batteries.

Spring Creek

Latitude:	44.43100
Longitude:	110.75323
Elevation:	8000 feet
Habitat:	95% forested, 5% open (road, river).
Management Area:	Travel Corridor

The Spring Creek monitor was located about five miles east-southeast of Old Faithful, 100 feet from the Old Faithful- West Thumb Road within a forest of large lodgepole pines. The monitor was across the road from a summer-use only picnic area. The Spring Creek monitor was powered directly from 12 volt batteries.

Analyses:

<u>Audibility</u>

The daily 360 10-second digital recordings were calibrated and replayed using Adobe's Audition^{TM} software, Sound Devices USBPre^{TM} acoustical interface, and professional grade headphones. The Soundscape Database software (Ric Hupulo, Natural Sounds Program, Ft. Collins, CO) was used to analyze the audibility data. The entire 24 hour period was analyzed but the time period 8 am to 4 pm (120 samples totaling 20 minutes per day) is reported here as prescribed in the 2004 Temporary Winter Use Plan. When determining sound sources via playback of field recordings, the volume of the playback (after adjustment to the recorded calibration tone) was increased by 10 dB to approximate field audibility. This value was determined from comparisons between field recordings with identifications of sound sources 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 would be heard in the field. As a result, audibility determined through office playback of digital recordings likely represents a 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 combined 10-second samples as approximations of 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. 5 and 17 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.

<u>Event Analysis</u>
The event recordings of loud sounds were replayed and each sound source identified and tallied. The events caused by wind turbulence on the microphone were not included in these analyses.

<u>Sound levels</u>
Sound pressure level data (decibels) were compiled and common acoustic metrics were calculated using HourlyMetrics™ software (Ric Hupalo, NPS Natural Sound Program, Ft. Collins, CO). Wind contamination (distortion) causes false sound level data when wind speeds exceed the capacity of the microphone windscreens. Therefore, sound level data collected when wind speeds exceeded 11 mph 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 (but see Appendix F). Data influenced by visits to the monitoring site were also deleted. Although historically, arithmetic averages were generally used to aggregate hourly summary metrics, decibels are logarithmic and therefore logarithmic averages are more appropriate. The hourly sound level data presented here for comparative purposes from 2003-2004 were calculated using logarithmic averages. However, sound levels collected over long time intervals in national parks are rarely normally distributed (there are many more low levels than high

levels) therefore median values provide better estimates of central tendencies and are used for the analysis of 2004-2005 and 2005-2006 data.

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. Estimates of variability beyond the minimum and maximum values are also desirable. John Borkowski, a statistician from Montana State University is conducting additional detailed statistical analyses of these acoustic data and will report on his findings in a separate report.

Results from this sound monitoring project can be compared to the soundscape impact thresholds in the 2004 Temporary Winter Use Plans Environmental Assessment (Table 1). The 2000 and 2003 WUP acoustic thresholds (Appendix C) contain previous standards and thresholds for further comparison.

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

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

[1]Thresholds are calculated using the period 8 am-4 pm. Measurements are at 100 feet 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 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: Ch. 1 (2.12) p.21- 22. 1 July 2003).

Results and Discussion:

Winter-long acoustical measurements were collected at Old Faithful Weather Station and Madison Junction 2.3. Additional data were collected for shorter time periods at Old Faithful Upper Basin, West Thumb, and Spring Creek (see previous section for site details). Data collection began on 21 December 2005 and continued throughout the winter use season (21 December 2005-12 March 2006). Selected data (Tables 2 and 3) were chosen for analysis based on visitor usage patterns, distribution of days of the week, month, and season, daily wind conditions, timing of previous measurements, and availability of time for analysis. The WUP impact thresholds apply 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. 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 level data are presented for the 24 hour day although the WUP thresholds apply only to 8 am-4 pm.

A related, short-term study using specialized low noise instrumentation documented very low sound levels (below 6.5 dBA) on and near Sylvan Lake on the Fishing Bridge to East Entrance Road during February 2006 (Ambrose et al. 2006, and reproduced in its entirety in Appendix F). The findings have implications for winter use monitoring. The very low natural ambient sound levels were documented in Yellowstone areas not unlike the locations sampled in this current study. Audibility of oversnow vehicles is determined, in part, by the natural ambient sound levels. Lower levels result in higher percent time audible. At several monitoring locations the lowest minimum sound levels were clearly below the range (noise floor) of the instrumentation for many hours of the day. The actual minimum levels, and those that determine, in part, the audibility of oversnow vehicles, are therefore unknown. Because of this uncertainty, at the lowest sound levels the association between the number of OSVs, the natural sound levels and audibility remains ambiguous (see pg. 16-17 for more discussion).

Acoustic data were collected during the past four winter seasons. This dataset is beginning to provide information on trends, similarities among years and variability in time and location. Soundscapes are highly variable over time, both in minutes and seasons. All attempts to summarize long-term datasets therefore fail to describe or explain fully 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 and the percent time audible require more detailed analyses than are presented here. Nevertheless, the acoustic dataset that have been collected during the winter-use season and upon which this report is based is one of the most extensive national park acoustic datasets in existence and a substantial amount of useful information can be gathered from the data as presented.

When comparing winter seasons, note that oversnow travel was prohibited due to lack of adequate snowcover early and late in the 2004-2005 winter use season. Travel by snowmobile from the West Entrance to Madison Junction began 1 January and ended 9 March 2005. Therefore fewer snowmobiles traveled to Old Faithful during the early and late season of 2004-2005 and this was reflected in the acoustic data. Oversnow travel was permitted for the entire 2005-2006 season.

See Appendix C for acoustical standards and thresholds of the 2000 and 2003 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 new 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 a study of very low sound levels recorded during the winter season in Yellowstone National Park. These very low sound levels have important implications on how we think of natural soundscapes in national parks.

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

Table 2. Dates used for audibility analyses at five locations in Yellowstone National Park, December 2005-March 2006. Daily average number of snowmobiles was 267/day for the winter use season and 254/day for January and February. Listed at bottom of table are daily snowmobile averages for the days included in the analysis. Daily average number of snowcoaches for the winter use season was 30/day. These totals do not include oversnow vehicles originating at Old Faithful (about two snowmobiles and snowcoaches per day). See text for further details. Total number of days analyzed, 71.

Old Faithful Weather Station 24 days	Madison Jnct. 2.3 24 days	Old Faithful Upper Basin 10 days	West Thumb Geyser Basin 7 days	Spring Creek 6 days
24-Dec-05	21-Dec-05	24-Dec-05	13-Jan-06	16-Feb-06
25-Dec-05	24-Dec-05	25-Dec-05	14-Jan-06	18-Feb-06
26-Dec-05	25-Dec-05	26-Dec-05	15-Jan-06	19-Feb-06
12-Jan-06	26-Dec-05	1-Jan-06	16-Jan-06	20-Feb-06
13-Jan-06	6-Jan-06	2-Jan-06	17-Jan-06	21-Feb-06
16-Jan-06	10-Jan-06	16-Feb-06	18-Jan-06	22-Feb-06
19-Jan-06	12-Jan-06	17-Feb-06	19-Jan-06	
23-Jan-06	14-Jan-06	18-Feb-06		
24-Jan-06	25-Jan-06	19-Feb-06		
25-Jan-06	26-Jan-06	20-Feb-06		
5-Feb-06	4-Feb-06			
7-Feb-06	5-Feb-06			
8-Feb-06	8-Feb-06			
10-Feb-06	17-Feb-06			
11-Feb-06	18-Feb-06			
17-Feb-06	19-Feb-06			
18-Feb-06	20-Feb-06			
19-Feb-06	1-Mar-06			
20-Feb-06	2-Mar-06			
1-Mar-06	5-Mar-06			
2-Mar-06	6-Mar-06			
5-Mar-06	7-Mar-06			
6-Mar-06	10-Mar-06			
10-Mar-06	11-Mar-06			
			Total Days 71	
Average # of snowmobiles during sampling days*				
263/day	159/day	272/day	78/day	327/day

* Average number of snowmobiles was calculated using all snowmobiles entering Yellowstone except only West Yellowstone Entrance snowmobiles were used for Madison Junction 2.3 and only South Entrance snowmobiles were used for West Thumb.

Table 3. Dates used for sound level analyses at five locations in Yellowstone National Park, December 2005-March 2006. Total hours, 4,690.

Old Faithful (1,904 hours) 21 December 2005-12 March 2006	Madison Jct 2.3 (1,940 hours) 21 December 2005-12 March 2006
Old Faithful Upper Basin (473 hours) 22 December 2005- 4 January 2006 15-23 February 2006	West Thumb (189 hours) 12-20 January 2006
Spring Creek (184 hours) 15-23 February 2006	

Audibility:

The source of each sound (snowmobile, animal, aircraft, wind, thermal activity, etc.) that was audible was identified from the 120 10-second (for a daily total of 20 minutes) 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 and snowcoach percent time audible is presented here. Oversnow vehicles were often audible outside the 8 am- 4 pm time period, but these data are generally not presented here. 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. The average number of snowcoaches entering YNP during the winter season was 30/day (range 16-54). The average number of snowmobiles entering YNP during the winter season was 267/day (range 121-494). See Table 2 for further details.

The percent time audible calculations were based on days throughout the entire winter use season. However, days with the strongest winds were generally not analyzed for percent time audible due to the occasional wind contamination of the recording and the masking effects of wind turbulence. If days with high winds had been included, the overall percent time oversnow vehicles were audible would likely have been slightly lower.

An important question is the relationship between the number of snowmobiles and snowcoaches entering YNP and the percent time they are audible. 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 apparent in the some of the acoustic data collected during the past four winters. Several factors, though, complicate the relationship. First, not all snowmobiles are part of guided groups; there are NPS and concession snowmobiles used within the park, especially in destination areas such as Old Faithful (see Appendix E). 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 audibility. Second, 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. Third, audibility also depends on environmental conditions, such as temperature, wind conditions, inversions, the natural ambient sound level and other factors (next paragraph) that vary spatially and temporally, further complicating the relationship between the number of visitor snowmobiles and their percent time audible. Studies to address these issues are continuing.

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 would be the times when no oversnow vehicles were audible. Using common sense and logic, 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, but see Appendix D and 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 location. 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 fourth winter. Within the developed area at Old Faithful, the average daily percent time audible for snowmobiles and snowcoaches was 67% (Fig. 2). This compares to 69% during the previous winter use season and 61% during 2003-2004 (Fig. 3 and 4). The average daily percent time audible of OSVs during the last two winter use seasons was essentially the same. The increase in audibility from 2003-2004 may be explained in part by the addition of contractors commuting to work at the Old Faithful Inn, 600 feet from the monitor. Contractors comprised 9% of the total number of groups and 5% of the total number of snowmobiles audible in the Old Faithful area during observations in 2004-2005 and 2005-2006 (Appendix E). During the winter of 2005-2006 the daily OSV percent time audible was consistently between 60% and 80% other than during the last week of the season (Fig. 2). Three (12.5%) of the 24 days analyzed exceeded the WUP audibility threshold of 75% for developed areas (Table 1).

Oversnow vehicles traveling on the main road and within the Old Faithful developed area were audible at this site. When comparing the most recent winter to prior seasons note that there was restricted oversnow road use periods during the early and late season 2004-2005. All days were open during the winter use season of 2005-2006. The daily percent time audible values reflect those usage patterns (Fig. 2 and 3). 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, there appears to be no strong association between wind and oversnow vehicle percent time audible at Old Faithful (Fig. 3 and 4).

Percent time audible can be calculated by hour to understand the pattern of oversnow vehicle use between 8 am and 4 pm (Fig. 5, compare to previous season Fig. 6 and 7). Figures 5, 6 and 7 also show the relative proportion of snowmobiles and snowcoaches in the overall oversnow vehicle category. The only hour snowcoaches were audible more than snowmobiles was during the 8 am hour. This is a change from 2004-2005 and more closely resembles the 2003-2004 season (Fig. 5, 6 and 7). On average snowmobiles were audible for more than twice the time of snowcoaches (Fig. 5).

The analyses for the WUP measurement period are restricted to 8 am-4 pm but oversnow vehicle sounds beyond that time were common (e.g., Fig. 8). For comparative purposes, Figures 8, 9, and 10 show days with the maximum percent time audible during the past three seasons. Figure 8 also shows the increased snowmobile use during the late night and early morning hours compared to previous years. This unexplained increased use during the off-peak hours appears to be a general trend for the past three winters.

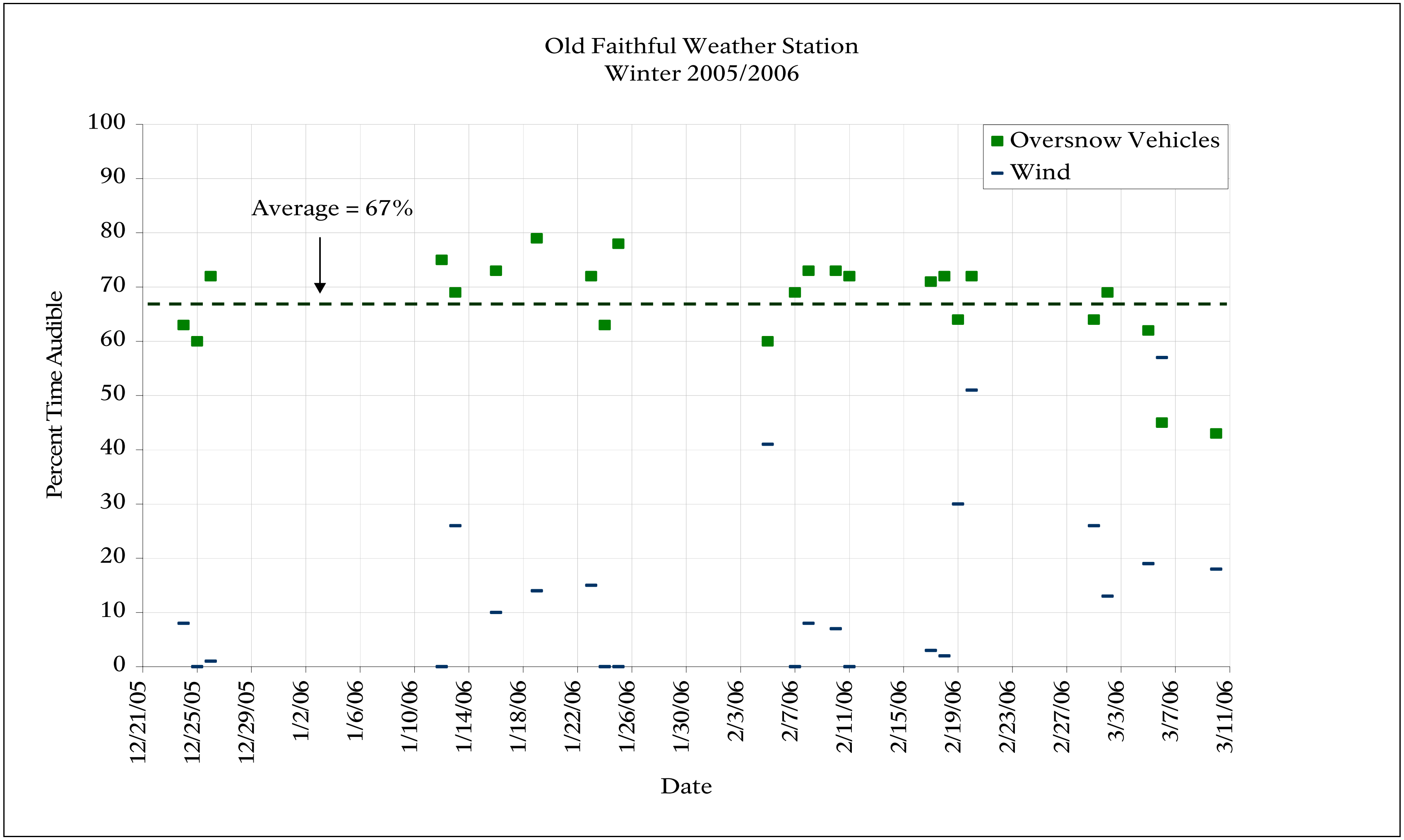


Figure 2. The percent time audible for snowmobiles and snowcoaches, and wind (dashes) by date at Old Faithful Weather Station, Yellowstone National Park from 8 a.m. to 4 p.m., 21 December 2005 to 12 March 2006. Compare to Fig. 3 and 4.

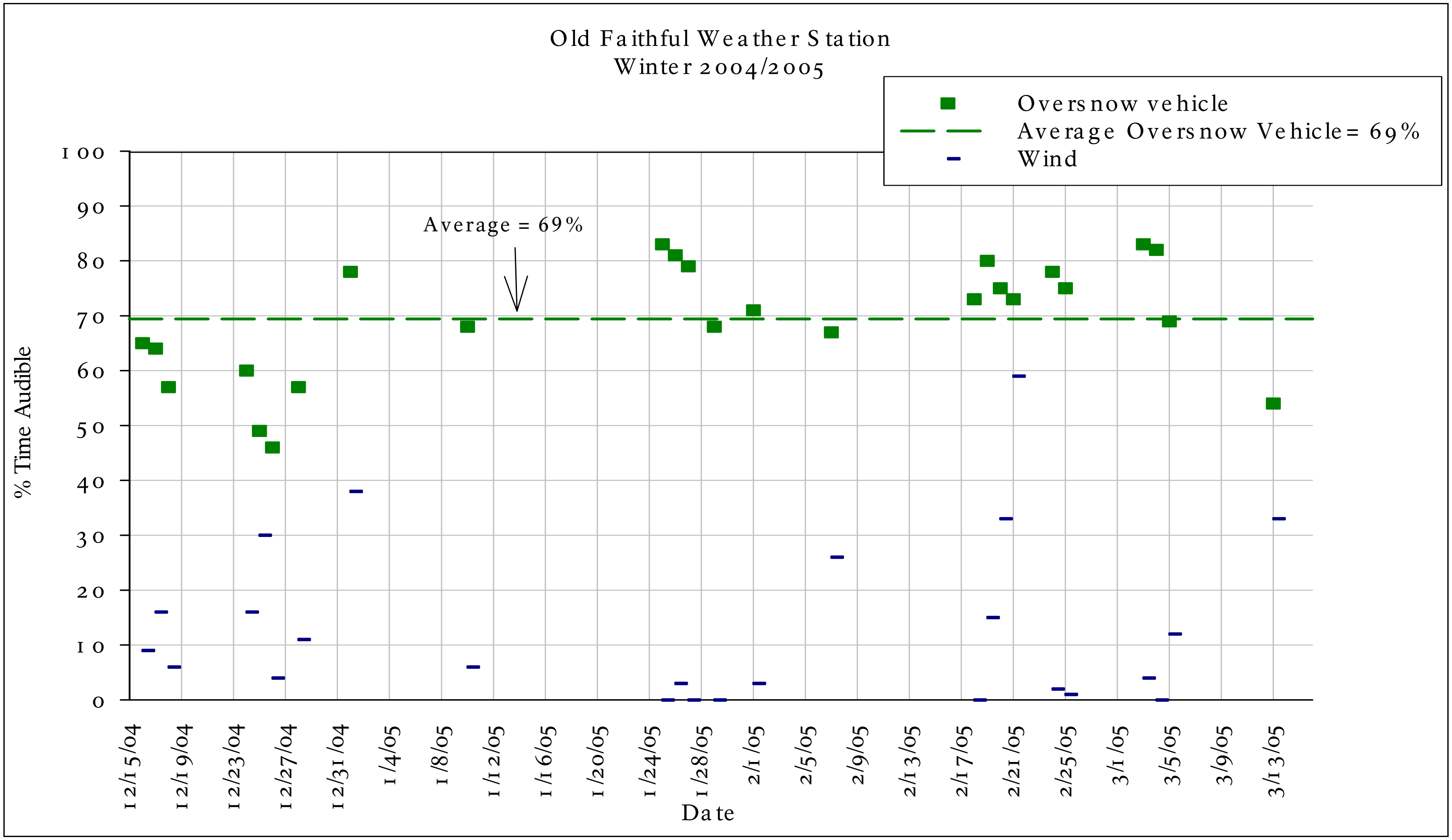


Figure 3. The percent time audible for snowmobiles and snowcoaches, and wind (dashes) by date at Old Faithful Weather Station, Yellowstone National Park from 8 a.m. to 4 p.m., 15 December 2004 to 13 March 2005. Compare to Fig. 2 and 4.

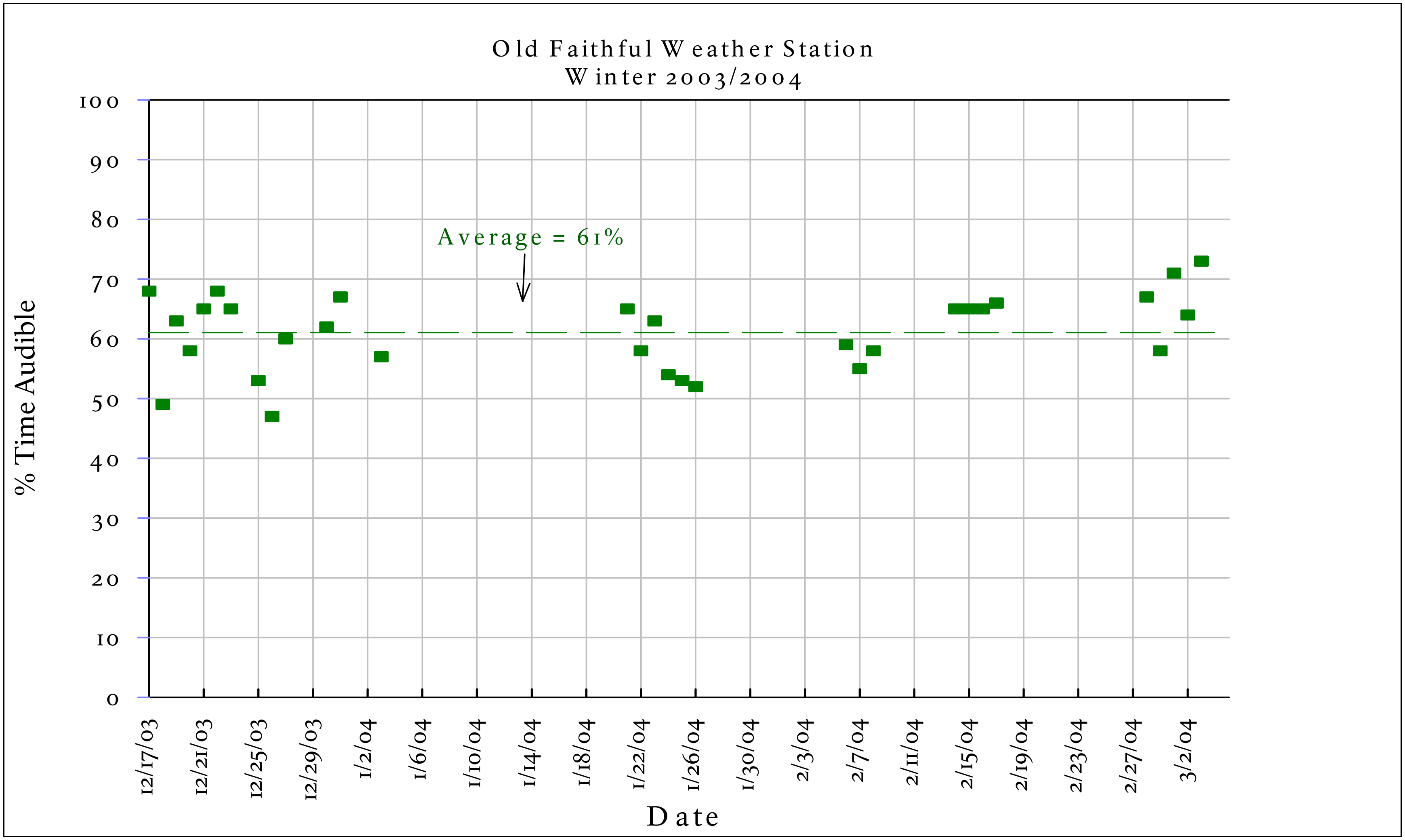


Figure 4. The percent time audible of snowmobiles and snowcoaches by date at Old Faithful Weather Station, Yellowstone National Park from 8 a.m. to 4 p.m., 17 December 2003 to 3 March 2004. Compare to Fig. 2 and 3.

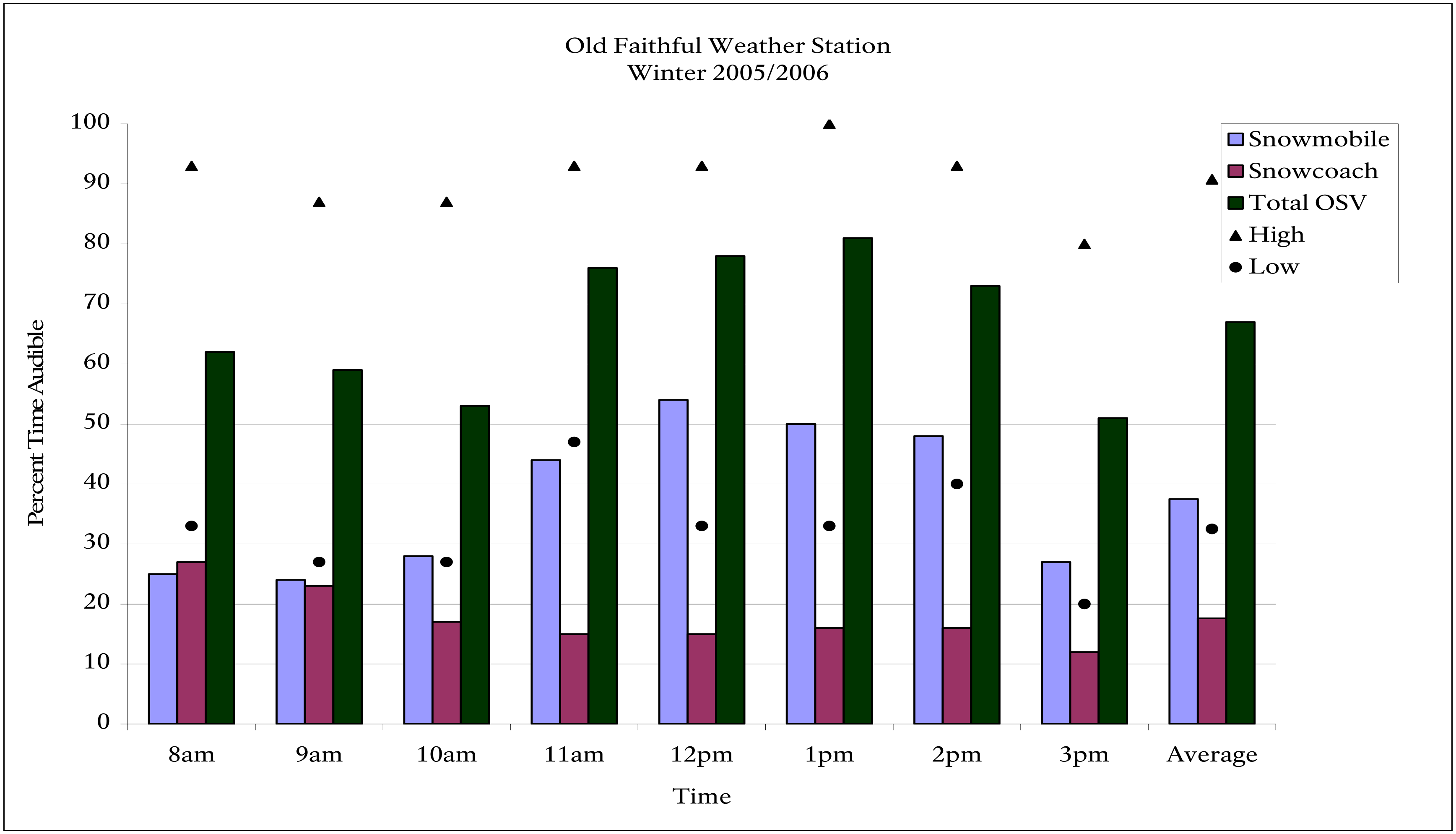


Figure 5. The average percent time audible by hour (8 am-4 pm) of snowmobiles (left light blue bar), snowcoaches (middle maroon bar), and combined category (right dark green bar), and high and low OSV values at Old Faithful Weather Station, Yellowstone National Park from 8 a.m. to 4 p.m., 21 December 2005 to 12 March 2006. Compare to Fig. 6 and 7.

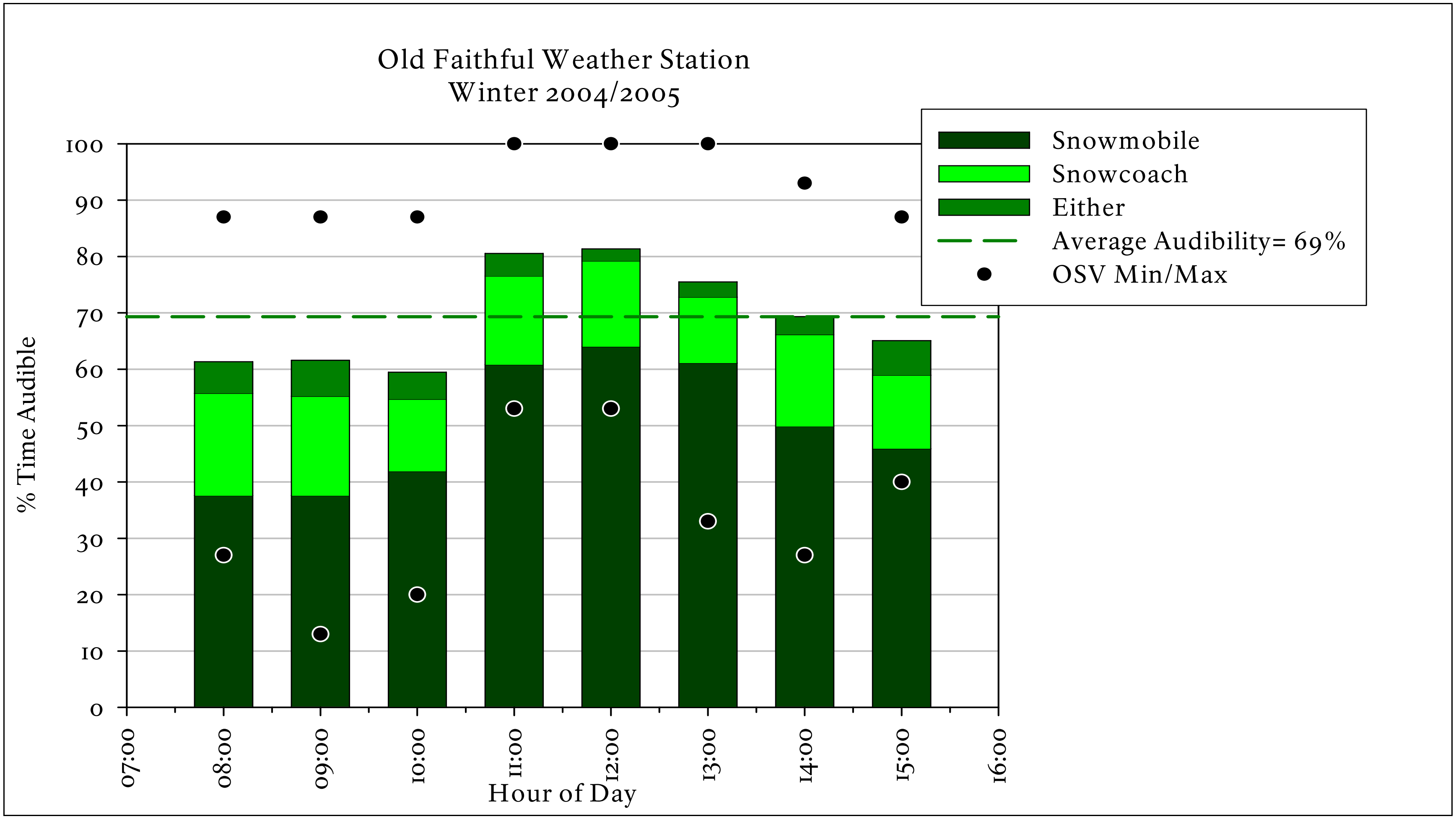


Figure 6. The average percent time audible by hour (8 am-4 pm) of snowmobiles (bottom bar category), snowcoaches (middle bar category), combined category (top), and high and low range at Old Faithful Weather Station, Yellowstone National Park from 8 a.m. to 4 p.m., 15 December 2004 to 13 March 2005. Compare to Fig. 5 and 7.

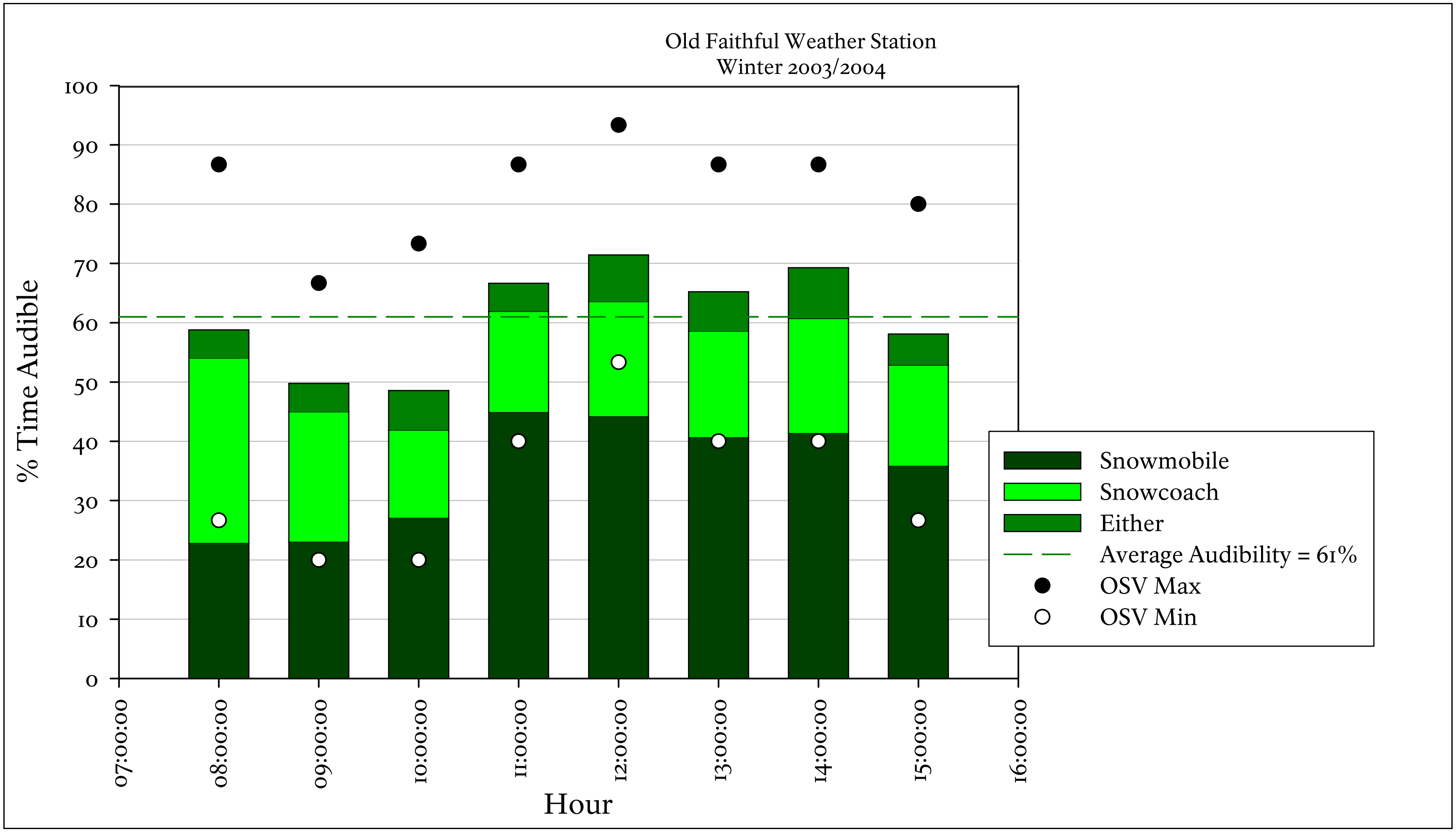


Figure 7. The average percent time audible by hour (8 am-4 pm) of snowmobiles (bottom bar category), snowcoaches (middle bar category), combined category (top), and high and low range at Old Faithful Weather Station, Yellowstone National Park from 8 a.m. to 4 p.m., 17 December 2003 to 14 March 2004. Compare to Fig. 5 and 6.

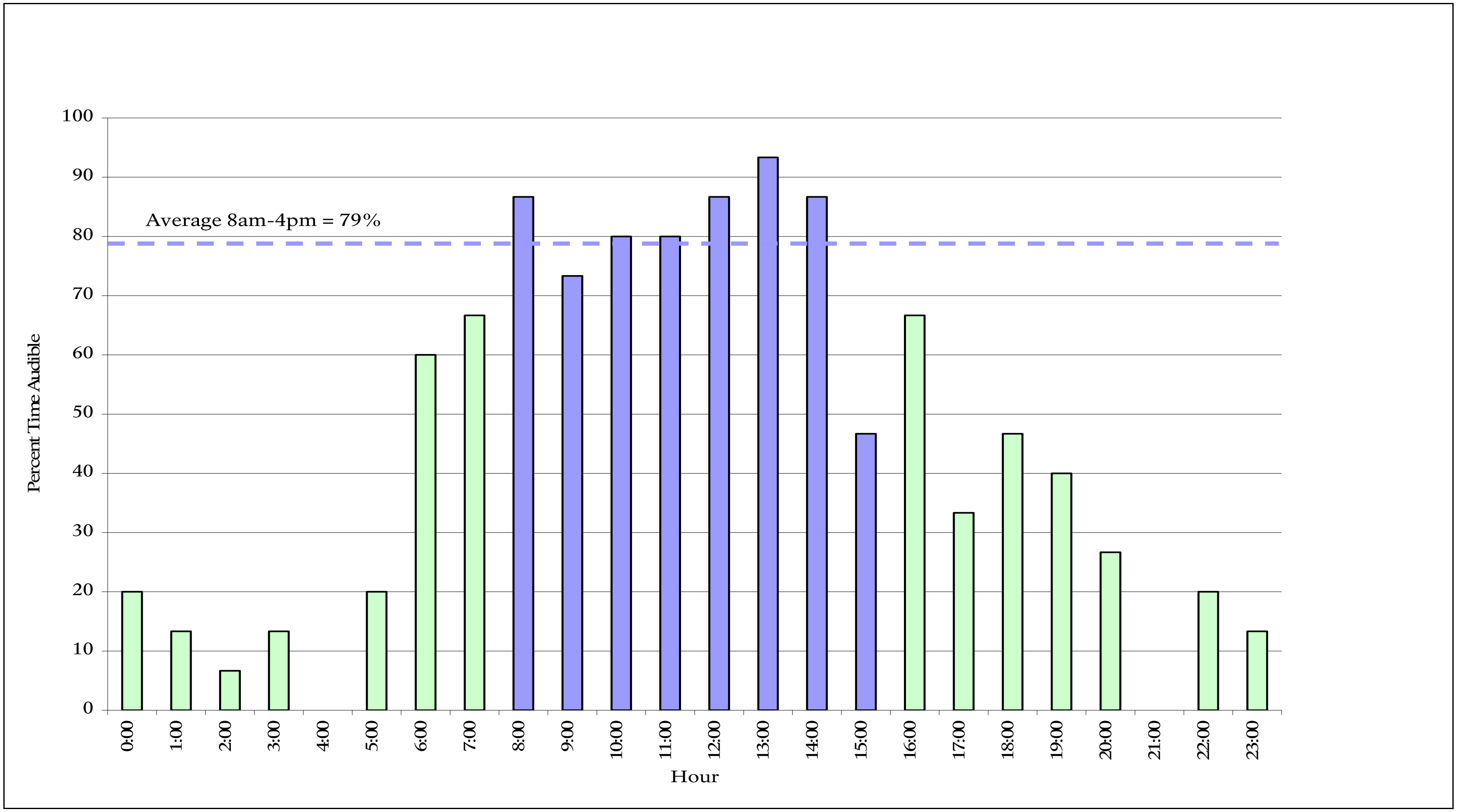


Figure 8. The percent time audible by hour (12am-11:59pm) of snowmobiles and snowcoaches at Old Faithful Weather Station, Yellowstone National Park, 19 January 2006, the day with the highest average audibility. The green histograms are

outside the WUP measurement period (8 am-4 pm) and are shown for comparative purposes. Compare to Fig. 9, 10, and 11.

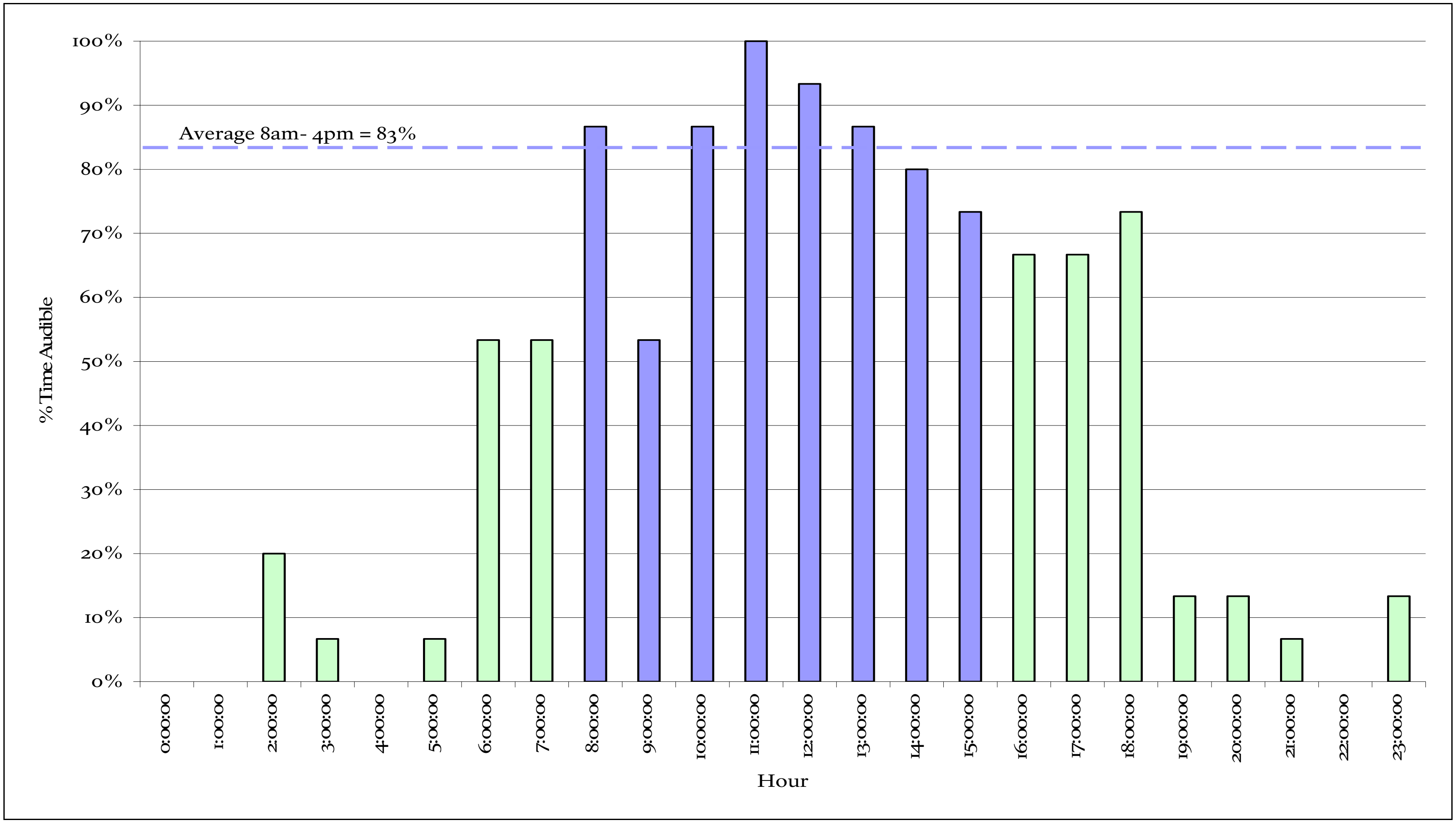


Figure 9. The percent time audible by hour (12am-11:59pm) of snowmobiles and snowcoaches at Old Faithful Weather Station, Yellowstone National Park, 25 January 2005, the day with the highest average audibility. The green histograms are outside the WUP measurement period (8 am-4 pm) and are shown for comparative purposes. Compare to Fig. 8, 10, and 11.

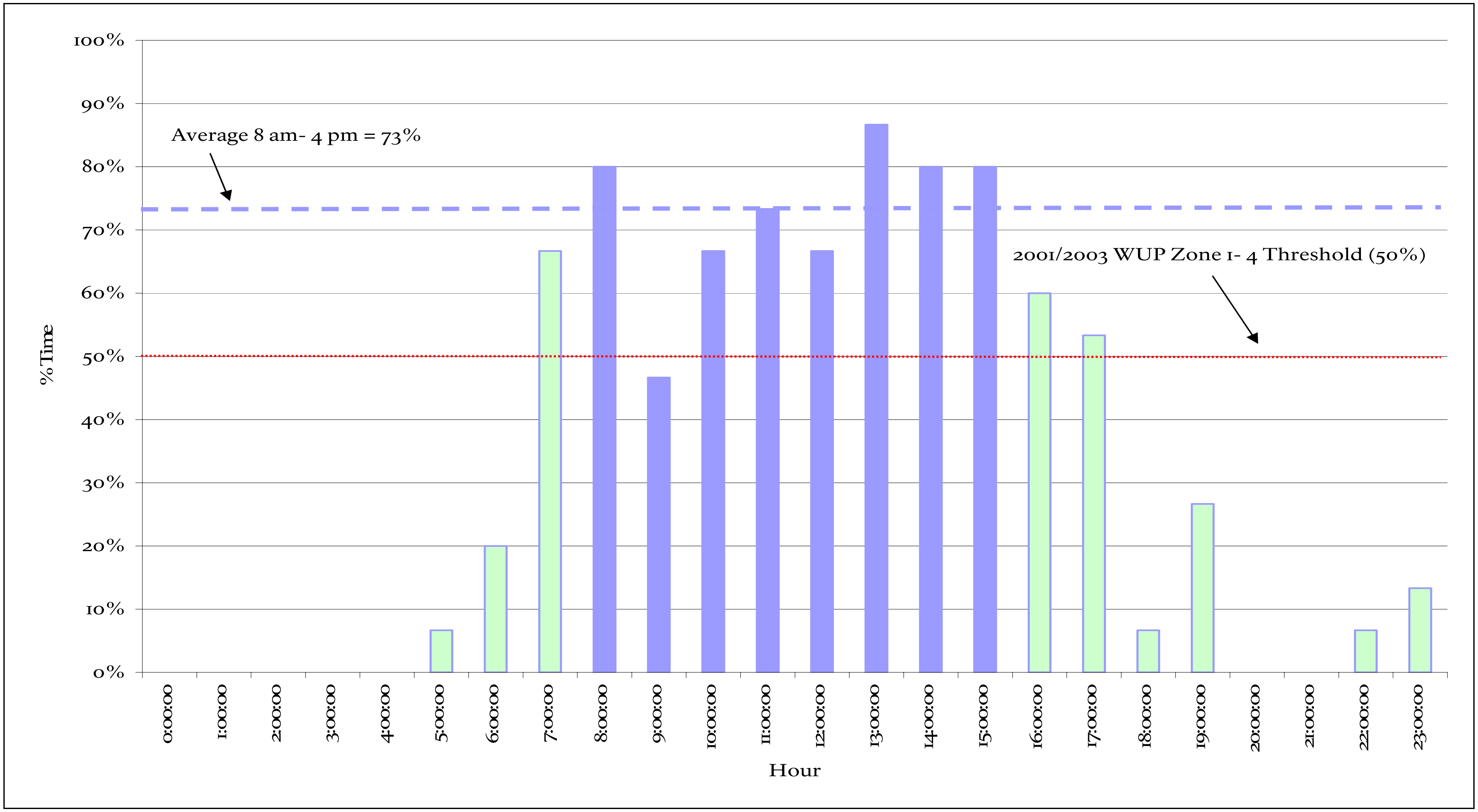


Figure 10. The percent time audible by hour (12am-11:59pm) of snowmobiles and snowcoaches at Old Faithful Weather Station, Yellowstone National Park, 3 March 2004, the day with the highest average audibility. The green histograms are outside the WUP measurement period (8 am-4 pm) and are shown for comparative purposes. Compare to Fig. 8, 9 and 11.

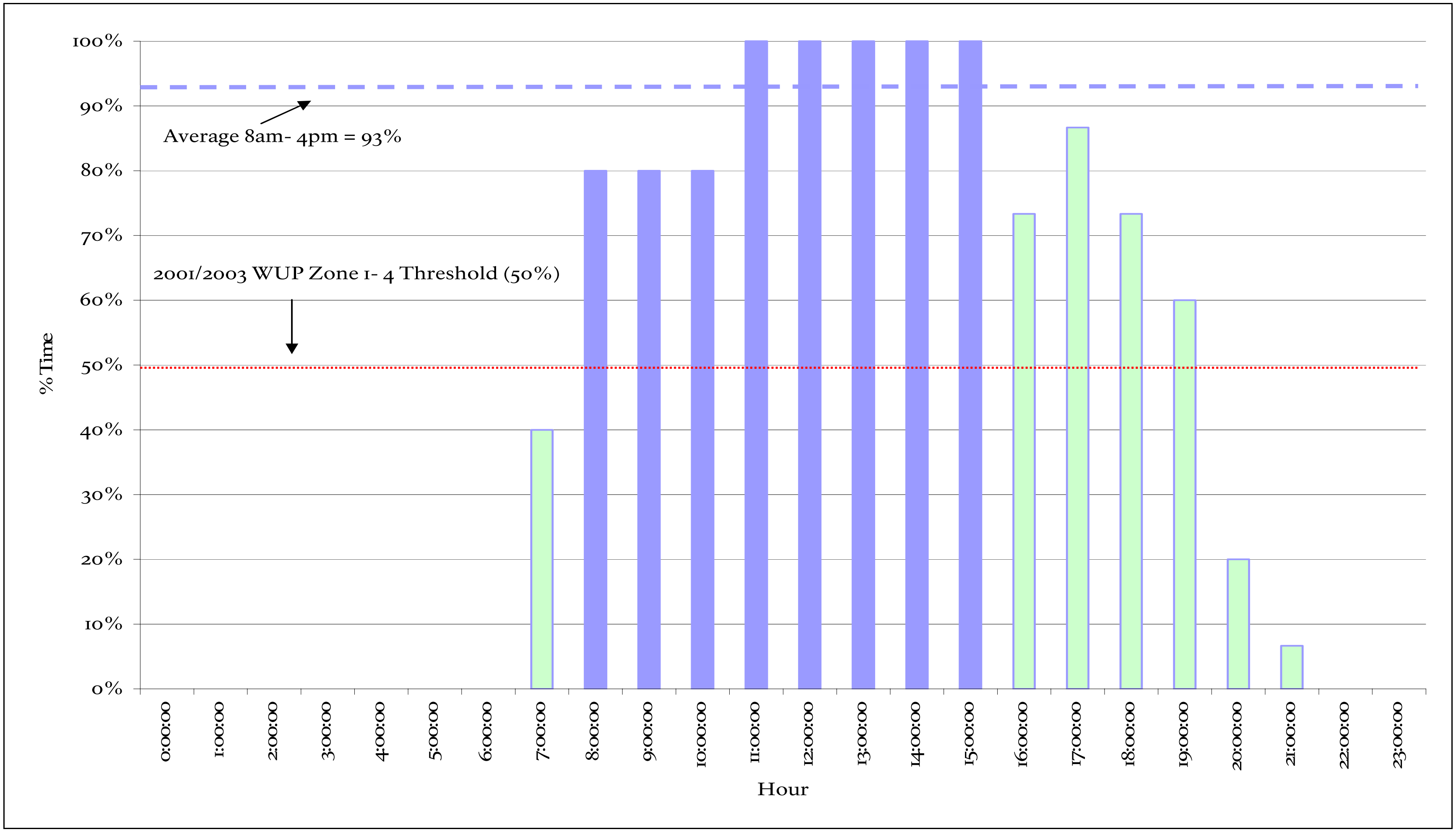


Figure 11. The percent time audible by hour (12am-11:59pm) of snowmobiles and snowcoaches at Old Faithful Weather Station, Yellowstone National Park, 14 February 2003. The green histograms are outside the WUP measurement period (8 am-4 pm) and are shown for comparative purposes. Compare to Fig. 8, 9, and 10.

Old Faithful Upper Basin

For the second winter, acoustic data were collected at a location in the developed area of the Old Faithful Upper Basin to estimate the percent time oversnow vehicles were audible (Fig. 12 and 14, compare to previous seasons Fig. 13 and 15). This monitor was located adjacent to a boardwalk within a popular thermal area about 1800 feet (1/3 mile) from the nearest motorized route, 24 December 2005-2 January 2006 and 16-20 February 2006. The sounds of the thermal features such as geysers and steam vents often masked distant OSV sound. Data collected at the Upper Basin provide a useful comparison to data collected at the Old Faithful Weather Station about 2600 feet (1/2 mile) away near the center of motorized activity (Fig. 2-11). Audibility data were analyzed at both sites for seven of the same days. For those days the percent time audible at the Upper Basin was 35% compared to 68% at the Weather Station. Oversnow vehicles that were audible at the Upper Basin site were often approaching or departing the Old Faithful area along the roads leading north or south and were not within the developed area itself. Those roads are about 4000 feet from the monitoring site.

The comparisons between these two Old Faithful sites also illustrates that as the distance increases between the sound source and the measurement location it becomes more difficult to assign specific sounds to their sources and categories begin to be combined. A larger proportion of audible sounds at the Upper Basin were coded as snowmobile or snowcoach rather than one or the other (Fig. 14 and 15).

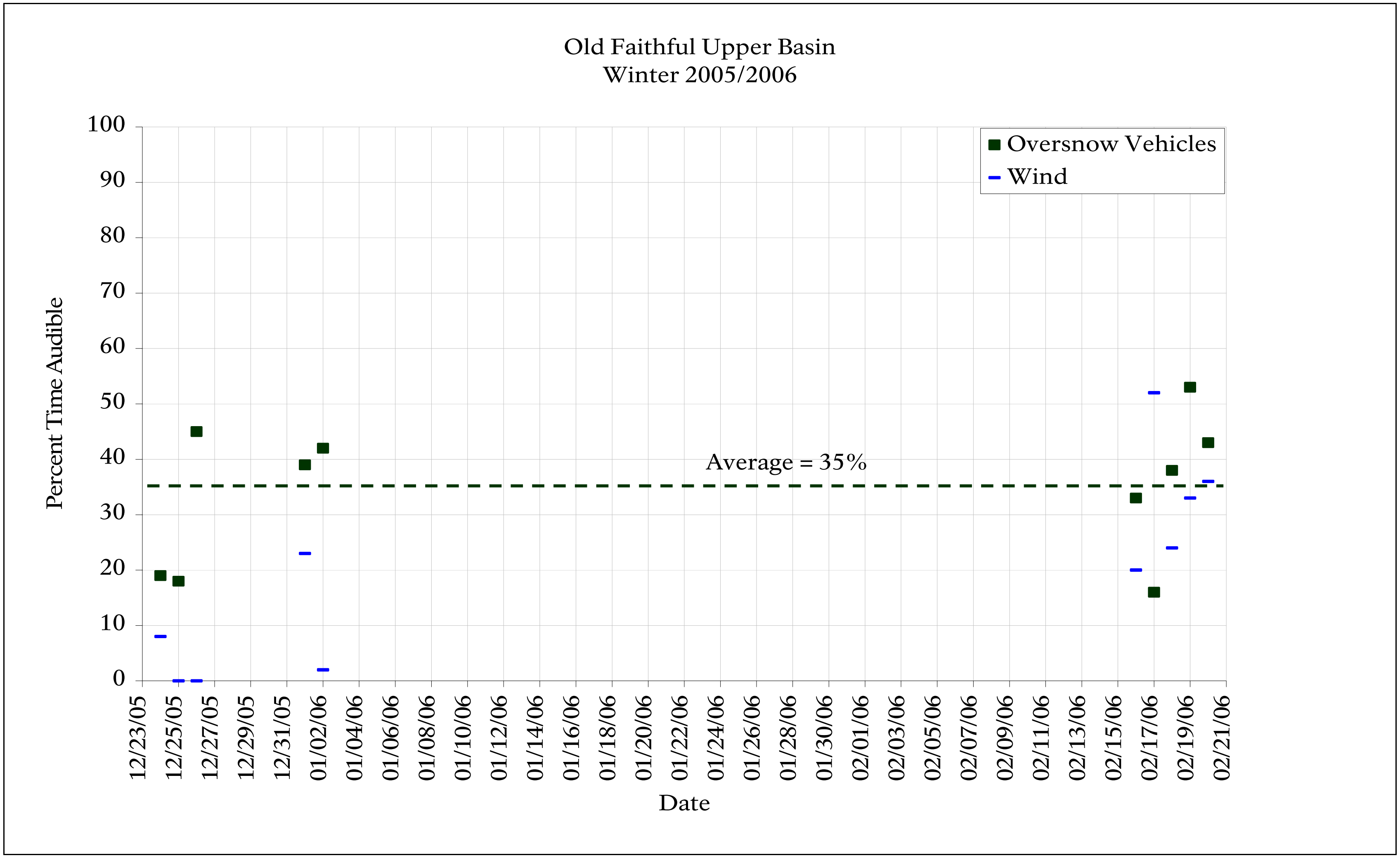


Figure 12. The average percent time audible of snowmobiles, snowcoaches, and wind by date at Old Faithful Upper Basin, Yellowstone National Park, (8 am-4 pm), 24 December 2005- 20 February 2006. Compare to Fig. 13.

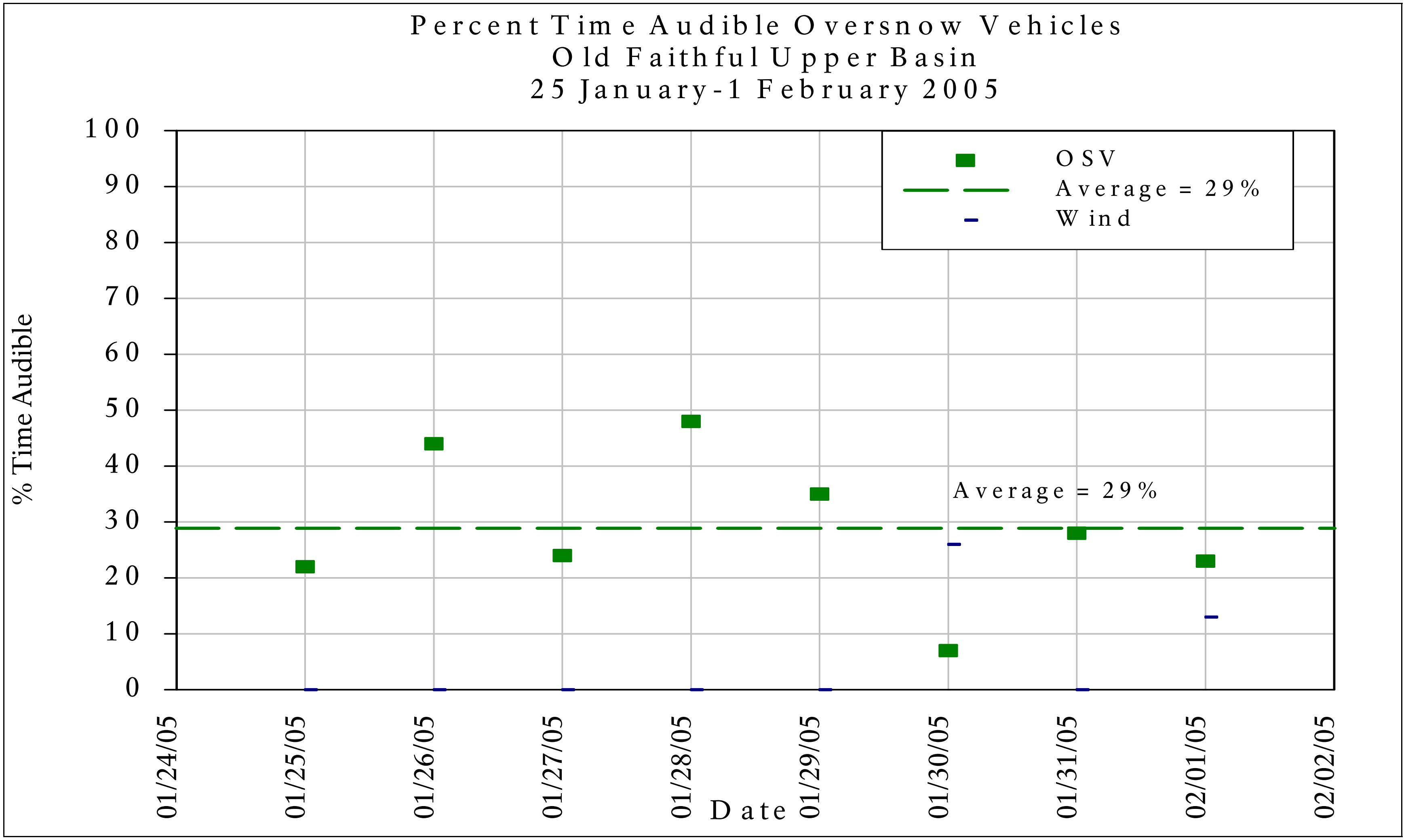


Figure 13. The average percent time audible of snowmobiles, snowcoaches, and wind by date at Old Faithful Upper Basin, Yellowstone National Park, (8 am-4 pm), 25 January- 1 February 2005. Compare to Fig. 12.

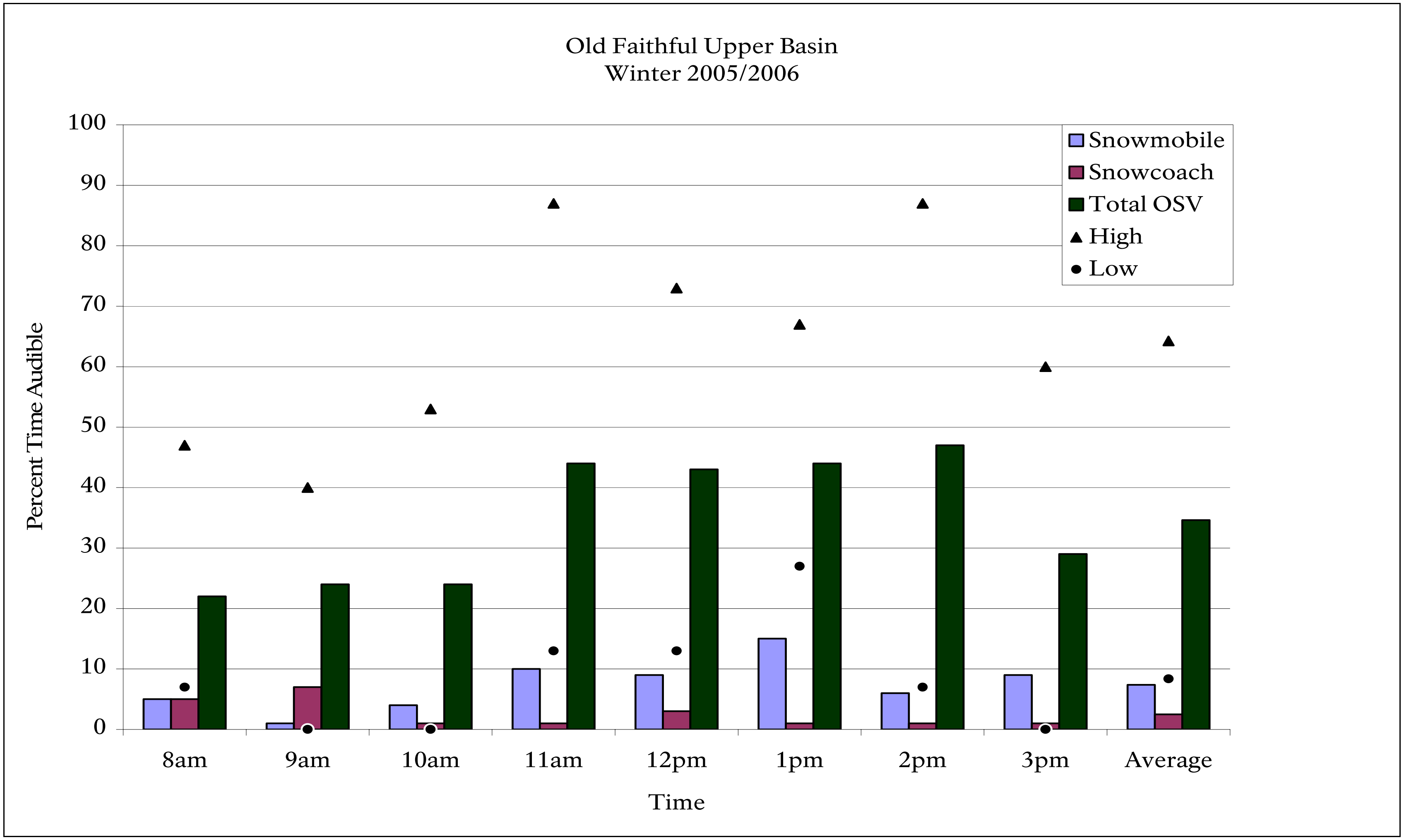


Figure 14. The average percent time audible by hour (8 am-4 pm) of snowmobiles and snowcoaches at Old Faithful Upper Basin, Yellowstone National Park, 25 January-1 February 2006. Compare to Fig. 15.

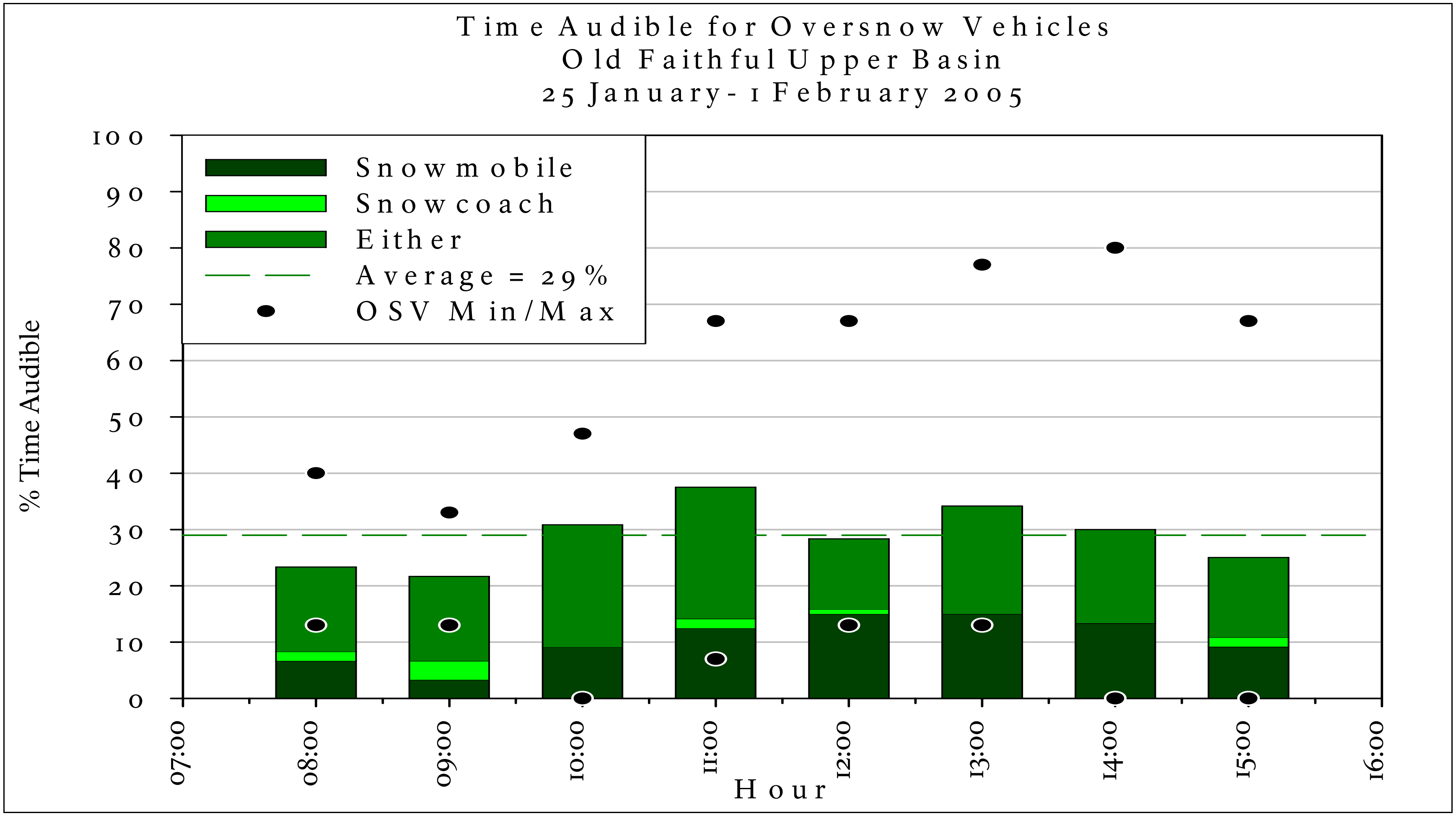


Figure 15. The average percent time audible by hour (8 am-4 pm) of snowmobiles and snowcoaches at Old Faithful Upper Basin, Yellowstone National Park, 25 January-1 February 2005. Compare to Fig. 14.

Madison Junction 2.3

Madison Junction 2.3 monitoring site was located 100 feet off the West Entrance Road 2.3 miles west of Madison Junction in a travel corridor soundscape management zone. Acoustic data were collected over the entire winter use season during 2005-2006 and during the Presidents Day Weekends of 2006, 2005, 2004, and 2003 (Fig. 16, 17, and 18). Snowmobiles and snowcoaches were audible for an average of 55% of the time during the winter use season (Fig. 16). This exceeds the WUP audibility threshold of 50% for travel corridors (Table 1). The percent time audible for 18 (75%) of 24 days analyzed exceeded 50% (Fig. 16).

There was a large difference in oversnow vehicle percent time audible during Presidents Day Weekend among the four years (Fig. 16 and 18). Oversnow vehicles were audible for 93% of the two day weekend in 2003, 24% in 2004, 61% in 2005 and 55% in 2006. The high percentage of 2003 can be explained by the use of 2-stroke snowmobiles and the greater numbers of snowmobiles passing the site. However, if the percent time oversnow vehicles were audible was strictly determined by the number of snowmobiles entering the park then the 2005 percent time audible should be similar to 2004. The percent time audible in 2006 and 2005 was twice the 2004 percentage (Fig. 18). After viewing a full winter season's data with similar numbers of oversnow vehicle, the 2004 result of 24% time audible looks to be an anomaly (Fig. 16). A non-typical result is not surprising due to the very small sample size of two days during each of the previous three years.

The bimodal distribution (Fig. 17) reflects the pulse of OSVs passing by the site in the morning on the way to Old Faithful and in the afternoon on the way back to West Yellowstone. Figure 17 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.

The difference in audibility between 2002-2003 and the subsequent years can likely be explained by fewer overall numbers and the required grouping of snowmobiles in the three subsequent winters. In addition, the predominate use of quieter four-stroke snowmobiles after the winter of 2002-2003 likely reduced the time that snowmobiles were audible.

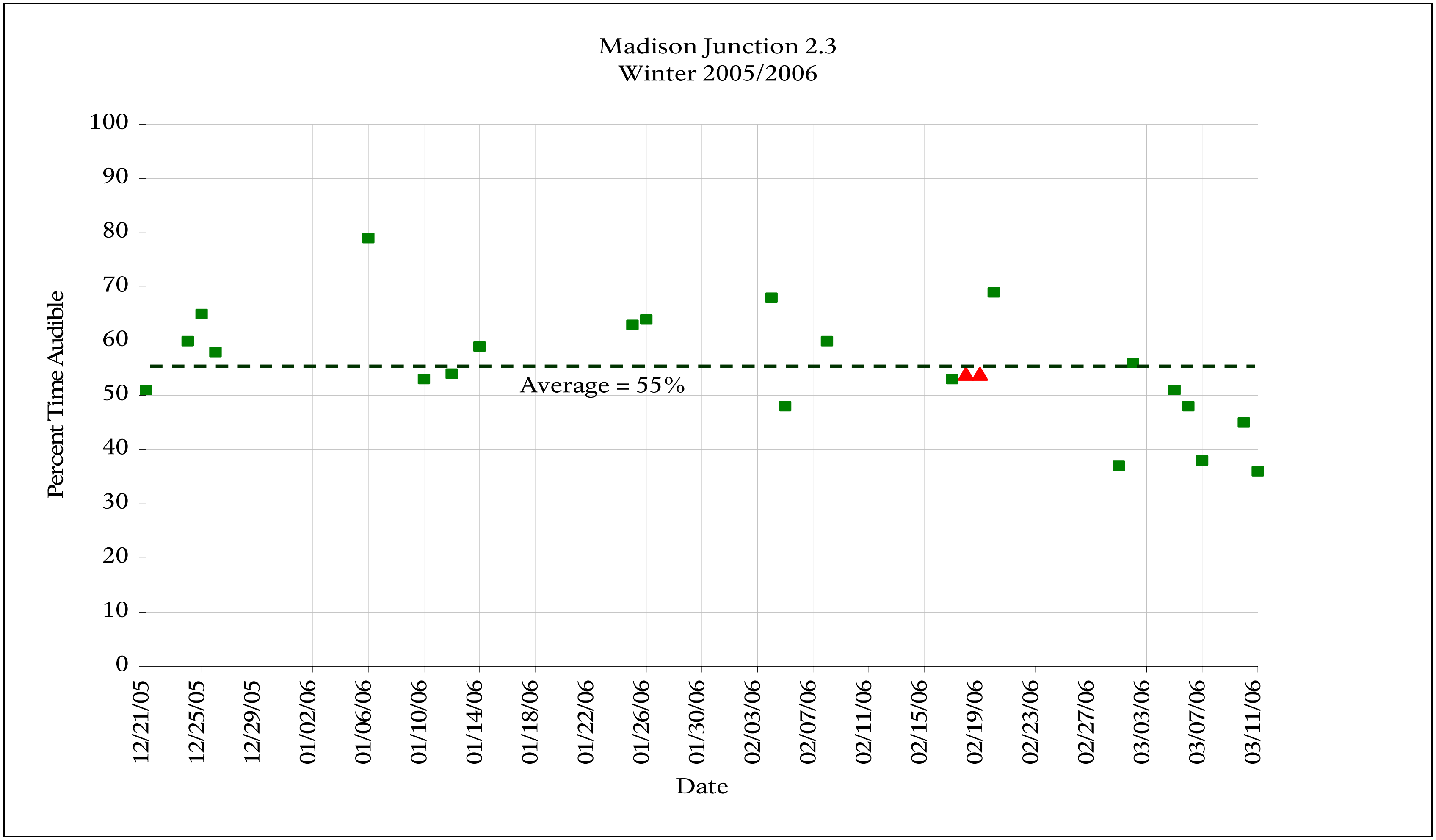


Figure 16. The average percent time audible by date of snowmobiles and snowcoaches at 2.3 miles west of Madison Junction along the West Entrance Road Yellowstone National Park, 21 December 2005-12 March 2006. Red triangles indicate Presidents Day Weekend for 2006 (54%) for comparison to prior years (Fig. 18).

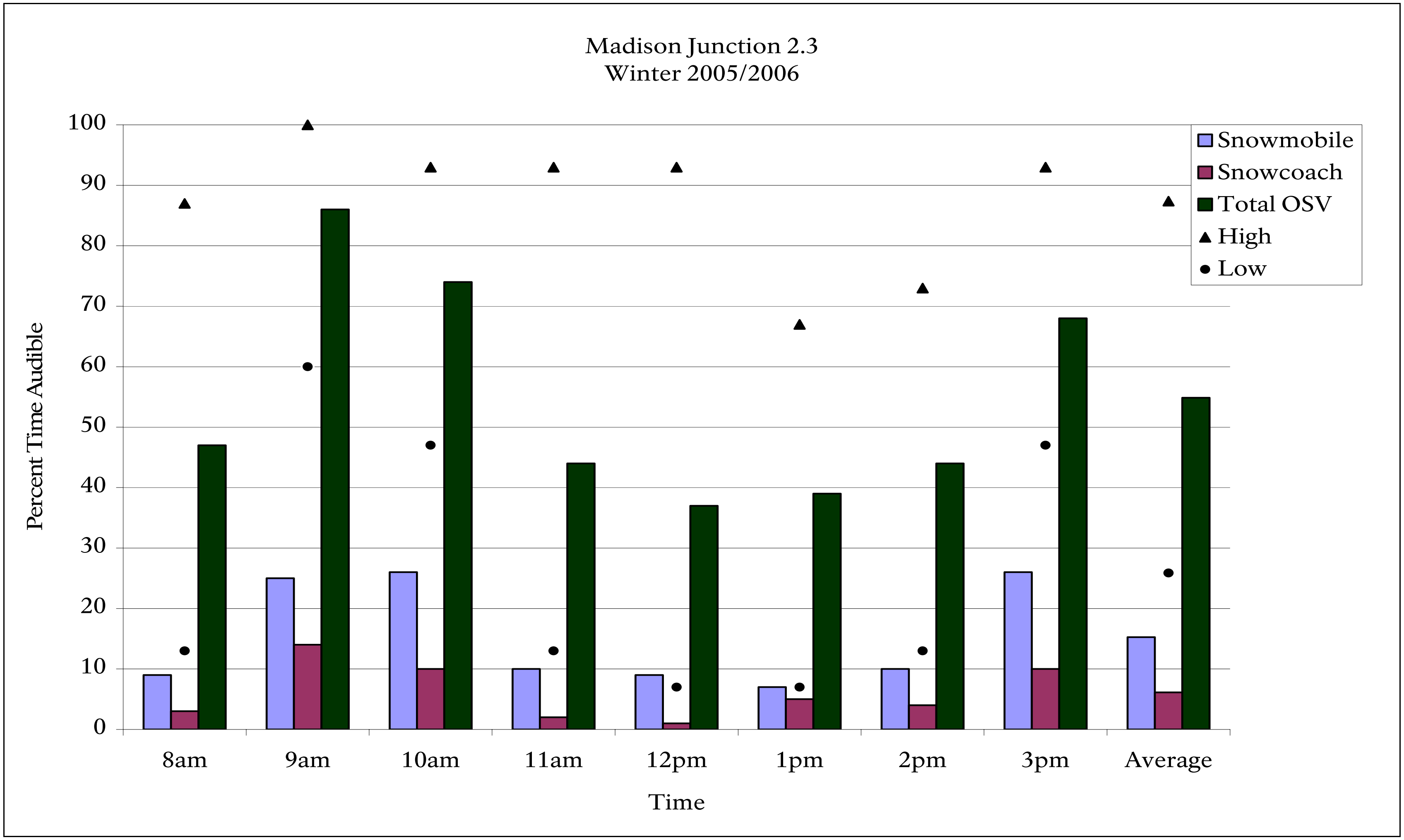


Figure 17. The average percent time audible by hour (8 am-4 pm) of snowmobiles and snowcoaches at 2.3 miles west of Madison Junction along the West Entrance Road Yellowstone National Park, 21 December 2005- March 2006.

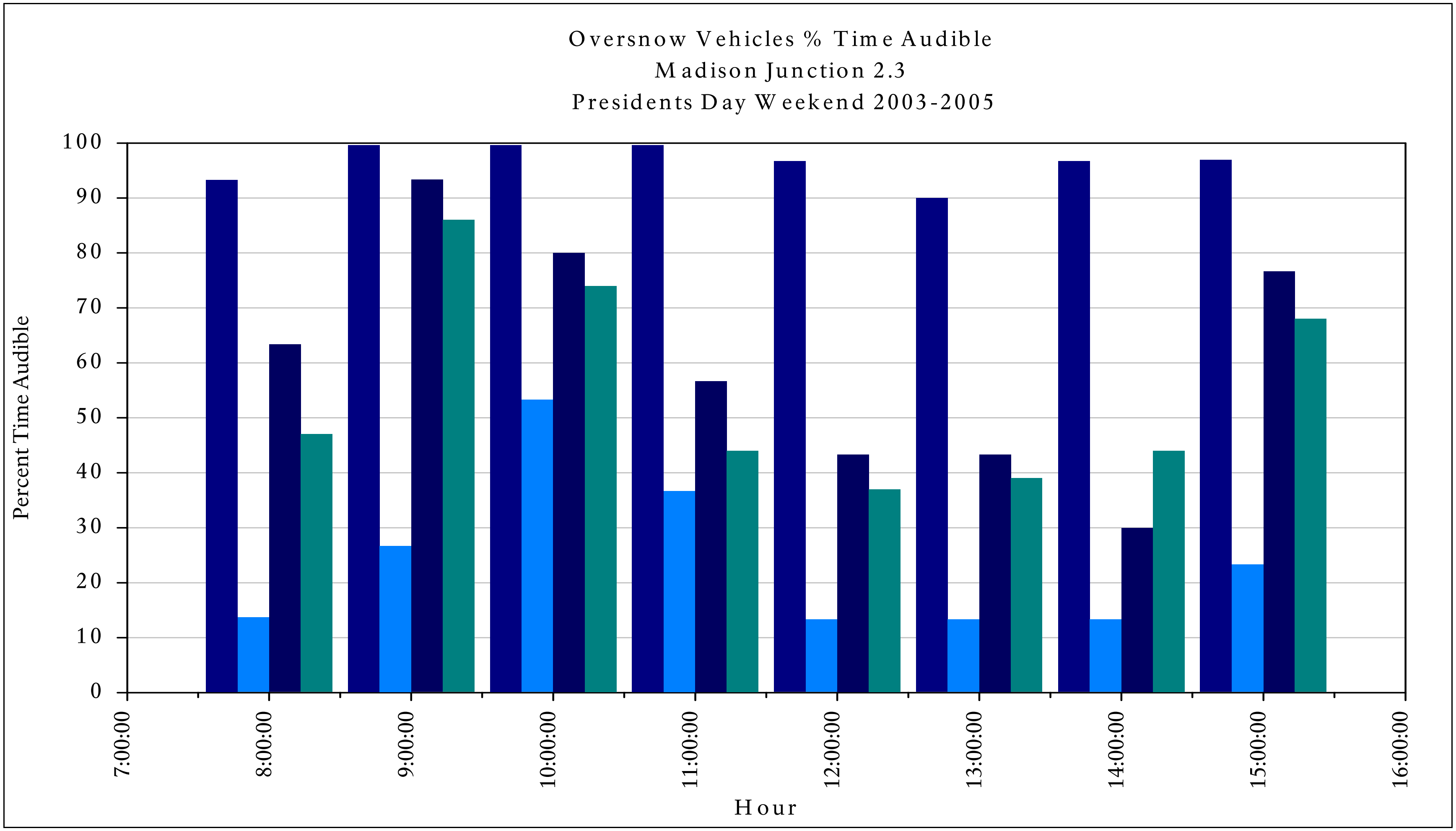


Figure 18. The average percent time audible by hour (8 am-4 pm) of snowmobiles and snowcoaches at 2.3 miles west of Madison Junction along the West Entrance Road Yellowstone National Park during Saturday and Sunday of Presidents Day Weekend 2003-2006.

West Thumb

Acoustic data were collected for one week in mid January 2006 to estimate the percent time oversnow vehicles were audible within the developed area of the geyser basin at West Thumb (Fig. 19). Oversnow vehicles were audible at this site 62% of the time between 8 am and 4 pm (Fig. 19). This was an increase of 15% compared to data collected in February 2005 (Fig. 20).

The percent time audible by hour had a bimodal distribution with oversnow vehicles audible more during peaks in the 10 am and 2 pm hours (Fig. 21). This pattern was present at all monitoring sites along travel corridors.

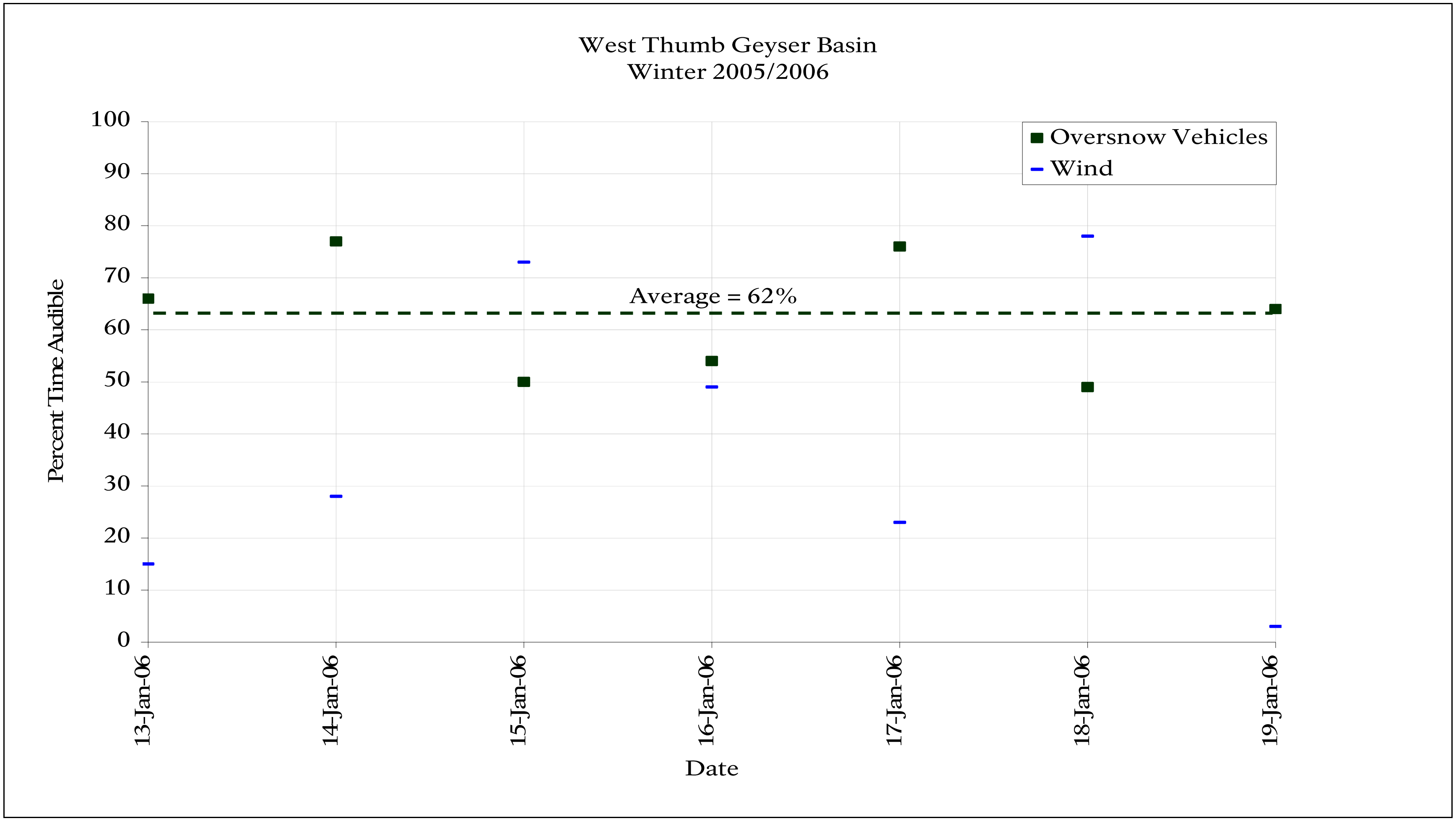


Figure 19. The percent time audible of snowmobiles, snowcoaches, and wind by date at West Thumb Yellowstone National Park, (8 am-4 pm), 13-20 January 2006.

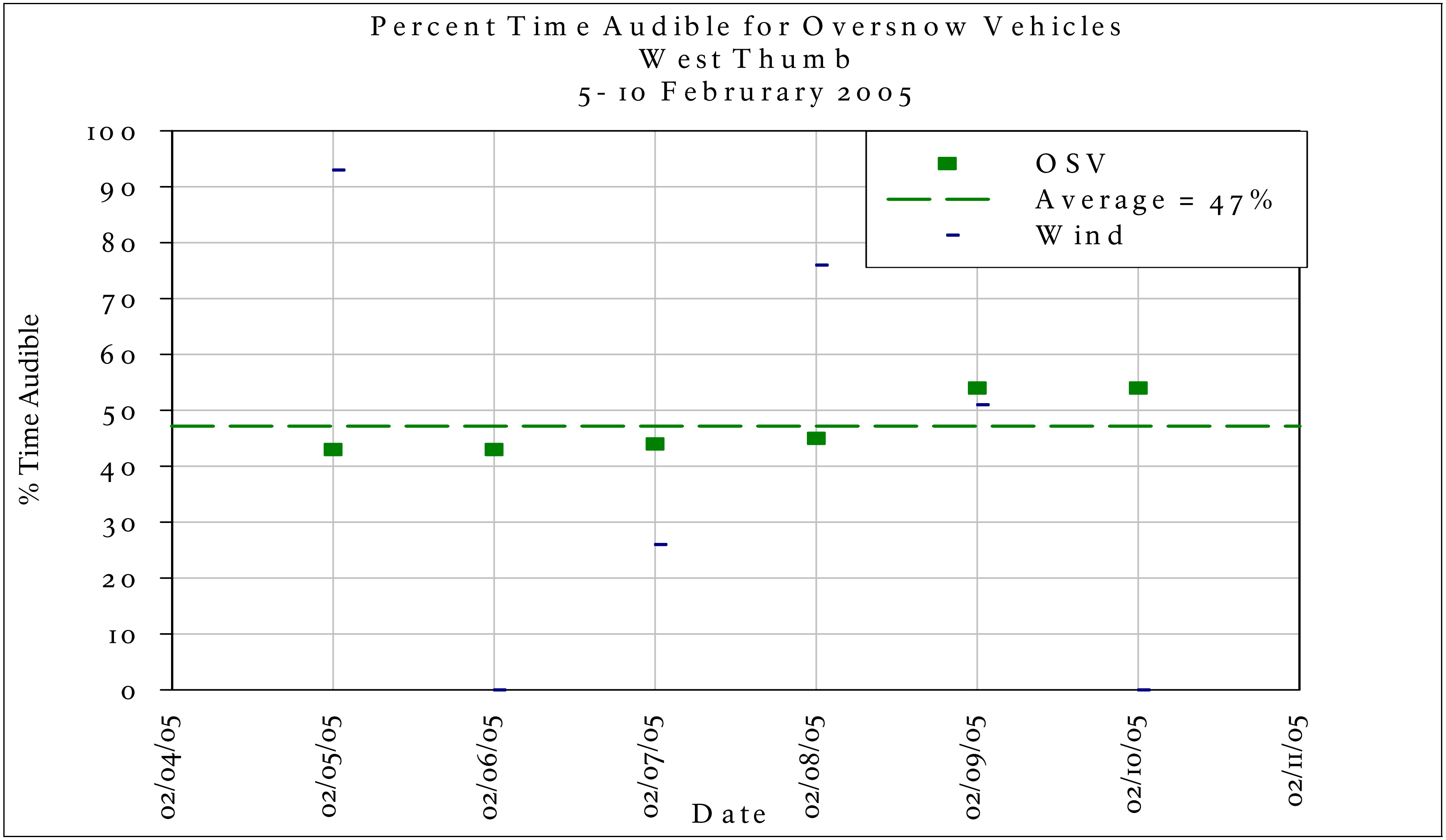


Figure 20. The percent time audible of snowmobiles, snowcoaches, and wind by date at West Thumb Yellowstone National Park, (8 am-4 pm), 5-10 February 2005.

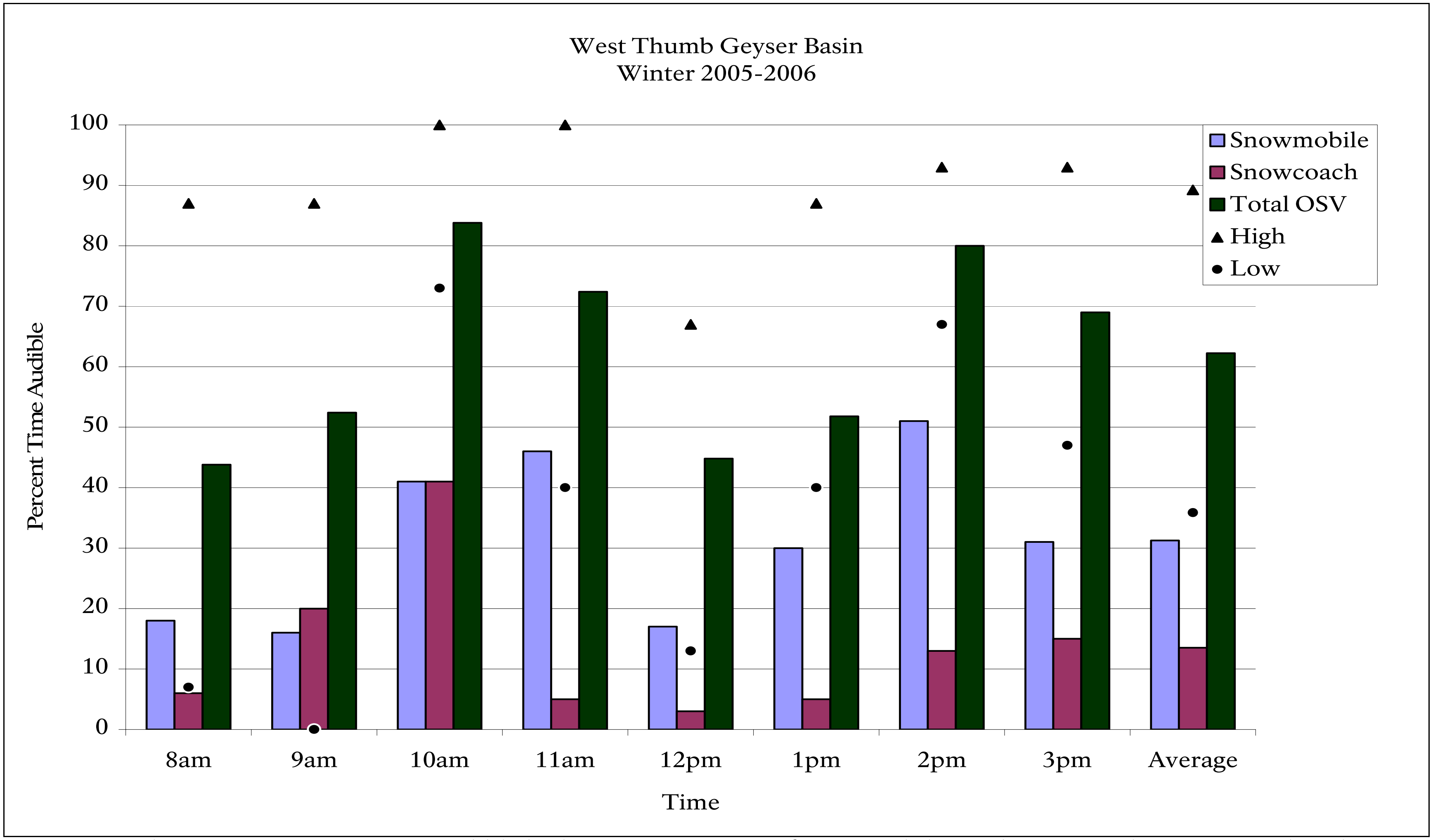


Figure 21. The average percent time audible by hour (8 am-4 pm) of snowmobiles and snowcoaches at West Thumb, Yellowstone National Park, 13-20 January 2006.

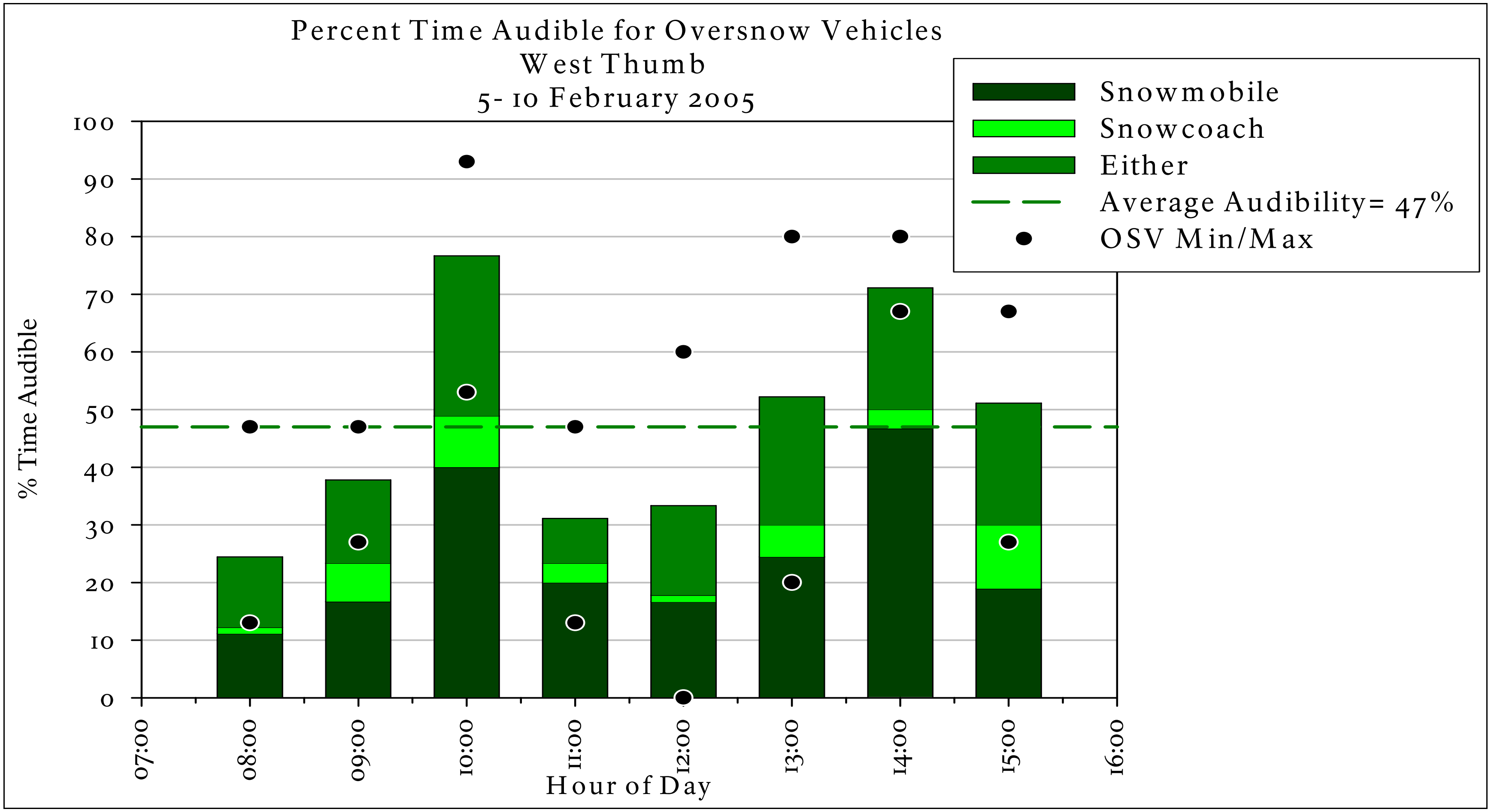


Figure 22. The average percent time audible by hour (8 am-4 pm) of snowmobiles and snowcoaches at West Thumb, Yellowstone National Park, 5-10 February 2005.

Spring Creek

Spring Creek monitoring site was chosen to represent a travel corridor south of Old Faithful. The average percent time audible for all OSVs was 34% (Fig. 23). The expected travel corridor bimodal pattern is again shown by the hourly percent time audible (Fig. 24). The week of monitoring was mostly very windy, masking distant and quiet OSV sounds. The OSV percent time audible would likely be higher than that shown on days without wind.

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

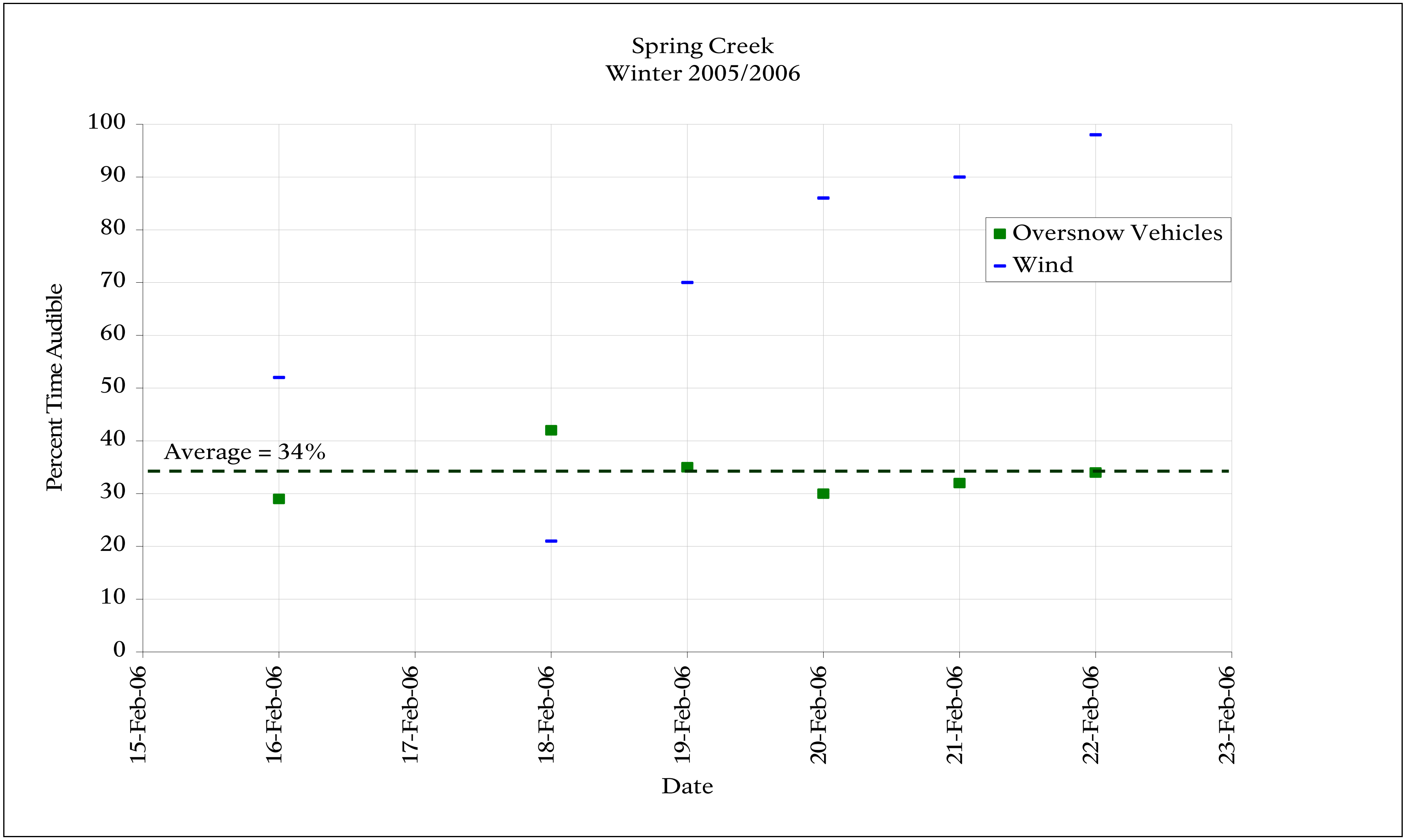


Figure 23. The percent time audible of snowmobiles, snowcoaches, and wind by date at Spring Creek, Yellowstone National Park, (8 am-4 pm), 16-22 February 2006.

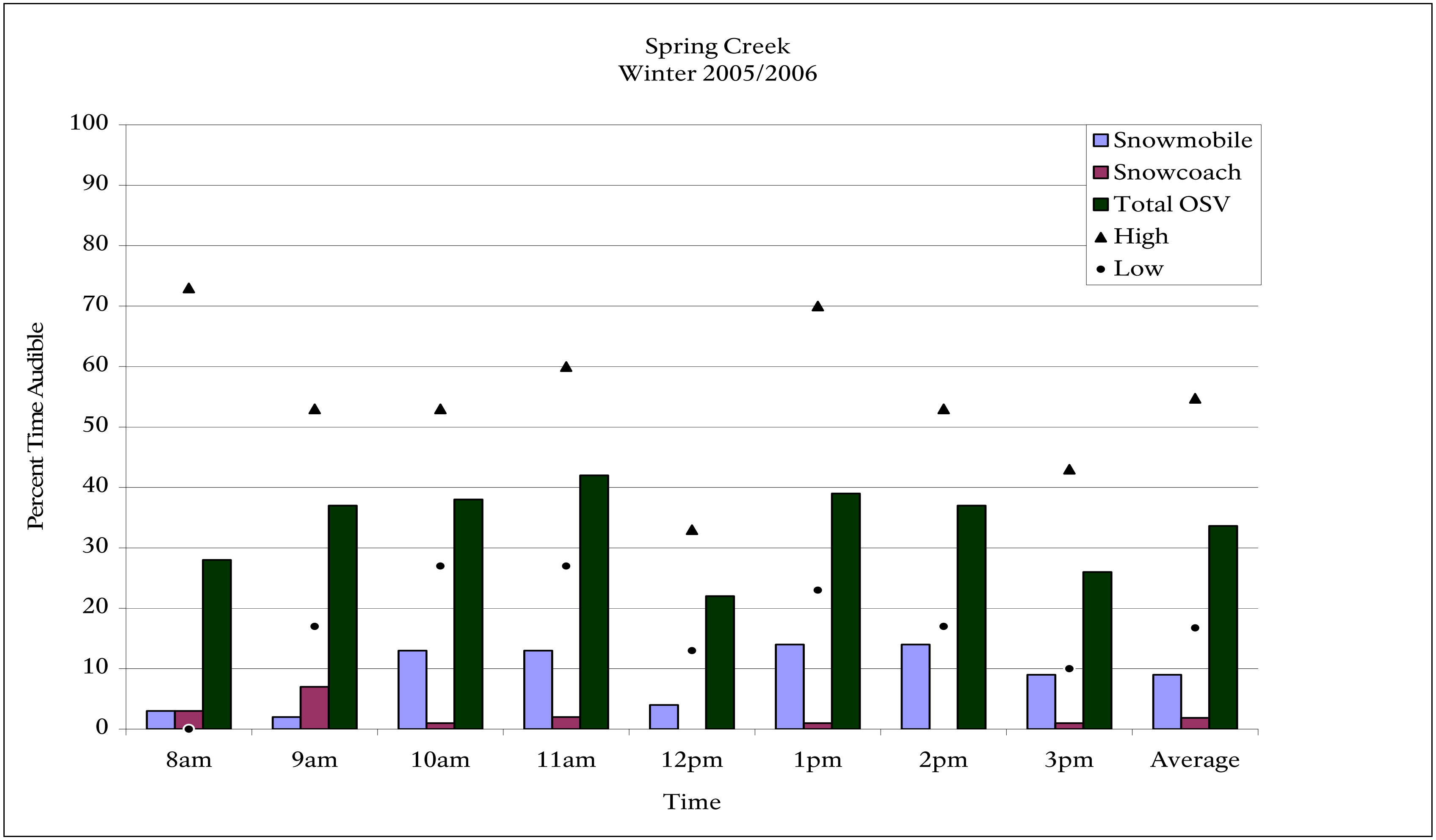


Figure 24. The percent time audible by hour (8am – 4pm) of snowmobiles, snowcoaches, and wind at Spring Creek, Yellowstone National Park, (8 am-4 pm), 16-22 February 2006.

Event Analysis:

The loudest sound events at each site were recorded and later identified. These data include all periods of the day, including night. Most of the groomer events occurred outside the WUP period, 8 am to 4 pm. Event threshold triggers were maintained just above the level that prevented wind from creating the majority of the events. Event analysis augments audibility analysis by distinguishing the loudest sound sources from those less loud. Table 4 lists the loudest sound sources by percent of all loud sources. Madison Junction 2.3 and Spring Creek were 100 feet from a 35 mph and 45 mph travel corridor, Old Faithful Weather Station was 230 feet from a 15 mph motorized travel corridor, but only 40 feet from a well-traveled foot path. Therefore, the greater distance the monitor was from the motorized travel route at Old Faithful reduced the number of oversnow vehicles exceeding the threshold at this location compared to Madison Junction 2.3 and Spring Creek. The Spring Creek monitoring site recorded many of the loud Bombardier snowcoaches at cruising speed. The helicopter events at Old Faithful were all from emergency landings at the helipad near the monitoring site. Few to no loud motorized events occurred at the West Thumb and Old Faithful Upper Basin monitoring sites and therefore are not included here.

Table 4. The number and percentage of sound events exceeding user-defined thresholds of sound level and duration at three locations in Yellowstone National Park, winter use season 2005-2006. These represent the loudest sounds recorded at these locations. Wind-caused events were excluded from analysis.

	Old Faithful Weather Station[1]		**Spring Creek[1]**		**Madison Junction 2.3[1]**	
	21 Dec-23 Feb		**16-22 Feb**		**21 Dec-12 Mar**	
Sound Source	**Number**	**%**	**Number**	**%**	**Number**	**%**
Snowmobile	1	3%	0	0%	118	31%
Snowcoach	2	7%	70	89%	124	33%
Oversnow Vehicle	0	0%	0	0%	3	1%
Snow Groomer	5	16%	9	11%	127	34%
Wheeled Vehicle	0	0%	0	0%	0	0%
Jet	0	0%	0	0%	0	0%
Prop	1	3%	0	0%	1	0%
Helicopter	17	55%	0	0%	0	0%
People	1	3%	0	0%	0	0%
Natural	3	10%	0	0%	5	1%
Unknown	1	3%	0	0%	0	0%
Total	31		79		386	

[1] Thresholds were over 70 dBA/1 second or 60 dBA/10 seconds

Sound levels:

Sound level analysis is not as easily understood as audibility analysis. The WUP 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 17 million seconds of data collected 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.

The 2004 Temporary Winter Use Plans Environmental Assessment defined oversnow vehicles having maximum sound levels greater than 70 dBA in developed areas and travel corridors and greater than 45 dBA in backcountry areas as a major adverse effect (Table 1). To compare to previous winter use plans' standards and thresholds see Appendix C. Table 5 has typical sound levels of some common sound sources to introduce decibel levels.

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 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," 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, and insects) may heavily influence its value, even though the sound levels are typically lower.

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_{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, 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. The L_{50} or the median is also not affected by a few loud sounds as is the L_{eq} and therefore provides another useful measure of the sound environment.

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 in locations other than those most heavily impacted from non-natural sounds. However, using this or any L_x metric can give misleading results in areas where natural sounds such as thermal activity (Old Faithful Upper Basin), wind, or other natural sounds are common and louder than the quietest x% of the sounds. Also using L_{90} or other L_x metrics as the natural ambient is inappropriate in locations with constant non-natural sounds (Old Faithful Weather Station). In very quiet areas the L_{90} may overestimate the true natural ambient because of limitations of the instrument noise floor threshold (See Appendix F). The noise floor, the lowest level the acoustic equipment could measure, was approximately 19-20 dBA (see Table 5 for reference levels). The quietest sound levels in YNP (Appendix F) are below this noise floor so the lowest documented measurements 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.

Two differences between the analyses of the winters 2003-2004 and the following two winters should be noted. The hourly sound levels by month are calculated using median values for the L_{eq}, L_{50}, and L_{90} values for 2004-2005 and 2005-2006. The same metrics were calculated as log means for winter 2003-2004. All sound levels collected when the wind speed was greater than 11 mph were deleted from the analysis in 2004-2005 and 2005-2006. During 2003-2004 some data were retained with wind speeds higher than 11 mph. These differences among years would tend to increase the L_x values for the winter 2003-2004 during those periods with high wind and at sites with few loud events. The log means are more influenced by higher values than is the median and the retention of high wind speeds would also have increased the L_x values. However, at the YNP monitoring sites there would be generally less then 5% difference between the metrics calculated using the two methodologies (Mike Donaldson, pers. comm.).

Table 5. 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 defined as 0 – 130 dBA.

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	Snake River at 300 ft	Quiet bedroom
20		Winter wilderness	Recording studio
10	Barely audible	Below noise floor	

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.

Old Faithful Weather Station

The average hourly sound levels by month from the soundscape monitoring at Old Faithful Weather Station are shown in Figures 25-36 for the winters 2003-2004 to 2005-2006. The Old Faithful monitor was 230 feet from the entrance/exit road used by oversnow vehicles. The 2004 WUP impact definition thresholds assume a distance of 100 feet 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, adding an additional 6 dBA to the maximum sound levels shown in the following figures would approximate the levels at 100 feet, using the reasonable assumption that the maximum sound levels originate from oversnow vehicles traveling 230 feet from the sound monitor. This assumption is reasonable for only 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 instrumentation near the sound monitor, etc. and therefore the distance is unknown and thus the correction factor is also 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 on all but the windiest days when the wind created microphone distortion. Oversnow vehicles were often used outside the period covered by the WUP measurement periods, even in the middle of the night.

The lowest sound levels (about 25 dBA) were determined by the nearly constant utility sounds (exhaust and heating fans) from the Snow Lodge and Old Faithful Ranger Station (Fig. 25, 28. 31, and 34).

To demonstrate some of the hourly sound level variability, Figure 37 shows each of the hourly sound metrics for the month of January 2004.

Figures 38, 39, 40, and 41 show the sound levels over Presidents Day Weekend during 2006, 2005, 2004, and 2003. The L_x values for this comparison are calculated the same way for all four years so can be compared directly. Recalling that a 10 dBA difference is perceived as a doubling of loudness there were large differences among years. The change from two-stroke snowmobiles to four-stroke and reduced numbers after 2002-2003 likely explains much of the difference between the winter of 2002-2003 (Presidents Day 2003) and the subsequent winters.

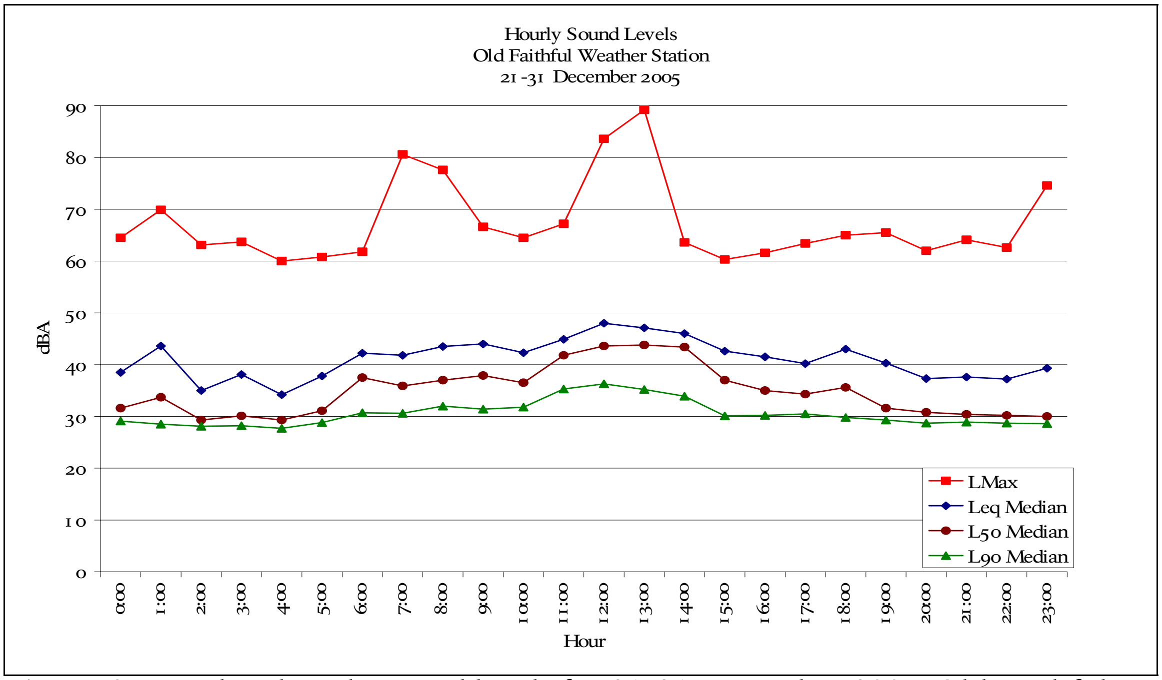


Figure 25. Median hourly sound levels for 21-31 December 2005, Old Faithful Weather Station, Yellowstone National Park. These sound levels include all natural and non-natural sounds. L_{max} is the highest sound level measured during the measurement period. (n=258 hours).

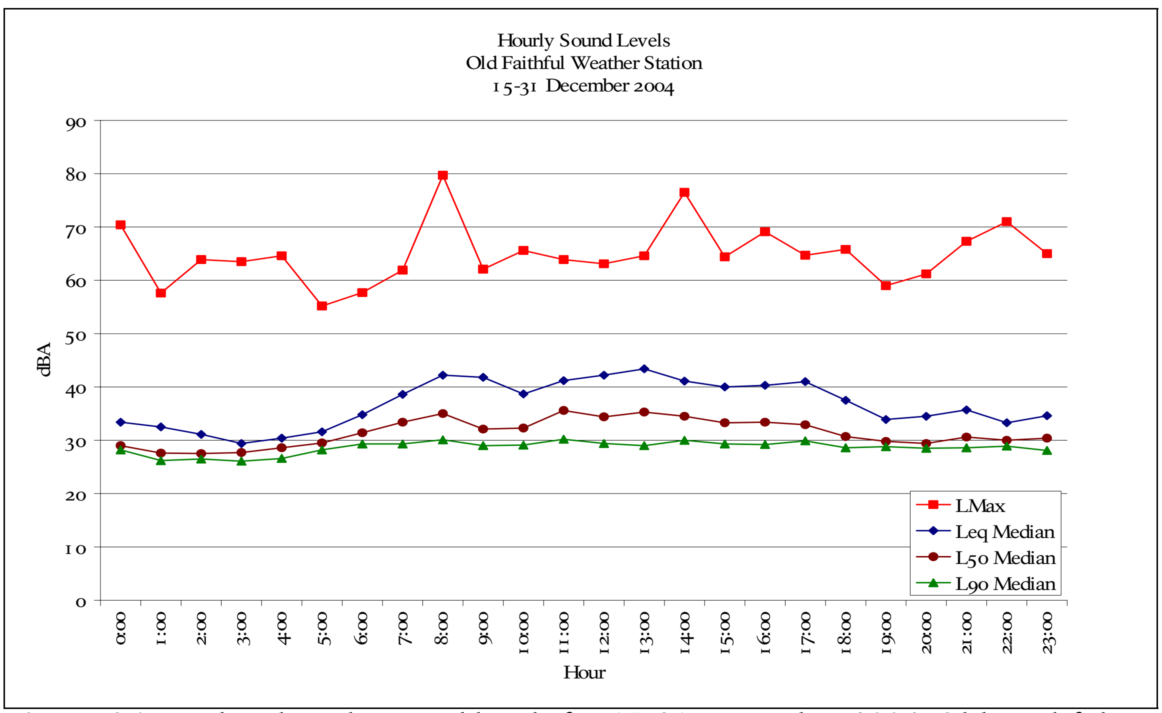


Figure 26. Median hourly sound levels for 15-31 December 2004, Old Faithful Weather Station, Yellowstone National Park. These sound levels include all natural and non-natural sounds. See Fig. 25 caption for more details. (n=370 hours).

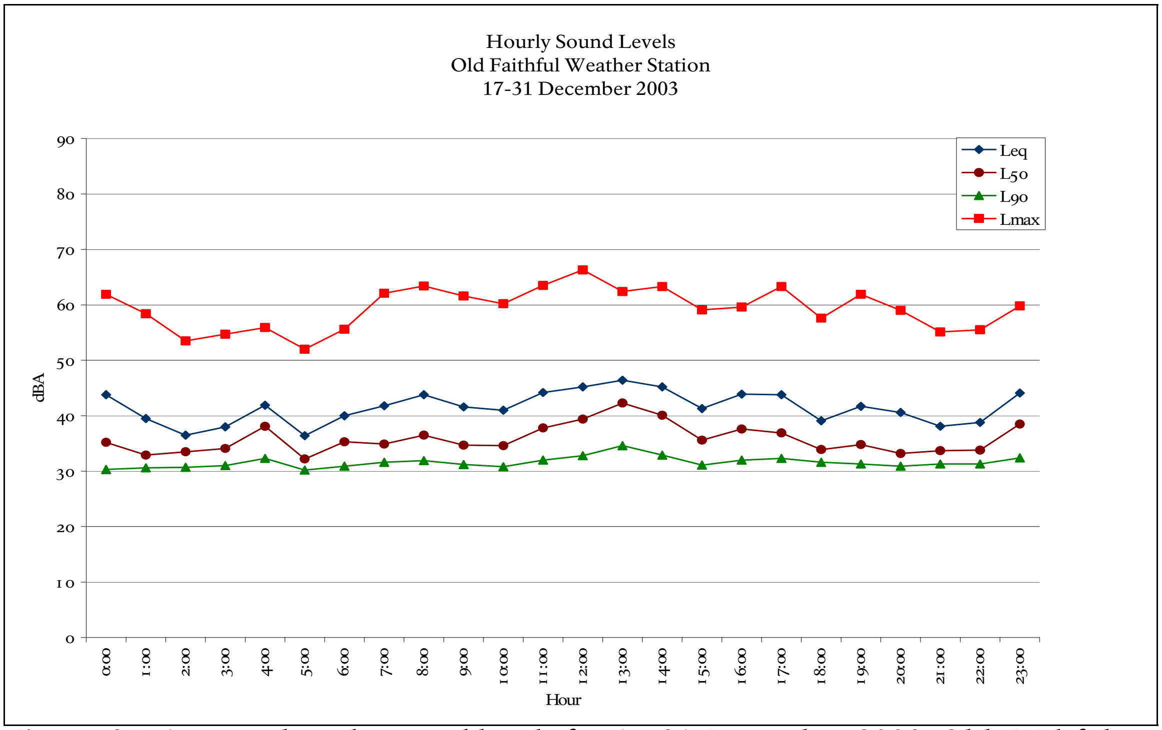


Figure 27. Average hourly sound levels for 17-31 December 2003, Old Faithful Weather Station, Yellowstone National Park. These sound levels include all natural and non-natural sounds. See Fig. 25 caption for more details. (n=358 hours).

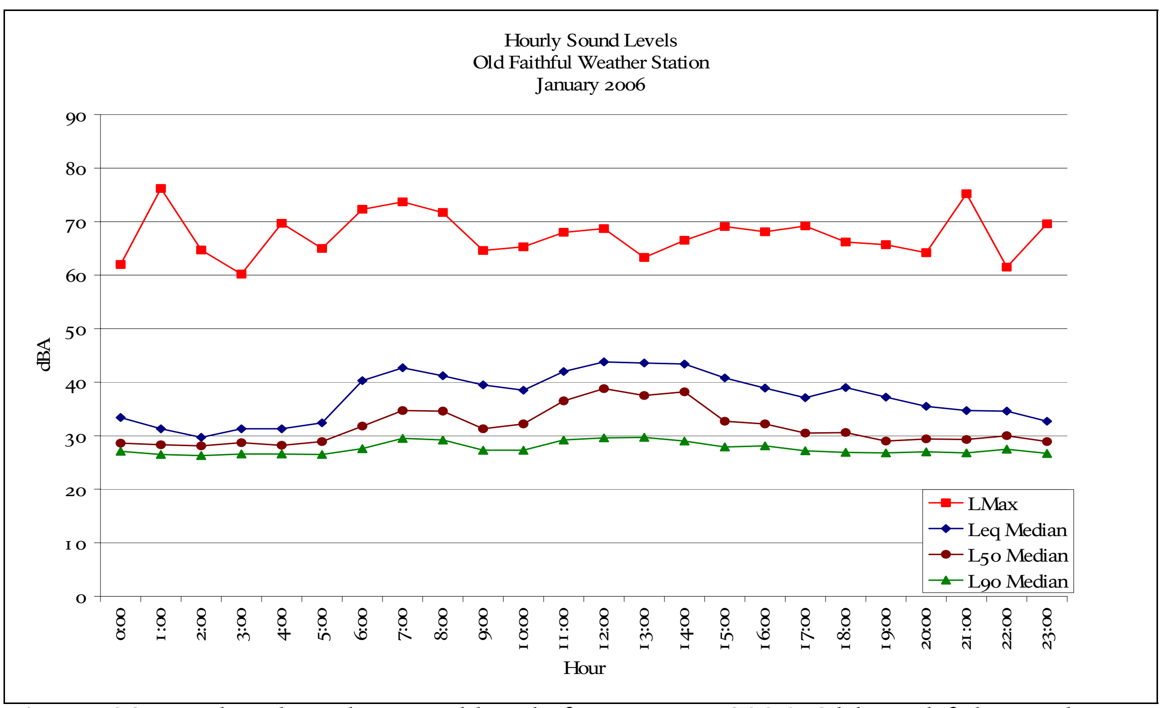


Figure 28. Median hourly sound levels for January 2006, Old Faithful Weather Station, Yellowstone National Park. See Fig. 25 caption for more details. (n=728).

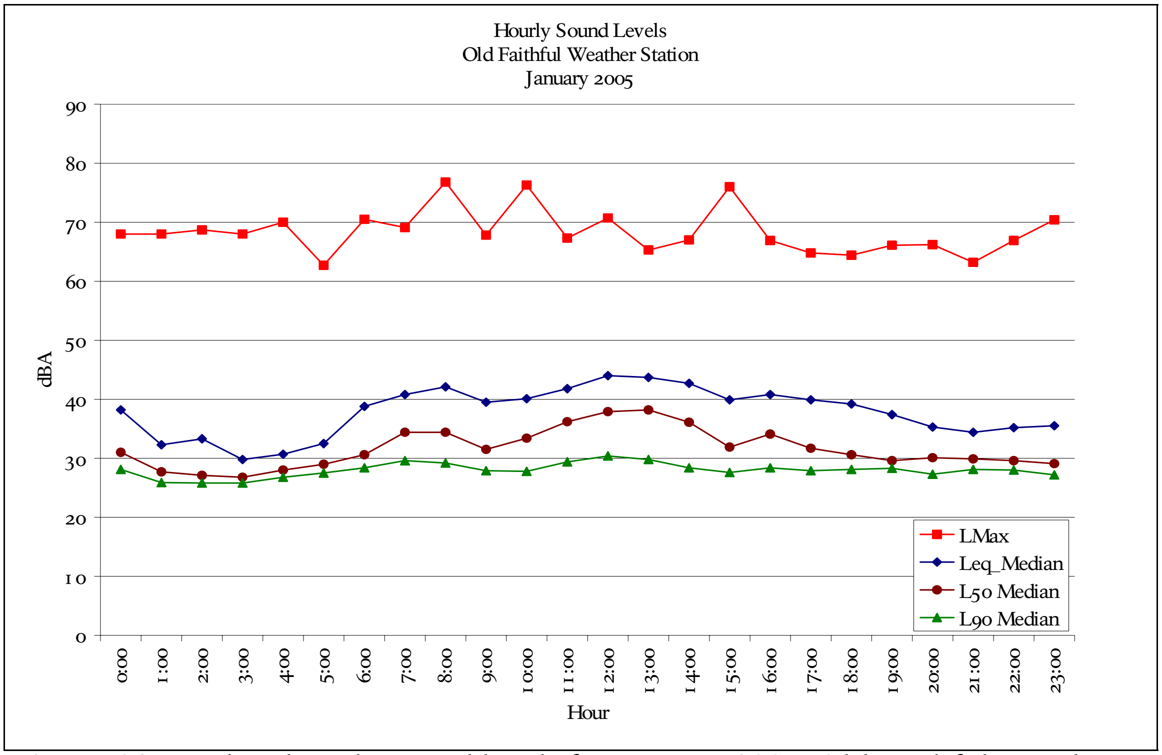


Figure 29. Median hourly sound levels for January 2005, Old Faithful Weather Station, Yellowstone National Park. See Fig. 25 caption for more details. (n=736).

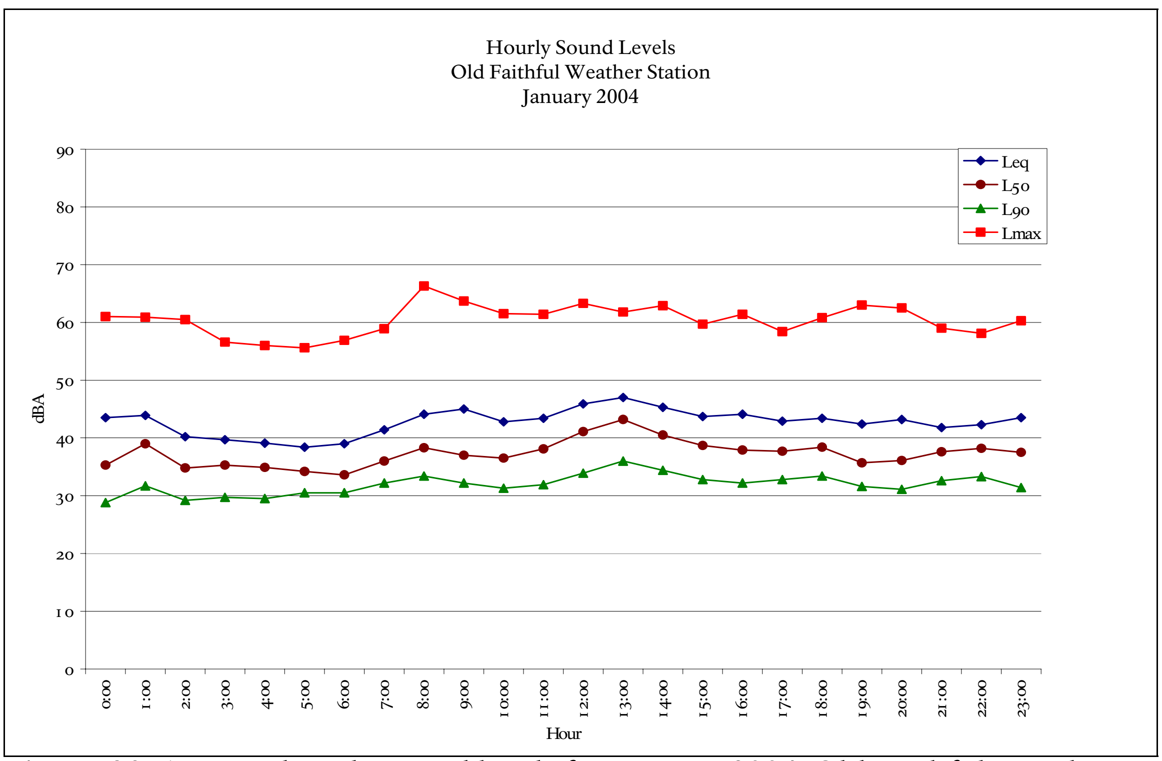


Figure 30. Average hourly sound levels for January 2004, Old Faithful Weather Station, Yellowstone National Park. S See Fig. 25 caption for more details. (n=735).

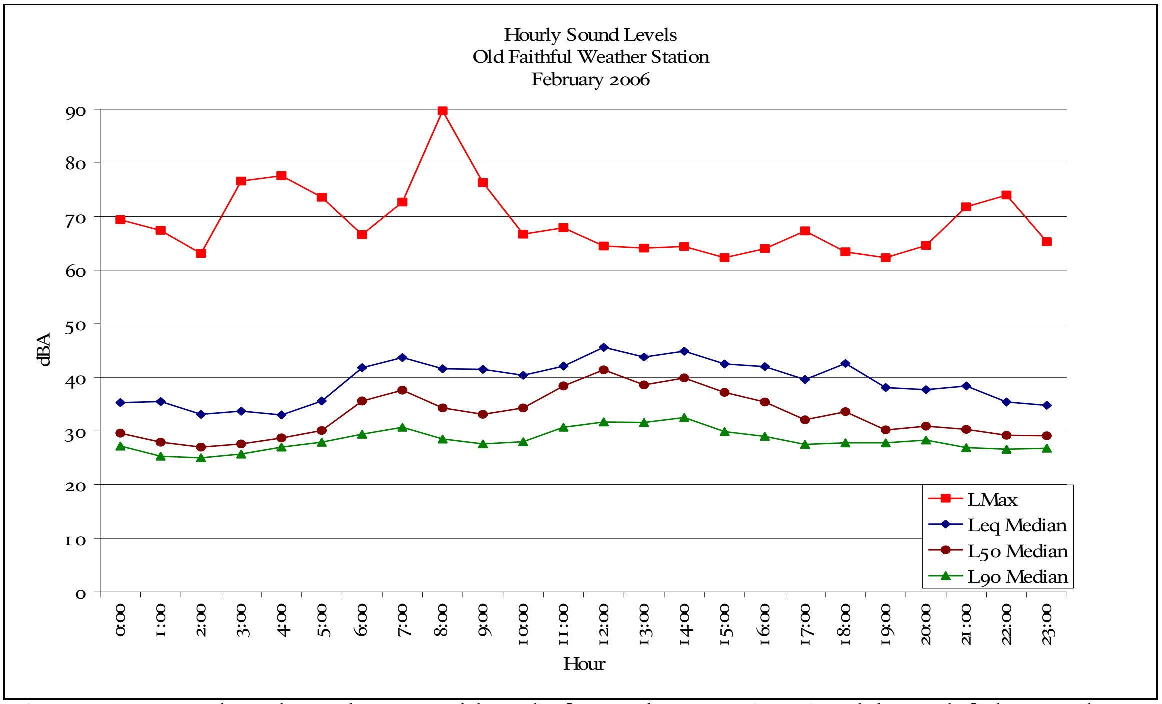


Figure 31. Median hourly sound levels for February 2006, Old Faithful Weather Station, Yellowstone National Park. See Fig. 25 caption for more details. (n=637).

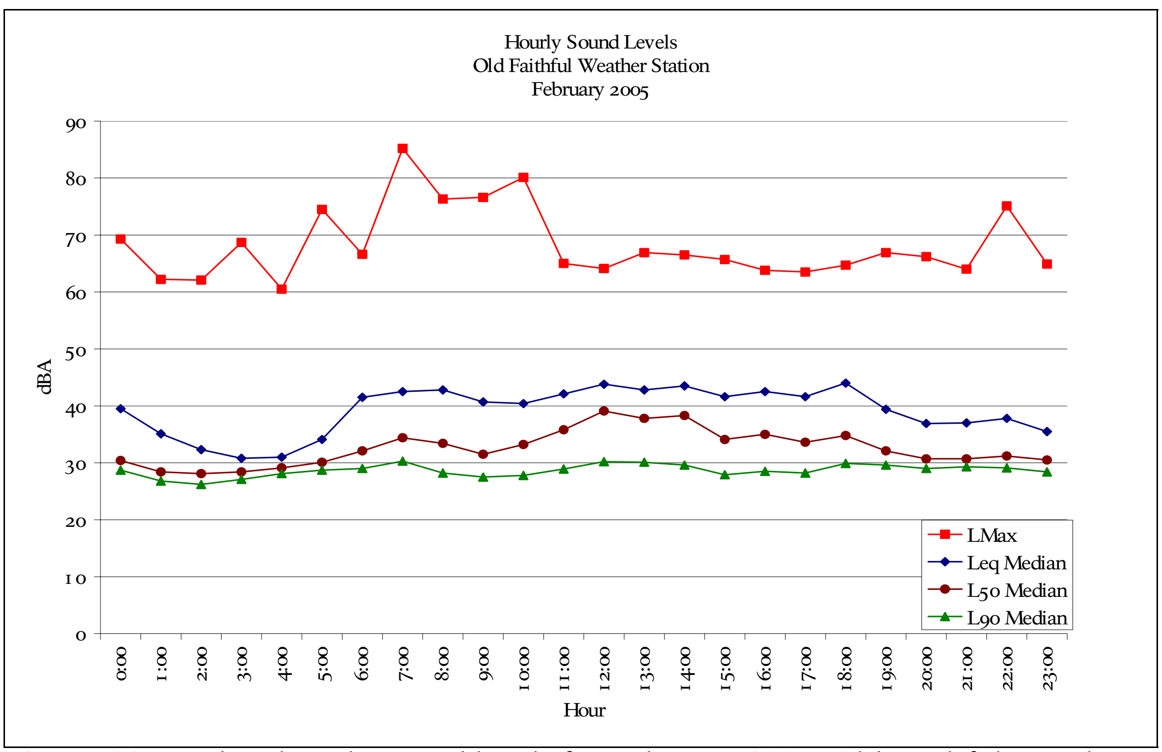


Figure 32. Median hourly sound levels for February 2005, Old Faithful Weather Station, Yellowstone National Park. See Fig. 25 caption for more details. (n=609).

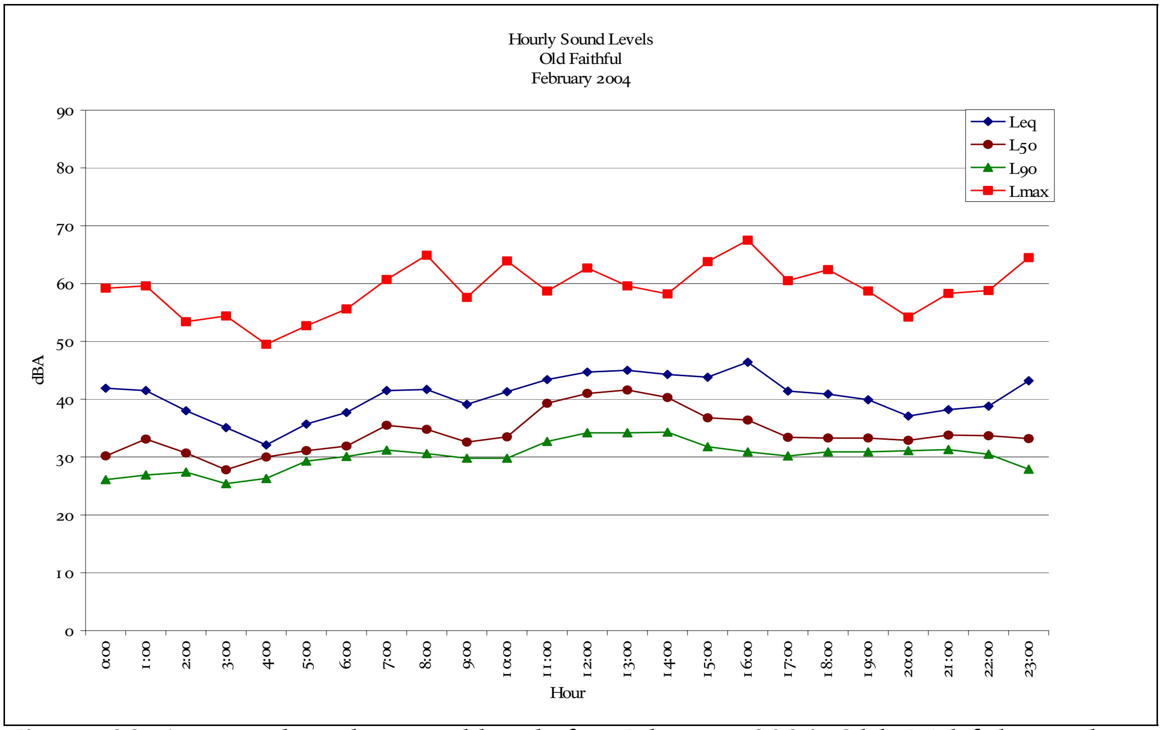


Figure 33. Average hourly sound levels for February 2004, Old Faithful Weather Station, Yellowstone National Park. See Fig. 25 caption for more details. (n=435).

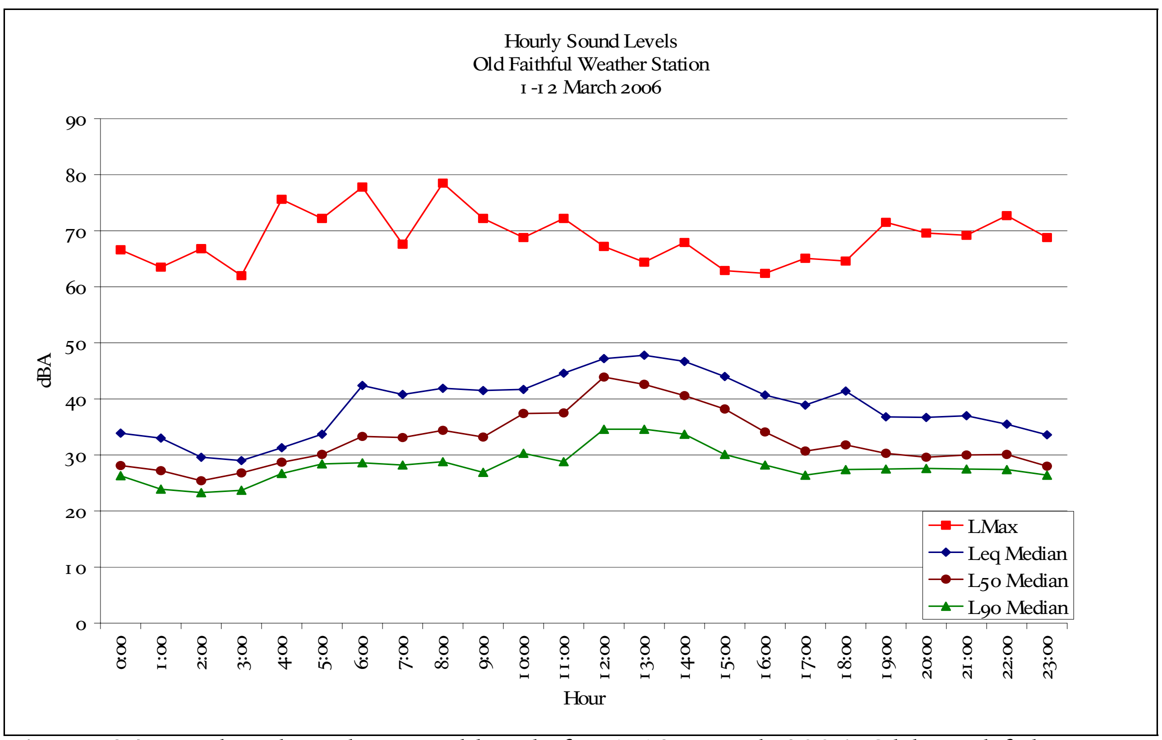


Figure 34. Median hourly sound levels for 1-12 March 2006, Old Faithful Weather Station, Yellowstone National Park. See Fig. 25 caption for more details. (n=281).

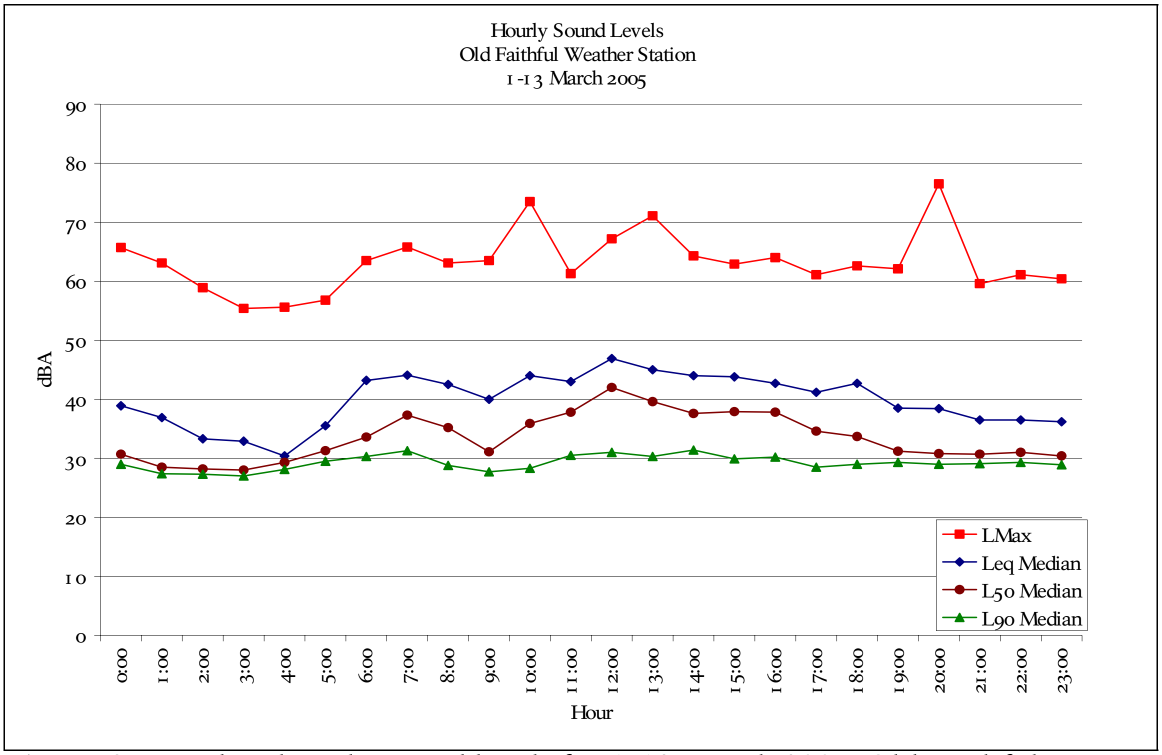


Figure 35. Median hourly sound levels for 1-13 March 2005, Old Faithful Weather Station, Yellowstone National Park. See Fig. 25 caption for more details. (n=281).

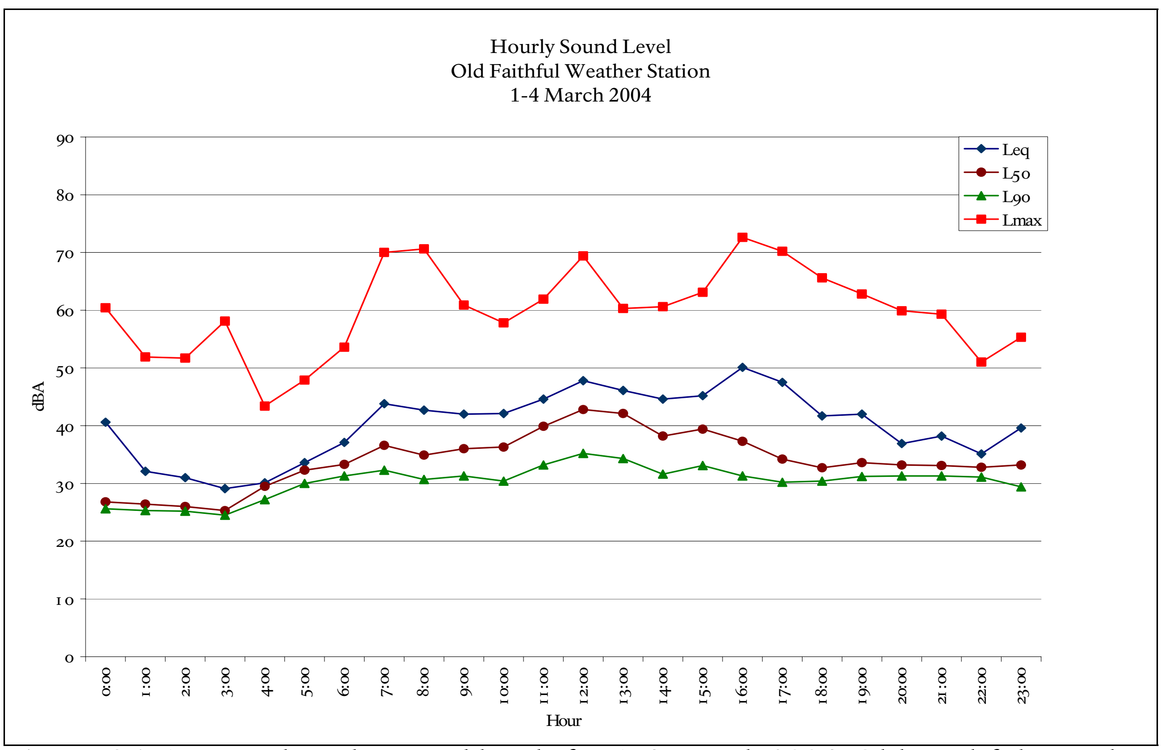


Figure 36. Average hourly sound levels for 1-4 March 2004, Old Faithful Weather Station, Yellowstone National Park. See Fig. 25 caption for more details. (n=82).

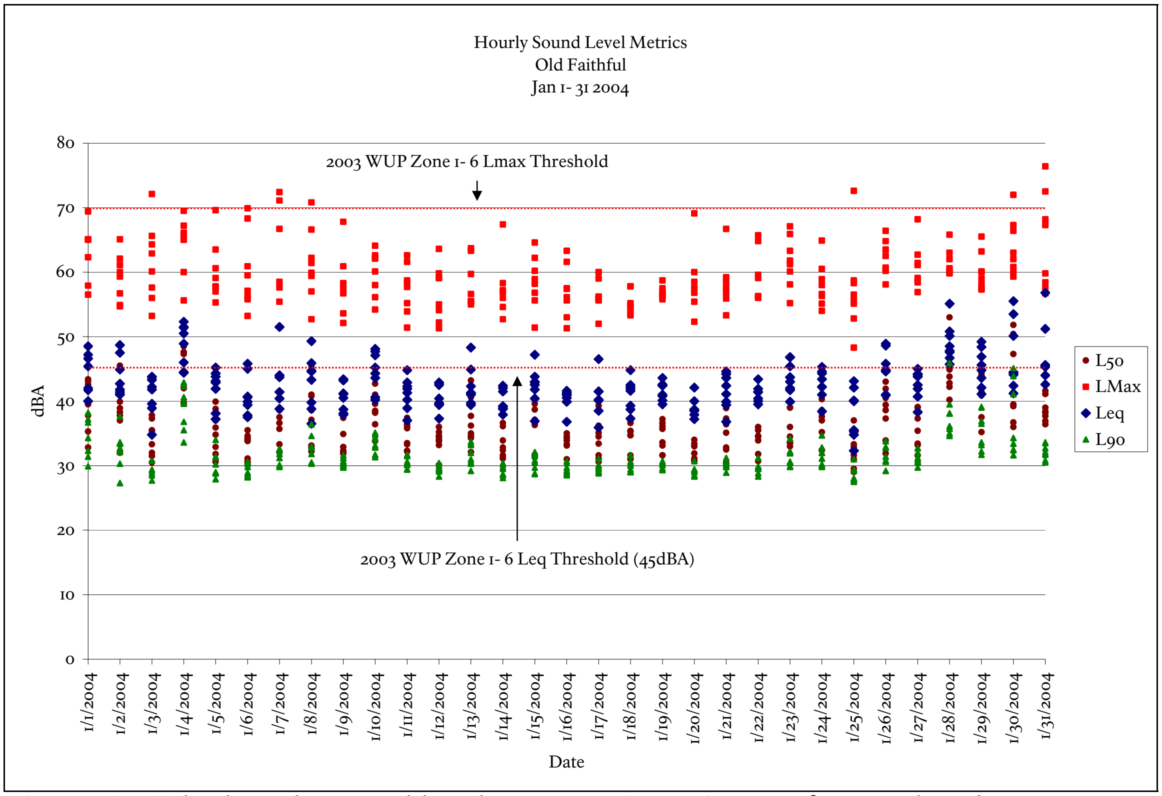


Figure 37. The hourly sound level metrics (8 am-4 pm) of natural and non-natural sounds at Old Faithful Weather Station, Yellowstone National Park, January 2004. See Fig. 25 caption for more details. (n=243).

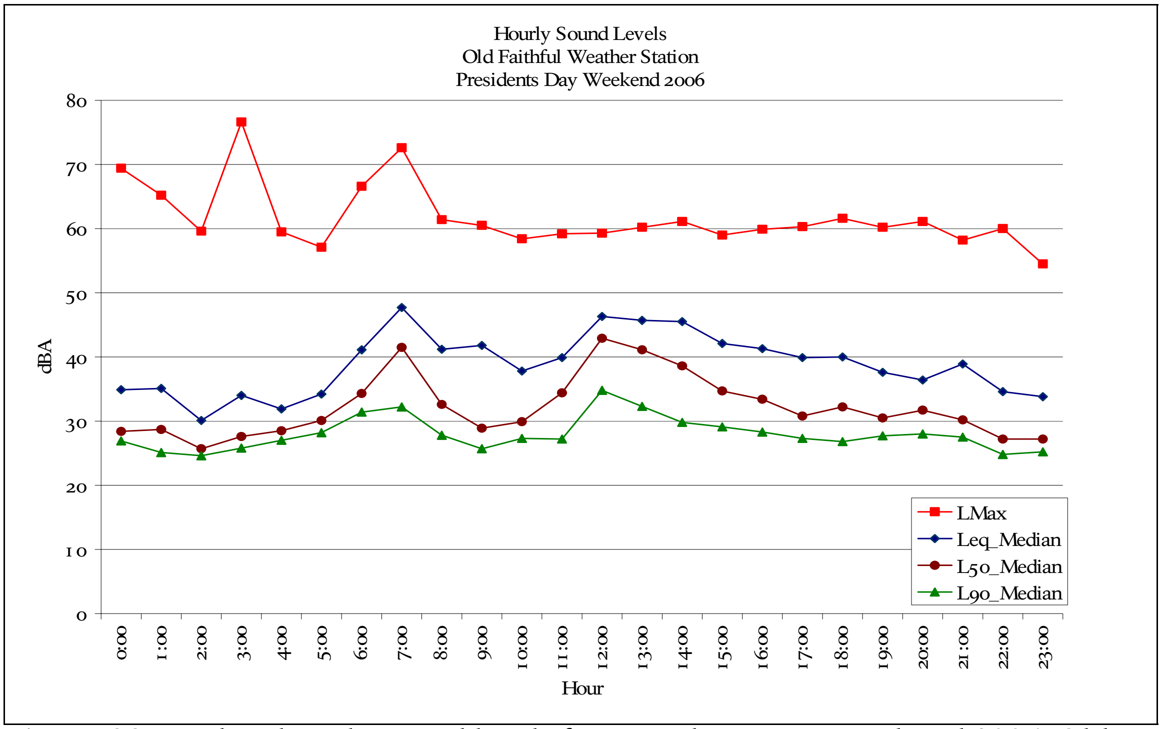


Figure 38. Median hourly sound levels for Presidents Day Weekend 2006, Old Faithful Weather Station, Yellowstone National Park. See Fig. 25 caption for more details. (n=72).

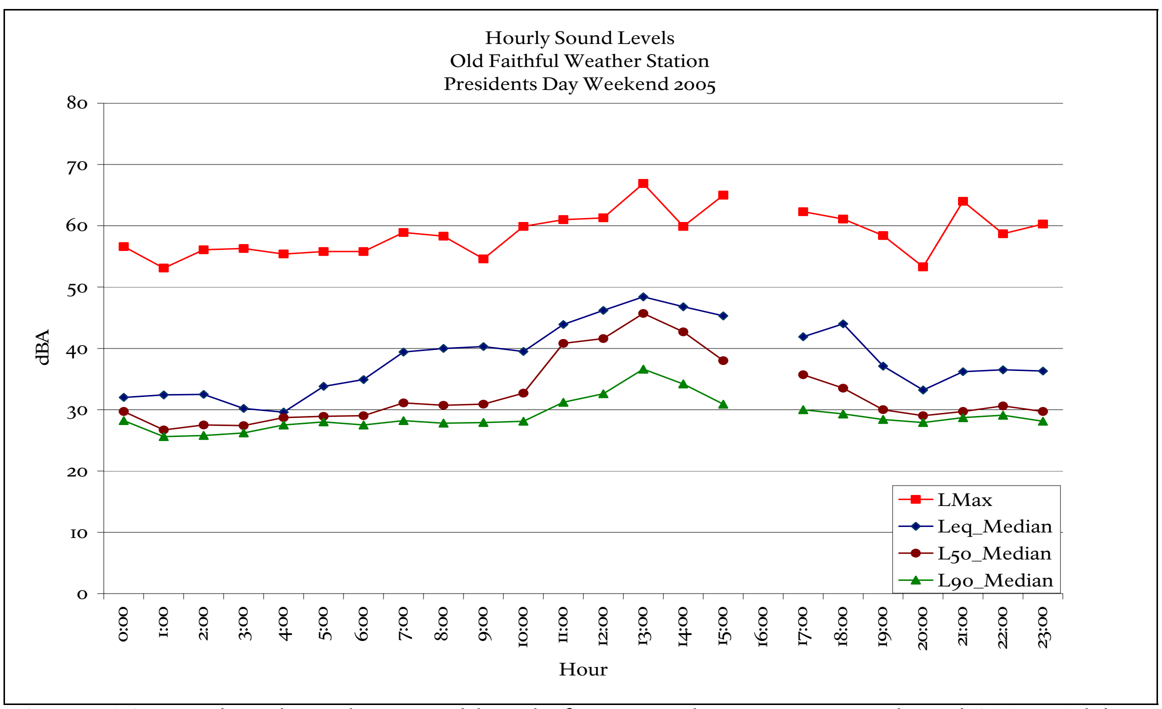


Figure 39. Median hourly sound levels for Presidents Day Weekend 2005, Old Faithful Weather Station, Yellowstone National Park. See Fig. 25 caption for more details. Missing hours due to excessive wind speeds. (n=61).

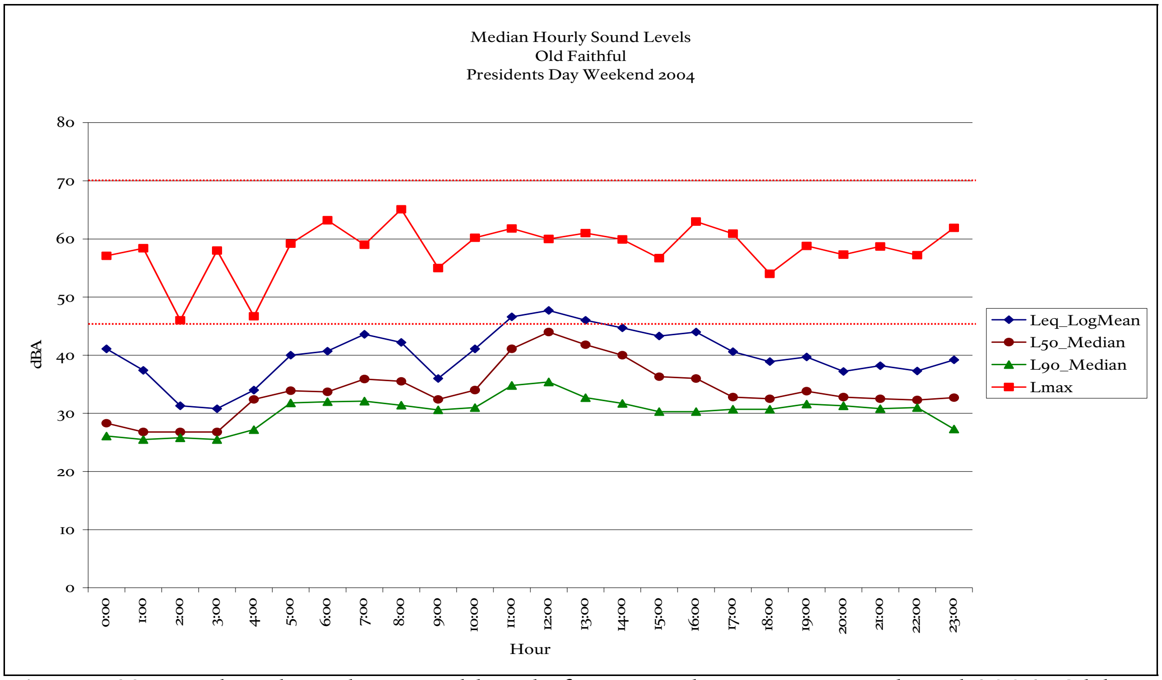


Figure 40. Median hourly sound levels for Presidents Day Weekend 2004, Old Faithful Weather Station, Yellowstone National Park. See Fig. 25 caption for more details. (n=55).

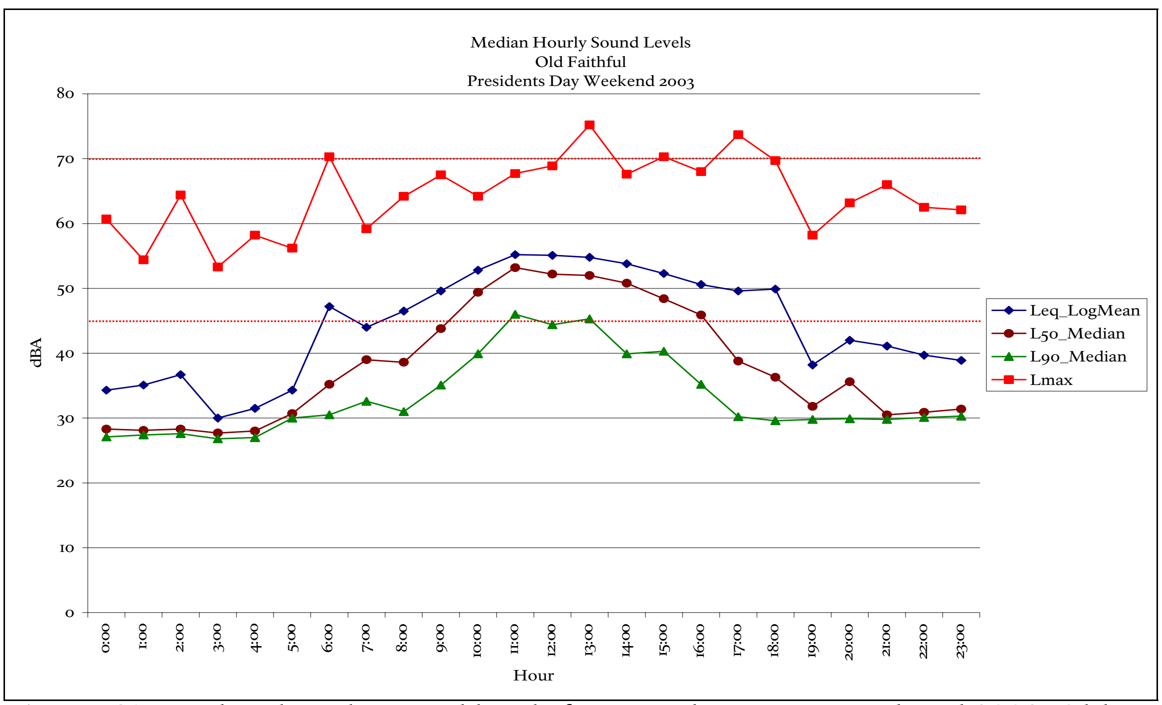


Figure 41. Median hourly sound levels for Presidents Day Weekend 2003, Old Faithful Weather Station, Yellowstone National Park. See Fig. 25 caption for more details. (n=71).

Old Faithful Upper Basin

Relatively tight clustering of the hourly L_{eq}, L_{50}, and L_{90} sound levels indicates consistent sound levels with few loud events. This occurred at the Old Faithful Basin in early winter (Fig. 42) compared to those in February (Fig. 43) and at the nearby Old Faithful Weather Station (Fig. 25). Both the minimum and maximum sound levels were largely determined by natural thermal activity, gurgling and sputtering at low levels and erupting geysers at the higher levels. Footsteps on the nearby boardwalk, people's voices, and wind in the trees also contributed to the sound levels documented. Construction activity at the Old Faithful Inn 1,100 feet away also was audible at low sound levels. Oversnow vehicles were often audible (Fig. 12 and 14) and contributed to the soundscape, but only at intermediate and lower sound levels.

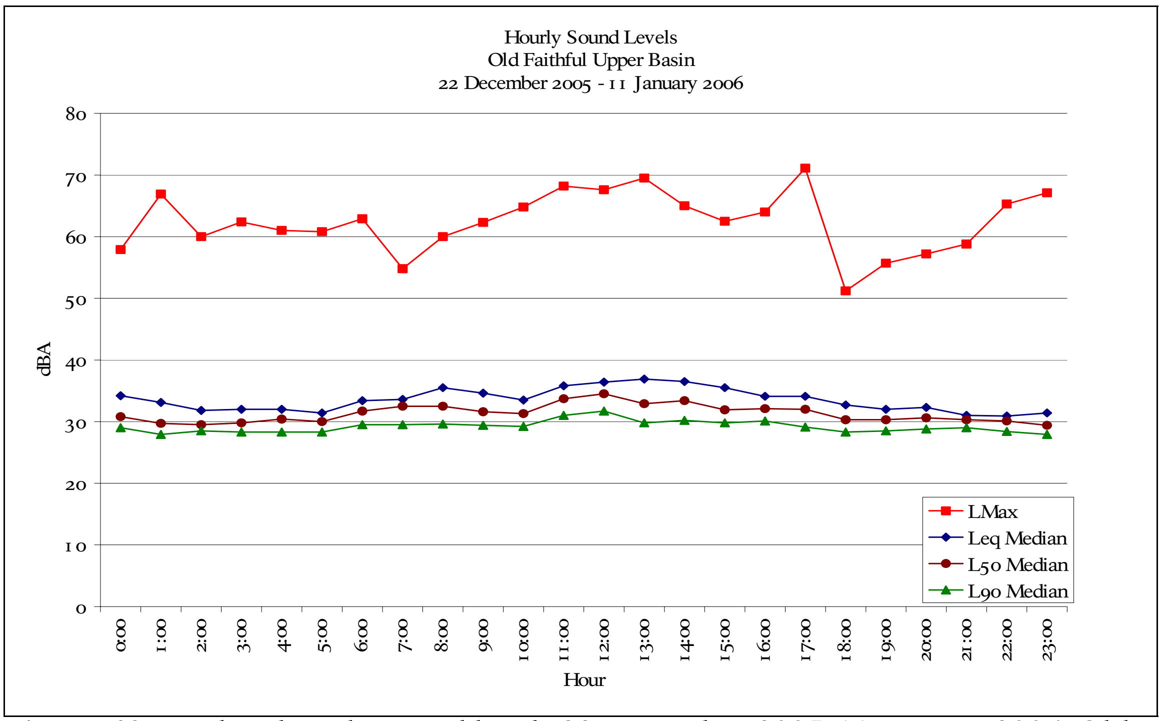


Figure 42. Median hourly sound levels 22 December 2005-11 January 2006, Old Faithful Upper Basin, Yellowstone National Park. See Fig. 25 caption for more details. (n=291).

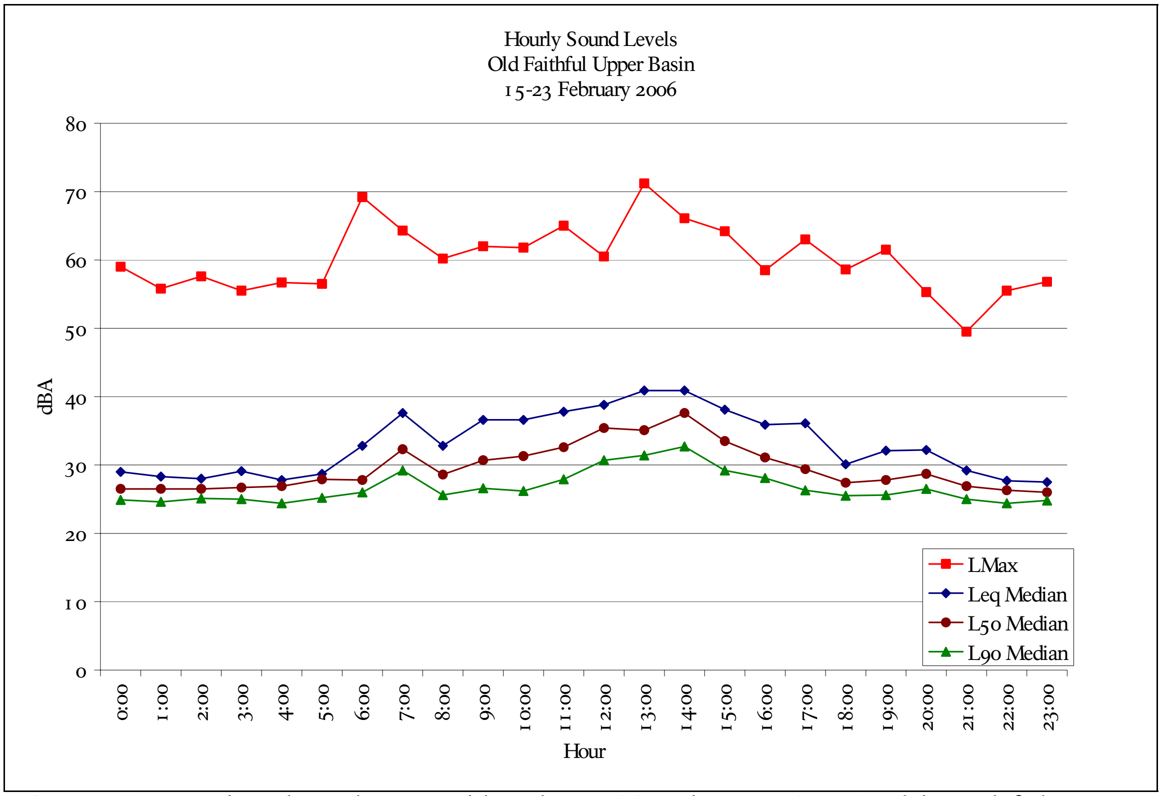


Figure 43. Median hourly sound levels 15-23 February 2006, Old Faithful Upper Basin, Yellowstone National Park. See Fig. 25 caption for more details. (n=182).

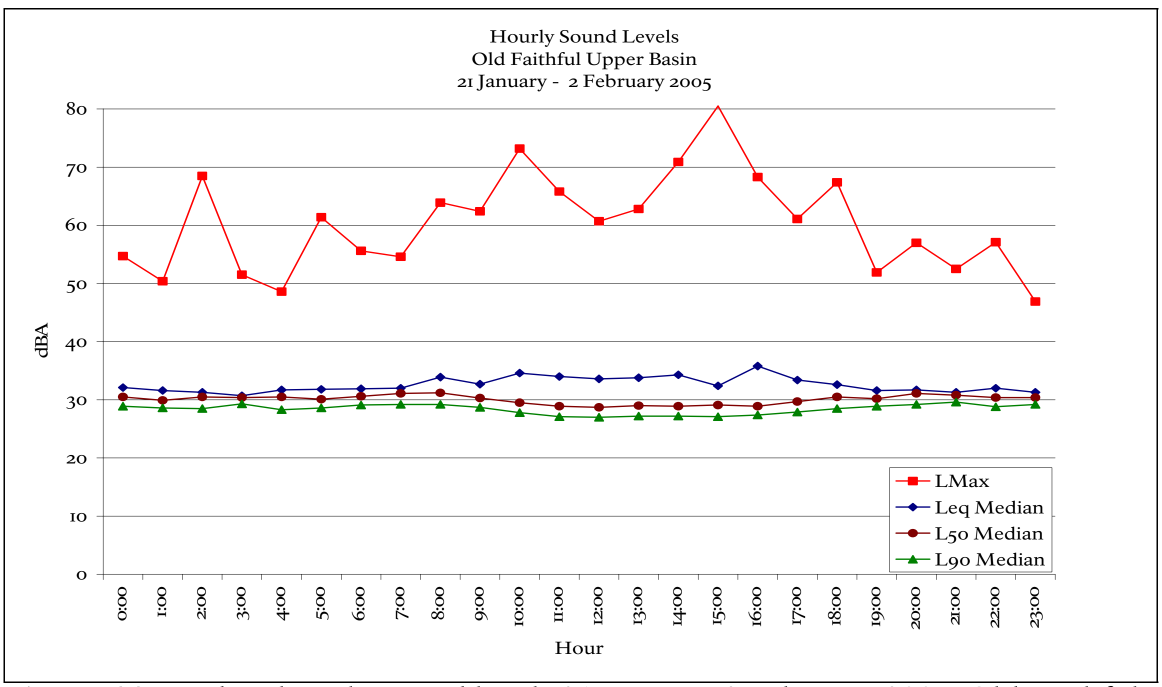


Figure 44. Median hourly sound levels 21 January-2 February 2005, Old Faithful Upper Basin, Yellowstone National Park. See Fig. 25 caption for more details. (n=280).

Madison Junction 2.3

Consistent with previous seasons, the sound levels from oversnow vehicles at Madison Junction 2.3 exceeded the 2004 WUP maximum sound level impact definition threshold (70 dBA) during most of the hours of the measurement day (8 am-4 pm) in 2005-2006 (Fig. 45-48).

Figure 49 shows the sound levels for the 2006 Presidents Day Weekend. For comparison, Figures 50, 51 and 52 presents sound level data collected at the same location during the two day Presidents Day Weekend in 2005, 2004 and 2003. The hourly pattern between 2006, 2005 and 2004 is remarkably similar. These years, however, differ from 2003. During 2003 there were both greater numbers of snowmobiles and louder two stroke snowmobiles. These two factors are reflected in the sound level data by higher overall sound levels of L_{max} and L_{50}.

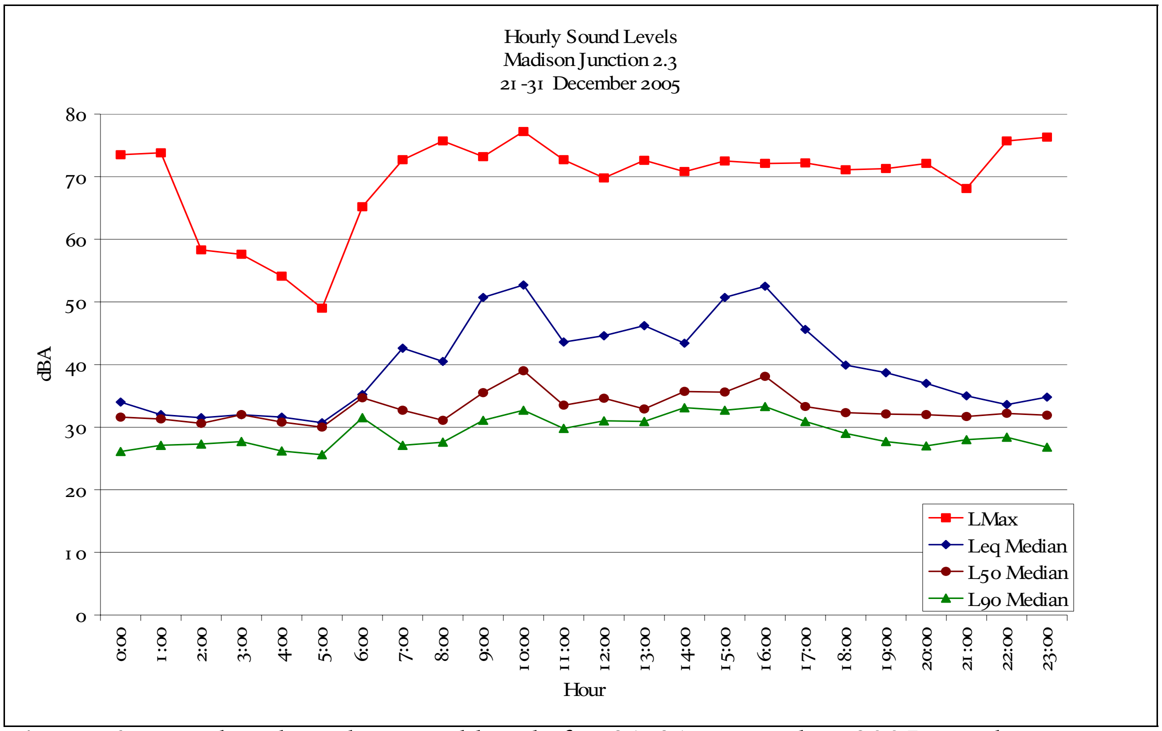


Figure 45. Median hourly sound levels for 21-31 December 2005, Madison Junction 2.3, Yellowstone National Park. See Fig. 25 caption for more details. (n=259)

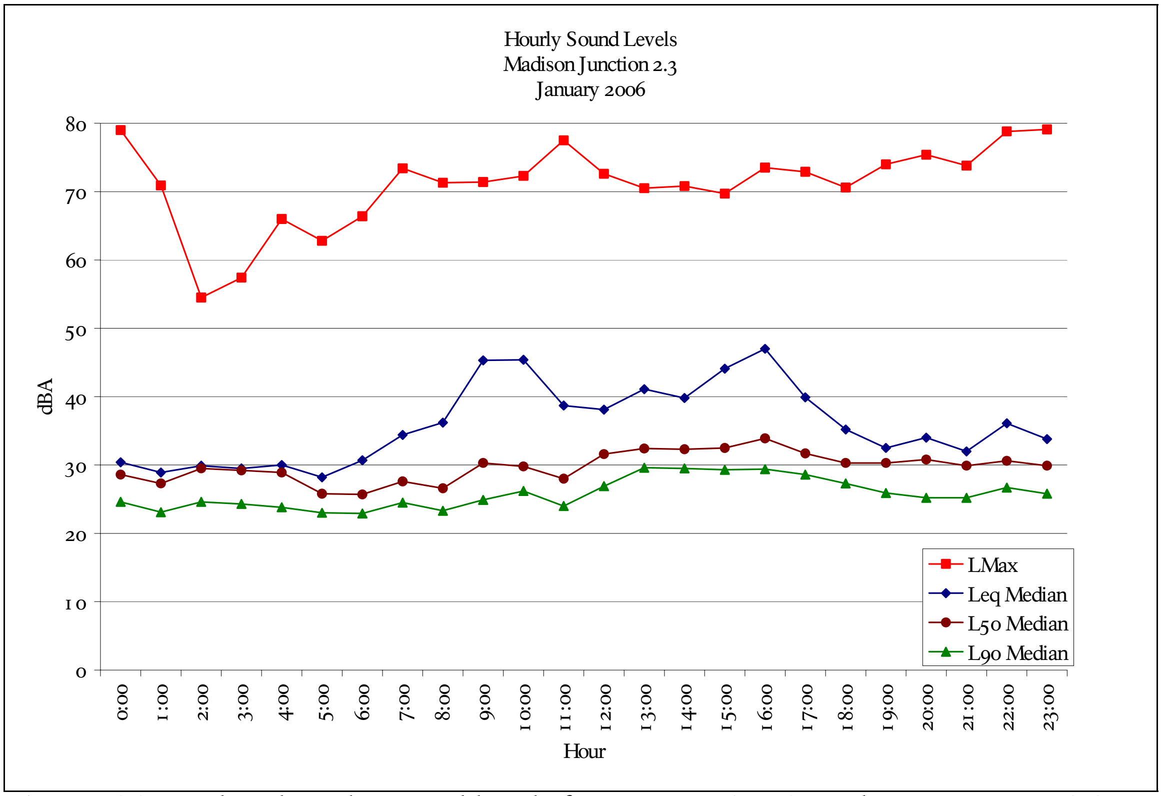


Figure 46. Median hourly sound levels for January 2006 Madison Junction 2.3, Yellowstone National Park. See Fig. 25 caption for more details. (n=729)

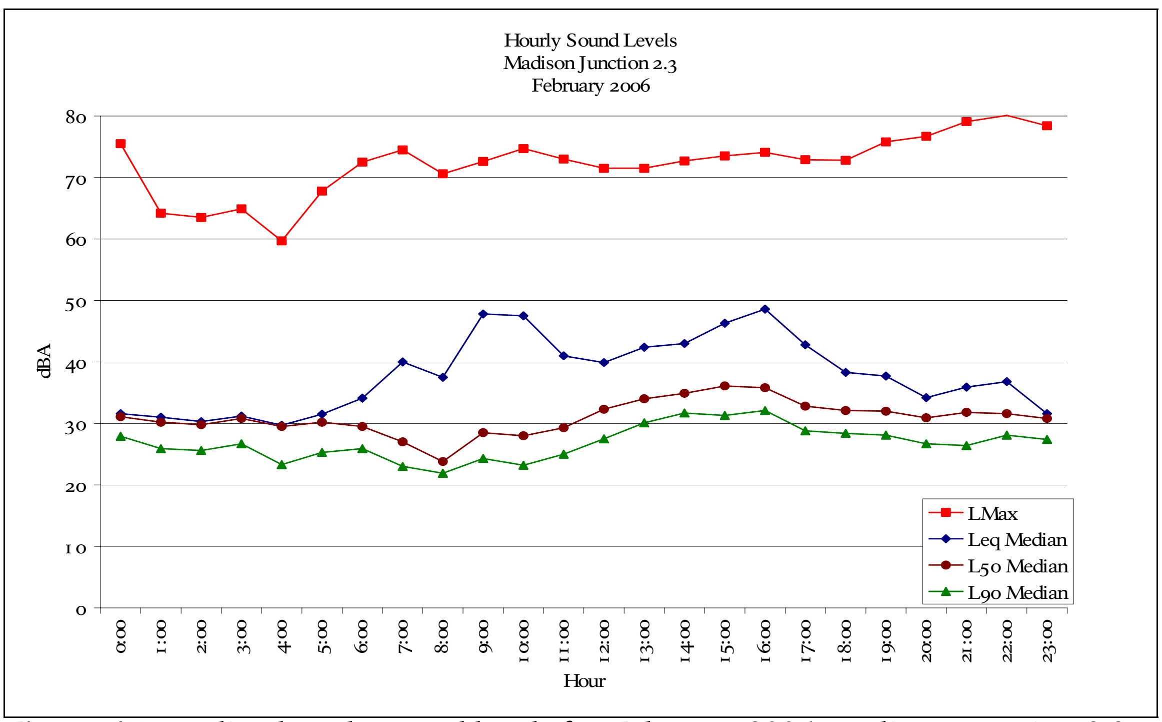


Figure 47. Median hourly sound levels for February 2006 Madison Junction 2.3, Yellowstone National Park. See Fig. 25 caption for more details. (n=666)

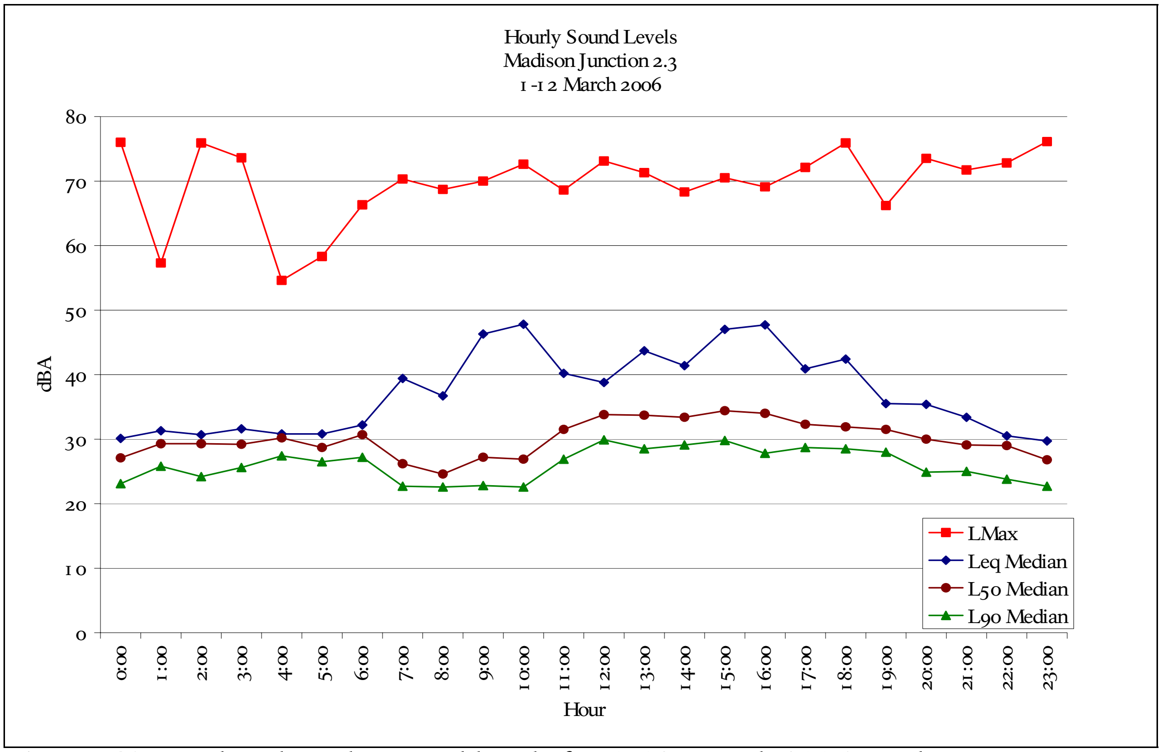


Figure 48. Median hourly sound levels for 1-12 March 2006 Madison Junction 2.3, Yellowstone National Park. See Fig. 25 caption for more details. (n=286)

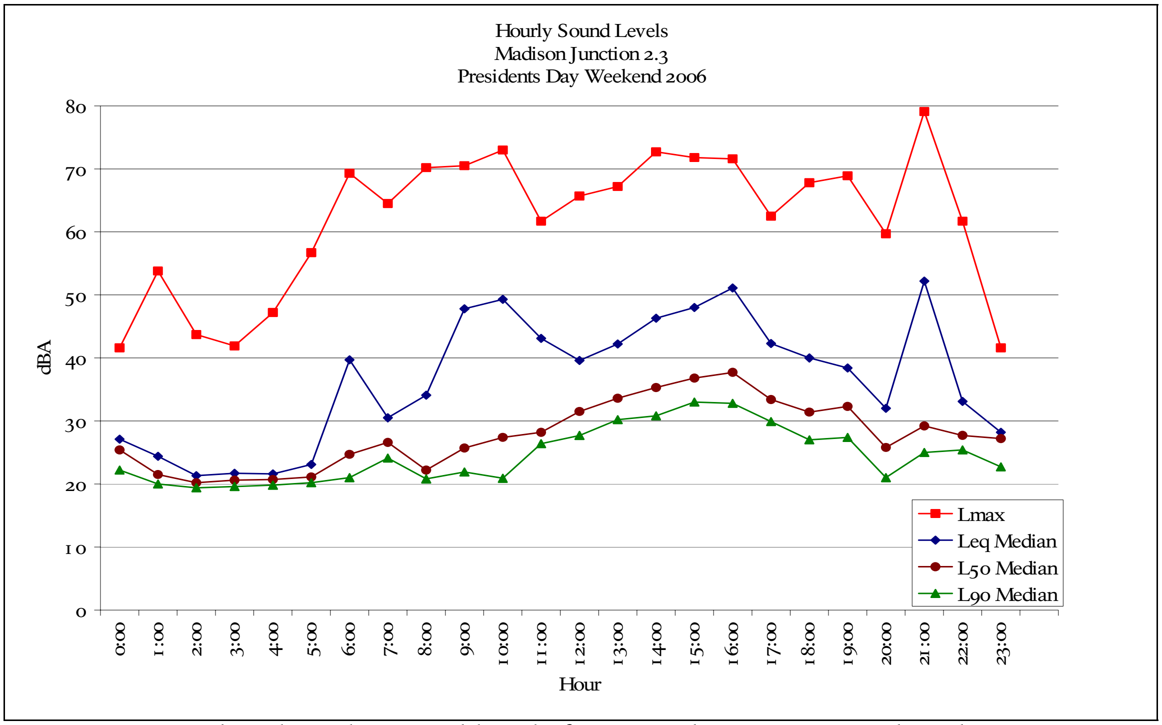


Figure 49. Median hourly sound levels for Presidents Day Weekend, 18-19 February 2006, Madison Junction 2.3, Yellowstone National Park. See Fig. 25 caption for more details. (n=48)

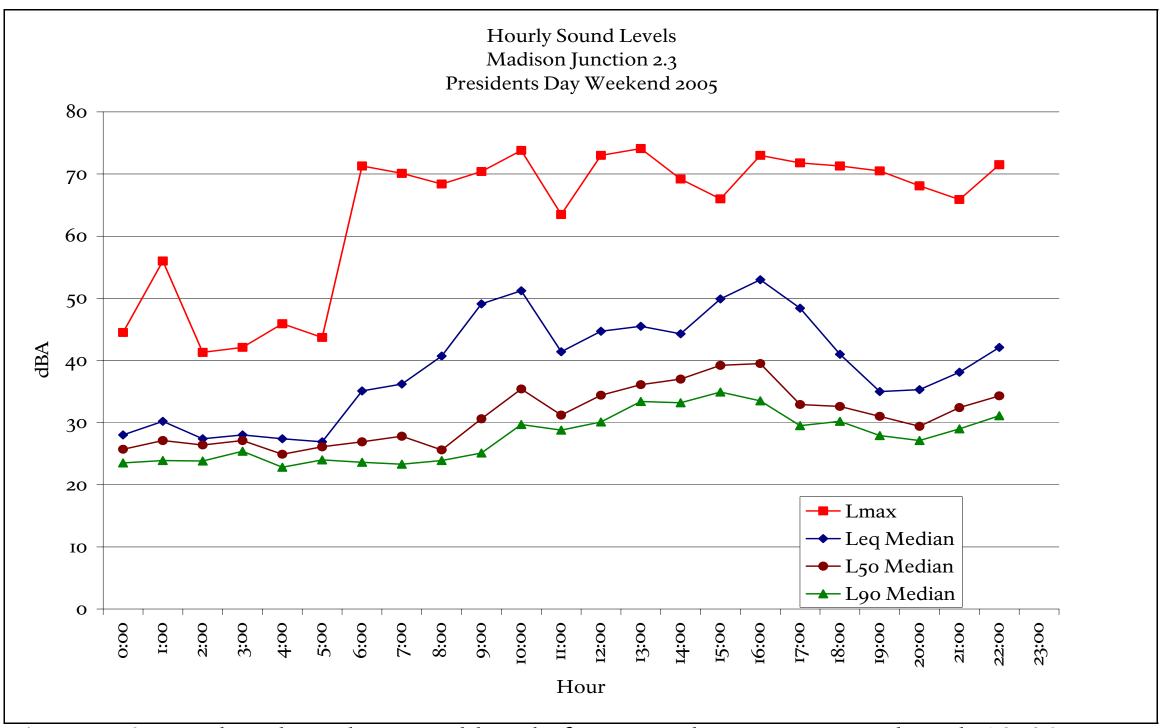


Figure 50. Median hourly sound levels for Presidents Day Weekend, 19-20 February 2005, Madison Junction 2.3, Yellowstone National Park. See Fig. 25 caption for more details. (n=46)

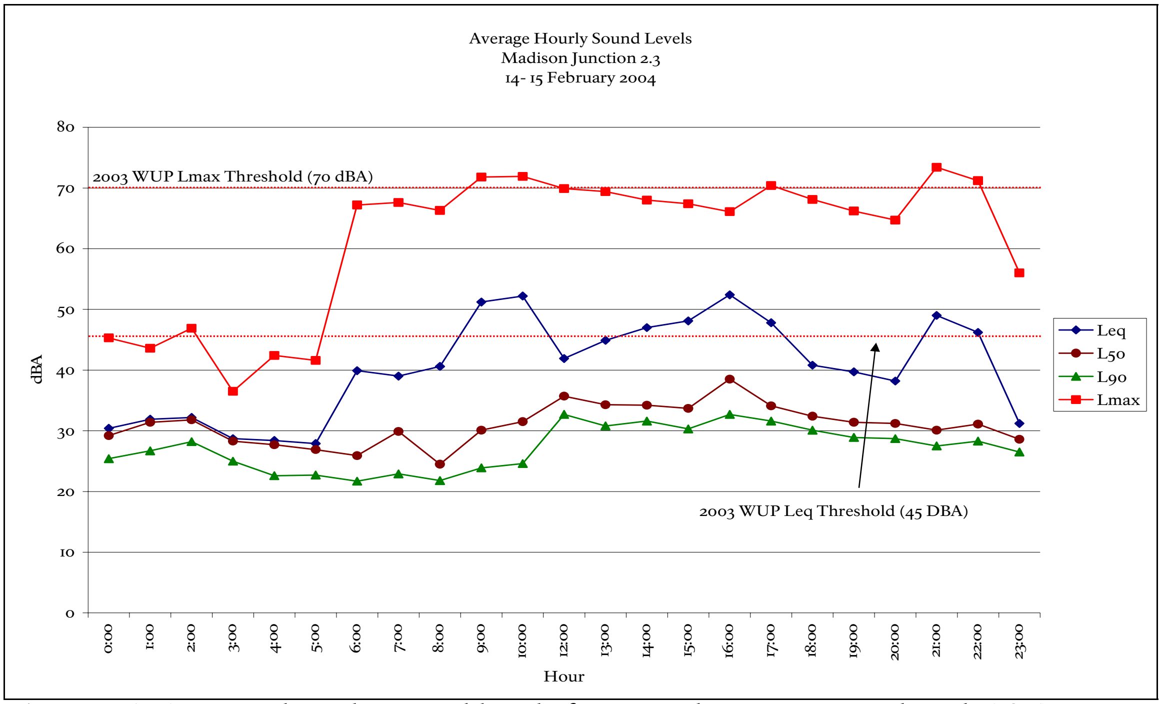


Figure 51. Average hourly sound levels for Presidents Day Weekend, 14-15 February 2004, Madison Junction 2.3, Yellowstone National Park. See Fig. 25 caption for more details. (n=47)

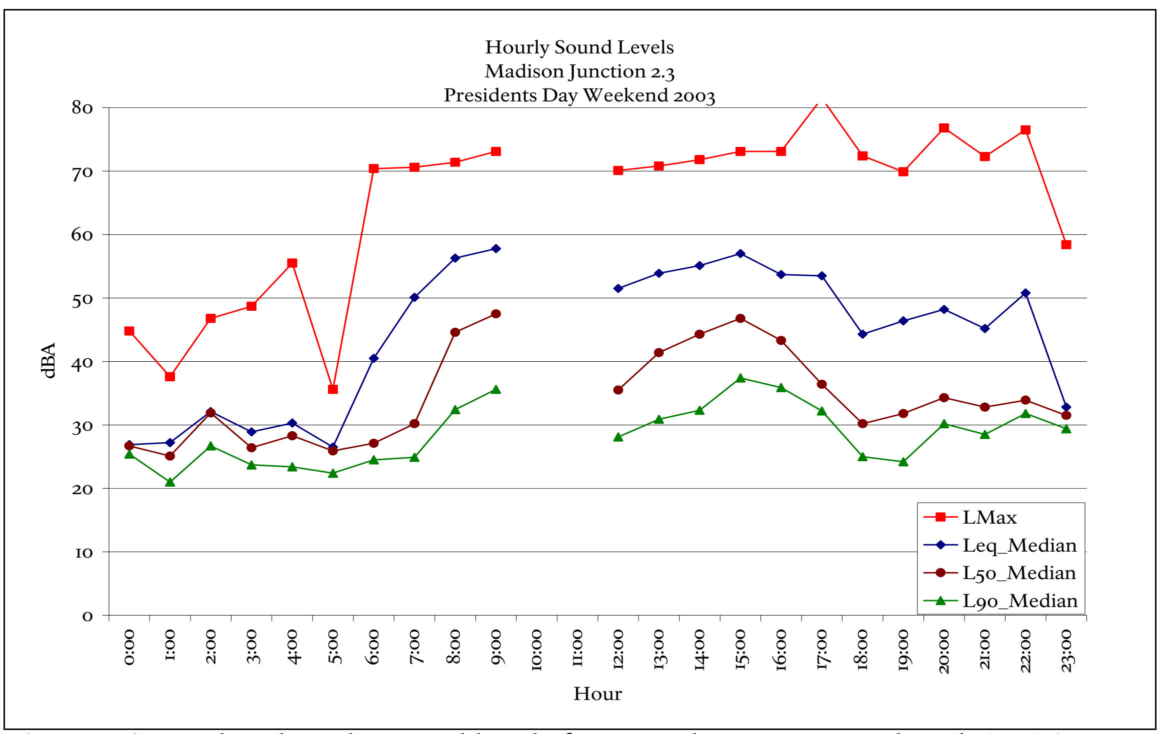


Figure 52. Median hourly sound levels for Presidents Day Weekend, 15-16 February 2003, Madison Junction 2.3, Yellowstone National Park. See Fig. 25 caption for more details. Missing hours are due to site visits. (n=44)

West Thumb

The measurement site at West Thumb was adjacent to a boardwalk within the geyser basin 450 feet from the nearest motorized area (parking lot) and 850 feet from the nearest groomed main road (West Thumb to Lake road). The 9 am-5pm period (extending one hour past the WUP 8am-4pm measurement period) when oversnow vehicles were generally present is shown by increased L_{90}, L_{50}, and L_{eq} (Fig. 53). Human voices were commonly the maximum sound levels during the day and natural sounds (wind and splashes) during the night. The minimum sound levels were determined by the noise floor of the instrumentation and the nearly constant low level thermal activity.

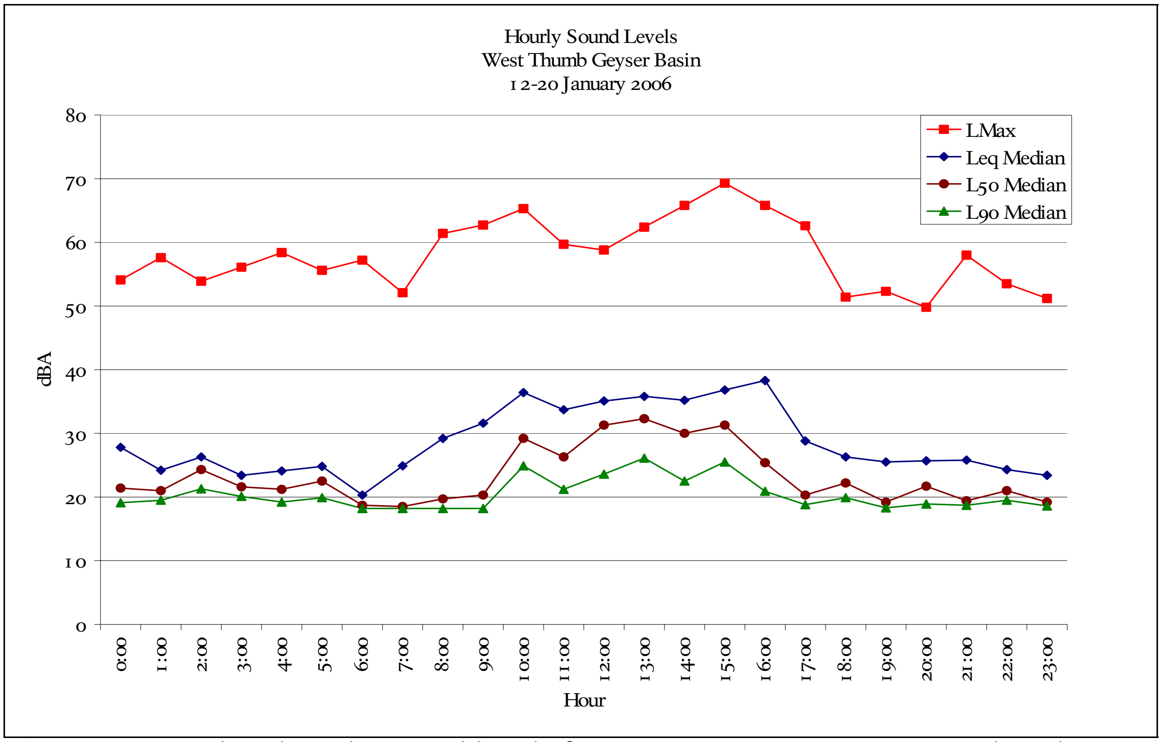


Figure 53. Median hourly sound levels for12-20 January 2006, West Thumb Geyser Basin, Yellowstone National Park. See Fig. 25 caption for more details. (n=189)

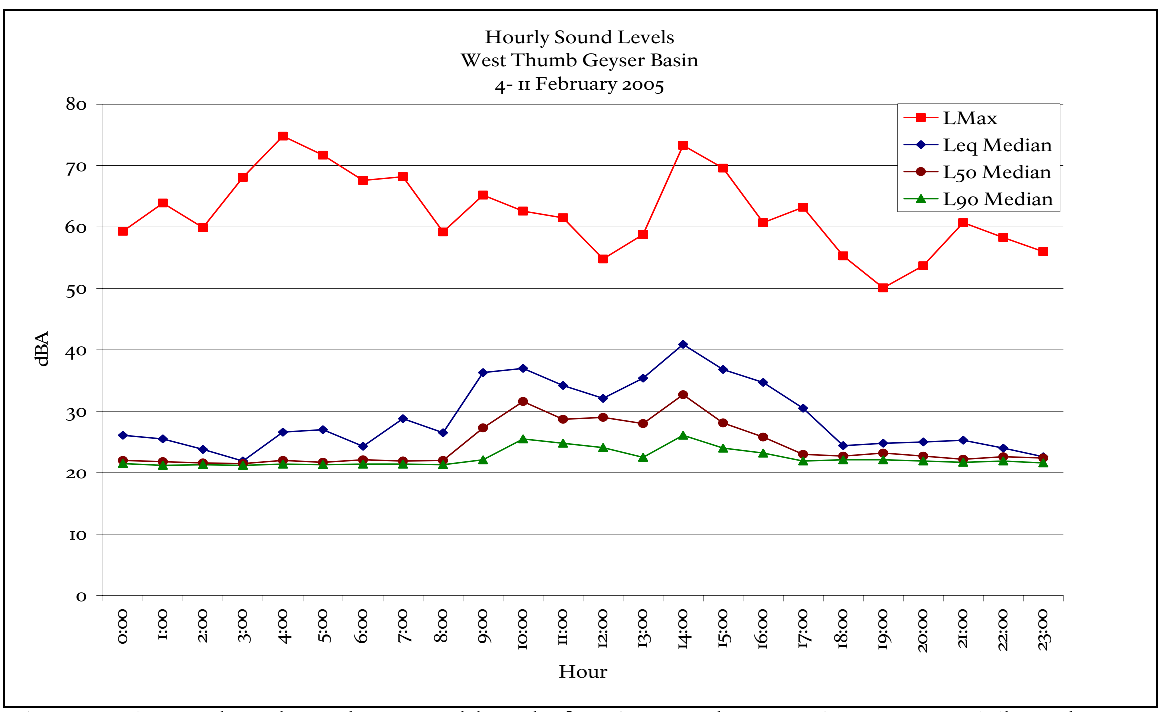


Figure 54. Median hourly sound levels for 4-11 February 2005, West Thumb Geyser Basin, Yellowstone National Park. See Fig. 25 caption for more details. (n=172)

Spring Creek

The Spring Creek monitoring site was along a travel corridor east-southeast of Old Faithful and away from any developed areas. It was within a forest of large lodgepole pines. 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. Wind and oversnow vehicles increased the sound levels during the day. High exhaust Bombardier snowcoaches and conversion van snowcoaches traveled at cruising speeds past this monitoring site. The Bombardiers were generally loudest, but all 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.

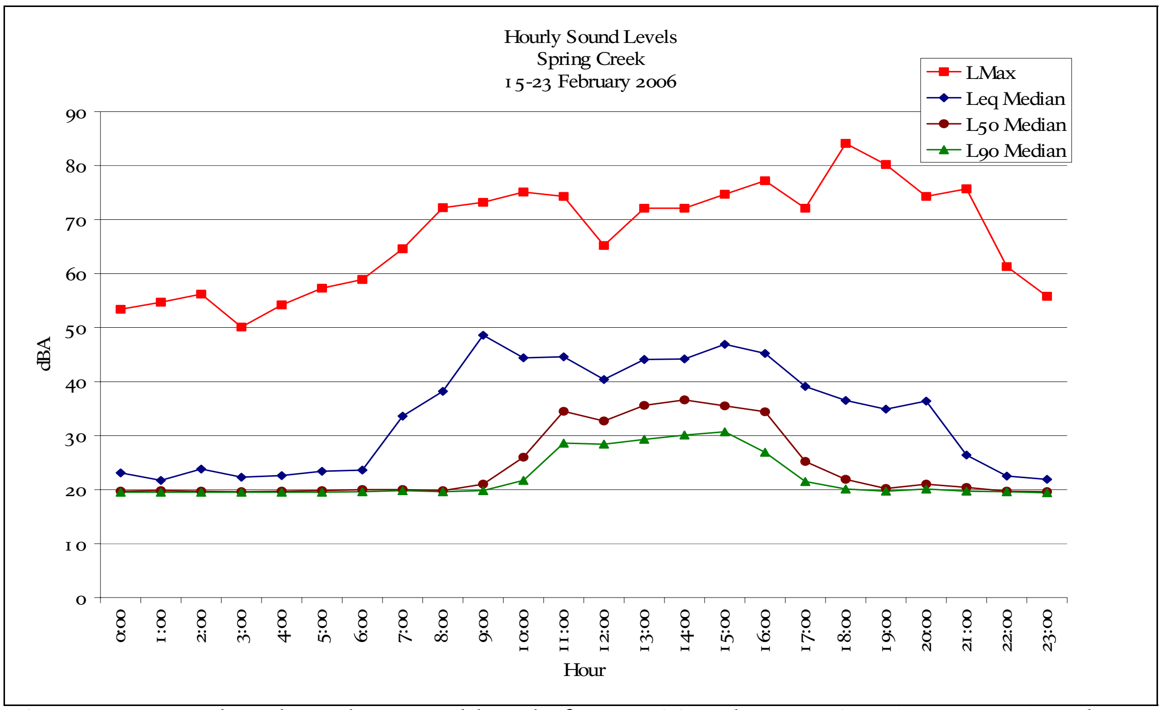


Figure 55. Median hourly sound levels for 15-23 February 2006, Spring Creek, Yellowstone National Park. See Fig. 25 caption for more details. (n=184)

Recommendations:

1- Continue to monitor both audibility and sound levels.

The combined sound level and audibility data gathered for this study provide 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. Collecting acoustical data provides the means to validate results from computer acoustical modeling.

2- Conduct acoustical experiments to fill in gaps in our understanding of the impacts of oversnow vehicles on the natural soundscape.

YNP can better manage the impacts of oversnow vehicles on the natural soundscape with answers to specific questions such as how group size and type of oversnow vehicle affects sound levels and audibility, what is the distance to limits of audibility in different habitat types (acoustic zones) and weather conditions, the effects of road surface on sound levels and audibility, how speed influences percent time audible and sound levels, and other currently unanswered questions. Acoustic computer modeling can begin to answer some of these questions but need 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.

3- Audibility and sound level metrics standards and thresholds should continue to be used for impact definitions in planning documents. These standards should include percent time audible and maximum sound level. A new combination acoustical metric should be developed to improve impact assessment.

The ability to determine if the acoustic impacts of winter oversnow use are meeting the management objectives require that quantitative acoustical standards and thresholds are defined. Acoustical monitoring and the understanding of natural soundscapes in parks are 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 (such as percent time audible and maximum sound levels). A new metric that combines percent time audible, maximum sound level and percent of park area impacted by a sound source should be pursued.

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

Although substantial improvements have been made by the switch from 2-stroke to 4-stroke snowmobiles and by the guiding requirement, the WUP Lmax sound levels and audibility thresholds are being exceeded at developed areas and travel corridors. Improvements to snowcoach sound levels should be made, especially to the older and louder Bombardier snowcoaches. Sound levels and audibility from motorized oversnow vehicles can be reduced immediately by lowering speed limits, especially in popular areas for visitors such as near thermal features and around Old Faithful. Decreasing the speed limit on all roads to 35 mph would reduce oversnow vehicle impacts on the natural soundscape and would have the added benefit of encouraging sightseeing while traveling. Reducing unnecessary idling and rapid acceleration, and other driver behavior modifications would also minimize sound impacts from oversnow vehicles. Reducing the total number and reducing single and small groups of 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 to reduce further sound levels of oversnow vehicles.

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

The representativeness of the expanding 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, it may be preferable to gather multiple weeks of data at one location rather than weeklong periods at many locations. Data collected during non-winter seasons allows comparisons to other seasons 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. Brent Hetzler (on detail from Zion National Park) smoothly kept the systems running during the depth of winter. The Old Faithful Ranger staff, especially Bonnie Schwartz, and the Old Faithful Maintenance staff provided logistical and much appreciated help on this project. Margaret Wilson and especially Robin Long expertly analyzed much of the audibility data. Skip

Ambrose and Chris Florian provided ongoing assistance on many aspects of this project. Mike Donaldson provided statistical expertise and computer software. The NPS Natural Sound Program also provided analysis software. Debbie VanDePolder remained cheerful during the unenviable task of digitizing the 2005 observational logging data and Chris Florian skillfully entered the 2006 data. This report heavily relies on last year's report and John Sacklin, Denice Swanke, Mike Yochim, Kevin Schneider, Robin Long, and Margaret Wilson provided valuable editorial comments on one or both reports. Last year's report also was improved from a technical review by Temple Stevenson of the Office of the Governor, State of Wyoming, by Patrick Flowers of the Montana Fish, Wildlife and Parks, and Gregg Fleming of the U.S. DOT Volpe Center, Cambridge, Massachusetts.

Literature Cited:

Ambrose, S. and S. Burson. 2004. Soundscape studies in national parks. George Wright Forum 21(1): 29-38

Ambrose, S., C. Florian. and S. Burson. 2006. Low-level soundscape measurements, Yellowstone National Park, 7-9 February 2006. Unpublished Report for Yellowstone National Park. April 2006. Sandhill Company, Castle Valley, UT.

American National Standards Institute (ANSI). 1992. Quantities and procedures for description and measurement of environmental sound. Part 2: Measurement of long-term, wide-area sound. Accredited Standards Committee S12, Noise. Acoustical Society of America, New York, NY. 12 pp.

Burson, S. 2004. Natural soundscape monitoring in Yellowstone National Park December 2003- March 2004. Unpublished Grand Teton National Park Soundscape Program Report #200403. Moose, WY. 64 pp.

Burson, S. 2005. Natural soundscape monitoring in Yellowstone National Park December 2004- March 2005. Unpublished Grand Teton National Park Soundscape Program Report #200502. Moose, WY. 91 pp.

Dunholter, P. H., V. E. Mestre, R. A. Harris, and L. F. Cohn. 1989. Methodology for the measurement of and analysis of aircraft sound levels within national parks. Unpublished report to National Park Service, Contract No. CX 8000-7-0028. Mestre Greve Associates, Newport Beach, CA.

Fleming, G., C. J. Roof, and D. R. Read. 1998. Draft guidelines for the measurement and assessment of low-level ambient noise (DTS-34-FA865-LR1). U. S. Department of Transportation, Federal Aviation Administration, John A.

Volpe National Transportation Systems Center, Acoustics Facility, Cambridge, MA. 83 pp.

Harris Miller Miller and Hanson, Inc. 2001. Technical report on noise: winter use plan final environmental impact statement for the Yellowstone and Grand Teton National Parks and John D. Rockefeller, Jr. Memorial Parkway. Report No. 295860.18. June 2001.

Harris Miller Miller and Hanson, Inc. 2002. Draft supplemental technical report on noise: winter use plan final supplemental environmental impact statement for the Yellowstone and Grand Teton National Parks and John D. Rockefeller, Jr. Memorial Parkway. Report No. 295860.360. October 2002.

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, Less Source of Interest
All sounds in a given area excluding a specific sound of interest. For example, when assessing the potential impacts of air tour aircraft, the "ambient sound level less source of interest" would be all sources of sound except air tour aircraft.

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.

Amplitude
The instantaneous magnitude of an oscillating quantity such as sound pressure. The peak amplitude is the maximum value.

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.

Audiogram
A graph showing hearing acuity as a function of frequency and amplitude.

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.

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.

Events per Hour
The number of times a non-natural sound source is heard, on average, in one hour (this may be specific to a particular non-natural sound or to all non-natural sounds). If this information is known, presentation and documentation provides another easily comprehended measure of how often the particular intruding sounds are heard. It provides an additional means for communicating the sense of the soundscape.

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 Parts 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).

Infrasound
Frequencies below 20 Hz. Humans perceive frequencies below about 20 Hz as pressure rather than sound.

Intensity

The sound energy flow through a unit area in a unit time.

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

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

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

Noise-free Interval
The period of elapsed time between human-caused sounds. The length of the continuous period of time during which only natural sounds are audible. Though little research has been conducted to relate how this measure correlates with ecological functioning, visitor judgments or with common experiences in park settings, it should provide a reasonable measure of the existence and availability of periods with only natural sounds. It is also a metric that requires no acoustics knowledge to be meaningful.

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

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

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

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

Percent Time Audible
The amount of time that various sounds are audible to animals, including humans, with normal hearing (hearing ability varies among animals). A specific sound may be below the natural ambient sound level, but still be audible to some animals. This information is essential for measuring and monitoring non-natural sounds in national parks. These data can be collected by either a trained observer (attended logging) or by making high-quality digital recordings (for later playback). Percent Time Audible is useful because it is a measure that is understandable without any acoustics knowledge. It is a metric that correlates well with park visitor judgments of annoyance and with visitor reports of interference from certain sound sources with the sounds of nature.

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

Sound
A wave motion in air, water, or other media. It is the rapid oscillatory compressional changes in a medium that propagate to distant points. It is characterized by changes in density, pressure, motion, and temperature as well as other physical properties. Not all rapid changes in the medium are sound (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 Exposure Level (SEL)
The total sound energy of an actual sound calculated for a specific time period. SEL is usually expressed using a time period of one second.

Sound Level
The *weighted* sound pressure level obtained by frequency weighting, generally A- or C-weighted.

Sound Level 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 Power (W)
The total sound energy radiated by a source per unit time. The unit of measurement is the Watt.

Sound Power Level (L_W)
The acoustic power radiated from a given sound source as related to a reference power level (typically 10^{-12} watts) and expressed as decibels. A sound power level of 1 watt = 120 dB (reference level = 10^{-12} watts).

Sound Pressure
Fluctuations in air pressure caused by the presence of sound waves. Sound pressure is the instantaneous difference between the actual pressure produced by

a sound wave and the average barometric pressure at a given point in space. Not all pressure fluctuations detected by a microphone are sound (e.g., wind over the microphone). Sound pressure is measured in Pascals (Pa), Newtons per square meter, which is the metric equivalent of pounds per square inch.

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.

Sound Speed
The speed of sound in air is about 344 m/sec (1,130 ft/sec or 770 mph) at 70^{o} F at sea level. It substantially varies depending on temperature and type of medium.

Time Weighting
The response speed of the detector in a sound level meter. For Slow response, the response speed is 1 second. Slow time weighting is frequently used in environmental sound measurements. Fast response time is 1/8 second (0.125). This is less frequently used, but will detect changes in sound levels more rapidly. Both Fast and Slow time weightings have been used in previous NPS acoustic studies, and, when compared over long measurement periods (over several days), there is very little difference in results (differences are often less than the accuracy of the meter). Fast and slow time weightings were developed, in part, to slow needle movement (called a “decay” factor) in analog meters so investigators could read and record sound levels. New digital sound level meters, while changing numbers rapidly on the screen, store sound level data in memory for later analysis, thus, the ability to read numbers on the screen is less important. Hence, the most accurate “weighting” is none.

Ultrasound
Sounds of a frequency higher than 20,000 Hz.

Wave
A particular type of disturbance that travels through a medium by virtue of the elastic properties of that medium.

Wavelength
Wavelength is the distance a wave travels in the time it takes to complete one cycle. A wavelength can be measured between successive peaks or between any two corresponding points on the cycle. Wavelength (ft) = Speed of Sound (ft) / Frequency (Hz).

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:

Acoustic Alliance. 2001. Glossary of Terms, Acoustic Alliance Products and Services Catalog. Provo, UT.

American National Standards Institute. 1976. Standard Acoustical Terminology, S1.1. American National Standards Institute, New York, NY. 1976.

Bruel & Kjaer. 2002. Environmental Noise. Bruel & Kjaer Sound and Vibration Measurement. Naerum, Denmark.

Everest, F. A. 2001. Master Handbook of Acoustics. McGraw-Hill, New York, NY.

Hirschorn, M. 2002. Noise Control Reference Handbook. Sound & Vibration, Bay Village, OH.

Kelso, D. and A. Perez. 1983. Noise Control Terms Made Somewhat Easier. Minnesota Pollution Control Agency, St. Paul, MN.

U. S. Environmental Protection Agency. 1976. About Sound. Environmental Protection Agency, Washington, D. C.

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 either side of road)	Audibility: NTE 50% at 100 feet
3	Groomed Motorized Route Clean and Quiet (within 100 feet either side route)	Audibility: NTE 50% at 100 feet
4	Groomed Motorized Route (within 100 feet either side route)	Audibility: NTE 50% at 100 feet
5	Groomed Motorized Trail Clean and Quiet (within 100 feet either side of trail)	Audibility: NTE 25% at 100 feet
6	Groomed Motorized Trail (within 100 feet either side of trail)	Audibility: NTE 25% at 100 feet
7	Ungroomed Motorized Trail (within 100 feet either side of trail)	Audibility: NTE 25% at 100 feet
8	Groomed Non-motorized Trail	Audibility: NTE 10% at 500 feet
9	Ungroomed Non-motorized Trail or Area	Audibility: NTE 10% at 500 feet
10	Backcountry non-motor trail or area	Audibility: NTE 10% at 500 feet Audibility: NTE 0% at 1000 feet

[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 either side of road)	Audibility: NTE 50% dBA: NTE 70 dBA L_{eq}: NTE 45 dBA
3	Groomed Motorized Route (within 100 feet either side route)	Audibility: NTE 50% dBA: NTE 70 dBA L_{eq}: NTE 45 dBA
4	Groomed Motorized Trail (within 100 feet either side route)	Audibility: NTE 50% dBA: NTE 70 dBA L_{eq}: NTE 45 dBA
5	Ungroomed Motorized Trail or Area (within 100 feet either side of trail)	Audibility: NTE 50% dBA: NTE 70 dBA L_{eq}: NTE 45 dBA
6	Groomed Non-motorized Trail (within 100 feet 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 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 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.

Appendix D. Visualizations of one-third octave band frequency sound levels

The NPS Natural Sound Program in Ft. Collins, CO developed a technique for plotting each of the 33 one-third octave band frequency decibel levels for each second of the day (ex. Fig. D-1). The major sources of sound at each monitoring location can be "seen" in these visualizations.

Viewing the pictures in color is essential. Each figure is one day, 24 hours from midnight to midnight. Each row contains two hours starting with the first hours of the day, labeled with white two digit numbers. The site and date is the title on top. The decibel level is plotted on a logarithmic scale as indicated in the left margin. The right margin contains the decibel range and associated colors. Brighter colors indicate higher sound levels; deep blue is the quietest.

Figures D-1-D-5 show example days from each of this study's monitoring sites. Determining the common sound sources signatures from the 1/3 octave band frequencies is not difficult, but takes a bit of experience. A brief introduction follows. Oversnow vehicle signatures are narrow yellow marks that extend from high to low frequency. Louder sounds are brighter yellow as shown in hour 09 in Fig. D-1. Snow groomers are the very bright marks with the extended green before and after trails in hours 19 and 21 (Fig. D-1). During the hours 01, 22, and 23, a jet shows its lower sound level and the Doppler effect of decrease frequency as the jet travels away from the monitoring location (Fig. D-1). Building utility sounds and wind create the extensive green at Old Faithful Weather Station (Fig. D-2). A nearby geyser eruption is the bright yellow blur during the hour 07 hour at Old Faithful Upper Basin (Fig. D-3). The sounds of riffles on the Madison River are shown especially during the early morning hours at Madison Junction 2.3 (Fig. D-4). Wind picks up in the afternoon of the 19 January 2006 at West Thumb and is shown by the extensive green in Fig. D-5. A day from a low sound level site near Sylvan Pass near the East Entrance is shown (Fig. D-6) for comparative purposes (See Appendix E for site details).

Figures D-7 and D-8 compare the sound levels during Saturday of Presidents Day Weekend at Madison Junction 2.3 during 2003 and 2006. 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-4 for another example of OSV activity at this site during the most recent winter season.

Not only can specific sound sources be identified from these visualizations, but patterns and the variability in number, timing, and sources of sounds can be deciphered. This technique will likely be refined and perhaps will lead to an automated, quantified process to characterize soundscapes in the future.

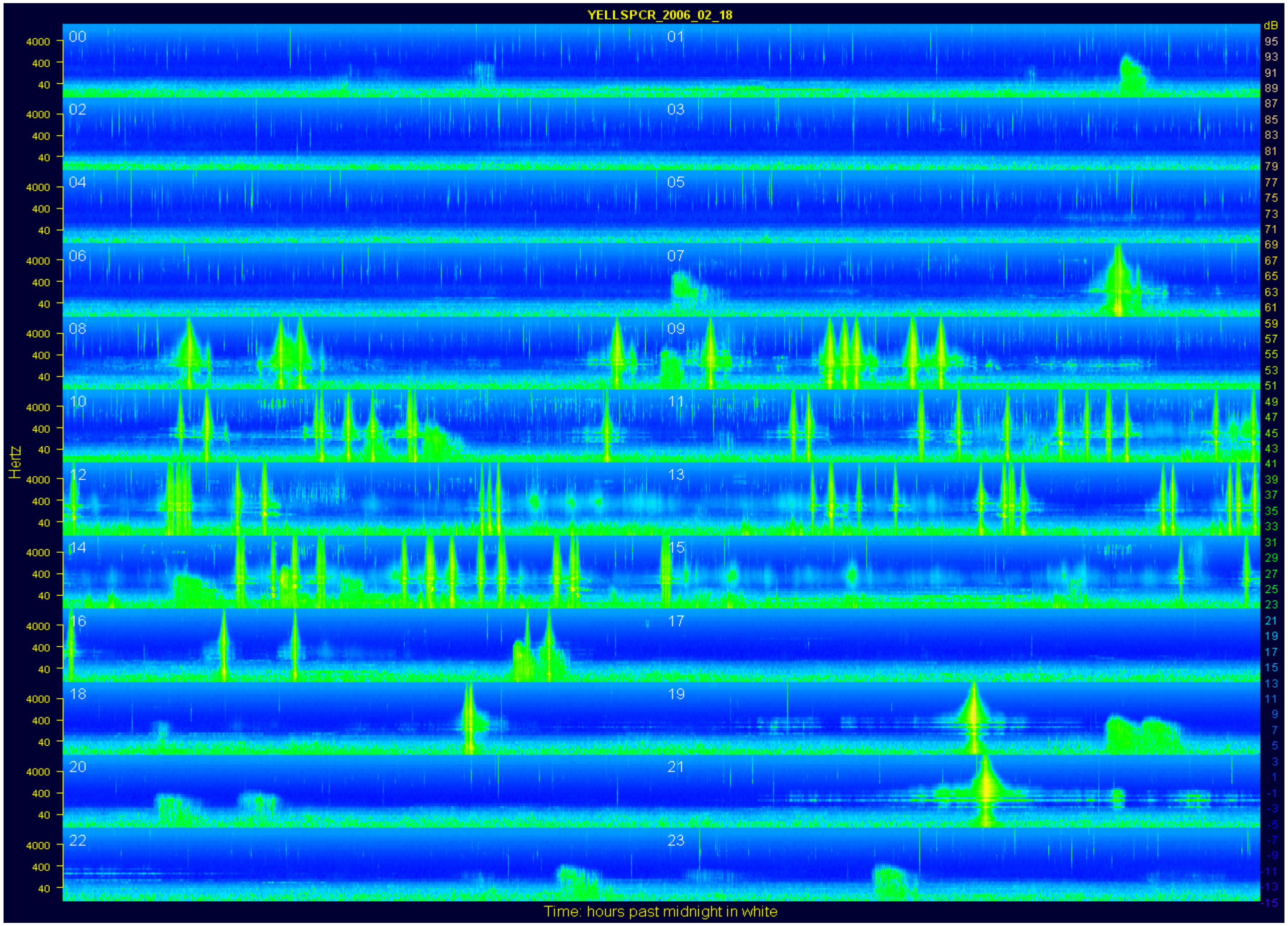


Figure D-1. Sound level visualization of 18 February 2006 at Spring Creek. See text for explanation.

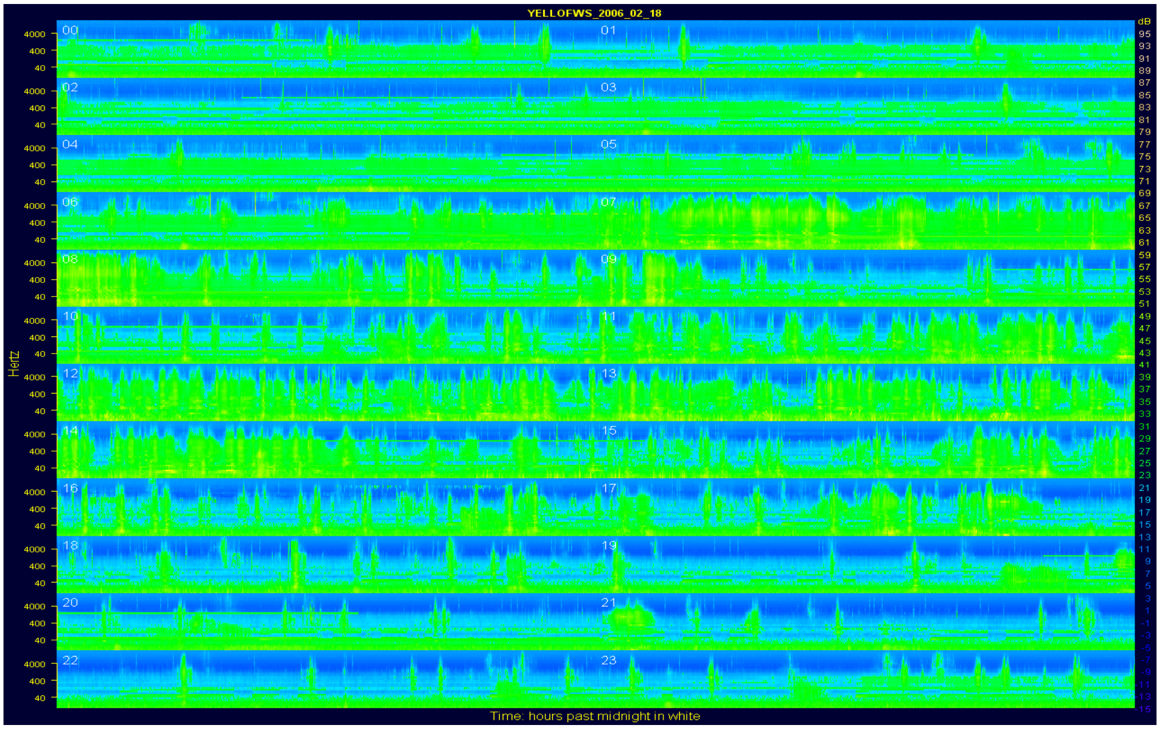


Fig D-2. Sound levels at Old Faithful Weather Station, 18 Feb 2006. See text for explanation.

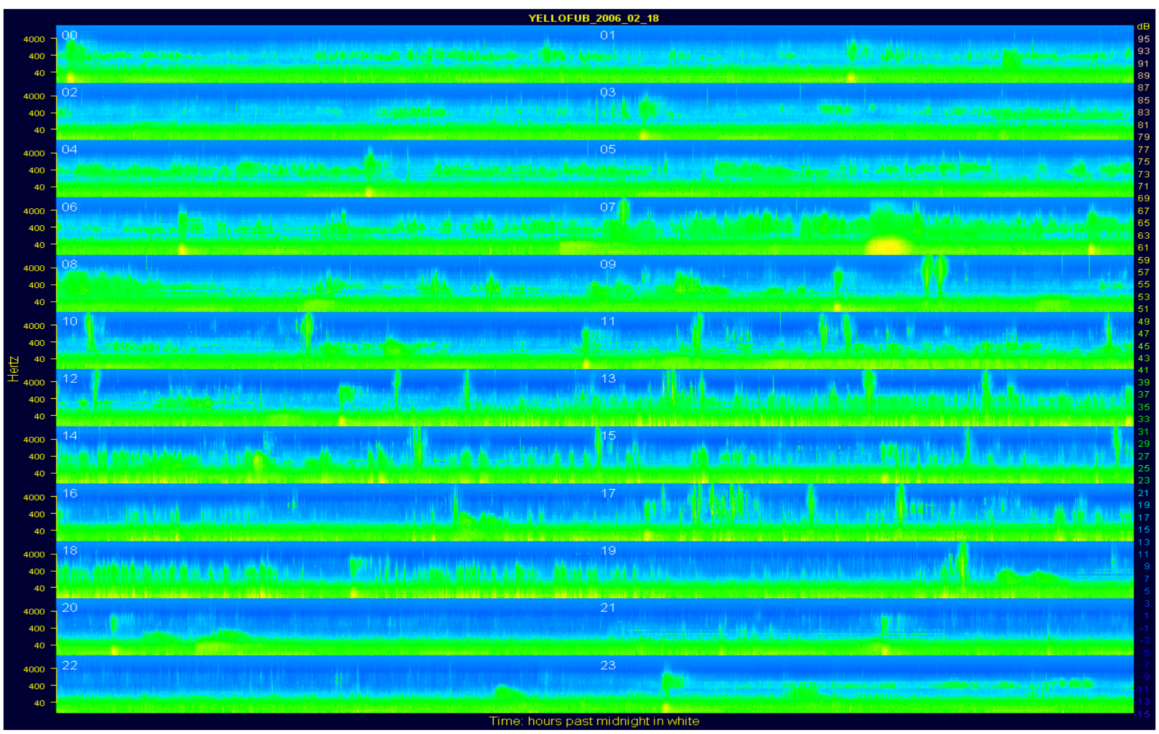


Fig D-3. Sound levels at Old Faithful Upper Basin, 18 February 2006. See text for explanation.

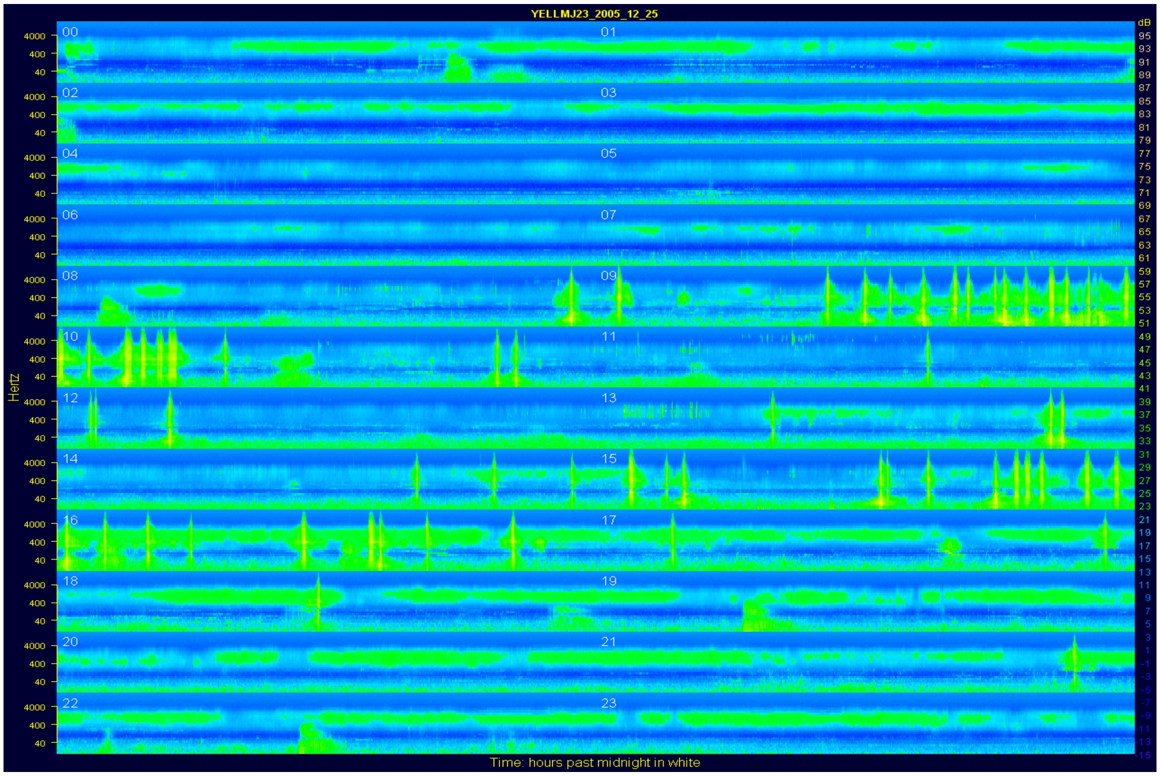


Fig D-4. Sound levels at Madison Junction 2.3, 25 December 2005. See text for explanation.

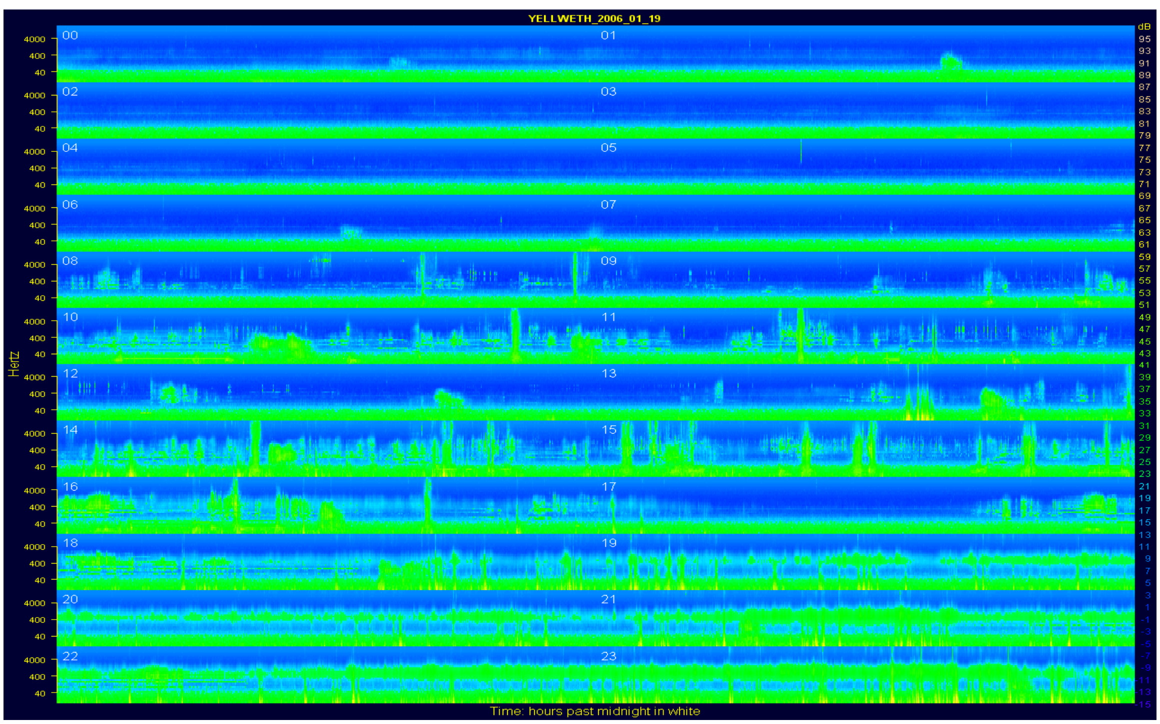


Fig D-5. Sound levels at West Thumb, 19 January 2006. See text for explanation.

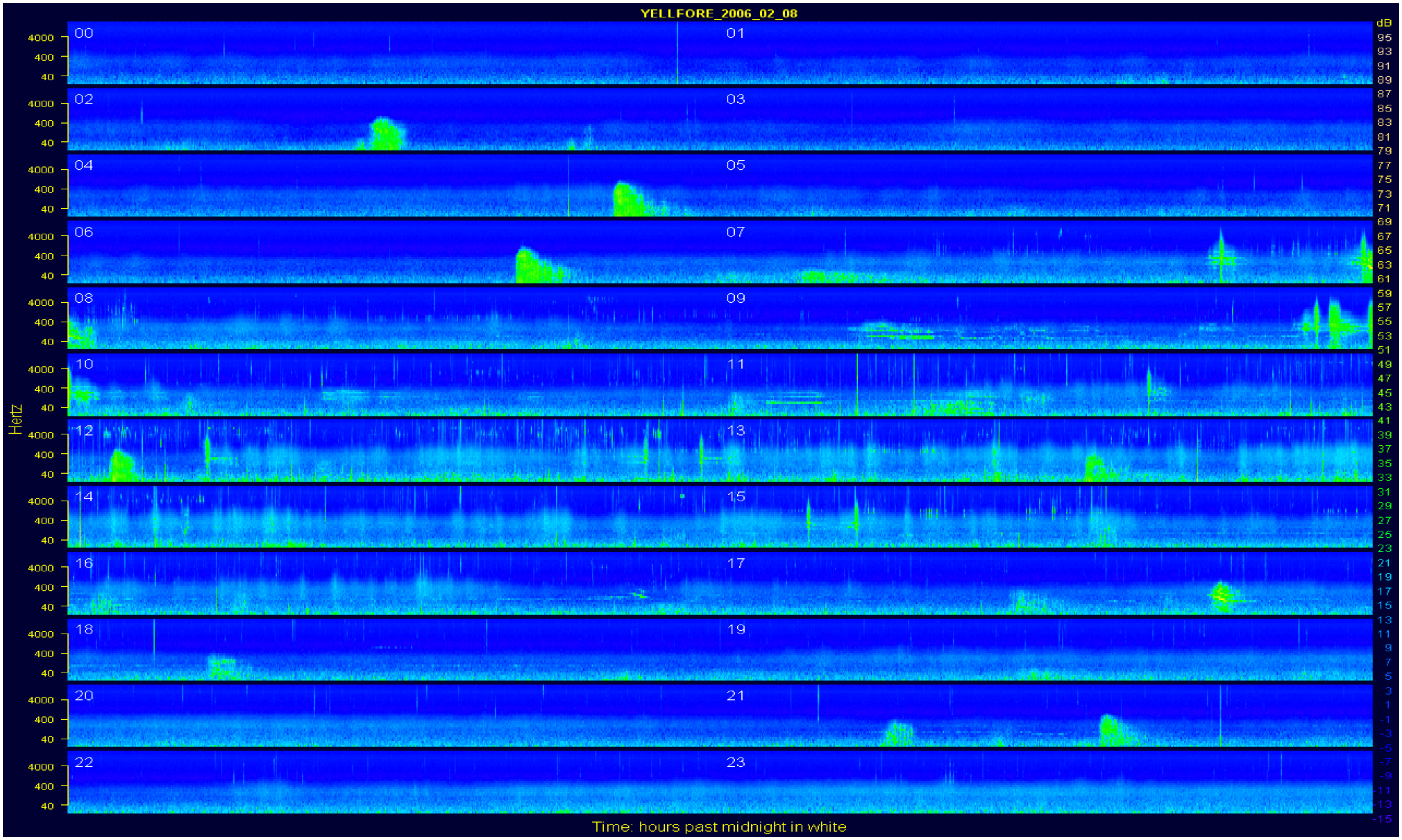


Fig D-6. Sound levels at Avalanche Creek low sound level monitoring site, 8 February 2006. See text for explanation of this visualization and Appendix F for details about this site.

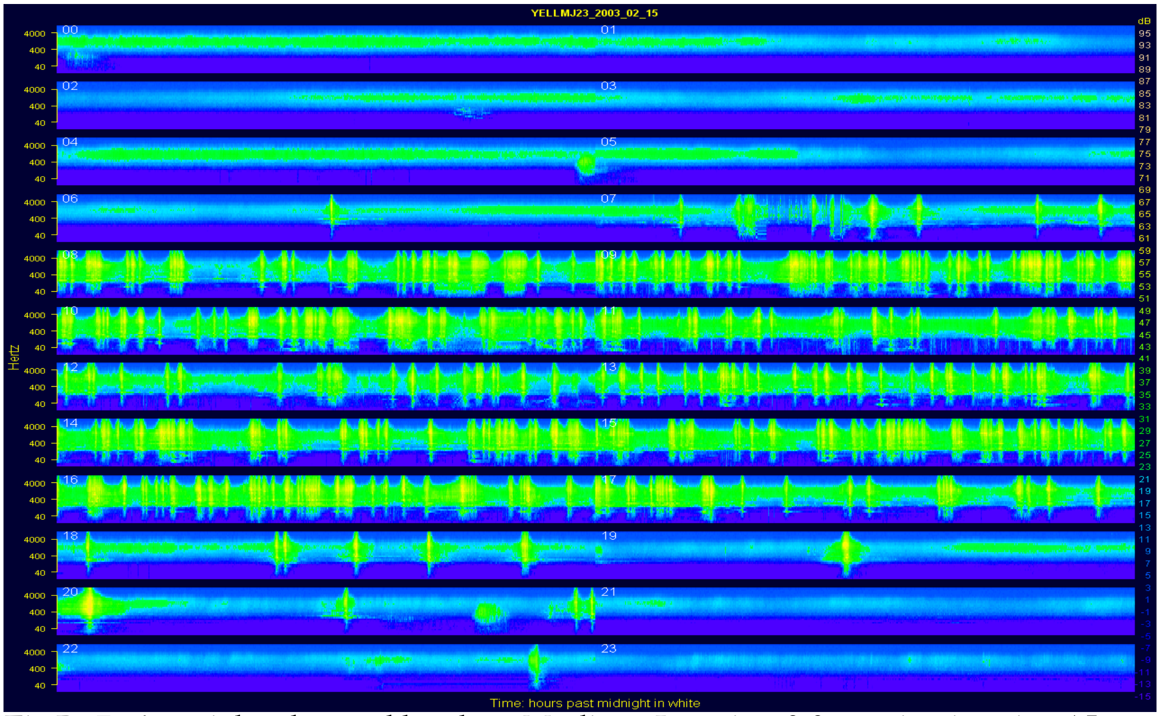


Fig D-7. A-weighted sound levels at Madison Junction 2.3 monitoring site, 15 February 2003. Compare to Fig. D-8 for number and timing of OSVs. See text for explanation.

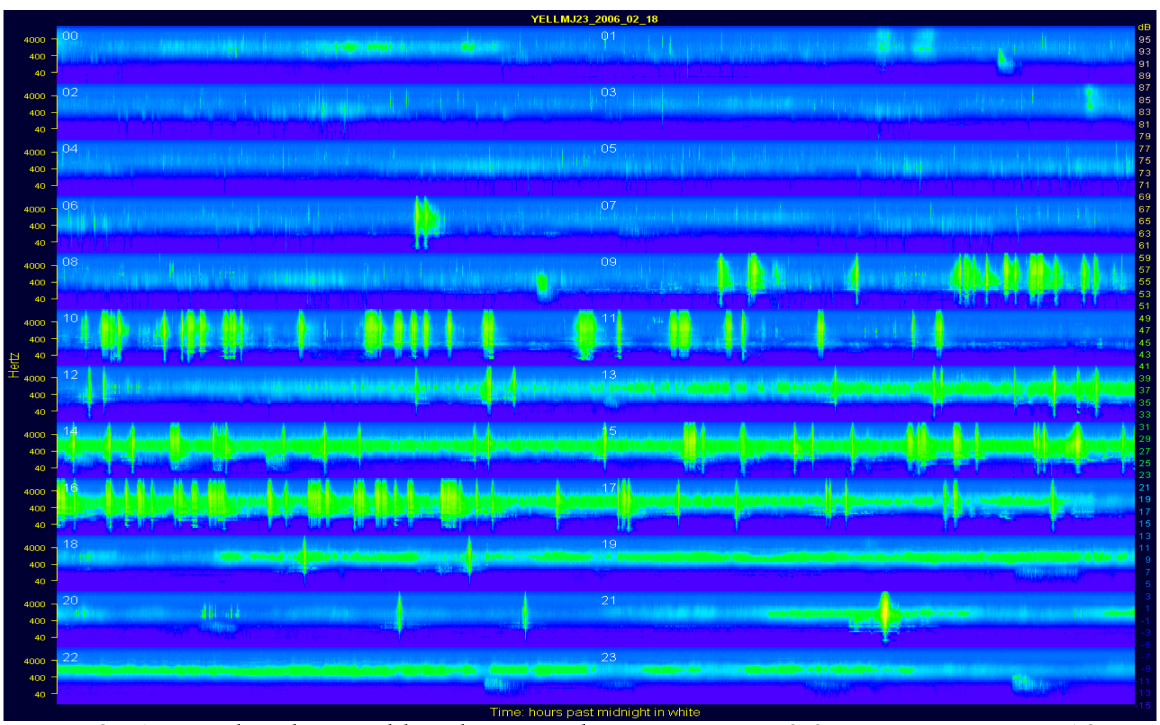


Fig D-8. A-weighted sound levels at Madison Junction 2.3 monitoring site, 18 February 2006. Compare to Fig. D-7 for number and timing of OSVs. See text for explanation.

Appendix E. Observational study of oversnow vehicle usage.

The audibility analysis using remote unattended sound monitoring equipment estimated the percent time all sounds are audible at those locations. It did not, though, 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 late winter 2005 and again in 2006. Observers were positioned within view of travel routes at a number of key locations and documented the time audible and type of usage for each oversnow vehicle observed. The data were collected during 44 logging periods at locations within the Old Faithful developed area and along the travel corridor mainly between Kepler Cascades and West Yellowstone (Table 1), 17 February-5 March 2005 and 20 January-9 March 2006. The total observer logging time was 66 hr 48 min 43 sec, 7am to 5pm, evenly split between morning and afternoon.

Table E-1. Locations used for observational study of oversnow usage patterns during winters 2005 and/or 2006 in Yellowstone National Park.

Developed Area	Travel Corridor
Old Faithful Entrance Road	Kepler Cascades Pullout
Old Faithful Parking Lot	Daisy Trailhead
Old Faithful Ranger Station	Mallard Lake Trailhead
Old Faithful Main Road	Midway Geyser Basin
	Mary Mountain Trailhead
	Madison Junction 2.3
	West Yellowstone 3.1
	Tuff Cliff Pullout

Oversnow usage types included guided visitors, NPS administrative use, contractors, and Xanterra administrative use. (See sample data sheet Table E-2). These data were then transferred to an MS Access^{TM} database for summary and analysis. Tables E-3 to E-5 present these summary analyses.

The number and proportion of snowmobiles was analyzed by group (Table E-3) and by individual machine (Table E-4). The developed, 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 1,182 groups of oversnow vehicles were documented, including 784 snowmobile groups (E-3). Group size ranged from 1-23. Average size for all snowmobile groups was just under four snowmobiles per group; seven snowmobiles per guided group and just over one snowmobile per administrative group. A total of 3,351 individual oversnow vehicles were tallied, including 2,847 snowmobiles (E-4).

Of all individual snowmobiles observed, guided visitors (recreational use) accounted for 90% along travel corridors and 77% at Old Faithful (Table E-4). Guided visitors comprised 61% of all groups documented along travel corridors (Table E-3). As would be expected, more administrative travel occurred in the Old Faithful developed area than along travel corridors between developed areas (Tables E-3 and E-4). Contractors working on the Old Faithful Inn comprised 9% of all groups of snowmobiles documented traveling in the Old Faithful area (Table E-3). This may help partially explain the increased oversnow percent time audible at Old Faithful in 2005-2006 and 2004-2005 compared to 2003/2004 (Figs. 2, 3, and 4). Other administrative travel totaled 44% of the total number of groups observed at Old Faithful (Table E-3).

Guided snowmobiles comprised 57% of all snowmobiles audible. All oversnow vehicles were audible for 52% of the study period and comprised 88% of the motorized sounds audible (Table E-5; compare to Figs. 2 and 16). Snowmobiles were audible for 21 hours 58 minutes and 02 seconds (34%) of the 66 hours 48 minutes and 43 second study period (Table E-5). Forty-one percent of the time during the study period no motorized sounds were audible (Table E-5).

Table E-2. Field data sheet for logging oversnow usage type in Yellowstone National Park, 17 February-5 March 2005 and 30 January-9 March 2006.

Date:	Time: Start/End	Page of
Name, Address, Telephone:		
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	19	Motorized, unk	Record other non-natural sounds as possible. Note when ignoring them.
1.2	Aircraft, propeller	20	Non-natural other	Record time in hours, minutes and seconds. Try to use GPS time (that is.
1.3	Aircraft, helicopter			accurate time). Record stop time as well as start time.
2	Vehicle (type)			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	Building sounds			

Table E-3. Number and proportion of snowmobile groups by usage type traveling within Yellowstone National Park, winters 2005 and 2006.

Location	Guided Snowmobiles	Contractor	NPS- Maintenance	Ranger	Research	NPS-Other/Unknown	Conces-Admin	Unk. Admin	Xanterra_Admin	*Unknown*
Developed Area										
Old Faithful	109	29	10	29	6	25	0	4	65	42
	34%	9%	3%	9%	2%	8%	0%	1%	20%	13%
				NPS-All[a]	70					
					22%					
				Admin-All[b]	139					
					44%					
Travel Corridor										
All Travel Corridors	283	5	7	25	19	39	15	0	9	63
	61%	1%	2%	5%	4%	8%	3%	0%	2%	14%
				NPS-All	90					
					19%					
				Admin-All	114					
					25%					
All Areas										
Total	392	34	17	54	25	64	15	4	74	105
	50%	4%	2%	7%	3%	8%	2%	1%	9%	13%
				NPS-All	160					
					20%					
				Admin-All	253					
					32%					

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

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

Table E-4. Number and proportion of individual snowmobiles by usage type traveling within Yellowstone National Park, winters 2005 and 2006.

Location	Guided Snowmobiles	Contractor	NPS-Maintenance	Ranger	Research	NPS-Other/Unk	Concess-Admin	Unk. Admin	Xanterra_Admin	*Unknown*	Total
Developed Area											
Old Faithful	745	45	13	29	6	26	0	5	69	34	**972**
	77%	5%	1%	3%	1%	3%	0%	1%	7%	3%	**100%**
				NPS-All[a]	74						
					8%						
				Admin-All[b]	148						
					15%						
Travel Corridor											
All Travel Corridors	1680	15	10	20	21	38	20	0	10	61	**1875**
	90%	1%	1%	1%	1%	2%	1%	0%	1%	3%	**100%**
				NPS-All	89						
					5%						
				Admin-All	119						
					6%						
All Areas											
Total	2425	60	23	49	27	64	20	5	79	95	**2847**
	85%	2%	1%	2%	1%	2%	1%	0%	3%	3%	**100%**
				NPS-All	163						
					6%						
				Admin-All	267						
					9%						

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

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

Table E-5. Elapsed time (hours:minutes:seconds) and percentages for motorized vehicles during an observational study, winters 2005 and 2006, Yellowstone National Park.

Snowmobiles Only			
User Group	Elapsed Time	Percentage	Combined Total
Guided Snowmobile	12:29:34	57%	57%
Contractor	0:38:14	3%	3%
NPS- Maintenance	0:21:47	2%	
NPS- Ranger	1:00:50	5%	
NPS_Research	0:26:29	2%	
NPS Other/Unknown	1:18:22	6%	14%
Admin- Concession	0:24:42	2%	
Administrative- Xanterra	1:34:58	7%	9%
Administrative- Unknown	0:02:20	0%	0%
Unknown User	3:40:46	17%	17%
	21:58:02		
All Motorized Sounds			
Jets	1:20:14	3%	
Props	1:00:27	3%	
Helicopters	0:30:00	1%	7%
Snowmobile	21:58:02	55%	
Snowcoach	8:54:44	23%	
Snowmobile or Snowcoach	0:07:32	0%	
Unknown Oversnow Vehicle	3:47:17	10%	88%
Groomer	0:42:05	2%	2%
Unknown/Other Motorized	1:15:00	3%	3%
	39:35:21		
Total Observation Time	66:48:43		
Motorized Sounds	39:35:21	59%	
Oversnow Vehicles	34:47:35	52%	
Snowmobiles	21:58:02	33%	

No Motorized Sounds	27:13:22	41%

Appendix F. Low-level soundscape measurements, Yellowstone National Park, February 7-9, 2006.

The report beginning on the following page was conducted and prepared by Sandhill Company on contract to Yellowstone National Park. Shan Burson, the author of the current report, assisted with the low sound level study and report.

Low-level Soundscape Measurements, Yellowstone National Park, February 7-9, 2006.

April 30, 2006

Skip Ambrose[1]
Chris Florian[1]
Shan Burson[2]

Summary

Acoustic data were collected at two locations in east-central Yellowstone National Park during the winter of 2006 using recently developed low-noise microphones, preamplifiers, and power supplies. The two locations were in different vegetation zones, one an open, non-forested area and the other a forested area.

Sound levels were occasionally at or below the noise floor of the low-noise equipment (6.5 dBA). At the open site, the L_{50} was 16.6 dBA and the L_{90} was 14.4 dBA; at the forested site, the L_{50} was 9.9 dBA and the L_{90} was 8.5 dBA. These metrics were below the noise floor of equipment typically used in these studies (15-17 dBA). Wind-related sounds and birds were the most common natural sounds. Aircraft and over-snow vehicles were the most common non-natural sounds.

Sound levels varied considerably among hours, indicating that use of a single number to characterize a park's soundscape (for example, the L_{90} or L_{50} of an entire day) may not be adequate. Further, the extremely low sound levels measured in this study indicate that specialized acoustic measurement equipment is necessary to accurately describe the park's soundscape. Such equipment should be used more frequently in acoustic studies in national parks where sound levels can be very low.

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Introduction

Acoustic data were collected at two locations in east-central Yellowstone National Park (YELL), February 7-9, 2006, using recently developed GRAS ½-inch low-noise microphone, preamplifier, and power supply. The two measurement sites were "open" (non-canopied) and "forested" sites, a two acoustic zone approach used in previous winter acoustical studies (HMMH 2001; Burson 2005). The purpose of this report is to summarize data analysis for this time period at these two locations.

Methods

Acoustic monitors consisted of a notebook computer (Panasonic CF-18), external USB sound card (Sound Devices USBPre), GRAS 40HH ½" low-noise microphone system (microphone, preamplifier, and power supply), anemometer (HOBO Weather Station Wind Speed Smart Sensor), 12-volt battery supply, and Soundscape Monitor Spectra RTA132 software (www.soundtechnology.com). Continuous 1-second decibel data (dBA and one-third octave band center frequencies 20-20,000 Hz) were collected. From these 1-second decibel data, a wide range of acoustic metrics were computed (L_{min}, L_{max}, L_{eq}, L_{10}, L_{50}, L_{90}). In addition, high-quality digital recordings (16-bit, 44100 Hz) were collected; a 10-second digital recording was collected every two minutes. From these digital recordings, sound sources were identified via playback in an office and the percent time natural and non-natural sounds were audible were calculated.

Decibel data were processed using programs developed by the National Park Service's Natural Sounds Program, Fort Collins, CO (NVFormat, HourlyMetrics, and DayAudibilityEntry). Data were first converted to a standard data format, NVFormat, developed jointly between the National Park Service and the Volpe Transportation Center. Data were processed using HourlyMetrics to provide daily, hourly, and frequency metrics. Digital recordings were analyzed using DayAudibilityEntry.

This study was conducted in accordance with Yellowstone Research Permit # YELL-SCI-5354.

Study Area

Both measurement locations were in east-central YELL, near Sylvan Pass along the East Entrance Road. The Open site was on Sylvan Lake, south of the East Entrance Road (44.47952N / 110.16026W) (Figure 1). The Forested site was .25 miles west of Sylvan Lake, north of the East Entrance Road (44.48553N / 110.16409W)(Figure 2).

Figure 1. Open site, on Sylvan Lake.

Figure 2. Forested site, .73 km northwest of the Sylvan Lake site.

Wind Speed Considerations

Sound pressure level data with associated wind speeds >5 m/s were not considered when computing metrics (L_{min}, L_{max}, L_{eq}, L_{10}, L_{50}, L_{90}). At the YELL Open site, 1050 seconds (of 33 hours) were not used in computing metrics (Table 1). The YELL Forested site had no wind speeds >5 m/s during the measurement period (44 hours).

Table 1. YELL Open, Feb. 7-9, 2006, number of seconds with wind speeds >5 m/s.

Date	Hour	Number of seconds with wind >5 m/s
2/7/2006	15	20
2/8/2006	11	10
2/8/2006	13	90
2/8/2006	14	150
2/8/2006	15	100
2/8/2006	16	30
2/9/2006	0	260
2/9/2006	1	390

Results

Sound Pressure Levels

Sound pressure levels (L_{min}, L_{max}, L_{eq}, L_{10}, L_{50}, L_{90}, dBA and 1/3 octave bands, 20-20,000 Hz) for YELL Open and Forested sites are presented in Tables 2-3, and Figures 3-5.

Hourly (0000-2400) sound pressure levels (dBA L_{min}, L_{max}, L_{eq}, L_{10}, L_{50}, and L_{90}) for February 8, 2006, for YELL Open and Forested sites are presented in Tables 4-5, and Figures 6-7.

Table 2. YELL Open sound pressure levels (L_{min}, L_{max}, L_{eq}, L_{10}, L_{50}, L_{90}), Feb. 7-9, 2006 (n=33 hrs).

dBA/Freq.	L_{min}	L_{max}	L_{eq}	L_{10}	L_{50}	L_{90}
dBA	9.2	59.4	20.4	19.6	16.6	14.4
20	-2.1	70.6	28.4	29.9	24.7	18.7
25	-1.5	68.3	26.6	28.3	22.9	17.6
31.5	-3.4	69.4	24.6	26.2	20.5	15.6
40	-1.7	62.6	22.4	24.1	18.4	14.2
50	-3.1	62.1	20.2	21.8	16.4	12.2
63	-6.2	57.8	21.2	19.9	14.7	10.4
80	-7.4	60.8	19.6	18.3	12.7	8.6
100	-6.3	73.1	19.6	17.1	11.5	7.7
125	-4.9	73.3	22.6	17.1	12.6	9.1
160	-2.4	56.7	23.9	18.4	14.2	11.1
200	0.1	67.6	22.9	20.2	15.5	13.0
250	-0.6	60.9	21.3	19.6	16.1	13.8
315	-1.2	62.7	20.3	19.2	15.8	12.8
400	-5.0	54.1	18.3	17.0	13.0	10.3
500	-5.7	51.4	14.4	14.1	9.9	7.2
630	-7.4	53.4	11.6	12.4	7.0	4.1
800	-8.0	47.2	9.0	9.2	4.8	1.3
1000	-8.1	46.9	5.5	5.5	1.4	-1.9
1250	-9.0	46.5	3.8	2.2	-2.1	-4.6
1600	-8.0	46.3	1.0	1.2	-4.2	-5.1
2000	-10.4	47.9	-1.2	0.7	-3.9	-4.6
2500	-10.9	43.7	-1.2	0.3	-3.3	-3.9
3150	-12.5	41.5	-1.1	-1.1	-2.6	-3.2
4000	-12.6	36.9	-0.9	-1.7	-2.1	-2.6
5000	-12.9	36.0	-0.7	-1.3	-1.7	-2.2
6300	-12.1	35.1	-0.6	-0.9	-1.3	-2.0
8000	-12.4	34.2	-0.8	-0.5	-0.9	-1.8
10000	-11.7	33.5	-0.4	-0.6	-0.8	-1.2
12500	-11.4	33.0	-1.4	-1.1	-1.5	-1.8
16000	-11.2	33.0	-1.3	-1.3	-1.6	-1.9
20000	-11.3	33.0	-1.0	-1.2	-1.5	-1.7

Table 3. YELL Forested sound pressure levels (L_{min}, L_{max}, L_{eq}, L_{10}, L_{50}, L_{90}) Feb. 7-9, 2006 (n=44 hrs).

dBA/Freq.	Lmin	Lmax	Leq	L10	L50	L90
dBA	6.5	74.4	15.9	13.1	9.9	8.5
20	-11.9	68.1	20.7	23.2	18.2	12.3
25	-6.4	60.2	19.1	21.3	16.5	11.3
31.5	-7.7	64.1	17.2	19.2	14.4	9.3
40	-6.6	63.7	15.6	17.4	12.0	7.6
50	-10.3	62.7	13.7	15.0	9.7	5.4
63	-11.7	62.2	12.7	13.3	8.3	4.3
80	-10.3	61.7	11.8	12.3	7.1	3.1
100	-11.5	72.3	12.8	11.8	6.5	2.9
125	-9.8	70.1	13.1	11.3	6.5	3.2
160	-8.3	67.2	14.3	12.1	8.0	4.5
200	-7.4	63.2	13.3	12.3	8.4	4.9
250	-7.5	66.7	13.8	11.4	7.7	4.3
315	-9.0	65.4	11.4	10.5	6.3	3.0
400	-9.6	67.3	10.1	8.0	3.3	-0.1
500	-10.0	72.5	7.4	5.6	1.2	-2.3
630	-10.3	63.5	3.0	2.9	-1.2	-4.2
800	-10.3	63.0	-0.4	0.5	-3.7	-6.0
1000	-11.0	74.2	-3.4	-2.6	-5.7	-7.3
1250	-10.2	61.6	-3.8	-4.3	-6.6	-7.6
1600	-9.5	61.2	-4.1	-5.3	-6.5	-7.3
2000	-8.2	57.9	-3.0	-5.0	-6.0	-6.7
2500	-7.5	57.7	-4.0	-4.6	-5.5	-6.1
3150	-6.7	55.9	-3.4	-4.2	-4.9	-5.5
4000	-6.1	56.5	-3.2	-3.8	-4.5	-4.9
5000	-5.6	58.6	-2.8	-3.5	-4.0	-4.4
6300	-5.3	58.5	-2.7	-3.2	-3.7	-4.1
8000	-4.7	53.8	-2.6	-2.8	-3.3	-3.7
10000	-3.8	51.1	-2.0	-2.0	-2.5	-2.9
12500	-4.4	49.0	-2.7	-2.7	-3.2	-3.4
16000	-6.5	46.7	-3.4	-3.4	-3.9	-4.3
20000	-10.8	46.3	-4.0	-4.0	-4.4	-4.7

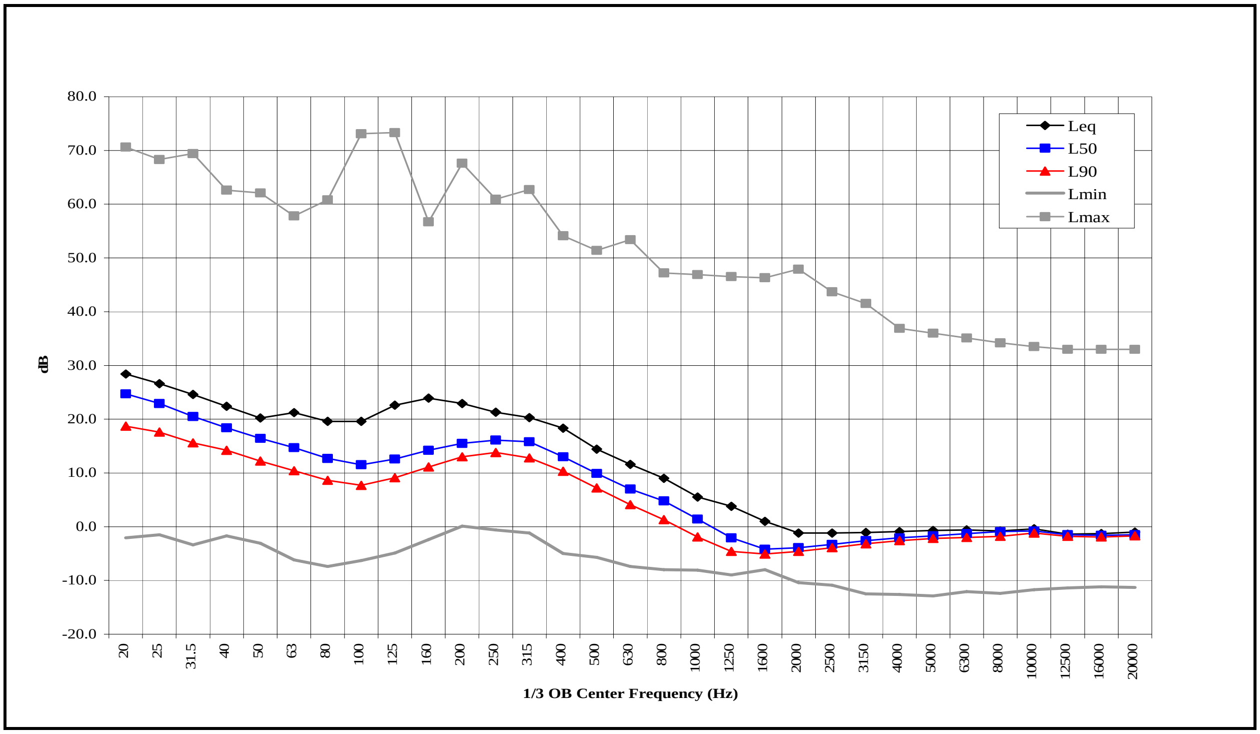

Figure 3. YELL Open L_{eq}, L_{50}, L_{90}, L_{min}, and L_{max}, Feb. 2-9, 2006 (n=33 hours).

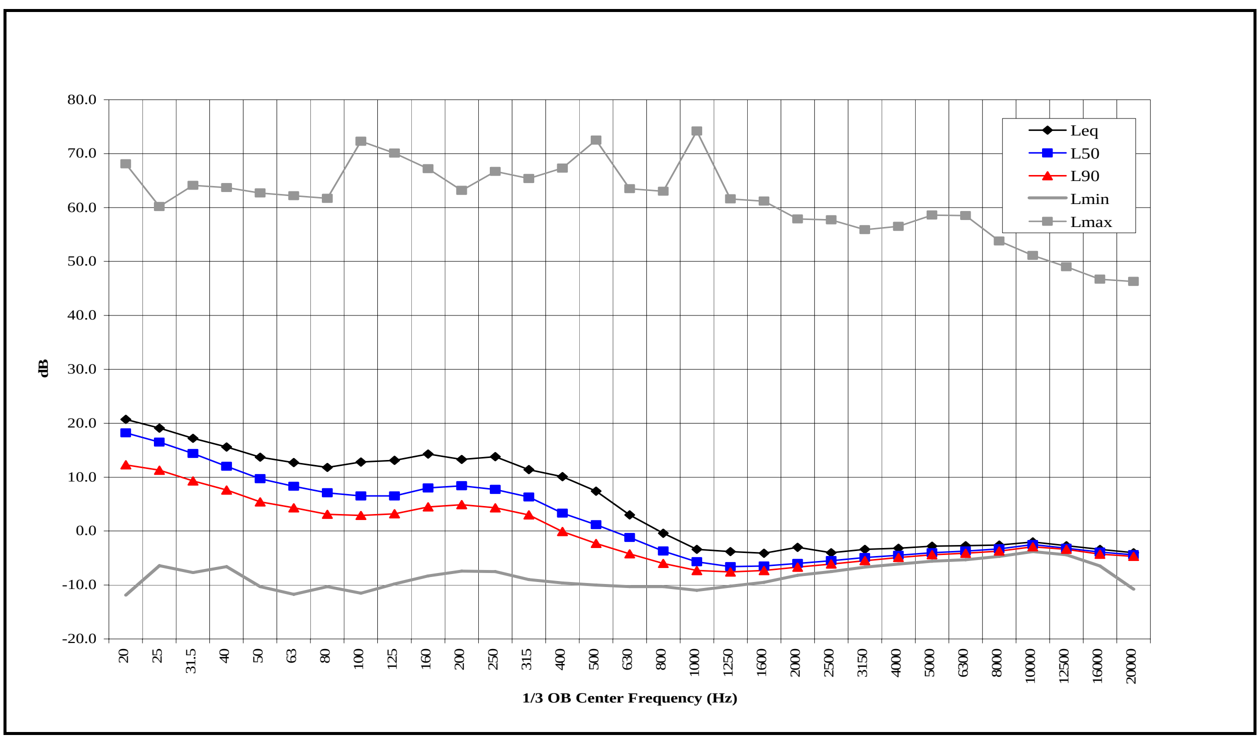

Figure 4. YELL Forested L_{eq}, L_{50}, L_{90}, L_{min}, and L_{max}, Feb. 2-9, 2006 (n=44 hours).

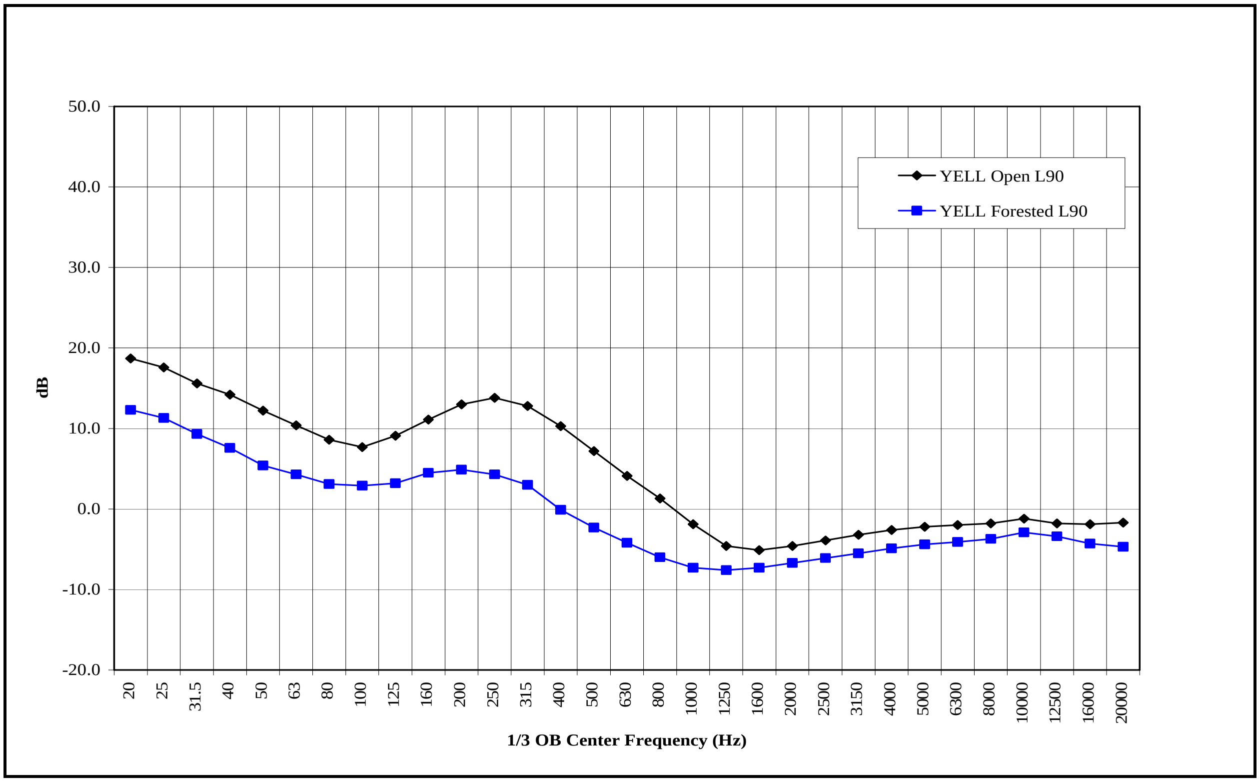

Figure 5. YELL open and forested L_{90}, 20-20,000 Hz.

Table 4. YELL Open hourly L_{eq}, L_{10}, L_{50}, L_{90}, L_{min}, and L_{max}, February 8, 2006.

Hour	L_{eq}	L_{10}	L_{50}	L_{90}	L_{min}	L_{max}
0	11.4	12.1	11.0	10.1	9.3	26.4
1	10.9	11.5	10.5	9.9	9.3	28.4
2	20.0	10.9	10.1	9.7	9.2	42.8
3	11.8	12.9	11.9	10.1	9.4	22.3
4	28.5	16.7	14.4	12.5	10.5	54.2
5	13.3	15.2	12.1	10.9	10.1	26.1
6	29.0	17.7	13.7	11.7	10.2	51.4
7	37.4	24.4	16.5	14.4	12.7	59.4
8	30.0	19.2	15.8	13.9	11.2	56.7
9	36.4	28.9	16.6	13.0	10.6	54.2
10	33.6	37.3	27.7	20.7	17.0	51.0
11	34.2	37.7	27.6	21.1	15.6	51.6
12	33.2	36.7	26.2	19.3	13.7	49.4
13	36.0	39.7	29.2	21.3	16.3	52.7
14	38.1	42.2	32.3	25.1	18.3	52.9
15	37.5	41.9	31.1	21.7	15.3	53.4
16	33.2	36.6	24.7	18.2	13.0	52.2
17	35.1	38.2	28.1	19.8	15.0	56.0
18	26.3	24.4	16.9	15.7	14.1	49.2
19	18.1	19.6	18.2	15.3	13.8	21.8
20	19.2	20.5	19.1	17.7	15.5	24.9
21	17.8	16.8	14.2	12.8	11.5	39.7
22	19.3	21.2	16.5	14.2	12.4	35.4
23	20.4	22.2	20.1	18.1	16.0	28.0

Table 5. YELL Forested hourly L_{eq}, L_{10}, L_{50}, L_{90}, L_{min}, and L_{max}, February 8, 2006.

Hour	L_{eq}	L_{10}	L_{50}	L_{90}	L_{min}	L_{max}
0	8.3	8.5	7.8	7.1	6.6	29.5
1	7.7	8.1	7.3	6.9	6.5	28.2
2	16.2	8.6	7.4	6.9	6.5	37.9
3	8.5	8.7	7.8	7.1	6.7	34.8
4	24.9	10.2	8.3	7.6	7.0	49.6
5	7.7	8.3	7.3	6.9	6.6	18.8
6	24.4	8.6	7.4	6.9	6.5	49.4
7	27.7	16.7	10.0	8.5	7.6	54.3
8	18.3	14.6	10.2	7.9	6.8	44.9
9	25.9	18.8	8.4	7.3	6.7	49.2
10	20.6	15.8	9.8	8.6	7.8	45.2
11	19.9	16.7	12.1	9.2	7.7	49.5
12	24.9	24.2	17.0	11.4	8.2	44.5
13	20.4	23.2	18.2	13.4	9.8	42.5
14	21.9	21.4	15.9	11.8	9.6	52.0
15	24.8	21.1	14.8	11.0	8.9	52.0
16	15.3	16.9	12.6	8.1	7.2	38.7
17	25.5	12.6	9.6	8.2	7.3	49.5
18	10.7	9.6	7.8	7.4	6.8	38.2
19	10.5	11.1	9.9	8.6	7.1	32.3
20	11.5	11.8	10.3	8.5	7.5	39.1
21	13.5	9.9	7.5	7.0	6.5	35.1
22	10.8	12.7	10.3	7.7	7.0	21.9
23	12.5	13.6	12.2	11.1	9.8	25.0

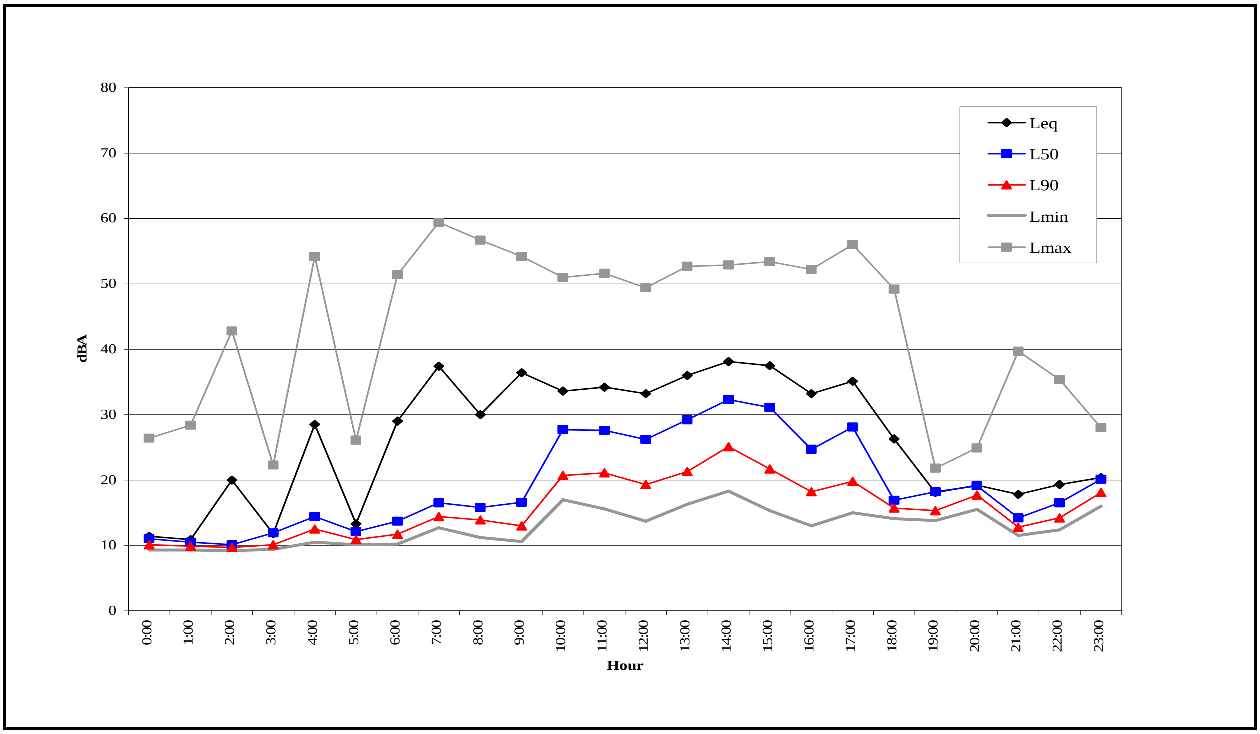

Figure 6. Hourly sound levels (dBA) for YELL Open, Feb. 8, 2006, 0000-2400.

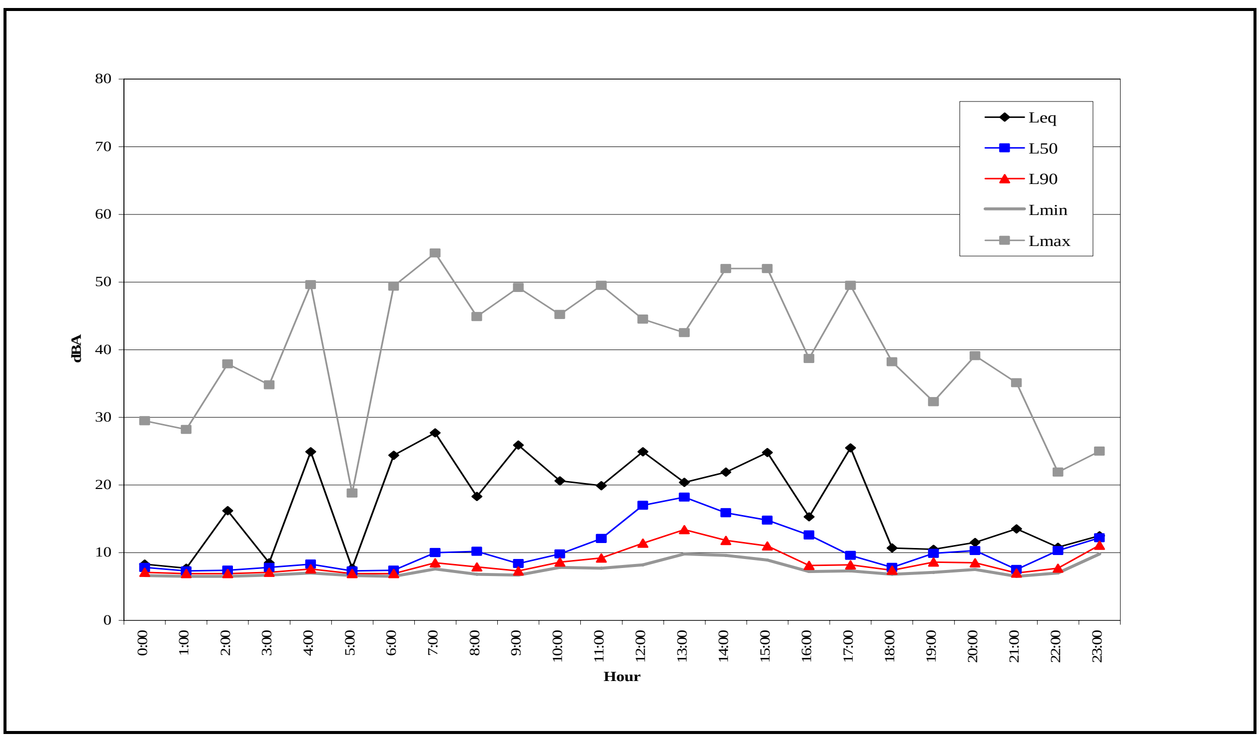

Figure 7. Hourly sound levels (dBA) for YELL Forested, Feb. 8, 2006, 0000-2400.

Percent Time Audible

The percent time natural and non-natural sounds were audible during all hours of the day (0000-2400) and daytime hours (0800-1600) are presented in Table 6.

Table 6. Percent time different sound sources audible, YELL open and forested, 0000-2400 and 0800-1600.

	Percent time audible			
Sound Source	Open	Forested	Open	Forested
	0000-2400		0800-1600	
No Sound Audible	22	64	3	29
Aircraft, Jet	2	2	1	2
Aircraft, Prop	1	1	2	3
Over-snow Vehicle	3	2	9	5
Motor Sounds	1	2	3	5
Wind	70	9	81	22
Bird	8	10	18	26
Natural other or not listed	7	17	14	29
Total Aircraft	3	3	3	5
Total Over-snow vehicle	3	2	9	5
Total Non-natural	7	7	15	15
Total Natural	74	31	89	61

Wind (wind sounds and wind in vegetation sounds) and birds were the most common natural sounds at both sites. Wind-related sounds were more common in the open habitat than at the forested site, although at the forested site, sounds classified as "natural other or not listed" were primarily trees cracking, creaking or rubbing, and snow falling from trees, sounds which could have been in part due to wind. The same tree sounds were also audible at the open site, although to a lesser extent. Birds were recorded at both sites. Of the 720 sample recording at each site, birds were audible in 6.9 percent of the samples at the open site and 7.4 percent of the samples at the forested sites. Bird species recorded are listed in Table 7.

Table 7. Percent of samples with bird sounds or calls, by species, at the open and forested site.

Open	Percent of Samples	Forested	Percent of Samples
Raven	0.7%	Raven	1.5%
Chickadee sp.	1.8%	Chickadee sp.	3.9%
Woodpecker sp.	4.2%	Woodpecker sp.	1.9%
Clark's Nutcracker	0.3%		

Aircraft and over-snow vehicles were the most common non-natural sounds. The unidentified motor sounds were almost certainly either aircraft or over-snow vehicles.

The percent time non-natural sounds (including over-snow vehicle sounds) were audible by hour for YELL Open and Forested sites are shown in Figures 8-10.

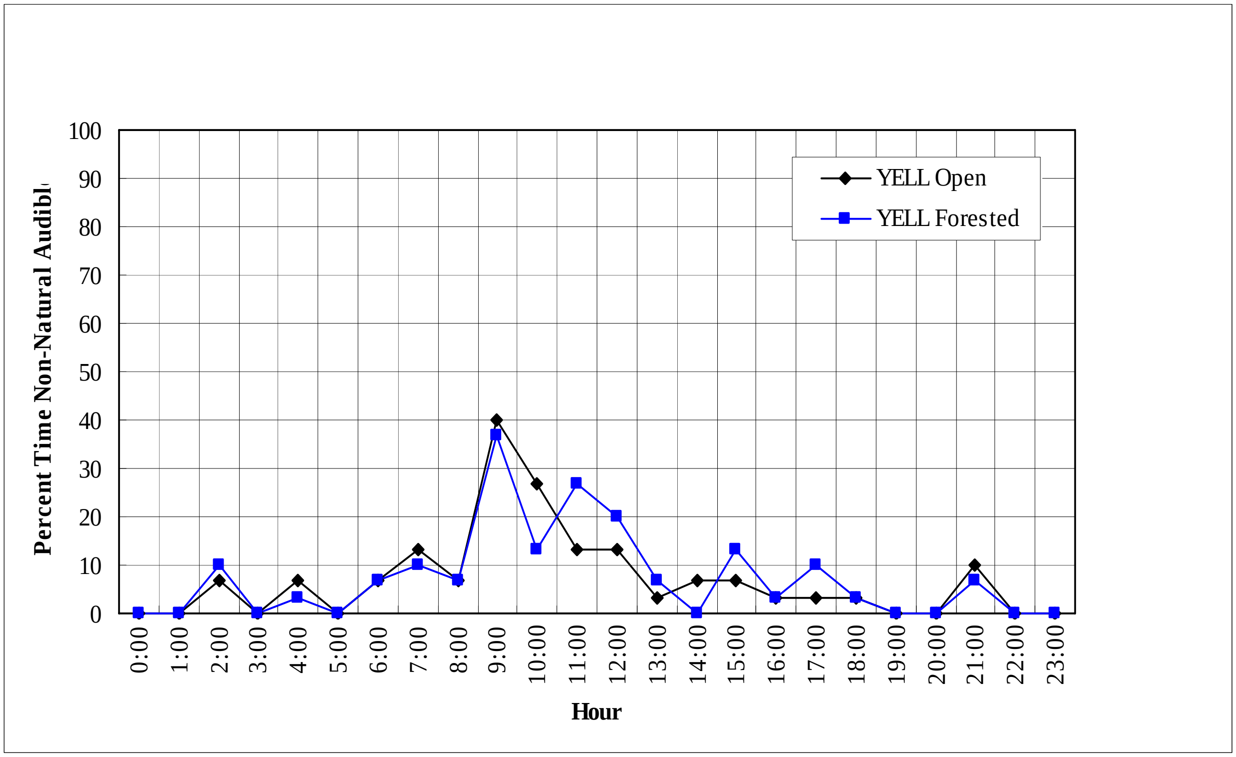

Figure 8. Percent time non-natural sounds audible at YELL open and forested measurement sites, Feb. 8, 2006.

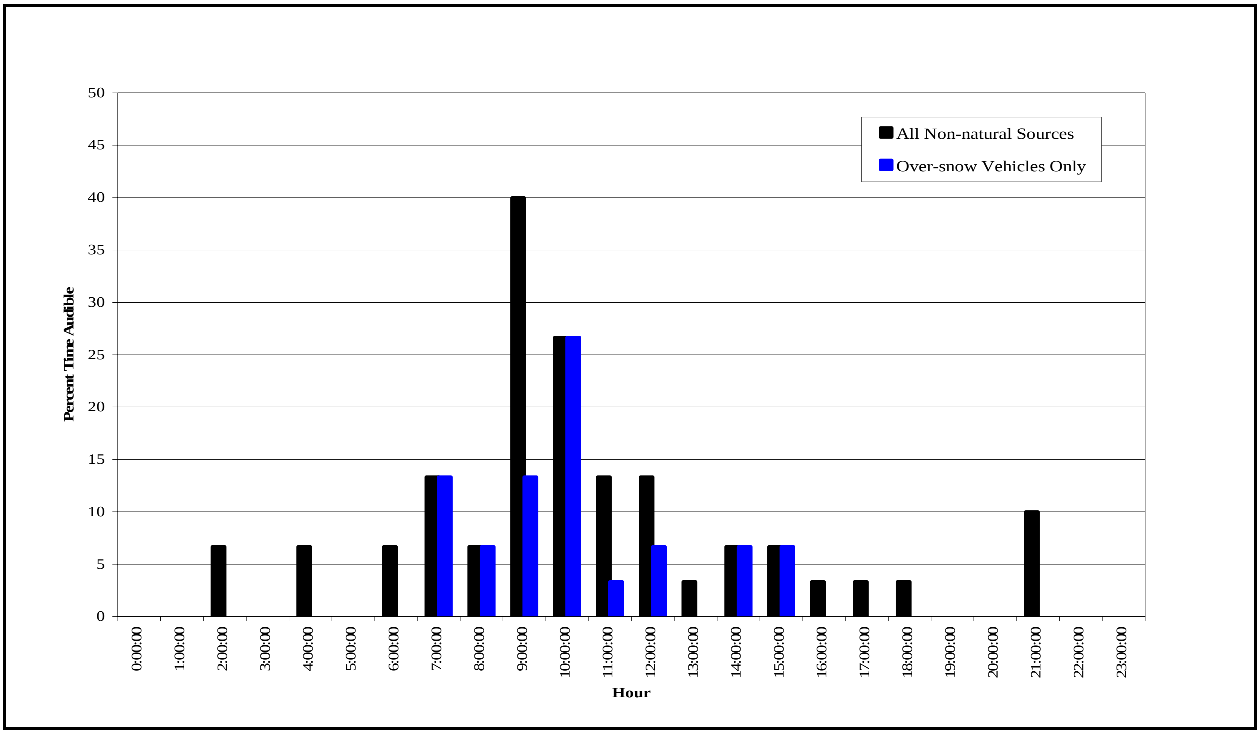

Figure 9. YELL open, Feb. 2-9, 2006, percent time all non-natural sound sources audible and percent time over-snow vehicles only audible.

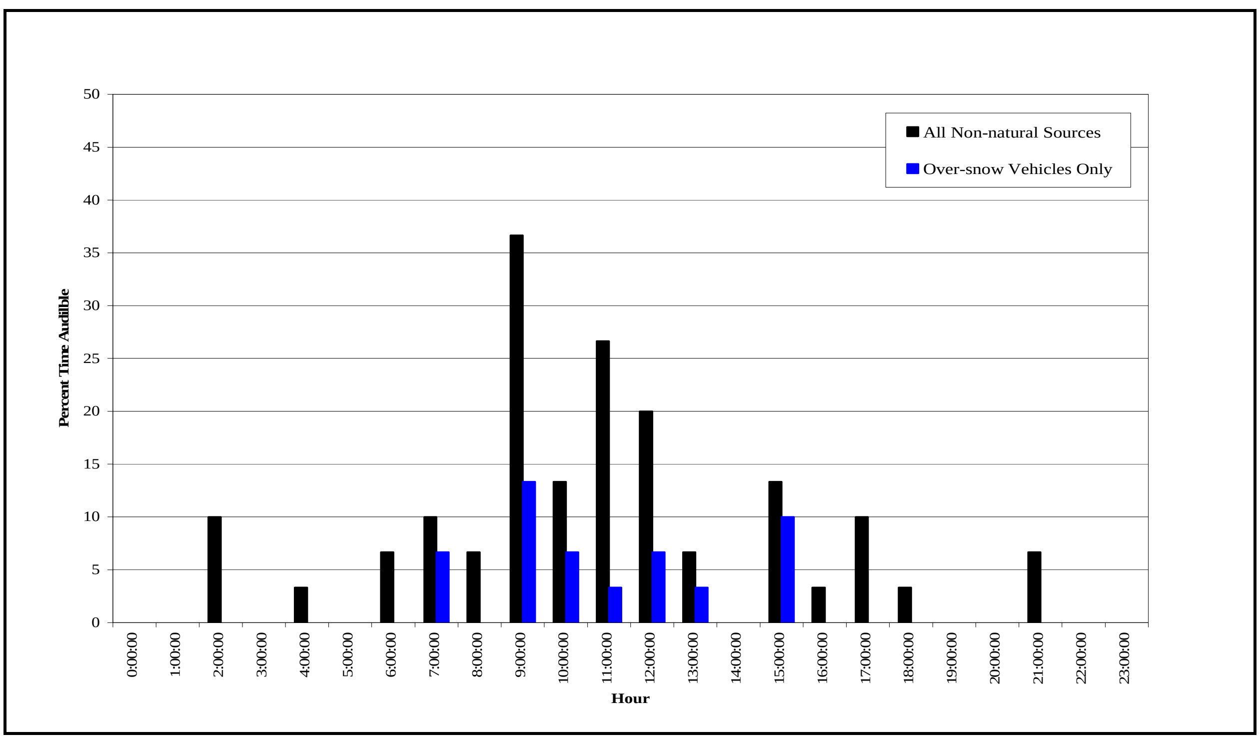

Figure 10. YELL forested, Feb. 2-9, 2006, percent time all non-natural sound sources audible and percent time over-snow vehicles only audible.

Instrumentation Noise Floor Issues

A GRAS 40HH ½" low-noise microphone, with GRAS preamplifier and power supply, was used during this study. The reported typical noise floor value for this microphone is 6.5 dBA (GRAS 2005), a level recorded at the YELL Forested site. However, when actual sound levels are near the noise floor values of the instrument, the displayed (and recorded) sound level may not be the actual SPL. An explanation follows.

Two sound levels of equal value, when added together, equal 3 dB more than original sound levels. For example, 6.5 dB + 6.5 dB = 9.5 dB; 20 dB + 20 dB = 23 dB. When the noise floor of an instrument (the combined noise floor of the microphone and system electronics) is 6.5 dBA, and the actual ambient SPL is 6.5 dBA, the displayed level on the sound level meter will read 9.5 dBA, based on the decibel level addition function: Lt=10*LOG((10^(Ls/10)+10^(Ln/10))), where Lt is total level, Ls is signal level & Ln is noise floor level, all in dB (Rasmussen 2001).

Therefore, with the GRAS 40HH microphone, a displayed sound level of 9.5 dBA equates to an actual sound level of 6.5 dBA. Displayed sound levels below 9.5 dBA indicate actual sound levels less than 6.5 dBA, but the amount below 6.5 dBA can only be estimated (computations based on the decibel addition function discussed above). For example, a displayed level of 7.4 dBA would mathematically compute to an actual (approximate) level of 0 dBA (see Table 9). However, such computations are only estimates, and the closer the instrument noise floor level is to the displayed level (such as a noise floor of 6.5 dBA and a displayed level of 6.5 dBA), the less precise the computed actual level.

Based on the displayed (recorded) sound levels at the YELL sites (as low as 6.5 dBA), and in consideration of the above, it is likely that dBA sound levels at this site were occasionally below 0 dBA.

Table 9. Displayed SPL level and actual SPL level (following A. Rasmussen 2001 "Larson Davis noise floor error study").

Noise Floor:	**6.5**
Displayed Level	**Actual Level**
6.5	-14.0
6.5	-13.0
6.6	-12.0
6.6	-11.0
6.6	-10.0
6.6	-9.0
6.7	-8.0
6.7	-7.0
6.7	-6.0
6.8	-5.0
6.9	-4.0
7.0	-3.0
7.1	-2.0
7.2	-1.0
7.4	0.0
7.6	1.0
7.8	2.0
8.1	3.0
8.4	4.0
8.8	5.0
9.5	6.5
9.6	6.6
9.6	6.7
9.7	6.8
9.7	6.9
9.8	7.0
10.3	8.0
10.9	9.0
11.6	10.0
12.3	11.0
13.1	12.0
13.9	13.0
14.7	14.0
15.6	15.0

Based on the decibel level addition function: Lt=10*LOG((10^(Ls/10)+10^(Ln/10))) where Lt is total level, Ls is signal level & Ln is noise floor level, all in dB. Two sound levels of equal value, when added together, equal 3 dB more than original sound levels. For example, 6.5 dB + 6.5 dB = 9.5 dB.

Noise Floor: Combined Noise Floor of Microphone and Electronics (dB)

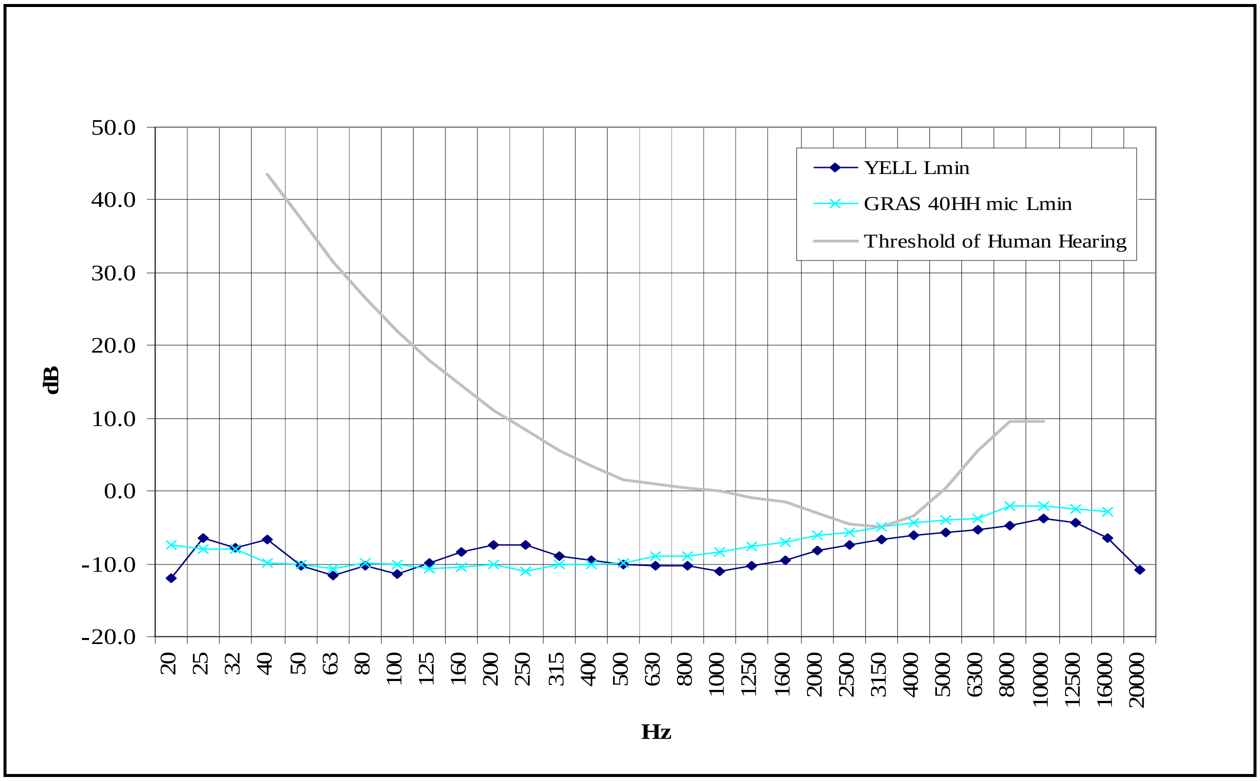

Figure 11. YELL Forested L_{min} sound pressure levels compared to GRAS 40HH microphone typical noise floor values (GRAS 2005) and the threshold of human hearing (ISO 2005).

Threshold of Human Hearing

In Figure 11, the minimum decibel levels (20-20,000 Hz) recorded during this study (at the forested site), the noise floor of the GRAS ½" low-noise microphone, and threshold of human hearing are shown. The specified noise floors of the GRAS ½" low-noise microphone for all frequencies between 20-20,000 Hz are less than the threshold of human hearing at the corresponding frequency. The minimum decibel levels measured in this study were below the threshold of human hearing at all frequencies (20-20,000 Hz) (Figure 11).

The threshold of human hearing can be defined as the intensity level where a sound becomes just audible. Measured thresholds of hearing are different for different frequencies. The standard threshold of hearing at 1000 Hz is generally assumed to be 0 dB, but the actual measured threshold at 1000 Hz is about 4 dB. There is discrimination against low frequencies. The maximum sensitivity at about 3500 to 4000 Hz is about -4 dB, and is related to the resonance of the auditory canal (Nave 2006).

The very low sound levels measured in this study, and similar very low sound levels in other national parks (Canyonlands National Park, unpublished data), suggest that specialized, very low sound level equipment should be used more frequently in acoustic studies in some national parks.

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Literature Cited

Burson, S. 2004. Natural Soundscape Monitoring in Yellowstone National Park, December 2003-March 2004. Grand Teton National Park Soundscape Program Report No. 200403. Unpublished NPS Report, Grand Teton National Park, Moose, WY.

GRAS Sound & Vibration. 2005. ½-inch Low-noise Level Microphone System Type 40HH, Product Data and Specifications. Skovlytoften 33, Holte, Denmark.

Harris Miller Miller and Hanson, Inc. 2001. Technical report on noise: winter use plan final environmental impact statement for the Yellowstone and Grand Teton National Parks and John D. Rockefeller, Jr. Memorial Parkway. Report No. 295860.18. June 2001.

International Organization for Standardization (ISO). 2005. 389-7:2005; Acoustics, Part 7: Reference threshold of hearing under free-field and diffuse-field listening conditions.

Nave, C. R. 2006. Hyperphysics. Department of Physics and Astronomy, Georgia State University, Atlanta, GA.

Rasmussen, A. 2001. Larson Davis noise floor error study. Larson Davis, Provo, UT.