Winter Acoustic Monitoring in Yellowstone National Park December 2017-March 2018


Neil Herbert/NPS Photo

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Executive Summary:

The natural soundscape of Yellowstone National Park is highly variable, ecologically important, valued by visitors, and protected by policy. Common natural sounds in winter include bird calls, mammal vocalizations, flowing water, wind, and thermal activity. These and other sounds vary by hour, day, month, and location. The natural soundscape is largely intact in the park's backcountry and during the night in developed areas. In contract with the summer season, the natural soundscape also predominates along travel corridors a majority of the time during the day in the winter use season. Environmental conditions, including air temperature and wind, have a substantial effect on how far both natural and non-natural sounds can be heard. When the ambient sound level is very quiet, such as it is in many areas of Yellowstone, sounds including oversnow vehicles are audible over much farther distances.

Noise associated with oversnow vehicles (snowmobiles and snowcoaches) is an important management concern at the park. The primary purpose of this study was to monitor the impact of oversnow vehicles on the natural soundscape. Sounds from both visitor and administrative oversnow vehicles were included in this study. We measured the sound levels and the duration and timing when oversnow vehicles could be heard (percent time audible and noise-free intervals) at specific locations along travel corridors and in destination areas.

Acoustical data were collected at two roadside sites (Madison Junction and near Lewis Lake) and one destination area (Old Faithful) in Yellowstone National Park during the winter use season, 15 December 2017-15 March 2018. This report includes, with few exceptions, only those sites sampled during the 2017-2018 winter. Detailed results of data collected in the preceding fourteen winters have been reported previously.

The audibility of oversnow vehicles during the 8 am to 4 pm time period was calculated in two ways. An overall winter use season average was calculated using all the sampled days at each site, and a daily audibility percentage was calculated by summing the time oversnow vehicles were audible during each eight hours of the day (8 am to 4 pm) and dividing by the eight hour period.

The noise-free interval was calculated as the period of time during 8 am to 4 pm that no motorized vehicles (oversnow and wheeled vehicles and aircraft) were audible. An additional noise-free interval was calculated using only oversnow vehicle noise. Noise-free intervals were not calculated for the developed area where human-caused sound was nearly constant.

The official winter use season was 91 days. Except where otherwise indicated, the summary statistics shown in this report are for the full 91-day winter use season although some segments of the road were temporarily closed during the winter.

The oversnow vehicles' overall winter use audibility in the most heavily-used developed area, Old Faithful, averaged 53% (*SD*=8%).

Oversnow vehicles were audible for an overall average of 47% (*SD*=13%) of the day near Madison Junction along the busiest road corridor in the winter, between Old Faithful and the West Entrance. The nine-winter average noise-free interval between 8 am and 4 pm was three minutes and 30 seconds but varied substantially by time of day. The 2017-2018 winter average oversnow vehicle noise-free interval was three minutes and 45 seconds.

Oversnow vehicles were audible for a winter use average of 28% (*SD*=11%) at Grant Village Lewis Lake monitor along the South Entrance Road just north of Lewis Lake. The average noise-free interval for the past four winters was 12 minutes and 45 seconds. The average oversnow vehicle noise-free interval the past winter was 11 minutes and 36 seconds, but varied greatly by hour.

The audibility of oversnow vehicles at all three monitoring locations was lower than long term average, but slightly higher than the previous winter Oversnow vehicle numbers were also higher (by over 10%) compared to the previous winter. The lower than long-term average audibility was likely from the advances in best available technology and the use of quieter snowcoaches.

The maximum sound levels of oversnow vehicles often exceeded 70 A-weighted decibels (dBA) along the groomed travel corridor at the Madison Junction 2.3 monitoring site and the Old Faithful Weather Station site. The majority of these higher sound levels at Madison Junction 2.3 were caused by tracked snowcoaches.

The highest average sound levels decreased at two of the three monitoring sites each of the past four winters. This was likely from the advances in best available technology and the use of quieter snowcoaches.

Consistent with acoustic data collected during the previous fourteen winter seasons, the sound levels 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 in the winters after 2002-2003 were largely explained by fewer snowmobiles, the change from two to four-stroke engine technology, the change from track to rubber tires on many snowcoaches, and the guided group requirements. The percent time that snowmobiles were audible continues to be more closely associated with the number and distribution of groups (transportation events) rather than the total number of individual snowmobiles.

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Introduction:

Natural soundscapes are a valued resource at national parks including Yellowstone National Park (YNP). The 2006 National Park Service (NPS) Management Policies state that natural soundscapes (the unimpaired sounds of nature) are to be preserved or restored as is practicable. Natural soundscapes are intrinsic elements of the environment and are necessary for natural ecological functioning and therefore associated with park purposes. Natural soundscapes are highly valued by park visitors during their winter trips into Yellowstone (Freimund et al. 2009). The existing winter soundscape at Yellowstone consists of both natural and non-natural sounds. Common natural sounds include bird calls, mammal vocalizations, flowing water, wind, and thermal activity. Non-natural sounds include motorized sounds of snowmobiles, snowcoaches, snow-grooming, wheeled vehicles, aircraft, and the sounds associated with facility utilities and other human activity in destination and support areas.

Previous Winter Use Plans of YNP and Grand Teton National Parks and the John D. Rockefeller, Jr., Memorial Parkway (NPS 2000, 2003, 2004, 2007, 2009, and 2013) concluded that historical oversnow vehicle (OSV) use created unacceptable adverse impacts on natural soundscapes and other resources. To minimize the impact of sounds from OSVs on the natural soundscape and other resources, the NPS established limits on the number and group sizes of transportation events and a guiding requirement. The primary purpose of this project's acoustical monitoring was to measure the impact of snowmobile and snowcoach sound on the park's natural soundscape. Data collected by automated sound monitors included sounds from both guided visitor and unguided administrative OSVs. See Burson (2004-2017) for additional information on park soundscapes and details of this study's methods, and the Winter Use Plans (NPS 2000, 2003, 2004, 2007, and 2009, 2013) for additional details of OSV management.

Study Area:

The major roads within YNP that are open to vehicles during the summer are groomed for OSV 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 15 December 2017 and 15 March 2018, 22,271 guided snowmobiles and 3,146 guided snowcoaches, totaling 25,417 oversnow vehicles, entered YNP (NPS unpublished data). This was an increase of 11% from the previous winter: the increase due to more snowcoaches. The majority (23,962 94%) of oversnow vehicles entered through the West and the South entrances. Most of these winter visitors traveled to Old Faithful. Guests staying overnight at Old Faithful can partake in daytrips that originate from Old Faithful. In past years these daytrips averaged about four snowmobiles and ten snowcoaches per day. These daytrips were not included in the number of OSVs given above or elsewhere in this report. The average number of snowcoaches entering YNP during the winter season was 36/day (range 8-52). The average number of guided snowmobiles entering YNP during the winter season was 242/day (range 35-360). The three days of the government shutdown in January accounted for the three lowest days of recorded snowmobile use although there may have been additional unrecorded commercial trips during those days.

Instrumentation:

Automated acoustic monitors (the predecessors of which were initially developed by Skip Ambrose, Sandhill Company, Castle Valley, UT and Mike Donaldson, Far North Aquatics, Fairbanks, AK) collected continuous one-second sound levels and digital recordings. See Burson (2012) for detailed information about the instrumentation.

Acoustic Measurement Locations:

The 2017-2018 sound monitoring locations (Fig. 1; Table 1) were chosen to include the two highest OSV use corridors and represented two soundscape management zones (Developed and Travel Corridor). Using aerial photos, habitat cover percentages listed below were calculated in a 500 meter radius of the sound monitor.

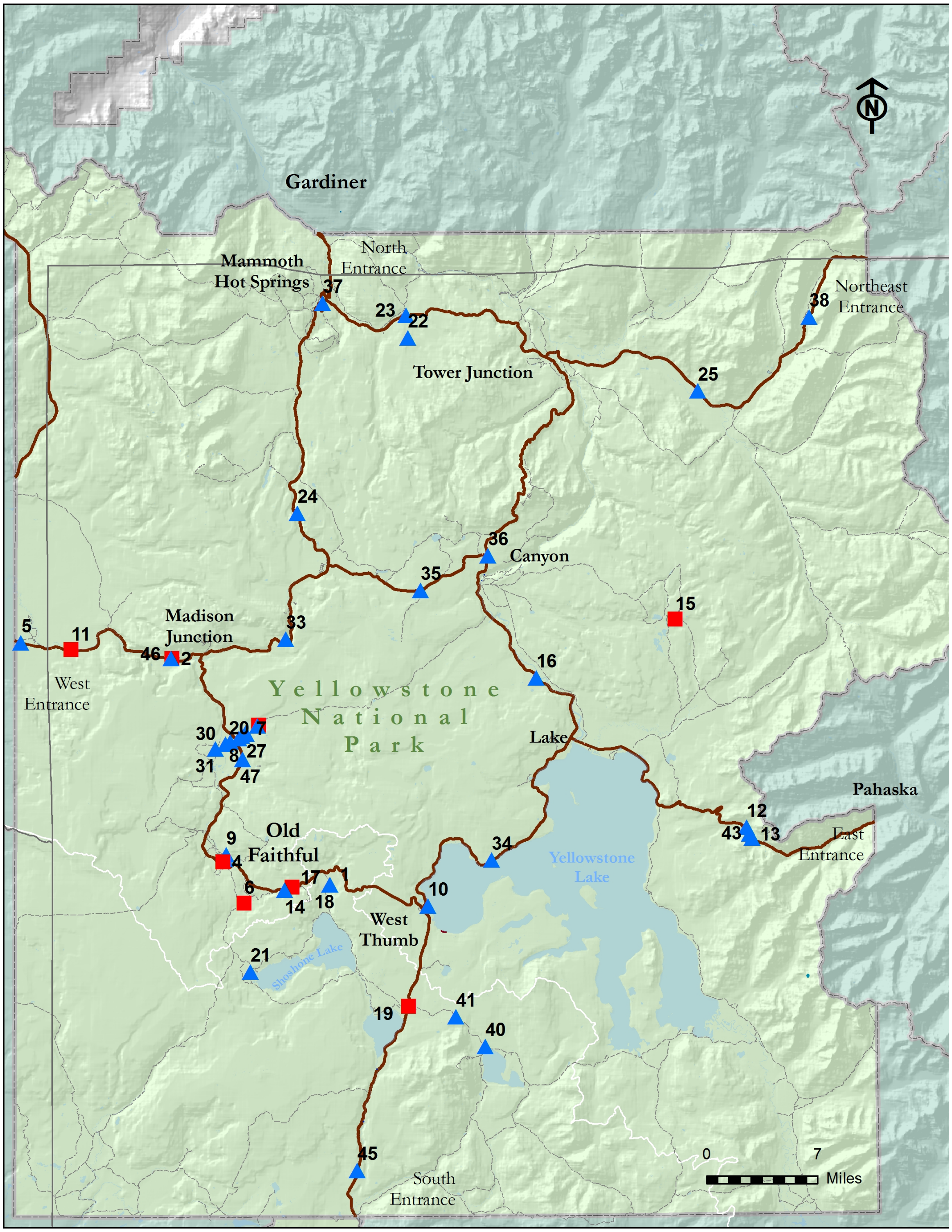

Figure 1. Locations of sound monitoring sites (blue triangles- winter only, and red squares- multiple seasons) within YNP, December 2003-March 2018. See associated table for year and labels (Table 1). Only the past winter's sampling locations are included in detail in this report (but see Burson [2004-2017] for previous winters' sampling results).

Table 1. Site name and years of sound monitoring locations within YNP, December 2003-March 2018. See associated map (Fig. 1) and labels.

Label	Site Name	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15	FY16	FY17	FY18
1	Delacy Creek	Y															
2	Madison Junction 2.3	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
4	Old Faithful Weather Station	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
5	West Yellowstone	Y															
6	Lone Star Geyser		Y	Y													
7	Mary Mountain 4K		Y														
8	Mary Mountain Trail		Y														
9	Old Faithful Upper Basin			Y	Y												
10	West Thumb			Y	Y												
11	W. Yellowstone 3.1			Y	Y												
12	Avalanche Creek				Y												
13	Sylvan Lake				Y												
14	Spring Creek				Y												
15	Fern Lake					Y											
16	Mud Volcano					Y											
17	Spring Creek 2					Y											
18	Delacy Creek 2						Y										
19	Grant Village Lewis Lake						Y							Y	Y	Y	Y
20	Mary Mountain 8K			Y	Y		Y										
21	Shoshone Geyser Basin						Y										
22	Blacktail Backcountry							Y									
23	Blacktail Roadside							Y									
24	North Twin Lake							Y									
25	Lamar Valley Willow								Y								
26	Mary Mountain Transect East 1								Y								
27	Mary Mountain Transect East 2								Y								
28	Mary Mountain Transect East 3								Y								
29	Mary Mountain Transect West 1								Y								
30	Mary Mountain Transect West 2								Y								
31	Mary Mountain Transect West 3								Y								
33	Caldera Rim Picnic Area									Y							
34	Pumice Point Roadside									Y							
35	Cygnet Lake Roadside										Y						
36	Canyon Village Developed Area										Y						
37	Mammoth Canary Springs										Y						
38	Middle Barronette Meadow										Y						
40	Heart Lake Backcountry											Y					
41	Paycheck Pass Backcountry											Y					
43	Sylvan Lake 3 Roadside											Y					
45	South Entrance Roadside												Y				
47	Fountain Paint Pots													Y			

Old Faithful Weather Station

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

Photo 1. Old Faithful Weather Station sound monitor location within fenced enclosure in center of photograph.

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

Madison Junction 2.3

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

Photo 2. Madison Junction 2.3 sound monitor location.

The Madison Junction 2.3 monitor (in the center of the photo above in trees) was located 2.3 miles (3.7 km) west of Madison Junction, 100 feet (30 m) west of the West Entrance-Madison Junction Road within a large area of small (6 to 15 feet [2-5 m]) lodgepole pines, and 275 feet (84 m) from the Madison River. The site and nearby motorized route were in a long mostly flat valley, one mile (1.6 km) wide, bounded on both sides by steep bluffs. The Madison Junction 2.3 monitor was powered by 12 volt batteries charged by solar panels. See Tables 2 and 3 for dates of operation.

Grant Village Lewis Lake

Latitude:	44.32449
Longitude:	110.59624
Elevation:	7900 feet (2400 m)
Habitat:	80% conifer forest (regenerating pine), 20% open (road and meadow)
Management Zone:	Travel Corridor

Photo 3. Grant Village Lewis Lake sound monitor location.

The Grant Village Lewis Lake monitor (in the center of the photo above) was located 100 feet (30 m) from the South Entrance Road about one mile north of Lewis Lake and three miles south of Grant Village. The microphone was in a small clearing within a large discontinuous forest of regenerating and dead burnt conifer trees. The Grant Village Lewis Lake monitor was powered by 12 volt batteries charged by solar panels. See Tables 2 and 3 for dates of operation.

Methods and Analyses:

Winter-long acoustical measurements were collected at Old Faithful Weather Station, Madison Junction 2.3, and Grant Village Lewis Lake. Data collection began on 15 December 2017 and continued throughout the winter use season (15 December 2017-15 March 2018). All sound level data collected during the winter use season were analyzed and are presented here. Selected digital recordings were chosen for analysis based on stratified sampling by site. Every second or third day was analyzed unless no data were available or a site visit fell on a day to be analyzed. In either case an adjacent day was randomly selected for substitution.

The Winter Use Plan (WUP) impact thresholds applied only to motorized OSV sounds from 8 am to 4 pm so for the audibility analyses only those periods are presented in this report. Because the majority of OSV use was during 8 am to 4 pm, using the full 14-hour period of the day when OSV use was permitted would lower the resulting average daily percent time audible values (see Appendix B). For comparative value the sound levels are presented for the 24 hour day although the WUP thresholds applied only to 8 am to 4 pm.

The very low natural ambient sound levels documented near Sylvan Pass and Craig Pass (Ambrose et al. 2006, Burson 2007) were similar in habitat to monitoring locations measured for this study. Audibility of OSVs is determined, in part, by the natural ambient sound levels. Lower natural ambient sound levels can result in higher OSV percent time audible. At some monitoring locations the lowest minimum sound levels can be below the range (noise floor) of the instrumentation for many hours of the day. The actual minimum sound levels may be below the measured and reported levels.

Acoustic data were collected at YNP during the past fifteen winter seasons, although the first winter consisted of only short-term data collection. This dataset provides information on trends, similarities among years and variability in time and location (Table 5 and Figure 11). Soundscapes are highly variable over time, both in minutes and seasons. All attempts to summarize long-term datasets therefore do not fully explain this inherent variability. Methods and techniques to completely address the soundscape's variability are currently unavailable. Attempts to draw tight correlations between certain actions, such as the daily number of OSVs that enter YNP and the percent time audible at a particular location require more detailed data collection and analyses than is available in this study. Nevertheless, the acoustic dataset that has been collected during the winter-use seasons and upon which this report is based is one of the most extensive national park winter acoustic datasets in existence and a substantial amount of useful information can be gathered from the data as collected and presented. See Burson (2012) for detailed methods.

Audibility

Ten seconds of every four minutes of the continuous digital recordings were analyzed. These daily 360 10-second samples were combined, calibrated, and analyzed. The entire 24-hour period was used, but to compare to previous years, the time period 8 am to 4 pm (120 samples totaling 20 minutes per day) is reported here.

The percent time audible for each sound source was calculated using the 10-second samples every four minutes as a surrogate for all periods of the day. For example, if a particular sound source was audible for half of the samples (180 of 360 samples) its percent time audible was calculated as 50%. Although any sampling scheme may miss an occasional sound, comparison with attended logging, other sampling schemes, and continuous recordings demonstrated that a 10 seconds/4 minute scheme, over multiple days, closely approximates 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. Snowmobiles were sometimes difficult to distinguish from snowcoaches. When the source was known to be either a snowcoach or a snowmobile but could not be positively identified to the exact source, that unknown OSV source was added into a third, total OSVs, category that included all OSVs (road maintenance snow groomers were not included as OSVs). Figures 3 and 6 provide examples of the relative proportions of snowmobiles, snowcoaches, and the total OSVs. When sound sources could only be identified as motorized vehicles they were not included in the OSV category, although it is likely that many were oversnow vehicles.

The noise-free interval was calculated by analyzing one full hour for each of the eight hours between 8 am and 4 pm at Madison Junction 2.3 and Grant Village Lewis Lake. At Madison Junction 2.3 these eight hours were combined with 64 hours collected the previous eight winters for a total of 72 hours. At Grant Village Lewis Lake these eight hours were combined with 24 hours collected the previous three winters. The days chosen to represent each hour were randomly selected. Noise-free intervals were not calculated for Old Faithful because human-made noise was nearly always audible. The average and maximum (the longest) noise-free interval was calculated for both each hour and for the entire sampling period for each site both for all human-made noise (NFI) and only oversnow vehicle noise (OSVNFI).

Sound levels

This report relies on a number of common acoustical metrics for the sound level data and descriptive statistics, mostly medians, for the audibility data. Because estimates of variability beyond the minimum and maximum values are also desirable, information about the sound levels exceeded 10, 50, and 90 percent of the time is provided.

See Appendix A for a discussion and examples of a technique to visualize daily sound levels. This technique provides another avenue to understand the natural soundscape and the sound impact of oversnow vehicles.

See Appendix B for additional considerations of OSV percent time audible summaries.

Results and Discussion:

Selected digital recordings (Table 2) were chosen for analysis based on stratified sampling by site. Hours selected for noise-free interval analyses were randomly selected (Table 3). All sound level data from each site was analyzed (Table 4).

Table 2. Dates used for audibility analyses at three locations in YNP, December 2017-March 2018. Total number of days analyzed, 94.

Old Faithful Weather Station	Madison Junction 2.3	Grant Village – Lewis Lake
15 Dec 17	15 Dec 17	15 Dec 17
18 Dec 17	6 Jan 18	17 Dec 17
21 Dec 17	8 Jan 18	18 Dec 17
24 Dec 17	10 Jan 18	21 Dec 17
27 Dec 17	12 Jan 18	24 Dec 17
30 Dec 17	14 Jan 18	27 Dec 17
2 Jan 18	16 Jan 18	30 Dec 17
5 Jan 18	18 Jan 18	2 Jan 18
8 Jan 18	21 Jan 18	5 Jan 18
11 Jan 18	24 Jan 18	8 Jan 18
14 Jan 18	26 Jan 18	11 Jan 18
17 Jan 18	29 Jan 18	14 Jan 18
20 Jan 18	1 Feb 18	17 Jan 18
23 Jan 18	3 Feb 18	20 Jan 18
26 Jan 18	5 Feb 18	23 Jan 18
29 Jan 18	7 Feb 18	26 Jan 18
1 Feb 18	9 Feb 18	29 Jan 18
4 Feb 18	11 Feb 18	1 Feb 18
6 Feb 18	13 Feb 18	4 Feb 18
10 Feb 18	15 Feb 18	6 Feb 18
13 Feb 18	17 Feb 18	10 Feb 18
16 Feb 18	19 Feb 18	13 Feb 18
19 Feb 18	22 Feb 18	16 Feb 18
22 Feb 18	25 Feb 18	19 Feb 18
25 Feb 18	27 Feb 18	22 Feb 18
28 Feb 18	1 Mar 18	25 Feb 18
3 Mar 18	4 Mar 18	28 Feb 18
6 Mar 18	7 Mar 18	2 Mar 18
9 Mar 18	10 Mar 18	6 Mar 18
12 Mar 18	13 Mar 18	9 Mar 18
15 Mar 18	15 Mar 18	12 Mar 18
		15 Mar 18

Table 3. Hours and dates used for analysis of noise-free intervals at Madison Junction and Grant Village Lewis Lake, YNP. Total number of days and hours analyzed, 104.

	Madison Junction 2.3	Grant Village Lewis Lake
Hour	Date	Date
8 am	12/24/09, 2/22/11, 12/25/11, 3/6/13, 12/29/13, 1/11/15, 1/31/16, 12/17/16, 3/13/18	1/12/15, 1/21/16. 12/17/16, 3/13/18
9 am	1/4/10, 1/7/11, 1/19/12, 1/29/13, 2/15/14, 1/15/15, 3/13/16, 1/11/17, 1/24/18	2/7/15, 3/13/16, 1/11/17, 1/24/18
10 am	1/10/10, 2/4/11, 2/27/12, 1/20/13, 3/13/14, 1/22/15, 12/24/15, 12/30/16, 1/21/18	2/8/15, 12/24/15, 12/30/16, 2/21/18
11 am	1/15/10, 12/19/10, 1/28/12, 2/8/13, 2/14/14, 12/27/14, 2/26/16, 2/11/17, 2/11/18	3/12/15, 2/26/16, 2/11/17, 2/11/18
12 pm	1/30/10, 2/7/11, 12/27/11, 2/13/13, 12/23/13, 2/6/15, 12/30/15, 2/23/17, 3/10/18	2/25/15, 12/31/15, 2/23/17, 3/10/18
1 pm	2/5/10, 3/2/11, 2/2/12, 2/4/13, 2/1/14, 1/20/15, 1/17/16, 2/18/17, 2/5/18	1/9/15, 1/17/16, 2/18/17, 2/5/18
2 pm	2/10/10, 1/21/11, 2/24/12, 2/16/13, 12/15/13, 1/28/15, 1/27/16, 3/6/17, 1/6/18	12/16/14, 1/27/16, 3/6/17, 1/9/18
3 pm	2/20/10, 12/25/10, 1/18/12, 2/4/13, 1/28/14, 1/30/15, 3/8/16, 2/5/17, 2/19/18	1/29/15, 3/8/16, 2/5/17, 2/19/18

Table 4. Dates used for sound level analyses at three locations in YNP, December 2017-March 2018. Total hours 5,984.

Old Faithful (2,174 hours) 15 December 2017-15 March 2018	Madison Junction 2.3 (1,656 hours) 15-16 December 2017 and 5 January-15 March 2018
Grant Village Lewis Lake (2,154 hours) 15 December 2017-15 March 2018	

Audibility:

Each audible sound (snowmobile, wheeled vehicle, animal, aircraft, wind, thermal activity, etc.) was identified each day during 8 am-4 pm. The proportion of each sound source sample out of the possible 120 was used to calculate the percent time audible for each sound source; however, only the snowmobile, snowcoach and wind percent time audible is presented. OSVs were often audible outside the 8 am-4 pm time period, but these data are generally not presented. Often multiple snowmobiles or snowmobiles and snowcoaches were audible simultaneously, but at other times one masked the sound of the other. Audibility of OSVs was calculated using existing ambient conditions, that is, other non-natural sound sources could have been present and may have masked OSV sounds. This potential masking was only regularly present at developed areas. The only non-natural sounds other than OSVs at travel corridors and backcountry sites were occasional aircraft.

Regarding oversnow vehicles, an important question is the relationship between the number of snowmobiles and snowcoaches entering YNP and the percent of time that they are audible at a particular measurement location. At first glance this appears an easily answered question. It seems intuitively obvious that more snowmobiles and snowcoaches would make more sound and that they would be heard a greater proportion of the day. This is true in general and is obvious in the acoustic data collected during the past winters. Several factors, though, complicate the relationship. First, not all snowmobiles are part of guided groups; there are many NPS and concession snowmobiles and snowcoaches used within the park, especially in destination areas such as Old Faithful (see Appendix B in Burson (2012) for information about the relative contribution of guided versus administrative OSV use). Second, not all OSVs that enter the park travel along the same route. Therefore the number of OSVs entering the park is not directly related to the number passing any particular section of the road and hence their impact on the natural soundscape of that area. Third, as the numbers of visitors entering the park increases, additional snowmobiles are often added to existing groups enlarging group size, but not creating additional groups. The percent time that snowmobiles are audible is more closely associated with the number and distribution of groups rather than the number of individual snowmobiles. In part because of this, the current winter use plan organizes snowmobile trips by transportation events (groups of snowmobiles) rather than number of individual vehicles. Fourth, audibility also depends on environmental conditions, such as temperature, wind conditions, inversions, the natural ambient sound level and other factors (as discussed in the next paragraph) that vary spatially and temporally. These factors added together reduce the potentially close relationship between the number of visitor snowmobiles and snowcoaches and OSV percent time audible.

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

A related audibility issue involves an acoustical metric called the noise-free interval (NFI). NFIs measure the uninterrupted periods of time when only silence or natural sounds are audible. For the purposes of this report, NFIs were the times when no oversnow or wheeled vehicles or aircraft (on average audible 5% or less of the day) were audible. Oversnow vehicle noise-free intervals (OSVNFI) were the times when no oversnow vehicle noise was audible. Using logic and common sense, the number and distribution of groups of vehicles largely determine the OSVNFI. Given the same number of vehicles, OSVNFIs measured near travel corridors would be longer with larger rather than smaller groups (however as group size increases they would likely be heard at increasing distances). A particular percent time audible can have varying NFIs. For example, if OSVs were audible for 50% of an hour, depending on the distribution of these vehicles they could be audible for all of the first 30 minutes and not audible the remaining 30 minutes. Or OSVs could be audible every other 10 minute period during the hour. The OSVNFI of the first scenario would be 30 minutes but only 10 minutes for the second. The management requirement for groups of guided snowmobiles have increased the OSVNFIs at YNP compared to non-grouped snowmobiles (personal observation, and Appendix A; Fig. A-4 and A-5).

Old Faithful Weather Station

Acoustic data were collected at this site for the fifteenth full winter (Table 5). Even though this site was Yellowstone's busiest developed area accessed by OSVs, many natural sounds were present, including wind, snow, wolves, coyotes, bison, red squirrels, ravens, ducks, and geese. Non-natural sounds of building utilities and people's voices were frequently audible along with oversnow vehicles. Aircraft (a total of 18 helicopters, 15 propeller aircraft, and 91 jets in the analyzed sample) were audible for a daily (8 am and 4 pm) average of 3% during the winter use season.

For the winter use season the average daily percent time audible for snowmobiles and snowcoaches was 53% (*SD* = 8%) within the developed area at Old Faithful (Fig. 2). This compares to 50% (*SD*=9%) the previous winter and 55-69% during the thirteen winter use seasons before that (Table 5). The daily variability was similar to previous winters.

Oversnow vehicles traveling on the main road and within the Old Faithful developed area were audible at this site. Wind, depending on direction and speed, can increase or decrease the distance OSV sounds are audible. However, though typically OSVs are heard at greater distances during calm wind conditions, there appears to be no strong association between days with low to moderate wind and OSV percent time audible at Old Faithful (see Burson 2017). This is because the higher ambient sound levels at Old Faithful mask the distant faint OSV sounds that would otherwise be audible during calm conditions.

Percent time audible can be calculated by hour to show the pattern of OSV use between 8 am and 4 pm (Fig. 3). On average, OSVs were audible for more time as visitors arrived closer to mid-day. On average, of the OSVs that were identified, snowmobiles and snowcoaches were audible for 10% and 20% of the day (Fig. 3). OSVs were audible on average 64% during the peak noon hour. In addition to average audibility, Figure 3 shows the range of OSV audibility for each hour of the day for the entire sampling period (labeled high and low OSV).

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

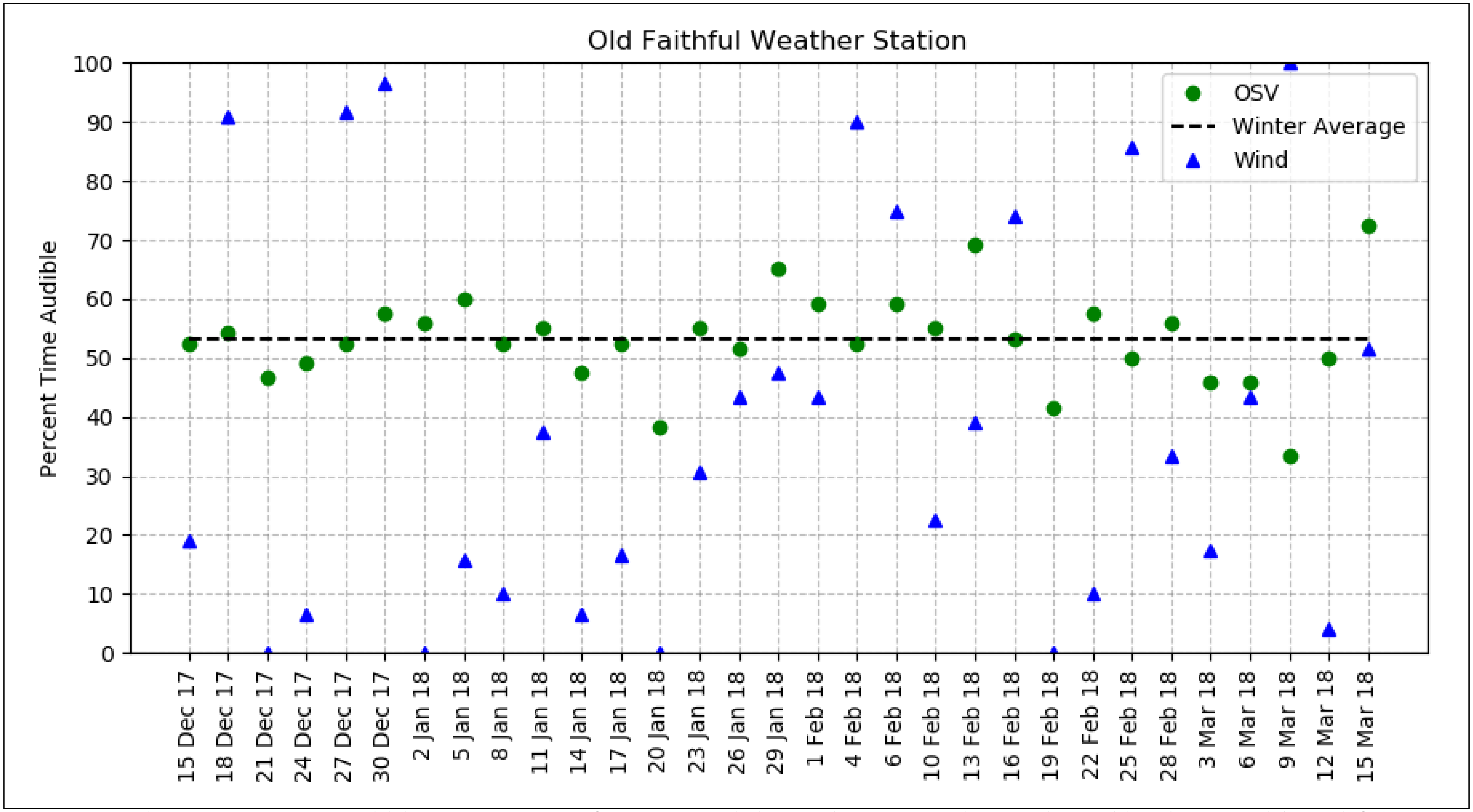

Figure 2. The percent time audible (8 am - 4 pm) for snowmobiles and snowcoaches and wind by date at Old Faithful Weather Station, YNP, 15 December 2017-15 March 2018.

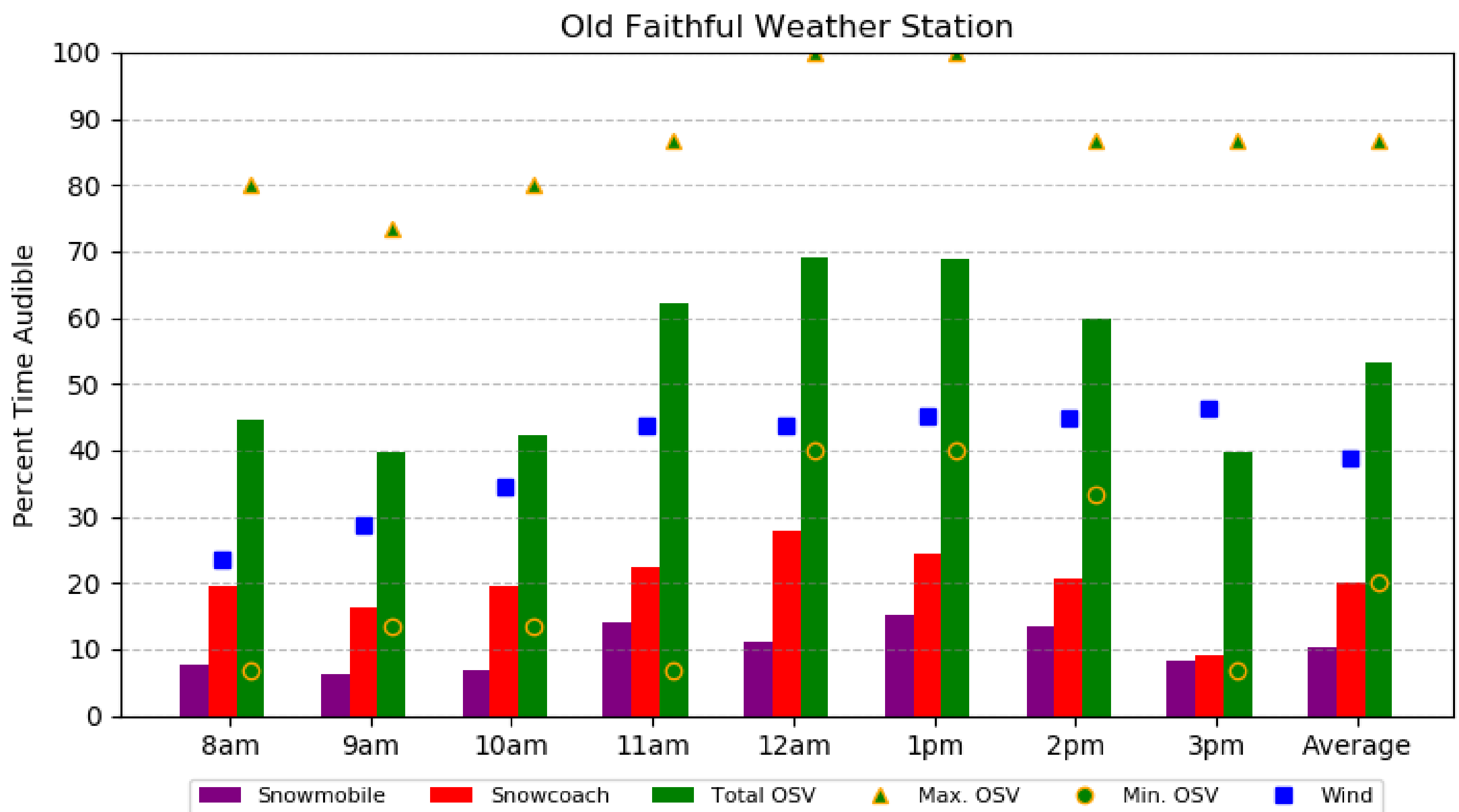

Figure 3. The season average percent time audible by hour of snowmobiles (left purple bar), snowcoaches (middle red bar), wind, and a total OSV category including unidentified OSVs (right green bar), and the season's hourly maximum and minimum OSV percent time audible values by hour at Old Faithful Weather Station, YNP from 8 am - 4 pm, 15 December 2017-15 March 2018.

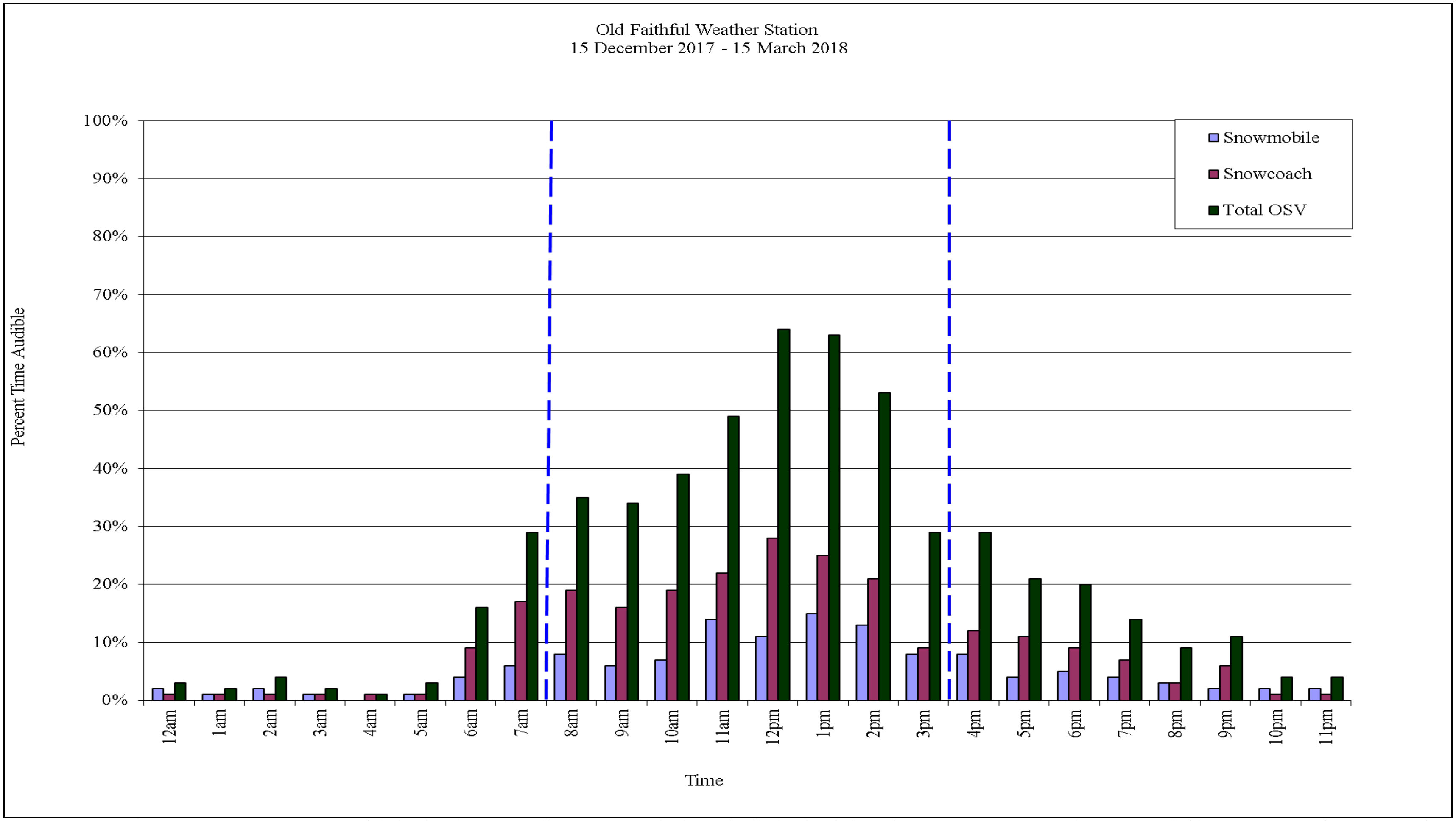

Figure 4. The percent time audible by hour of snowmobiles (left light blue bar), snowcoaches (middle maroon bar), and a total OSV category including unidentified OSVs (right dark green bar) at Old Faithful Weather Station, YNP, 15 December 2017 – 15 March 2018. The winter use analysis time period is between the vertical dashed lines.

Madison Junction 2.3

Madison Junction 2.3 monitoring site was located 100 feet (30 m) off the West Entrance Road 2.3 miles (3.7 km) west of Madison Junction along Yellowstone's busiest OSV travel corridor. Acoustic data have been collected for all or parts of fifteen winter use seasons (Table 1) at this location. Riffles of the Madison River were audible during quiet periods. River riffles and wind were often audible as were swans, ducks, and geese on the river. Coyotes and wolves were more rarely heard, but squirrels, ravens, and other birds were audible almost daily. Aircraft (a total of 24 propeller aircraft, 6 helicopters, and 178 jets in the analyzed sample) were audible for a daily (8 am and 4 pm) average of 6% during the winter use season.

Snowmobiles and snowcoaches were audible for an average of 47% (*SD*=13%) of the time during the winter use season (Fig. 5). The range during the previous thirteen full seasons was 30%-59% (Table 5), with the lowest values during winters with road closures. Wind speed was associated with the audibility of OSVs at this site. OSVs were less audible on days with more wind due to the masking effect of wind on the distant and faint OSV sounds.

The hourly pattern follows a bimodal distribution (Fig. 6) documenting the pulse of OSVs passing the site in the morning on the way into the park and in the afternoon on the way back to West Yellowstone. In addition to average audibility, Figure 6 shows the range of OSV audibility for each hour of the day for the entire sampling period (labeled high and low OSV). Figure 6 also shows that many of the OSVs could not be distinguished as a snowmobile or a snowcoach. This is because it was not possible to specifically identify many distant faint OSVs because of the similar acoustic signature of snowmobiles and snowcoaches.

For the past nine winters combined, the average noise-free interval at Madison Junction 2.3 was three minutes and 30 seconds (Figure 7a) during 8 am to 4 pm. Noon had the longest average noise-free interval (10 minutes and 54 seconds) and longest maximum NFI (22 minutes and 30 seconds), and 10 am had the shortest average NFI (42 seconds) and shortest maximum NFI (2 minutes 48 seconds) during the winter use day. To measure the contribution of aircraft (the only other noise at this site) to the NFI, Fig. 7b shows separately the noise-free interval for both oversnow vehicles (OSVNFI) and OSVs and aircraft (NFI) for the winter of 2017-2018. This noise-free interval analysis again reflects the pulse of OSVs traveling by the site during the morning and afternoon hours (Figure 7a).

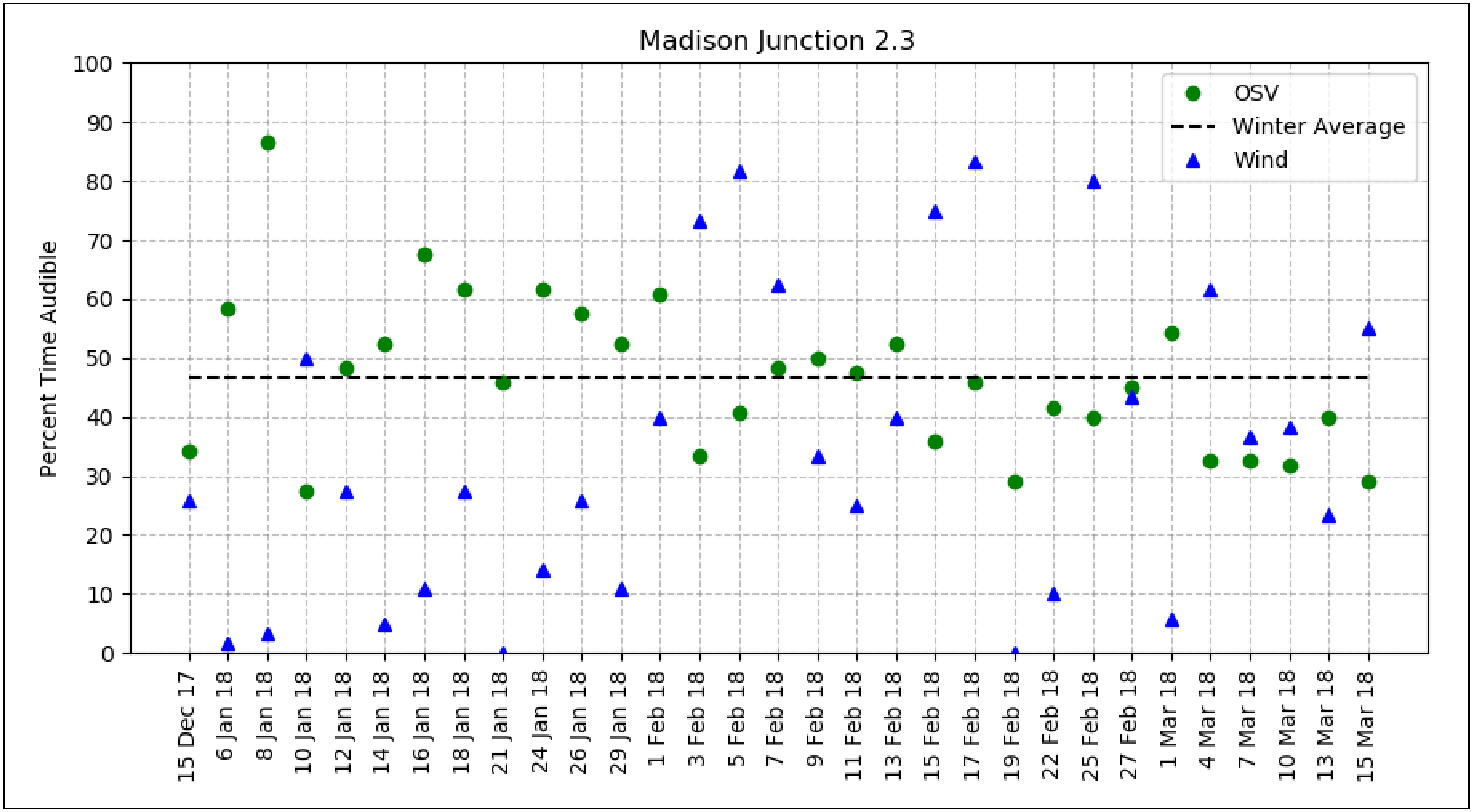

Figure 5. The average percent time audible (8 am - 4 pm) by date of snowmobiles and snowcoaches, wheeled vehicles, and wind at 2.3 miles 3.7 km) west of Madison Junction along the West Entrance Road YNP, 15 December 2017-15 March 2018.

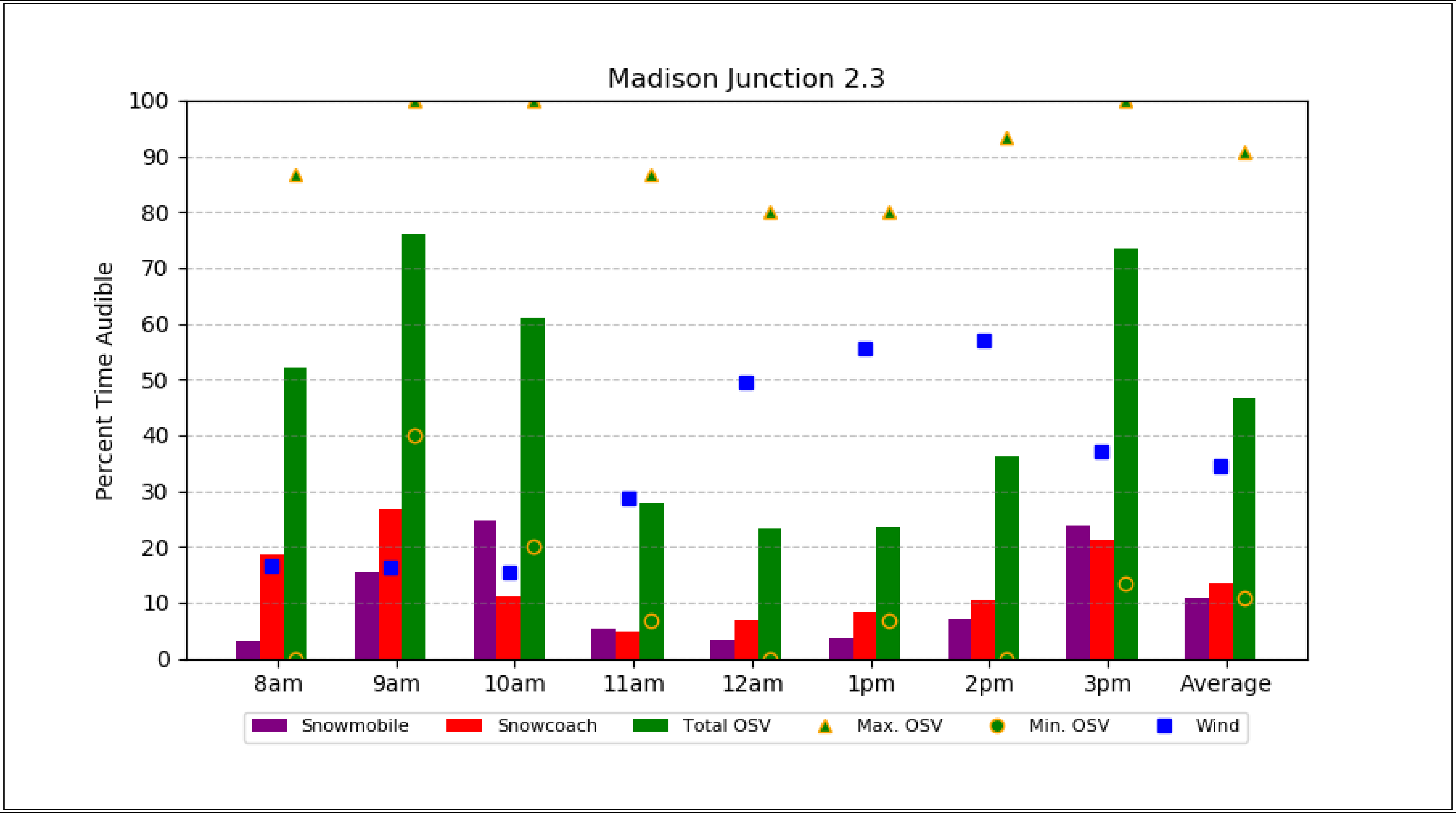

Figure 6. The average percent time audible by hour of snowmobiles and snowcoaches, and total OSVs including unidentified OSVs, wind, and the season's hourly maximum and minimum OSV percent time audible values by hour west of Madison Junction along the West Entrance Road, YNP, 15 December 2017-15 March 2018.

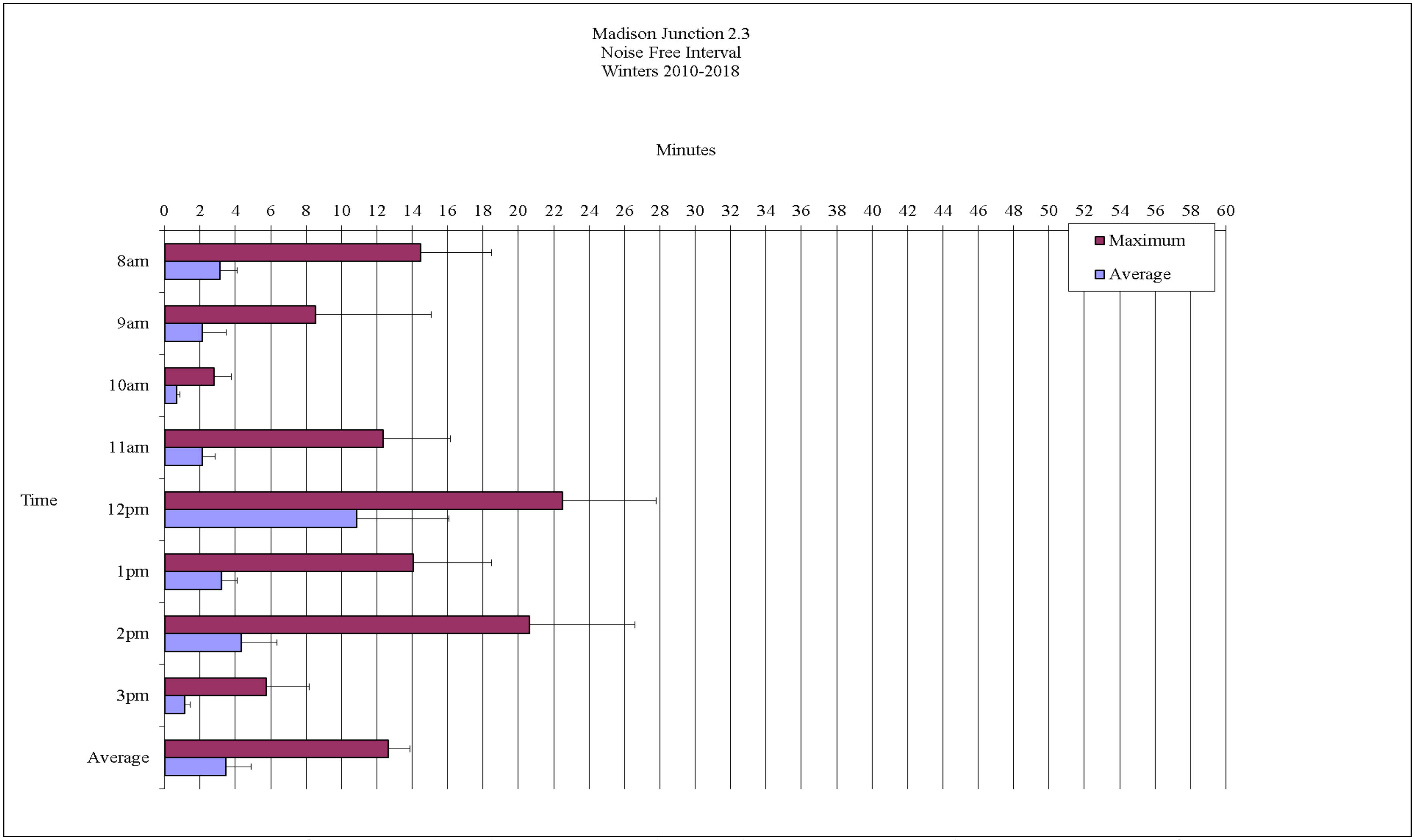

Figure 7a. Average noise-free interval (and *SD*) measured at Madison Junction 2.3 during the winters of 2010-2018, YNP. See Table 3 for dates used, and text for more details.

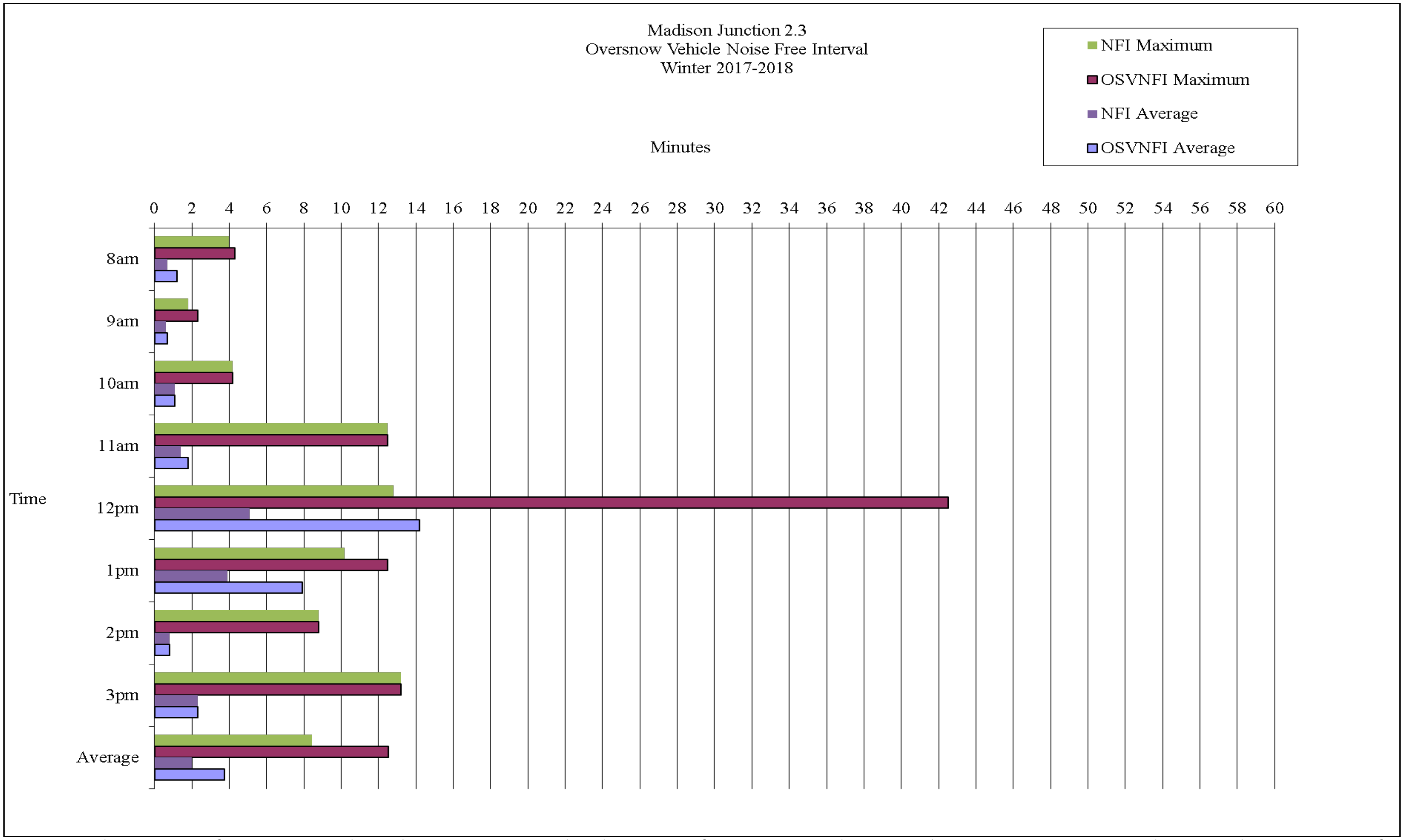

Figure 7b. Noise-free interval and oversnow vehicle noise free-interval at Madison Junction 2.3 during the winter of 2017-2018, YNP. See Table 3 for dates used, and text for more details.

Grant Village Lewis Lake

Winter-long acoustic monitoring data were collected along the South Entrance Road north of Lewis Lake at the same location where monitoring occurred during the winters of 2007-2008 and since 2014-2015. Woodpeckers, chickadees, nuthatches, ravens, and red squirrels were audible at this site. Wind was audible an average of 60% of the day (8 am to 4 pm) and an average of 15% of the day was silent with no sounds audible. Aircraft (a total of 13 propeller and 226 jets in the analyzed sample) were audible for a daily (8 am and 4 pm) average of 6% during the winter use season.

Oversnow vehicles were audible an average of 28% (*SD*=11%) of the time between 8 am and 4 pm during the sampling period (Fig. 8). This compares to a daily average of 22% last winter, and 37% ten winters ago. A likely reason for this audible decrease over the last decade is the recent use of quieter snowcoaches with rubber tires.

Grant Village Lewis Lake shows the typical bi-modal pattern of peak OSV audibility in the morning and afternoon with a lull around noon (Fig. 9). In addition to average audibility, Figure 9 shows the range of OSV audibility for each hour of the day for the entire sampling period (labeled high and low OSV). When the wind and nearby OSV traffic was not present, this site had very low ambient sound levels (Fig. 17). This allows faint distant OSVs to be audible.

The average noise-free interval (3 minutes and 55 seconds) at Grant Village Lewis Lake during this last winter use season is shown in Figure 10a. Many of these noise events were high flying jets. To separate the contribution of only oversnow vehicles to the NFI, Figure 10a shows the average oversnow vehicle noise-free interval (OSVNFI) at 11 minutes and 36 seconds. The last four winter seasons were averaged in Figure 10b. Additional winters would give a better representation of typical noise-free conditions because only four hours were analyzed for each of these eight hour days (Table 3).

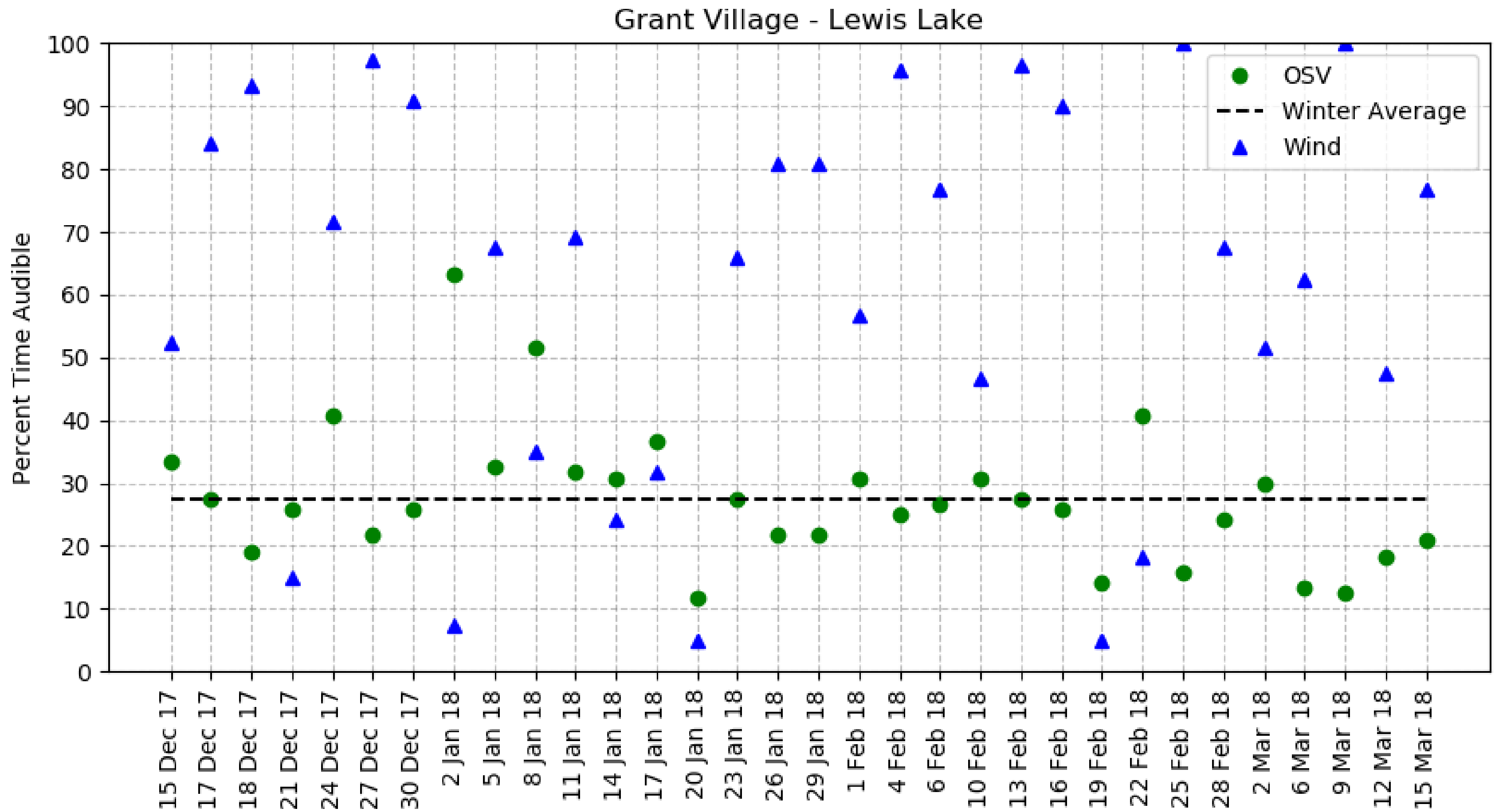

Figure 8. The average percent time audible (8 am - 4 pm) by date of oversnow vehicles, and wind at Grant Village Lewis Lake YNP, 15 December 2017 - 15 March 2018.

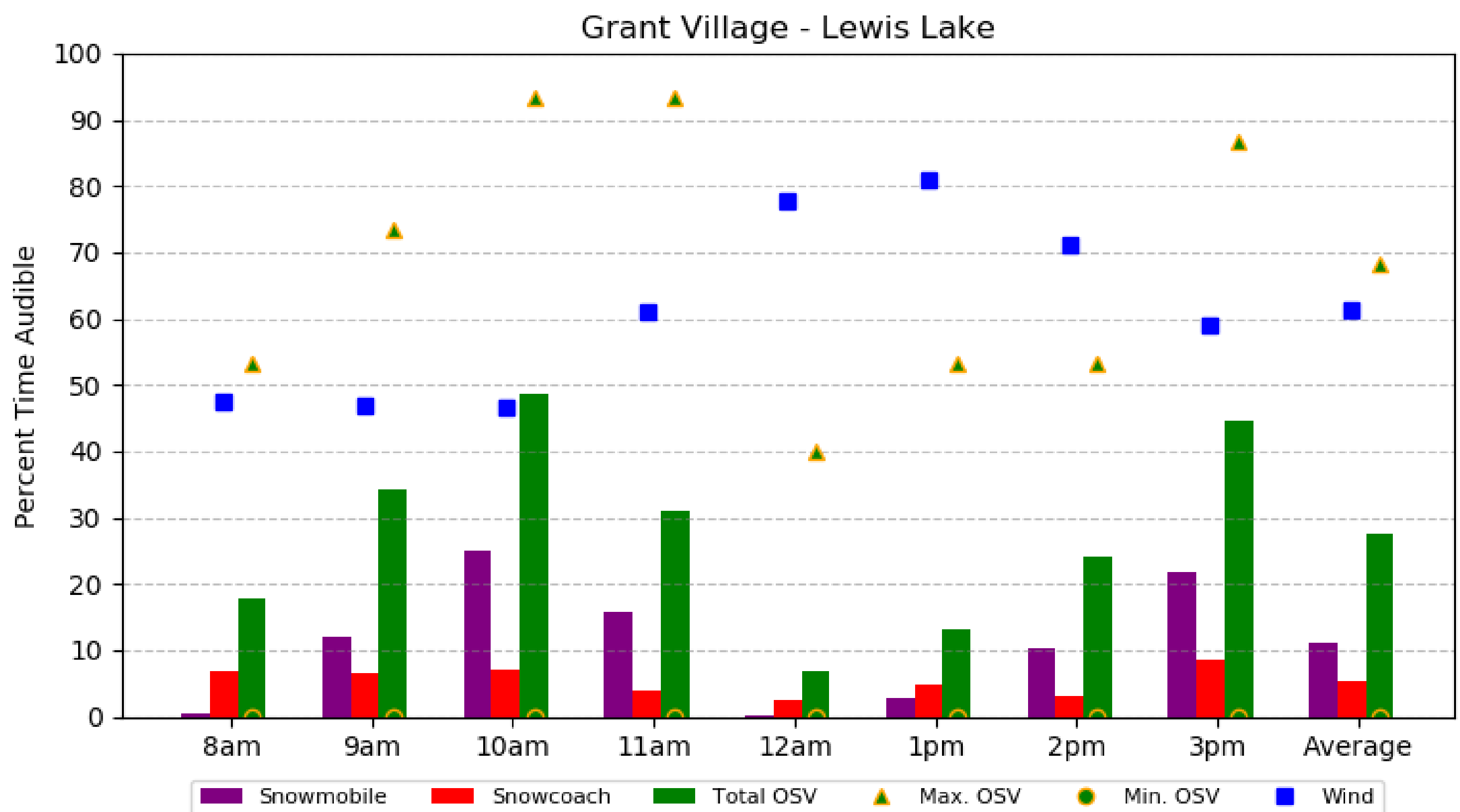

Figure 9. The average percent time audible by hour of snowmobiles, snowcoaches, wind, and the season's hourly maximum and minimum OSV percent time audible values by hour at Grant Village Lewis Lake, YNP, 15 December 2017 - 15 March 2018.

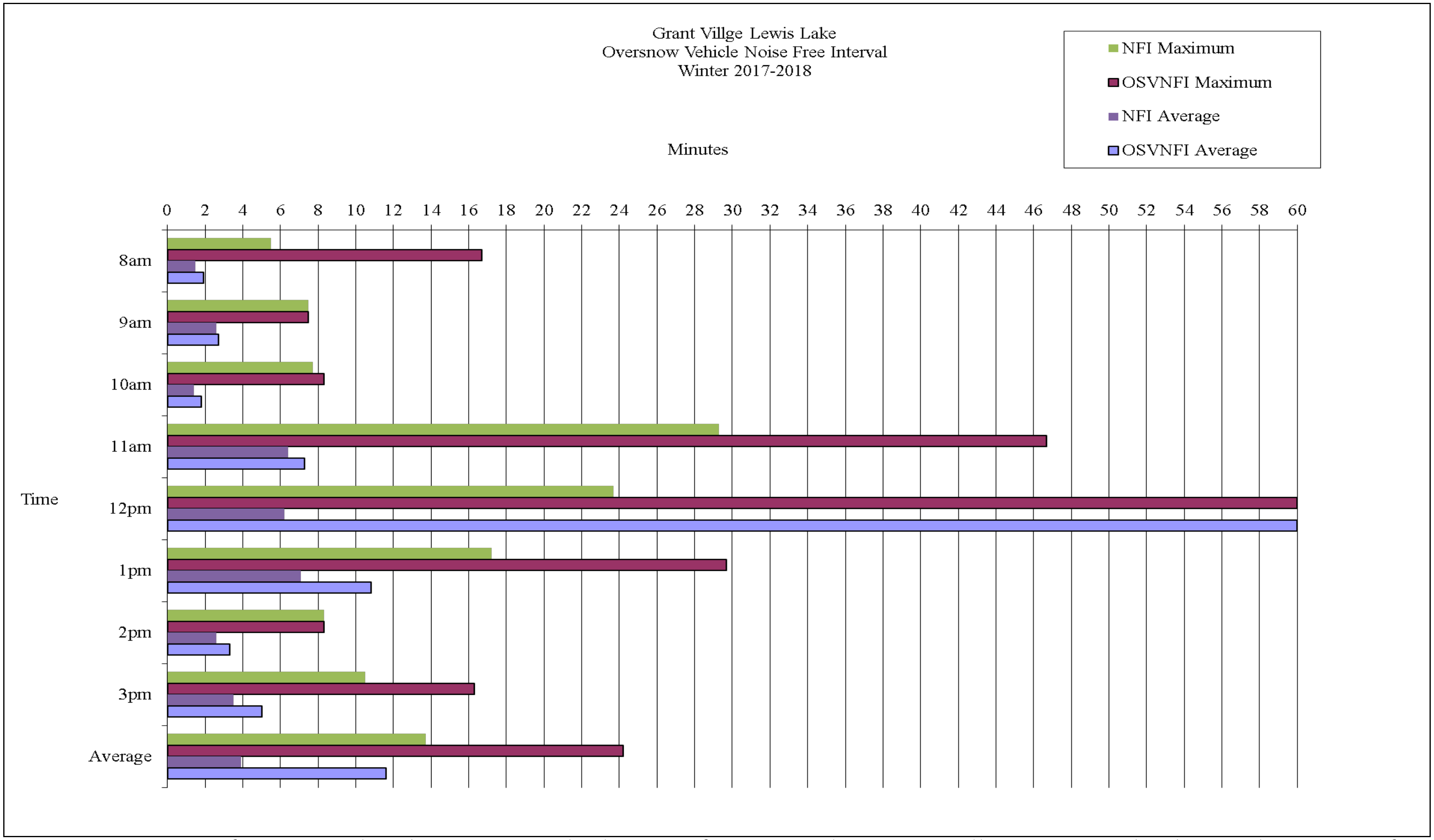

Figure 10a. Noise-free interval and oversnow vehicle noise-free interval at Grant Village Lewis Lake during the winter of 2017-2018, YNP. See Table 3 for dates used and text for more details.

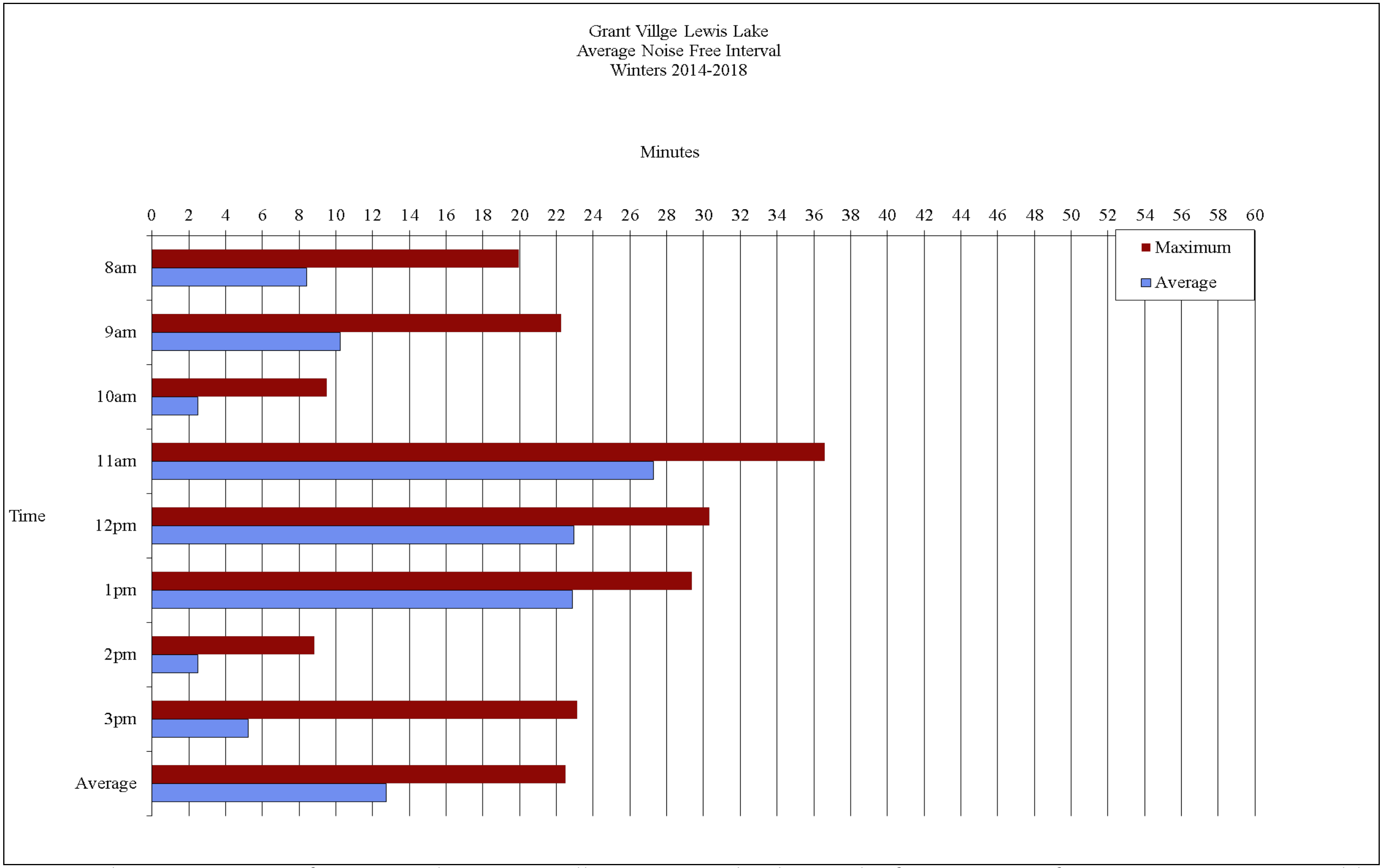

Figure 10b. Average noise-free interval at Grant Village Lewis Lake during the four winters of 2014-2018, YNP. See Table 3 for dates used and text for more details.

Audibility Trends:

Oversnow audibility is summarized for 21 locations in YNP during the past fifteen winters (Table 5). These locations include the four winter use plan management zones (developed, travel corridors, transition and backcountry). The monitoring sites in Table 5 are ordered left to right from most busy (closer to OSV activity or busier road corridor) to most distant to OSV activity. Interpret sites with small sample sizes, those with seven days of data, with caution. Acoustic conditions vary widely due to wind and other atmospheric conditions, and on the daily number of OSVs; therefore small sample sizes may not represent typical or average acoustic conditions.

The percent time audible values illustrate the expected pattern that sites farthest from OSV activity have the lowest OSV audibility. Based on all monitoring data, the average percent time audible was 50% for developed areas, 32% for travel corridors, 29% for transition zone, and 13% for backcountry areas (Table 5).

The difference in audibility between Old Faithful and Canyon Village demonstrates the popularity of the sites and that the Canyon Village data were collected early in the season when road conditions were poor thereby reducing the number of OSVs traveling to Canyon Village. Sites had relatively consistent audibility values when monitored in multiple years unless the winter use season differed in length due to road closures. Sites along the West Entrance Road (WY31 and MJ23) had similar OSV audibility. OSVs operating outside YNP were often audible at WY31, three miles from the park boundary. Sites along the South Entrance Road varied from SERS's 24% to GVLL's 37% in 2008. It is likely that OSVs were audible while traveling the long straight stretch of road passing Lewis Lake below the GVLL site, whereas the rolling hills near SERS block the noise from distant OSVs.

The increasing number of quieter snowmobiles, and especially quieter snowcoaches likely explains the decreased audibility over the last few winters. Backcountry sites ranged from just over one and a half miles from the busy Old Faithful to West Yellowstone road (MM8K) to eight miles from the less busy East Entrance Road (FLBC). The Shoshone Geyser Basin (SHGB) monitoring site was five miles from the busy Old Faithful to West Thumb road. The monitor at Lone Star Geyser (LSGY) was also along this route one mile from the road. Topography and frequent prolonged geyser activity were likely the reasons that OSVs were less audible at Lone Star Geyser than at Shoshone Geyser Basin more than four miles farther from the road (Table 5).

Table 5. Percent time audible (8 am - 4 pm) of OSV sounds at monitoring sites by management zone during the winters (2003-2018).

	Management Zone: Sites[1]																				
	Developed[2]		Road Corridor[2]										Transition[3]				Backcountry[3]				
Year	OFWS	CVDA	MJ23	WY31	SPC2	CRPA	GVLL	SERS	MUVO	CLRS	PPRD	SYL3	FOPP	MMTR	OFUB	LSGY	MM8K	PAYP	SHGB	HLBC	FLBC
2003-2004	61%													32%		3%					
2004-2005	69%			55%											29%	4%	26%				
2005-2006	67%		55%												35%						
2006-2007	68%		59%		44%				26%												0%
2007-2008	68%		53%				37%										26%		18%		
2008-2009	55%		47%																		
2009-2010	55%		54%																		
2010-2011	61%		51%			44%					22%										
2011-2012	66%	39%	45%							22%											
2012-2013	63%		51%									5%						8%		11%	
2013-2014	60%		47%					24%													
2014-2015	49%		30%				28%						50%								
2015-2016	57%		45%				26%														
2016-2017	50%		43%				22%														
2017-2018	53%		47%				28%														
Site Average	60%	39%	48%	55%	44%	44%	28%	24%	26%	22%	22%	5%	50%	32%	32%	4%	26%	8%	18%	11%	0%
Management Zone Average		50%										32%				29%					13%

	# of Oversnow Vehicles (OSVs) /day		
	Snowmobile	Snowcoach	OSVs incl. OF[5]
2003-2004	254	23	281
2004-2005	206	25	236
2005-2006	267	30	302
2006-2007	299	30	336
2007-2008	290	32	338
2008-2009	196	29	234
2009-2010	181	28	221
2010-2011	214	30	261
2012-2012	162	26	204
2011-2013	185	28	229
2013-2014	195	28	233
2014-2015	154	20	188
2015-2016	206	30	250
2016-2017	217	29	260
2017-2018	245	35	293
Average	218	28	258

1	OFWS-Old Faithful Weather Station; CVDA-Canyon Village Developed Area; MJ23-Madison Junction 2.3; WY31-West Yellowstone 3.1; SPC2-Spring Creek 2; CRPA-Caldera Rim Picnic Area; GVLL-Grant Village Lewis Lake; SERS-South Entrance Road; MUVO-Mud Volcano; CLRS-Cygnet Lake Roadside; PPRD-Pumice Point Roadside; SLY3-Sylvan Pass 3; FOPP-Fountain Paint Pots; MMTR-Mary Mountain Trail; OFUB- Old Faithful Upper Basin; LSGY-Lone Star Geyser Basin; MM4K-Mary Mountain 4K; PAYP-Paycheck Pass Backcountry; SHGB-Shoshone Geyser Basin; HLBC-Heart Lake Backcountry; FLBC-Fern Lake Backcountry
2	Sites ordered from left to right, busiest to less busy
3	Sites ordered from left to right, closest to motorized route to most distant
4	Red underlined indicates only seven days analyzed
5	Number of OSVs originating at Old Faithful prior to 2006-2007 and 2012-2013 and 2015-2018 were estimated at 14/day

Sound Levels:

The thousands of hours of sound level data collected include all sounds at each of the sampling sites. At times when no motorized or other human-caused sounds were present the data represent the natural conditions. These natural periods were predominant at night and for more than 50% of the day at Madison Junction 2.3 and Grant Village Lewis Lake, but not in the developed area of Old Faithful. Each site's acoustic metrics, including the L_{10}, L_{eq}, L_{50} (the median) and L_{90}, provide information about the typical sound levels and can be compared among years and across sites.

In conjunction with the audibility analyses, the sound levels of common sound sources can be determined. However, the sound level analysis of OSVs is not as easily understood as OSV audibility analysis. The sound levels for OSVs should be separated from other sounds. Unfortunately there is yet no automated process for separating different sound sources from the sound level data and the manual separation of OSVs sound levels during the millions of seconds of data collected this past winter in this study is practically impossible. Therefore the interpretation of sound levels becomes more difficult. In the developed areas and along travel corridors the loudest sounds during 8 am - 4 pm were almost always from oversnow vehicles. In all areas occasional natural sounds (wind, bird vocalizations, etc.) and other motorized sounds (aircraft, snow groomer, etc.) may be as loud as snowmobile and snowcoach sounds during some periods. Sound levels (decibels) of some common sound sources are shown in Table 6.

In addition to maximum (L_{max}) and minimum (L_{min}) sound levels, other common acoustical metrics such as the energy level equivalent or energy average (L_{eq}) and the L_{10}, L_{50}, and L_{90} sound level exceedance metrics are useful to provide a better understanding of the soundscape.

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

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

By examining these sound level metrics in combination, one can gain an insight into the typical sound level characteristics of a site. For example, very quiet sites will have tightly grouped L_{10}, L_{eq}, L_{50}, and L_{90} values. Sites with only occasional loud sounds will have tightly grouped L_{10}, L_{50}, and L_{90} values, but the L_{eq} and L_{max} values will be much higher.

Returning to the challenges of evaluating these sound level results, the L_{90} is the NPS (and other organizations) standard for use as an analog to the natural ambient sound level in locations other than those most heavily impacted from non-natural sounds and when other more site specific calculations are not possible. However, using L_{90} or other L_x metrics as the natural ambient sound level is inappropriate in locations with nearly constant non-natural sounds such as at the Old Faithful Weather Station monitoring site. In very quiet areas the L_{90} may overestimate the true natural ambient sound level because of limitations of the instrument noise floor threshold. The noise floor, the lowest level the acoustic equipment could measure, was approximately 14-16 dBA (see Table 6 for reference levels). The quietest sound levels in many areas of YNP are below this noise floor (Burson 2006) so the lowest documented measurements in this report likely overestimate the actual minimum sound levels.

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 or winters were identical, but patterns were regularly observed and differences among monitoring locations are apparent.

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

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

Sound Metrics by Monitoring Site

A number of sound level metrics at the three sound monitoring sites during the winter season 2017-2018 are compared in Table 7. These sites are individually discussed on the following pages.

Table 7. Sound level metrics (dBA) for three sites in two soundscape management areas in YNP, 8 am - 4 pm, winter 2017-2018. L_{90}, L_{50}, L_{eq} are median values from hourly calculations.

Site	L_{min}	L_{90}	L_{50}	L_{eq}	L_{10}	L_{max}	Hours
Developed Area							
Old Faithful Weather Station	15.1	32.2	37.2	37.7	40.1	88.4	724
Travel Corridor							
Madison Junction 2.3	14.6	24.2	28.7	37.9	37.3	75.2	547
Grant Village Lewis Lake	13.7	18.3	22.0	33.4	30.9	70.1	714

Old Faithful Weather Station

The median hourly sound levels from the soundscape monitoring site at Old Faithful Weather Station are shown in Figure 12 for the winter 2017-2018. The Old Faithful monitor was 230 feet (70 m) from the entrance/exit road used by oversnow vehicles. In a free-field, sound levels decrease by approximately 6 dBA for every doubling of the distance from a point source to the receiver. Therefore to compensate for the additional distance from the sound monitor using the reasonable assumption that, at least during the day, most of the maximum sound levels originate from OSVs traveling 230 feet (70 m) from the sound monitor, adding an additional 6 dBA to the maximum sound levels shown in the following figures would approximate the levels at 100 feet (30 m). This assumption is reasonable only for L_{max} because it is likely that lower sound levels commonly originate from areas other than the exit road such as the parking lot, the main road, and other sources near the sound monitor, and thus the source, distance, and therefore the correction factors, are unknown.

Because the loudest sounds have the most influence on L_{eq} values, OSV sounds largely determined the L_{eq} value during the day at Old Faithful. OSVs were often used outside the period covered by the WUP measurement periods, even in the middle of the night (Fig. 4), but other sources of sounds (people shouting, snow grooming, dogs barking, etc.) may have caused the maximum sound levels during the night. An unrecognizable crack/clap/sharp report was the loudest documented sound during the winter use season (08:17am, 21 December).

The lowest sound levels (about 15 dBA, Table 7) and the L_{90} were largely limited by the nearly constant utility sounds (exhaust and heating fans) from the Snow Lodge and Old Faithful Ranger Station (Fig. 11). In addition to displaying sound levels by hour, winter-long acoustic metric summaries are shown by date in Figure 13. The windiest days are obvious when the L_{90} values are high.

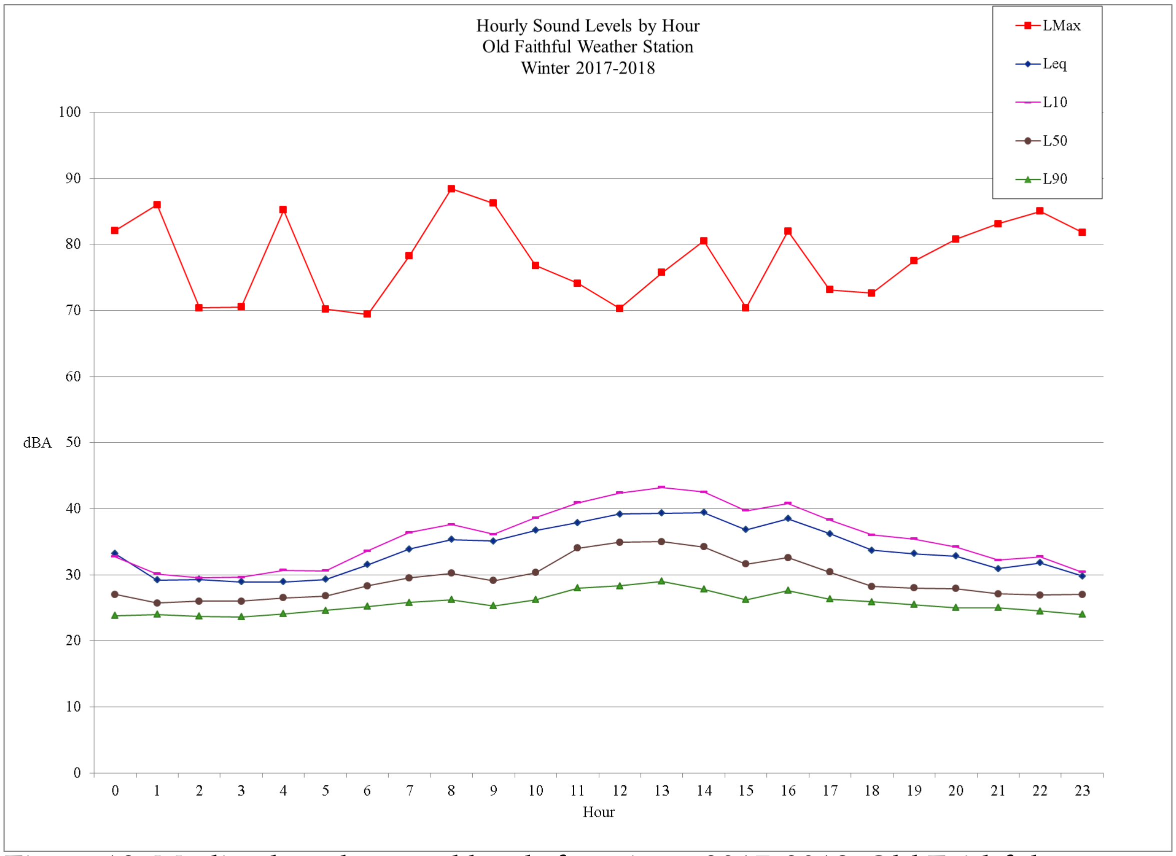

Figure 12. Median hourly sound levels for winter 2017-2018, Old Faithful Weather Station, YNP. These sound levels include all natural and non-natural sounds. L_{max} is the highest sound level measured during each hour of the winter use season. (n=2,174 hours).

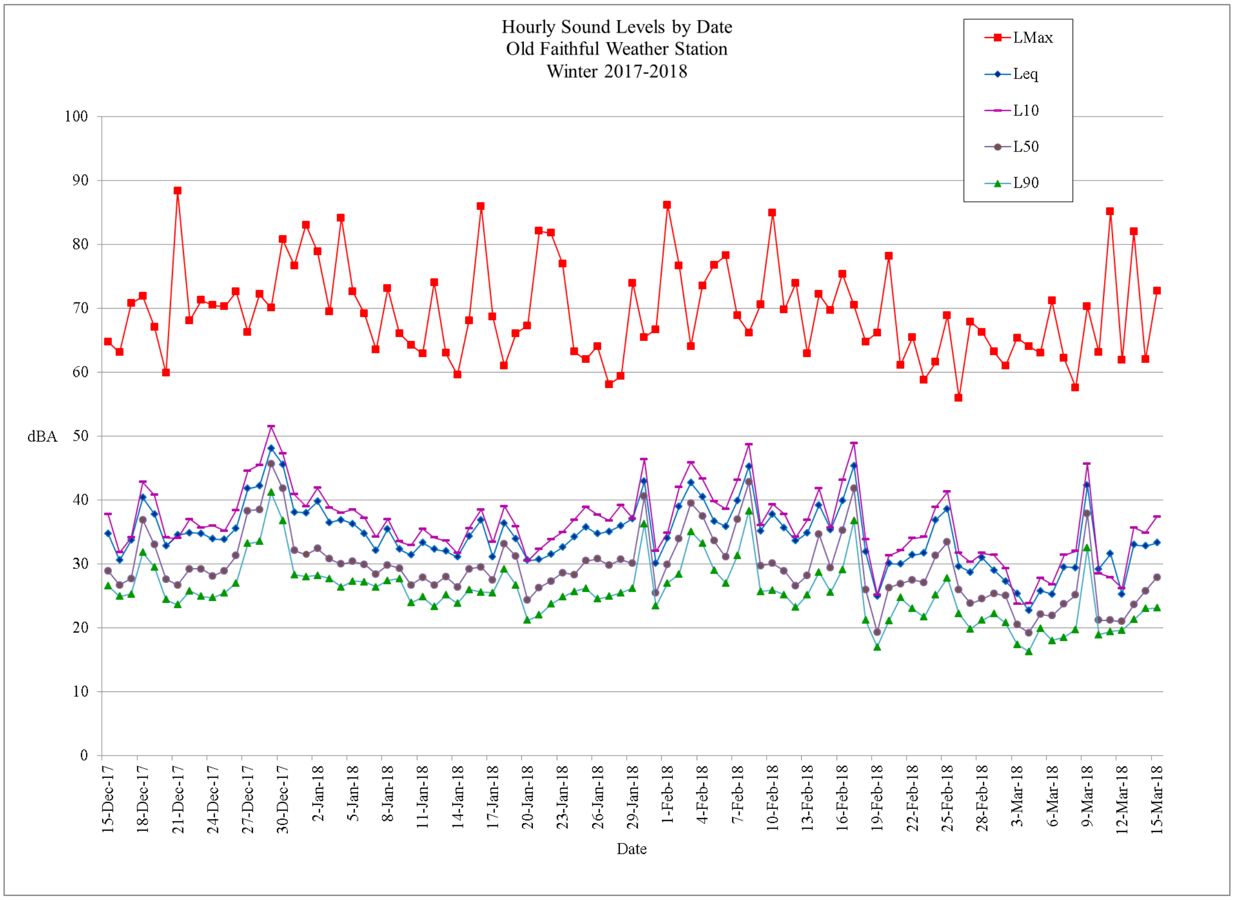

Figure 13. Median average daily (8 am – 4 pm) sound levels for winter 2017-2018, Old Faithful Weather Station, YNP. These sound levels include all natural and on-natural sounds. L_{max} is the highest sound level measured during each hour of the measurement period. (n=91 days).

Madison Junction 2.3

The median hourly L_{eq} (the average sound energy) roughly follows the predictable bimodal pattern with peaks mid-morning and late afternoon consistent with OSV traffic patterns (Fig. 14). The maximum sound levels (L_{max}) were generally caused by snow groomers at night and snowcoaches during the day. The lowest median hourly L_{90} values are constrained by riffles of the nearby Madison River (Fig. 14). Wind generally increases during the afternoons and is reflected in the median hourly L_{50} and L_{90} values (Fig. 14). An unrecognized large unmuffled oversnow vehicle was the loudest sound (10:31am, 13 February 2018).

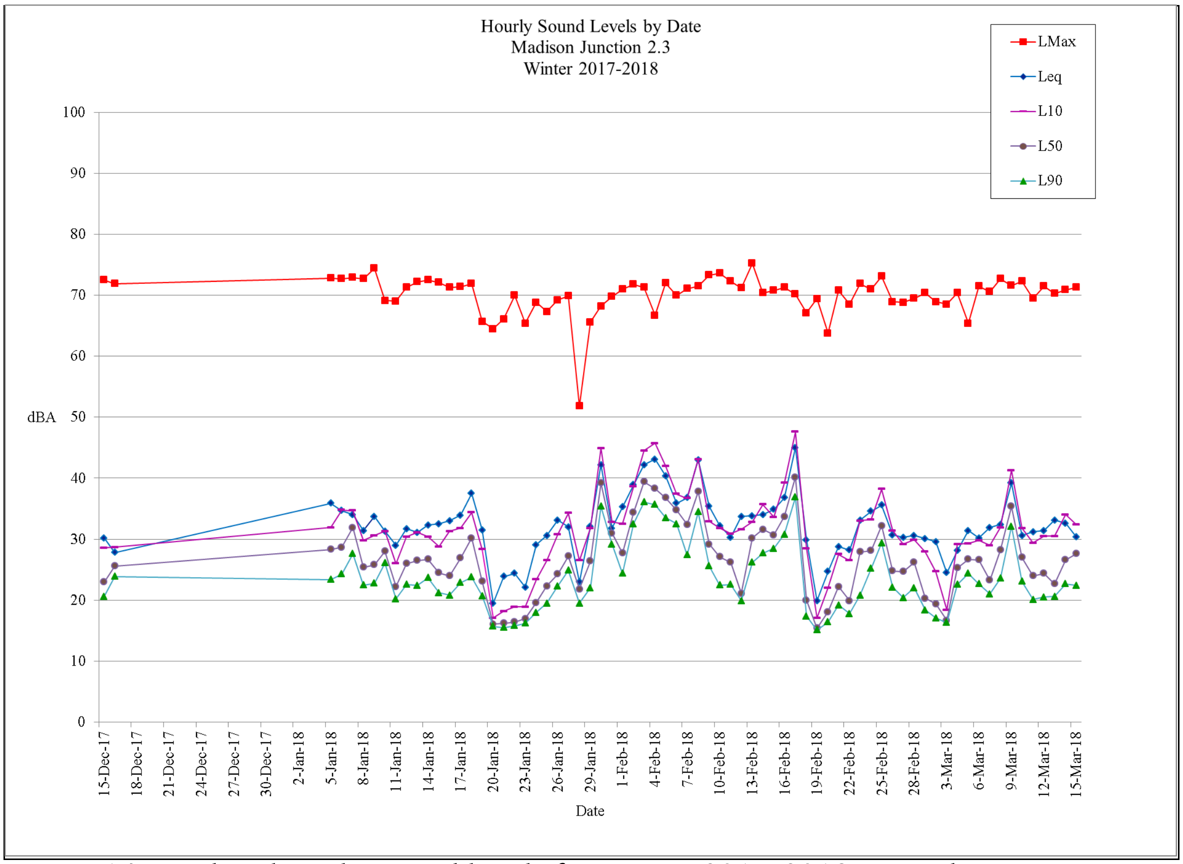

Figure 14. Median hourly sound levels for winter 2017-2018 at Madison Junction 2.3, YNP. See Fig. 11 caption for more details. (n=1,655 hours)

In addition to displaying sound levels by hour, winter-long acoustic metric summaries are shown by date in Figure 15 with the exception of 18 days in December with missing data. Especially windy days can be seen in the elevated L90 levels.

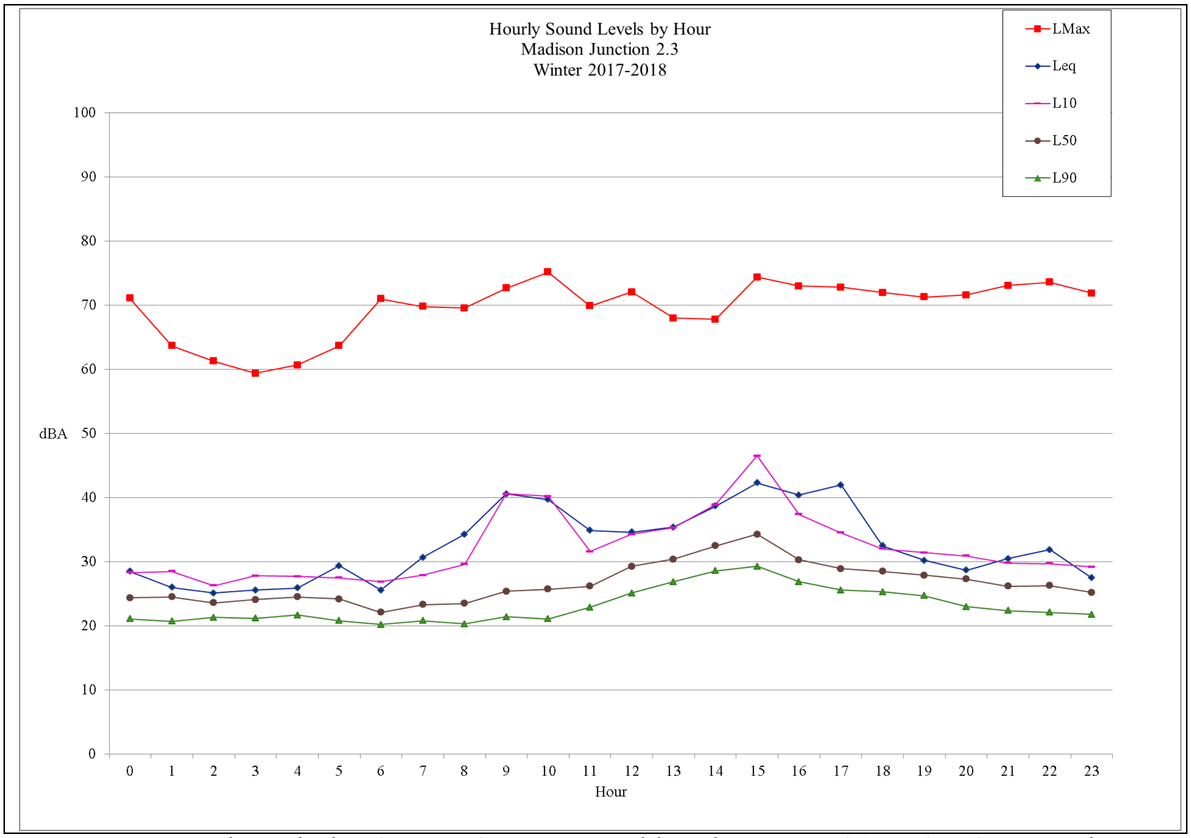

Figure 15. Median daily (8 am – 4 pm) sound levels winter 2017-2018 at Madison Junction 2.3, YNP. See Fig. 12 caption for more details. (n= 72 days)

Grant Village Lewis Lake

This sound monitoring site was 100 feet (30 m) from the groomed road between Grant Village and the South Entrance near Lewis Lake. Most of the loudest sounds at this site were OSVs traveling on the road, but the maximum sound level (70 dBA) was a group of snowmobiles (9:04am, 31 December 2017). The L_{eq} sound level during the day illustrates the typical bi-modal pattern for sites along the road corridor near the park entrances, and reflects the regular road snow groomer schedule between about 8 pm and 11 pm (Fig. 16). Aircraft sounds were sometimes present and at levels above the natural ambient. The very low sound levels were a result of no nearby human development or flowing water. Wind was often present, especially during the day, which elevated the ambient sound level.

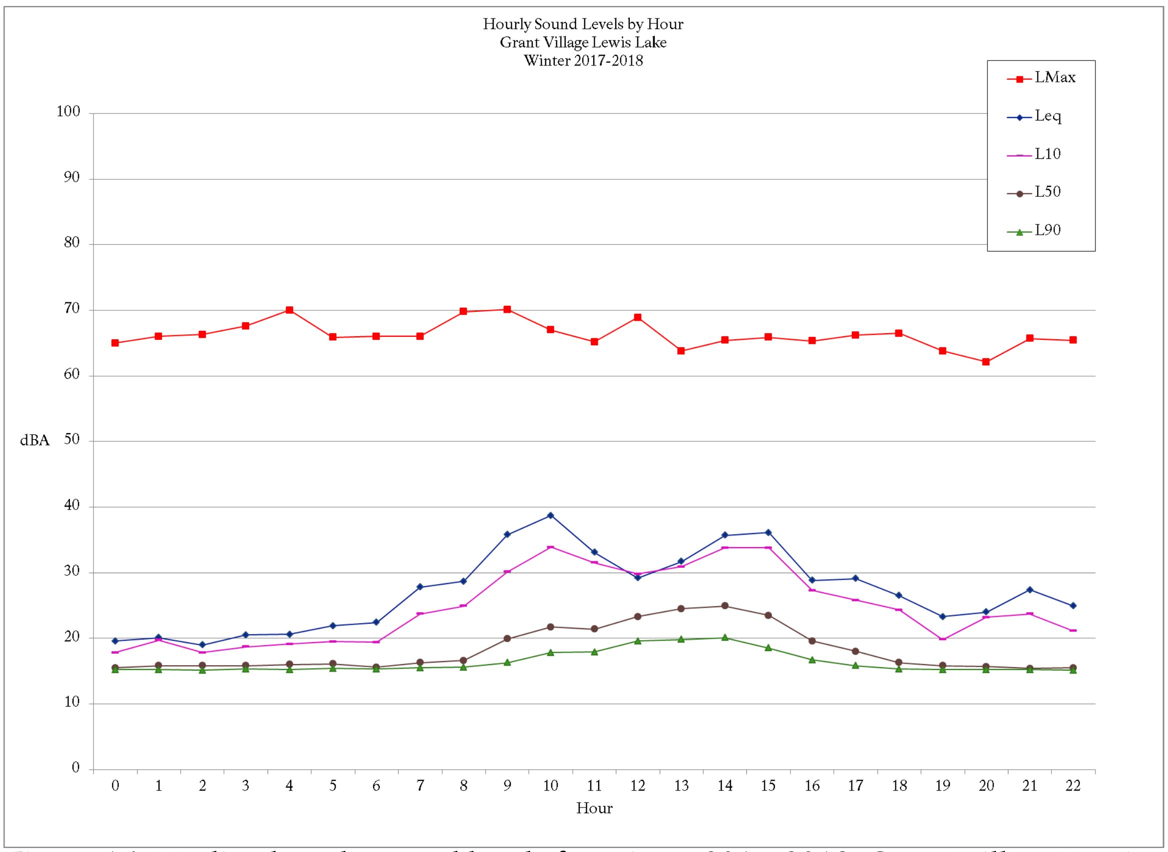

Figure 16. Median hourly sound levels for winter 2017-2018, Grant Village Lewis Lake YNP. See Fig. 11 caption for more details. (n=2,154 hours)

In addition to displaying sound levels by hour, winter-long acoustic metric summaries are shown by date in Figure 17. The days with high wind speeds, and thus elevated sound levels are shown by increased L90 values (Fig. 17).

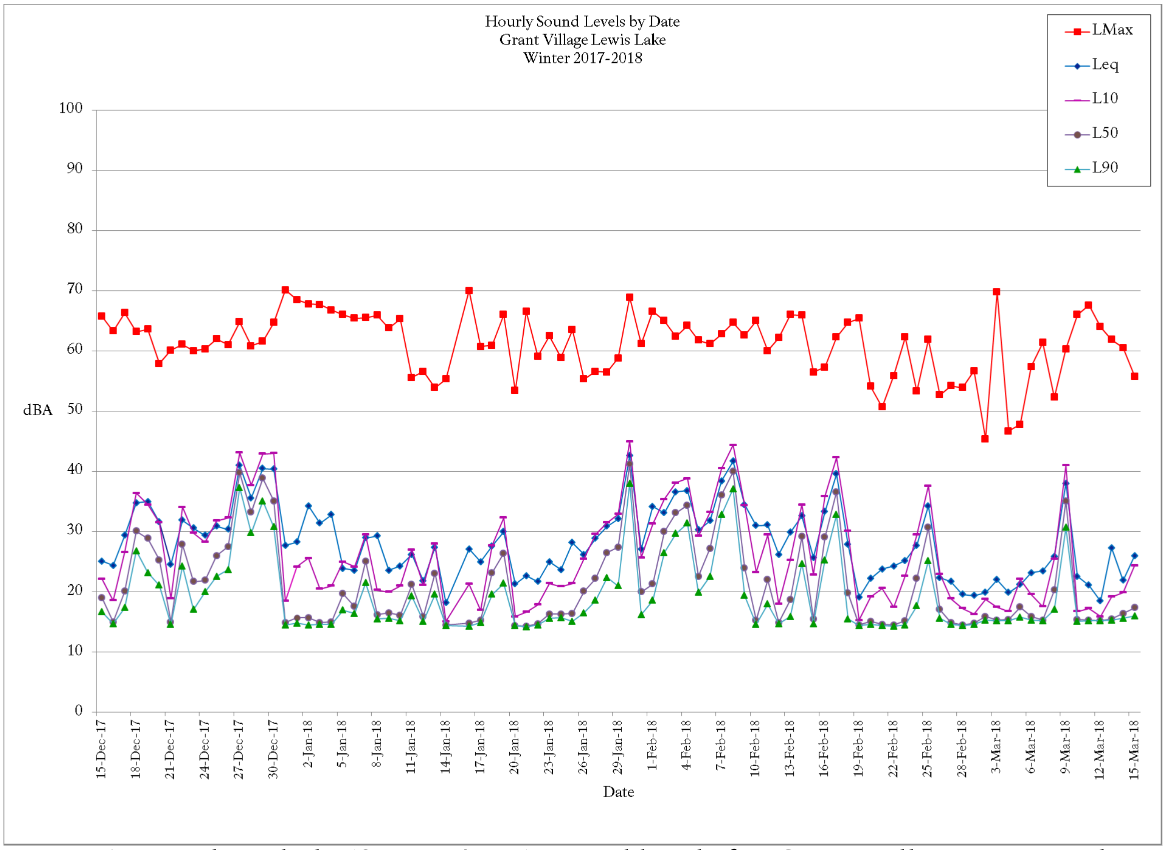

Figure 17. Median daily (8 am – 4 pm) sound levels for Grant Village Lewis Lake, winter 2017-2018, YNP. See Fig. 12 caption for more details. (n=90 days)

Sound Level Trends

This past winter's average median L_{10}, L_{50}, and L_{90} sound levels at the three current monitoring sites are plotted along with the equivalent data from past years for the time between 8 am and 4 pm (Figure 11a-c, next page). The winter's average daily oversnow vehicle numbers are plotted on each panel for comparative purposes.

Interpreting the results from these figures requires a little finesse and acceptance of uncertainty. The OSV numbers include all entrances and do not include administrative OSVs so may not represent the traffic passing each of these monitoring sites. Also, recall that the plotted sound levels include all sounds, not just those from OSVs. The highest sound levels can be caused by wind or people yelling (Old Faithful) or even a nearby raven or red squirrel, however, it is likely that the majority of the highest levels at all three sites are OSVs (with only groomers, mostly at night, consistently louder). Also, note that a 3 dBA decrease in sound level is a halving of sound energy, and a 10 dBA decrease is perceived as half as loud.

In the first panel of Figure 11 the L_{10} values illustrate the sound levels exceeded 10% of the time, or alternatively, 90% of the sound levels were below these values. Not surprisingly, Old Faithful's L_{10} levels were higher than Madison Junction 2.3s and both were higher than Grant Village Lewis Lake's reflecting the relative visitor use of these locations. The L_{10} values would not be expected to vary with the number of OSVs as long as the OSVs represented more than 10% of the highest sound levels. The L_{10} values would be expected to decrease with the removal of the loudest OSVs and with the overall quieting of the OSV fleet. This is occurring with the removal of the loud Bombardier snowcoaches, the increasing use of rubber tire snowcoaches and the use of quieter snowmobiles following the enhanced Best Available Technology option.

The L_{50} is the median sound level. OSV sounds are consistently audible for at least 50% of the time at Old Faithful Weather Station, and at least 50% of the time in some years at Madison Junction 2.3. Quieter snowcoaches would also be expected to influence L_{50} values in these locations (second panel of Figure 11). OSVs are would not influence L_{50} values at Grant Village Lewis Lake because they are not audible for 50% of the time.

The third panel of Figure 11 shows the trend in L_{90} (the level exceeded 90% of the time). At Old Faithful Weather Station the utility sounds from the Ranger Station and the exhaust vents from the Snow Lodge were constantly present. It is these sounds that largely determined the L90 levels. 2017 had unusually deep snow that may have caused a decrease in these utility sound levels at the monitoring location, but that doesn't fully explain the large 8 dBA increase this past winter. The L_{90} values at Madison Junction 2.3 have been variable over the years and are likely dependent on wind conditions and snow cover. The L_{90}s at Grant Village Lewis Lake are likely constrained by the instrument noise floor (the lowest measureable levels by the instrumentation) and the actual L_{90} values may be lower (third panel of (Figure 11).

Figure 11. Long-term median L_{10}, L_{50}, and L_{90} sound levels, 8 am to 4 pm, at two travel corridor and one developed area monitoring sites, and average daily number of oversnow vehicles of the winter use season by year, 2004-2018, YNP.

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Appendix A: Spectrograms of sound levels

The NPS developed a technique for plotting 33 one-third octave band frequency one-second L_{eq} levels for each hour of the day (ex. Fig. A-1). The major sources of sound at each monitoring location can be "seen" in these spectrographs. Viewing the pictures in color is preferable. Each figure is one day, 24 hours from midnight to midnight. Each row contains two hours starting with the first hours of the day, labeled with white two digit numbers. The sound frequency is plotted on a logarithmic scale as indicated in the left margin with high frequencies at the top and low frequencies at the bottom of each row. The right, or bottom, margin contains the decibel range and associated colors. Brighter colors indicate higher sound levels; deep blue is the quietest. Not only can specific sound sources be identified from these spectrographs, but patterns and the variability in number, timing, and sources of sounds can be seen. These spectrograms were made for every day at every site.

Figures A-1 to A-5 show example days from three monitoring sites. Determining the common sound sources signatures from the 1/3 octave band frequencies is not difficult, but takes a bit of experience. A brief introduction follows. Oversnow vehicle signatures are narrow orange-yellow marks that extend from high to low frequency, the first occurrence for the day at 0525 and the second at the more reasonable 0745 (Fig. 1-1). The louder sounds are brighter yellow as illustrated by a snow groomer at 1657 and 2215 (Fig. A-1). At 0104, 0856, 0859, 1254 and other times during the day, a jet appears as a low frequency blob. The sounds of riffles on the Madison River are shown as diffuse horizontal streaks most prominent starting at 1845 (Fig. A-1). A propeller plane can be seen at 1244 and 1441 shown as stacked curvy horizontal lines.

Building utility sounds and wind create the extensive and light yellow smears at Old Faithful Weather Station along with the sounds from OSVs and people's voices (Fig. A-2). The first snowmobile of the "day: was at 0123 and the second at 0230. A snow groomer was audible in the distance for 20 minutes after midnight (0000) and more loudly audible starting during the 1700 hour. A circling propeller plane was audible for several minutes around 1140.

Aircraft, OSVs, and wind are the main "visible" sounds at Grand Village Lewis Lake (Fig. A-3). The first two jets were audible at 0050 and less faintly at 0101, and louder ones throughout the day. The first OSV was at 0645. A snow groomer passed by at 1816 and 2152. Wind was audible throughout the day but most visibly during the 1400 and 1800 hours.

Figures A-4 and A-5 compare the sound levels during Saturday of Presidents Day Weekend at Madison Junction 2.3 during 2003 (1,679 snowmobiles during Saturday and Sunday) and 2018 (616 snowmobiles during Saturday and Sunday and an additional 88 snowcoaches). Although plotted using a different color scheme, one can see the yellow spikes of OSVs passing the monitoring site in 2003 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 A-1 for another example of OSV activity at this site during the most recent winter season.

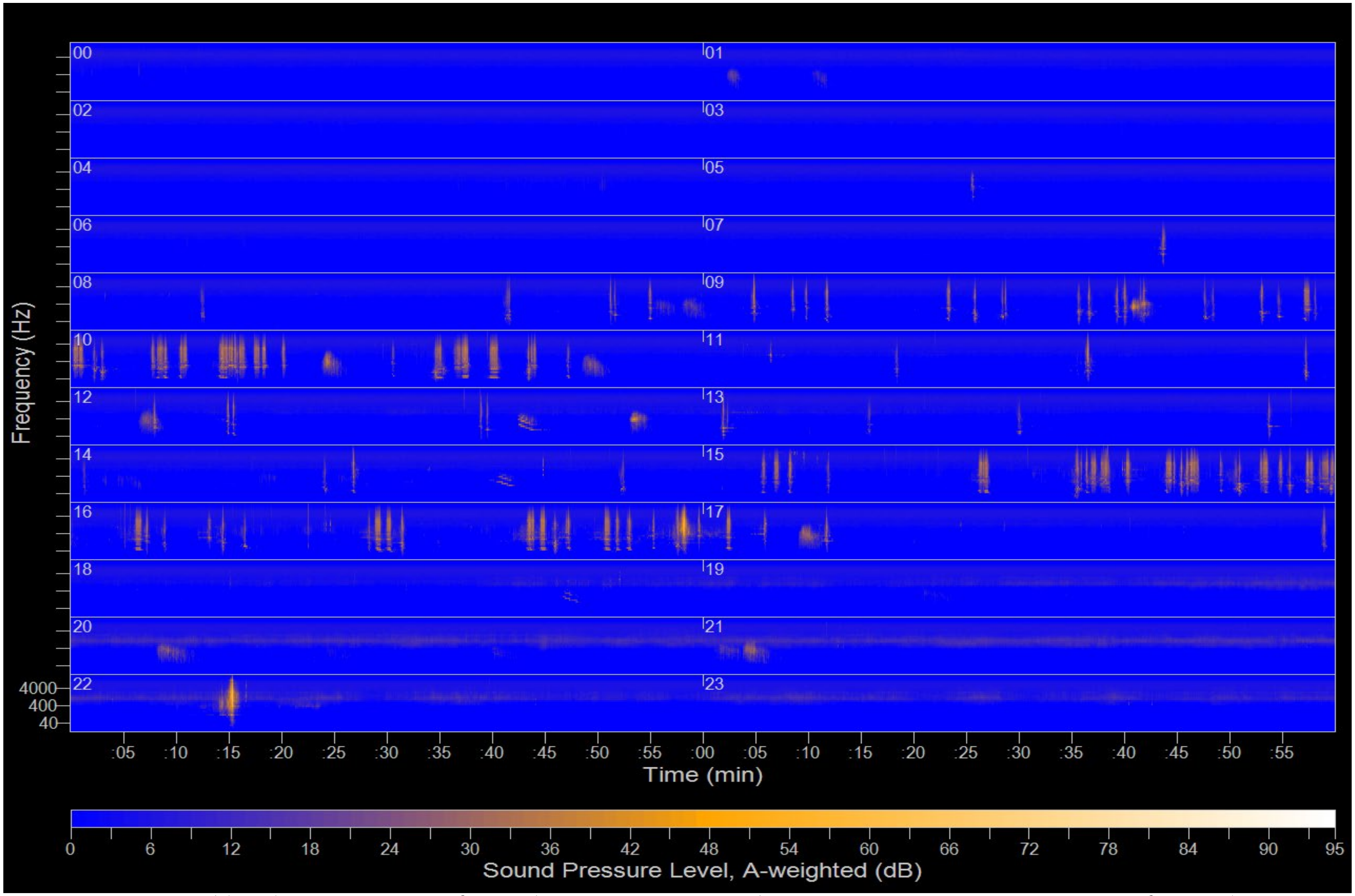

Figure A-1. Sound level spectrogram of 19 February 2018 at Madison Junction 2.3, YNP. See text for explanation.

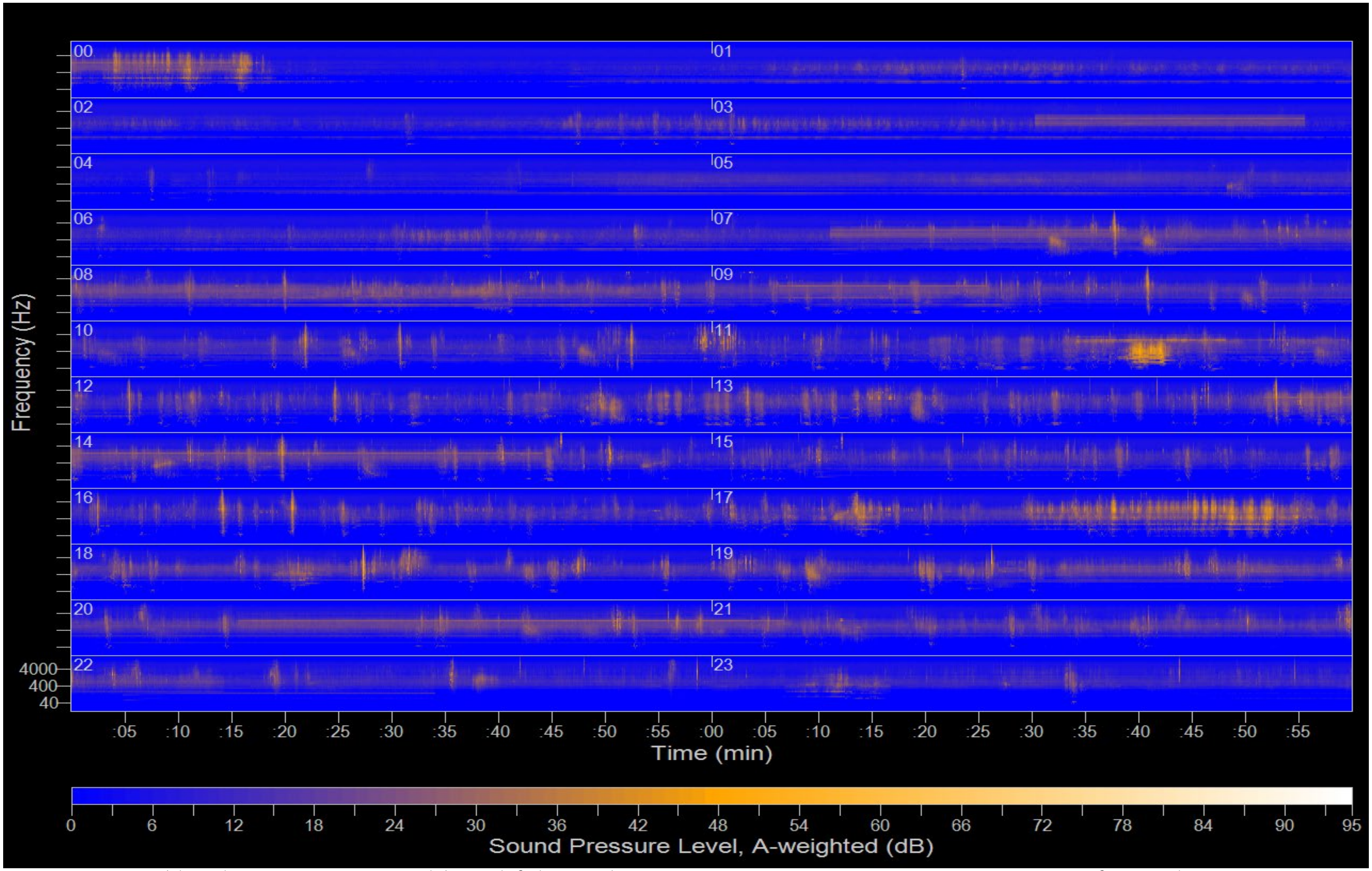

Fig A-2. Sound level spectrogram at Old Faithful Weather Station, 20 January 2018, YNP. See text for explanation.

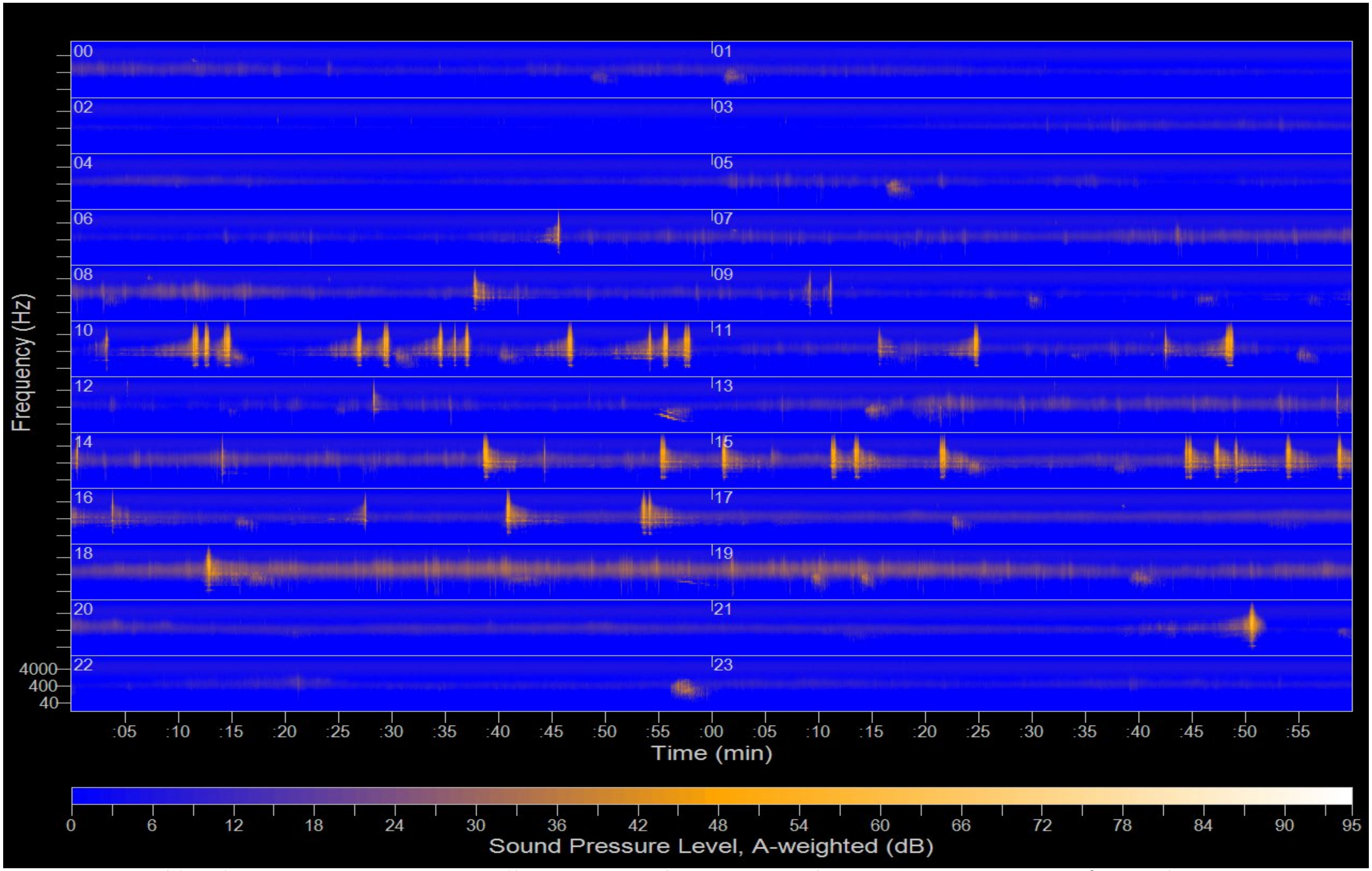

Fig A-3. Sound level spectrogram at Grant Village Lewis Lake, 15 December 2017, YNP. See text for explanation.

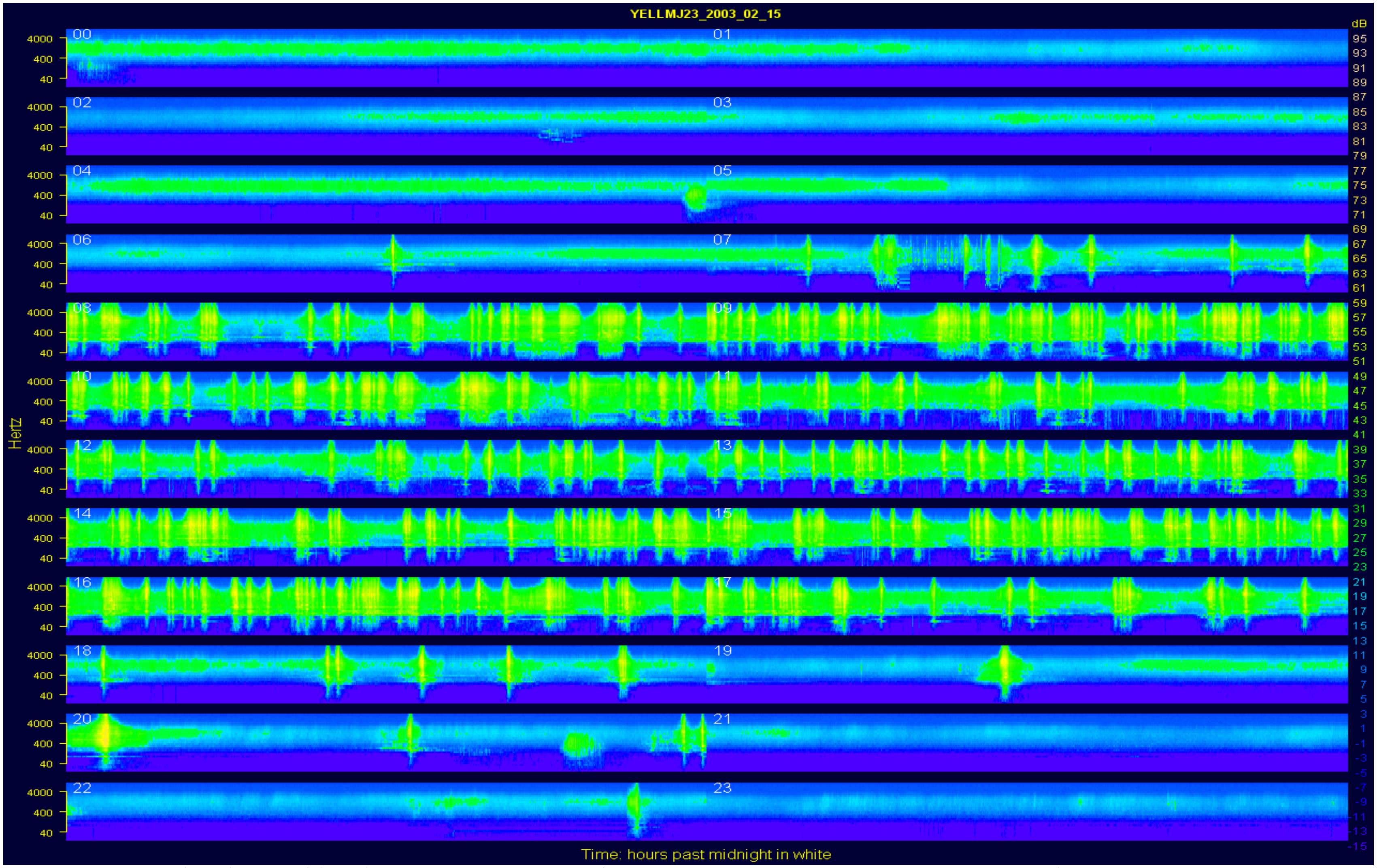

Fig A-4. A-weighted sound level spectrogram at Madison Junction 2.3 monitoring site, 15 February 2003, YNP. Compare to Fig. A-5 for number and timing of OSVs. See text for explanation.

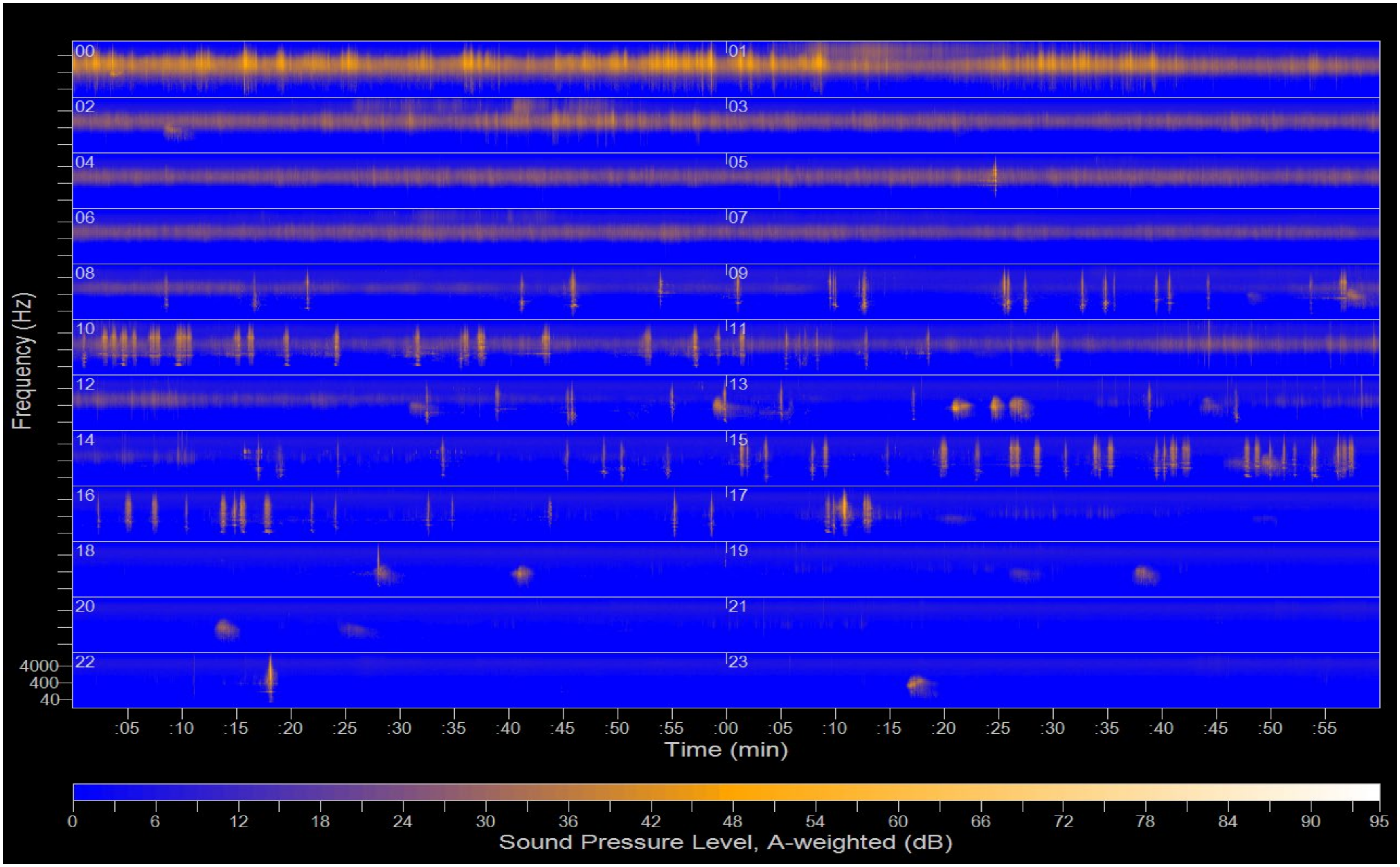

Fig A-5. A-weighted sound level spectrogram at Madison Junction 2.3 monitoring site, 18 February 2018, YNP. Compare to Fig. A-4 for number and timing of OSVs. See text for explanation.

Appendix B: Additional percent time audible considerations

As was discussed in the Results and Discussion section, the percent time OSVs were audible at any one point depended on several variables. For the winter use plans, audibility is measured by the percent of time between 8 am and 4 pm that OSVs were audible at a given point.

The longest term travel corridor monitoring site for this study has been Madison Junction 2.3 along the busiest travel corridor. For the winter season 2017-2018, OSVs were audible 47% of the 8-hour day. When the period of analysis is expanded to 7 am to 9 pm, the hours when the park is open to visitor OSV use, audibility fell to 37%. Audibility climbed to 76% during the busiest hour of the day, 9 am to 10 am, and was 23% during the noon hour. This pattern has been consistent during all the years of study. The average OSV audibility for all days analyzed of all travel corridor monitoring sites was 32% for 8 am to 4 pm. The time period and location of data collection can greatly influence the percent time audible results (Table B-1 and Table 5).

Table B-1: Oversnow audibility as a function of monitoring site and period of analysis, YNP, 15 December 2017-15 March 2018.

Site(s)	Period of Analysis	Audibility
Madison Junction	9 am to 10 am	76%
Madison Junction	noon to 1 pm	23%
Madison Junction	8 am to 4 pm	47%
Madison Junction	7 am to 9 pm	37%
All travel corridor monitoring sites in YNP all years	8 am to 4 pm	32%

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