Winter Acoustic Monitoring in Yellowstone National Park December 2014-March 2015

24 June 2015

Shan Burson/NPS Photo

Shan Burson
Yellowstone Center for Resources
Yellowstone National Park, WY 82190

and

Science and Resource Management
Grand Teton National Park
Moose, Wyoming 83012
(307) 739-3584

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 predominant in the park's backcountry and even in developed areas during the night. The natural soundscape 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.

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 2014-15 March 2015. This report includes, with few exceptions, only those sites sampled during the 2014-2015 winter. Results of data collected in the preceding twelve 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. Even though snowmobiles were restricted early and late season, except where otherwise indicated, the summary statistics shown in this report are for the full 91-day winter use season.

The oversnow vehicles' overall winter use audibility in the most heavily-used developed area, Old Faithful, averaged 49% (*SD*=17%).

Oversnow vehicles were audible for an overall average of 30% (*SD*=21%) of the day near Madison Junction along the busiest road corridor in the winter, between Old Faithful and the West Entrance. The six-winter average noise-free interval between 8 am and 4 pm was three

minutes and 42 seconds but substantially varied by time of day. The 2014-2015 winter average oversnow vehicle noise-free interval was also three minutes and 42 seconds.

Oversnow vehicles were audible for a winter use average of 28% (*SD*=10%) at Grant Village Lewis Lake monitor along the South Entrance Road just north of Lewis Lake. The noise-free interval averaged 11 minutes and 16 seconds. The average oversnow vehicle noise-free interval was 12 minutes and 2 seconds, but varied greatly by hour.

The audibility of oversnow vehicles at all three monitoring locations was lower than previous winters. The likely explanation is a combination of lower numbers of oversnow vehicles operating in the park, the early and late season poor road conditions that restricted snowmobiles and snowcoaches with skis, and the use of quieter rubber tires on a number of 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 and the Grant Village Lewis Lake monitoring sites and did occasionally at the Old Faithful Weather Station site. The majority of these higher sound levels were caused by old technology snowcoaches.

Consistent with acoustic data collected during the previous eleven 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, 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 rather than the total number of individual snowmobiles. The shortened season due to poor road conditions for oversnow vehicles with skis and the substitution of a number of much quieter rubber tired for tracked snowcoaches further reduced the sound level and audibility of oversnow vehicles.

Table of Contents:

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 (2004-2014) 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 2014 and 15 March 2015, 14,015 guided snowmobiles and 1,860 guided snowcoaches, totaling 15,875 oversnow vehicles, entered YNP (NPS unpublished data). The majority (13,980, 92.6%) of snowmobiles 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. These daytrips averaged about four snowmobiles and ten snowcoaches per day. These daytrips were not included in the number of OSVs given above and, unless otherwise indicated, elsewhere in this report. The average number of snowcoaches entering YNP during the winter season was 20/day (range 8-48). The average number of guided snowmobiles entering YNP during the winter season was 154/day (range 26-313).

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 2014-2015 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.

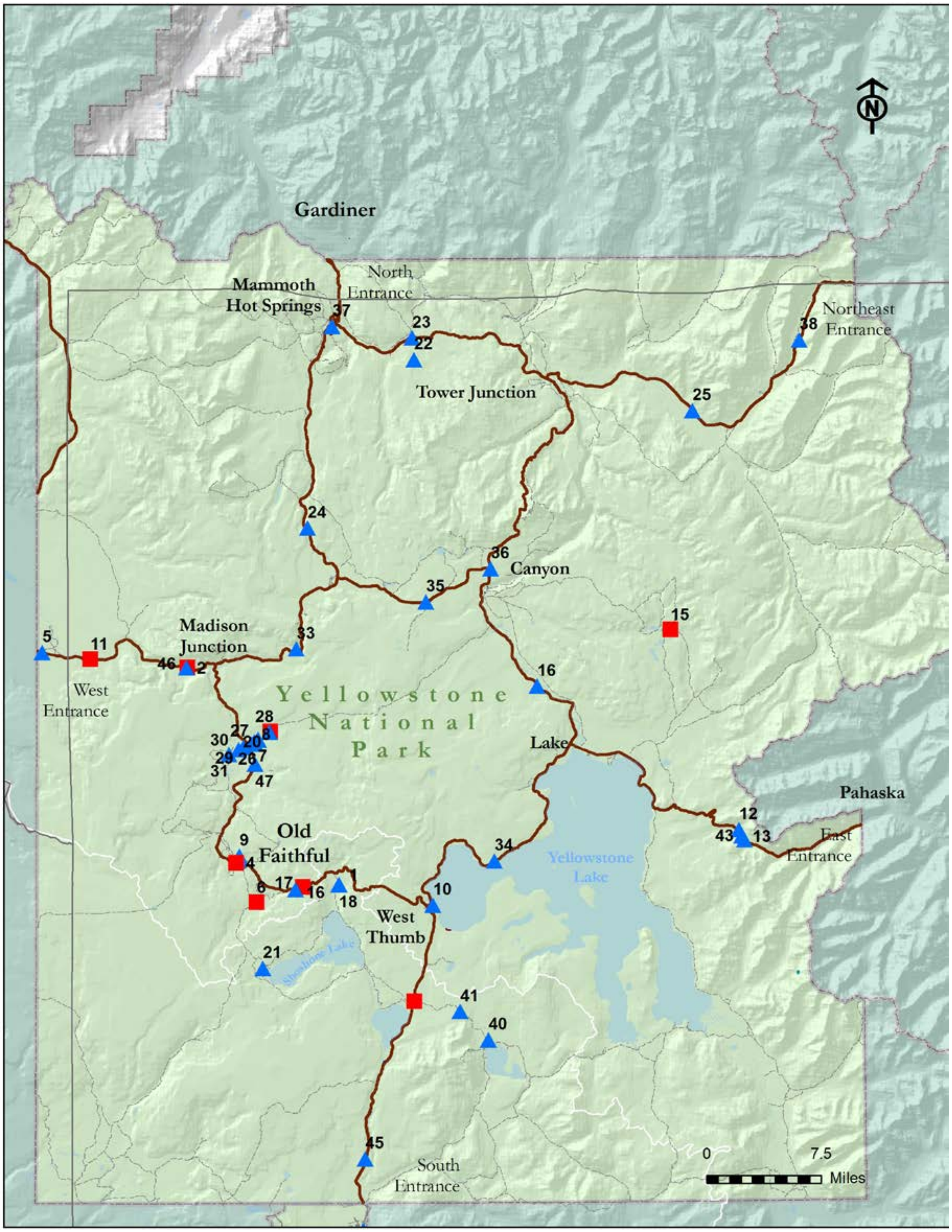

Figure 1. Locations of sound monitoring sites (blue triangles- winter only, and red squares- multiple seasons) within YNP, December 2003-March 2015. See associated table for year and labels (Table 1). Only the past winter's sampling locations are included in detail in this report (but see Burson [2004-2014] for previous winters' sampling results).

Table 1. Site name and years of sound monitoring locations within YNP, December 2003-March 2015. See associated map (Fig. 1) and labels.

Label	Site Name	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13	FY14	FY15
1	Delacy Creek	Y												
2	Madison Junction 2.3	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
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
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 (small post-burn lodgepole pines), 20% open (road, river)
Management Zone:	Travel Corridor

Photo 2. Madison Junction 2.3 sound monitor location.

The Madison Junction 2.3 monitor (in the center of the photo above in trees) was located 2.3 miles (3.7 km) west of Madison Junction, 100 feet (30 m) west of the West Entrance-Madison Junction Road within a large area of small (4 to 12 feet [1-4 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 2014 and continued throughout the winter use season (15 December 2014-15 March 2015). 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 fourth day was analyzed unless no data were available or a site visit fell on a day to be analyzed. In either case another day was randomly selected for substitution.

The recent 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 C). 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 twelve winter seasons, although the first winter consisted of only short-term data collection. This dataset provides information on trends, similarities among years and variability in time and location (Table 5). Soundscapes are highly variable over time, both in minutes and seasons. All attempts to summarize long-term datasets therefore fail to 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.

<u>Audibility</u>

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 40 hours collected the previous five winters for a total of 48 hours. 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).

<u>Sound levels</u>

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.

Appendix B provides preliminary acoustic analyses from a popular visitor destination site at Fountain Paint Pots. Data were collected at this site to evaluate the acoustic comparability of groups of snowmobiles to individual snowcoaches.

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

Results and Discussion:

Selected digital recordings (Tables 2 and 3) were chosen for analysis based on stratified sampling by site. All sound level data from each site was analyzed (Table 4).

Table 2. Dates used for audibility analyses at three locations in YNP, December 2014-March 2015. Daily average number of guided snowmobiles was 154/day[1] for the 91-day winter use season, excluding OSVs originating from Old Faithful. Average daily number of snowcoaches for the winter use season was 20/day. Total number of days analyzed, 93.

Grant Village Lewis Lake	Madison Junction 2.3	Old Faithful Weather Station
31 days	31 days	31 days
15 Dec 14	15 Dec 14	15 Dec 14
18 Dec 14	18 Dec 14	18 Dec 14
21 Dec 14	21 Dec 14	21 Dec 14
24 Dec 14	24 Dec 14	24 Dec 14
27 Dec 14	27 Dec 14	27 Dec 14
30 Dec 14	30 Dec 14	30 Dec 14
2 Jan 15	2 Jan 15	2 Jan 15
5 Jan 15	5 Jan 15	5 Jan 14
8 Jan 15	8 Jan 15	8 Jan 12
11 Jan 15	11 Jan 15	11 Jan 15
14 Jan 15	14 Jan 15	14 Jan 15
17 Jan 15	17 Jan 15	17 Jan 15
20 Jan 15	20 Jan 15	20 Jan 15
23 Jan 15	23 Jan 15	23 Jan 15
26 Jan 15	25 Jan 15	26 Jan 15
29 Jan 15	29 Jan 15	29 Jan 15
1 Feb 15	1 Feb 15	1 Feb 15
4 Feb 15	4 Feb 15	4 Feb 15
7 Feb 15	7 Feb 15	7 Feb 15
10 Feb 15	10 Feb 15	10 Feb 15
13 Feb 15	13 Feb 15	13 Feb 15
16 Feb 15	16 Feb 15	16 Feb 15
19 Feb 15	19 Feb 15	19 Feb 15
22 Feb 15	22 Feb 15	22 Feb 15
25 Feb 15	25 Feb 15	25 Feb 15
1 Mar 15	28 Feb 15	28 Feb 15
3 Mar 15	3 Mar 15	3 Mar 15
6 Mar 15	6 Mar 15	6 Mar 15
9 Mar 15	8 Mar 15	9 Mar 15
12 Mar 15	12 Mar 15	12 Mar 15
15 Mar 15	15 Mar 15	15 Mar 15

[1]Average number of snowmobiles was calculated using all snowmobiles entering Yellowstone. Not all snowmobiles would pass by each site and numbers varied by day. Administrative OSV use was not counted in these totals.

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, 56.

	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**	**1/12/15**
9 am	**1/4/10, 1/7/11, 1/19/12, 1/29/13, 2/15/14, 1/15/15**	**2/7/15**
10 am	**1/10/10, 2/4/11, 2/27/12, 1/20/13, 3/13/14, 1/22/15**	**2/8/15**
11 am	**1/15/10, 12/19/10, 1/28/12, 2/8/13, 2/14/14, 12/27/14**	**3/12/15**
12 pm	**1/30/10, 2/7/11, 12/27/11, 2/13/13, 12/23/13, 2/6/15**	**2/25/15**
1 pm	**2/5/10, 3/2/11, 2/2/12, 2/4/13, 2/1/14, 1/20/15**	**1/9/15**
2 pm	**2/10/10, 1/21/11, 2/24/12, 2/16/13, 12/15/13, 1/28/15**	**12/16/14**
3 pm	**2/20/10, 12/25/10, 1/18/12, 2/4/13, 1/28/14, 1/30/15**	**1/29/15**

Table 4. Dates used for sound level analyses at three locations in YNP, December 2014-March 2015. Total hours 6,128.

Old Faithful (1,774 hours) 15 December 2014-15 March 2015	Madison Junction 2.3 (2,176 hours) 15 December 2014-15 March 2015
Grant Village Lewis Lake (2,178 hours) 15 December 2014-15 March 2015	

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 were calculated using existing ambient conditions, that is, other non-natural sound sources could have been present and may have masked OSV sounds. This potential masking was only regularly present at developed areas. The only non-natural sounds other than OSVs 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 new 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.

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).

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.

Old Faithful Weather Station

Acoustic data were collected at this site for the twelfth 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, construction activities, and people's voices were frequently audible along with oversnow vehicles. Aircraft (a total of 2 helicopters, 17 propeller aircraft, and 65 jets in the analyzed sample) were audible for a daily (8 am and 4 pm) average of 2% during the winter use season.

For the winter use season the average daily percent time audible for snowmobiles and snowcoaches was 49% (*SD* = 17%) within the developed area at Old Faithful (Fig. 2). This compares to 60% (*SD*=8%) the previous winter and 55-69% during the eleven winter use seasons before that (Table 5). This year's much lower OSV audibility can be explained as follows. Because of inadequate snow cover snowmobiles and snowcoaches with skis were prohibited from using the road between West Yellowstone and Old Faithful early and late in the winter use season. This resulted in fewer OSVs entering the park during early and late season, as reflected in the audibility data (Fig. 2). In addition, some tracked snowcoaches were replaced with much quieter rubber tired snowcoaches (Fig. 2).

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 (Fig. 2). 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 were audible for 17% of the day versus 16% for snowcoaches (Fig. 3). OSVs were audible on average over 50% of the time during the busiest hours. 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.

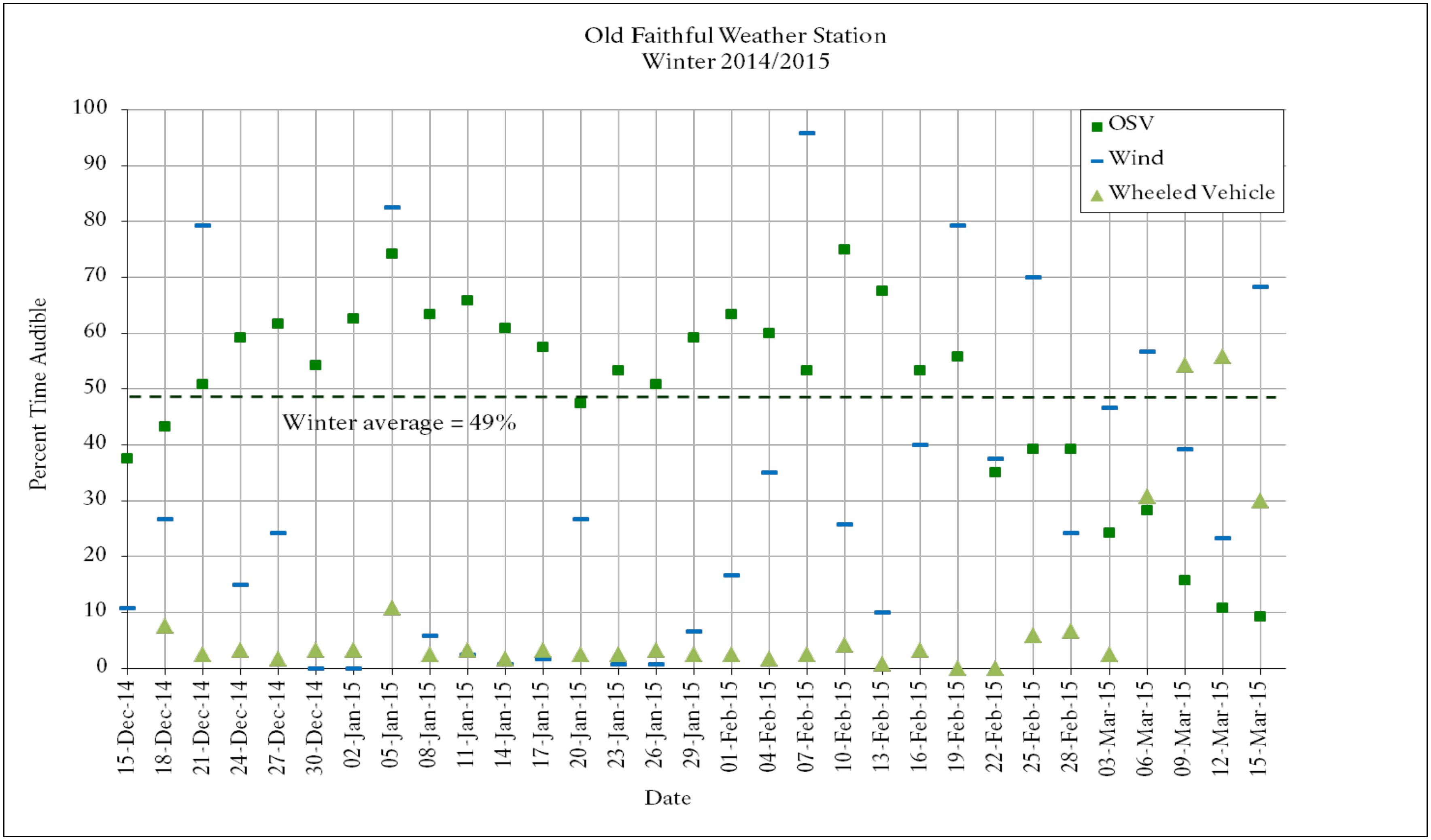

Figure 2. The percent time audible (8 am - 4 pm) for snowmobiles and snowcoaches, wheeled vehicles, and wind by date at Old Faithful Weather Station, YNP, 15 December 2014-15 March 2015.

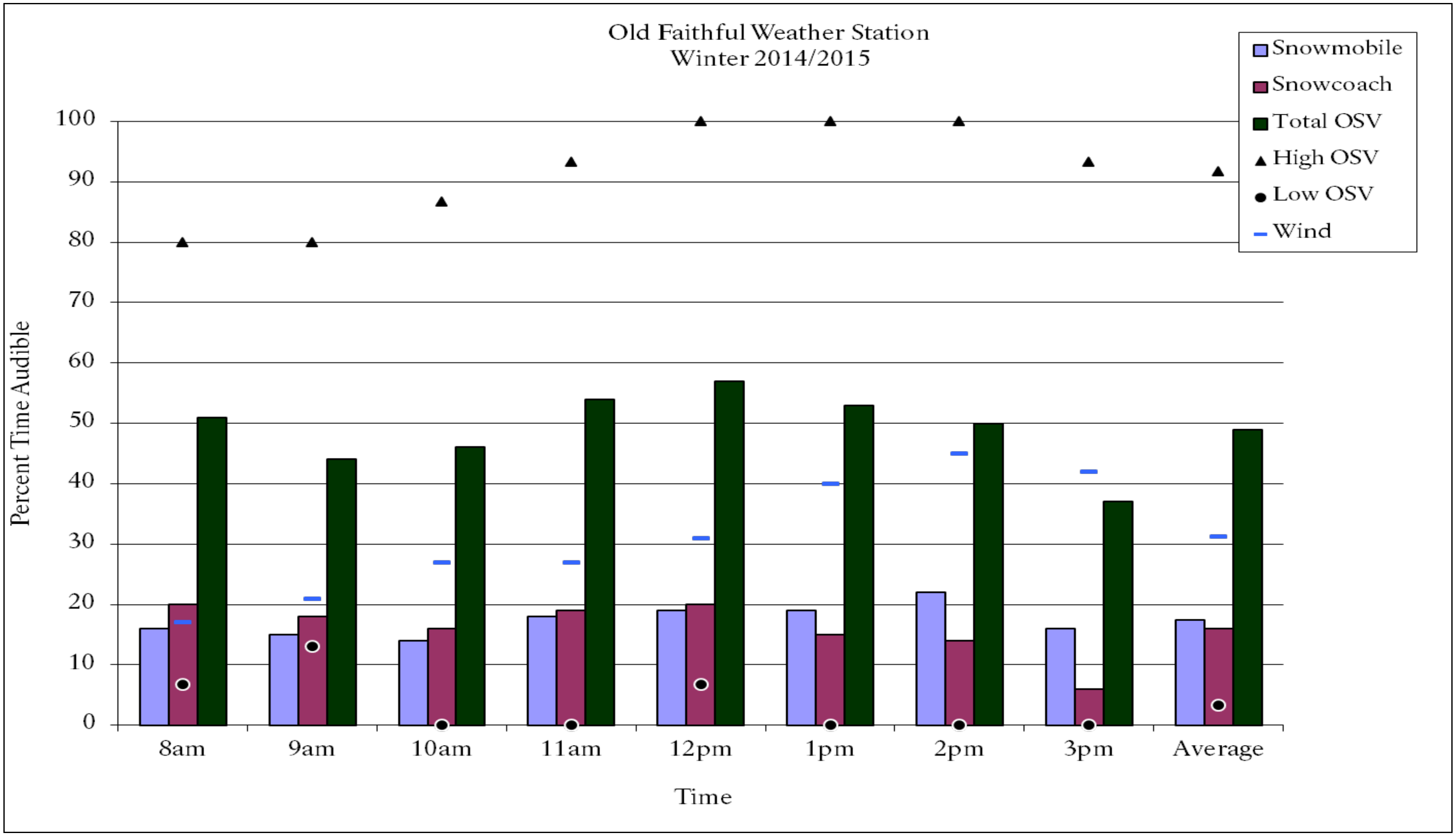

Figure 3. The season average percent time audible by hour of snowmobiles (left light blue bar), snowcoaches (middle maroon bar), wind, and a total OSV category including unidentified OSVs (right dark green bar), and the season's maximum and minimum OSV percent time audible values by hour at Old Faithful Weather Station, YNP from 8 am - 4 pm, 15 December 2014-15 March 2015.

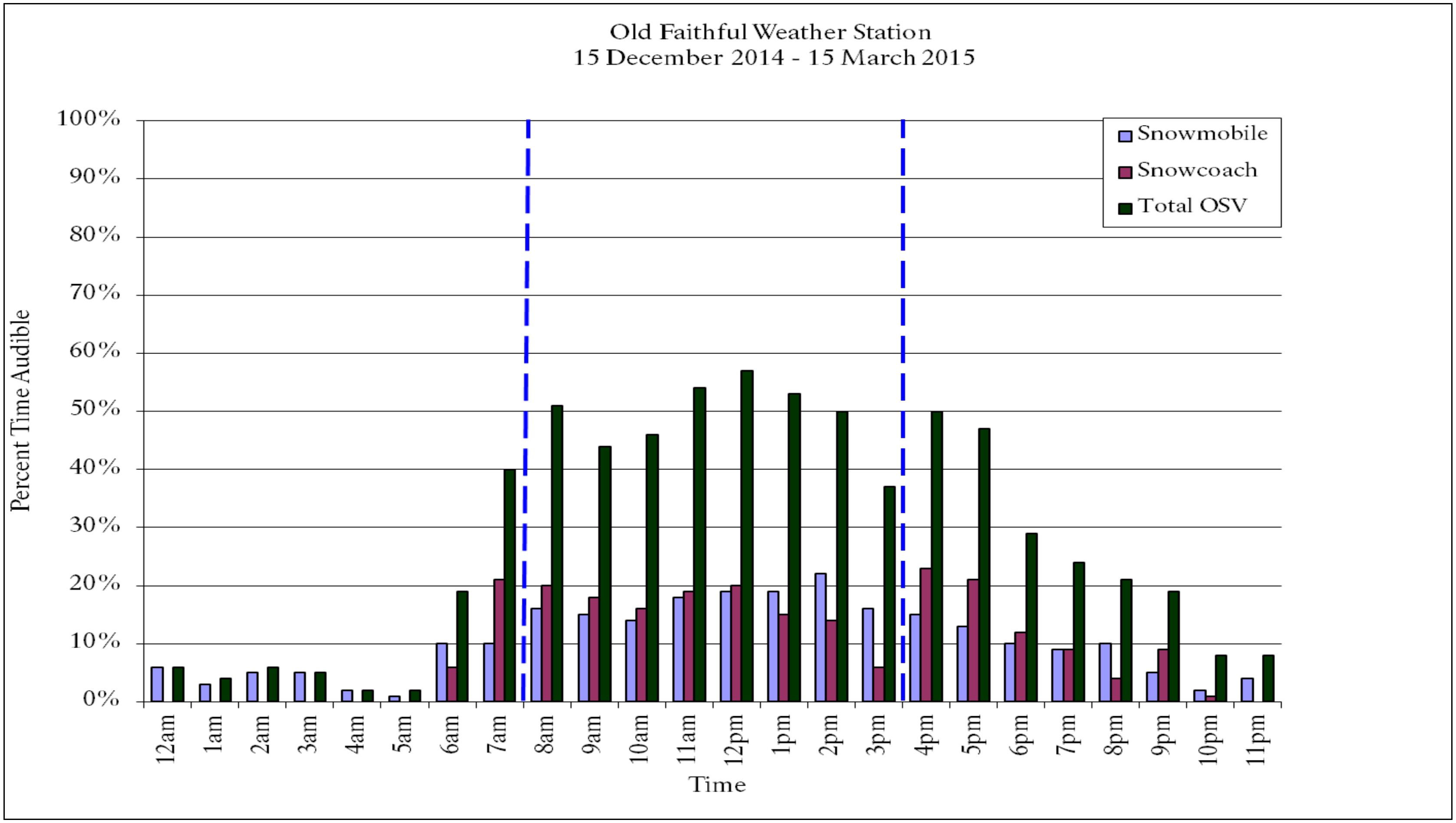

Figure 4. The percent time audible by hour of snowmobiles (left light blue bar), snowcoaches (middle maroon bar), and a total OSV category including unidentified OSVs (right dark green bar) at Old Faithful Weather Station, YNP, 15 December 2014 – 15 March 2015. The winter use analysis time period is 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 thirteen winter use seasons (Table 1) at this location. Riffles of the Madison River were audible during quiet periods. Wind was often audible as were swans, ducks, and geese on the river. Coyotes and wolves were more rarely heard, but squirrels and other birds were audible daily. Aircraft (a total of 5 helicopters, 9 propeller aircraft, and 129 jets in the analyzed sample) were audible for a daily (8 am and 4 pm) average of 4% during the winter use season.

Snowmobiles and snowcoaches were audible for an average of 30% (*SD*=21%) of the time during the winter use season (Fig. 5). The range during the previous nine full seasons was 47%-59% (Table 5). Similar to Old Faithful Weather Station results, this year's much lower OSV audibility can be explained as follows. Because of inadequate snow cover snowmobiles and snowcoaches with skis were prohibited from using the road between West Yellowstone and Old Faithful early and late in the winter use season. This resulted in fewer OSVs traveling to Old Faithful during early and late season, as reflected in the audibility data (Fig. 5). Quieter rubber tired snowcoaches were also used, especially late in the season (Fig. 5). OSV audibility was 45% during the period (24 December 2014 to 16 February 2015) with full OSV access (Fig. 5). Wind speed was associated with the audibility of OSVs at this site. OSVs were less audible on days with more wind due to the masking effect of wind on the distant and faint OSV sounds.

The hourly pattern follows a bimodal distribution (Fig. 6) documenting the pulse of OSVs passing 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 six winters combined, the average noise-free interval at Madison Junction 2.3 was three minutes and 42 seconds (Figure 7a) during 8 am to 4 pm. Noon had the longest average noise-free interval (just over 14 minutes) and longest maximum NFI (25 minutes), and 10 am had the shortest average NFI (36 seconds) and shortest maximum NFI (two minutes six seconds) during the winter use day. To measure the contribution of aircraft (the only other noise at this site) to the NFI, Fig. 7b that shows separately the noise-free interval for both oversnow vehicles (OSVNFI) and OSVs and aircraft (NFI) for the winter of 2014-2015. This noise-free interval analysis again reflects the pulse of OSVs traveling by the site during the morning and afternoon hours (Figure 7a).

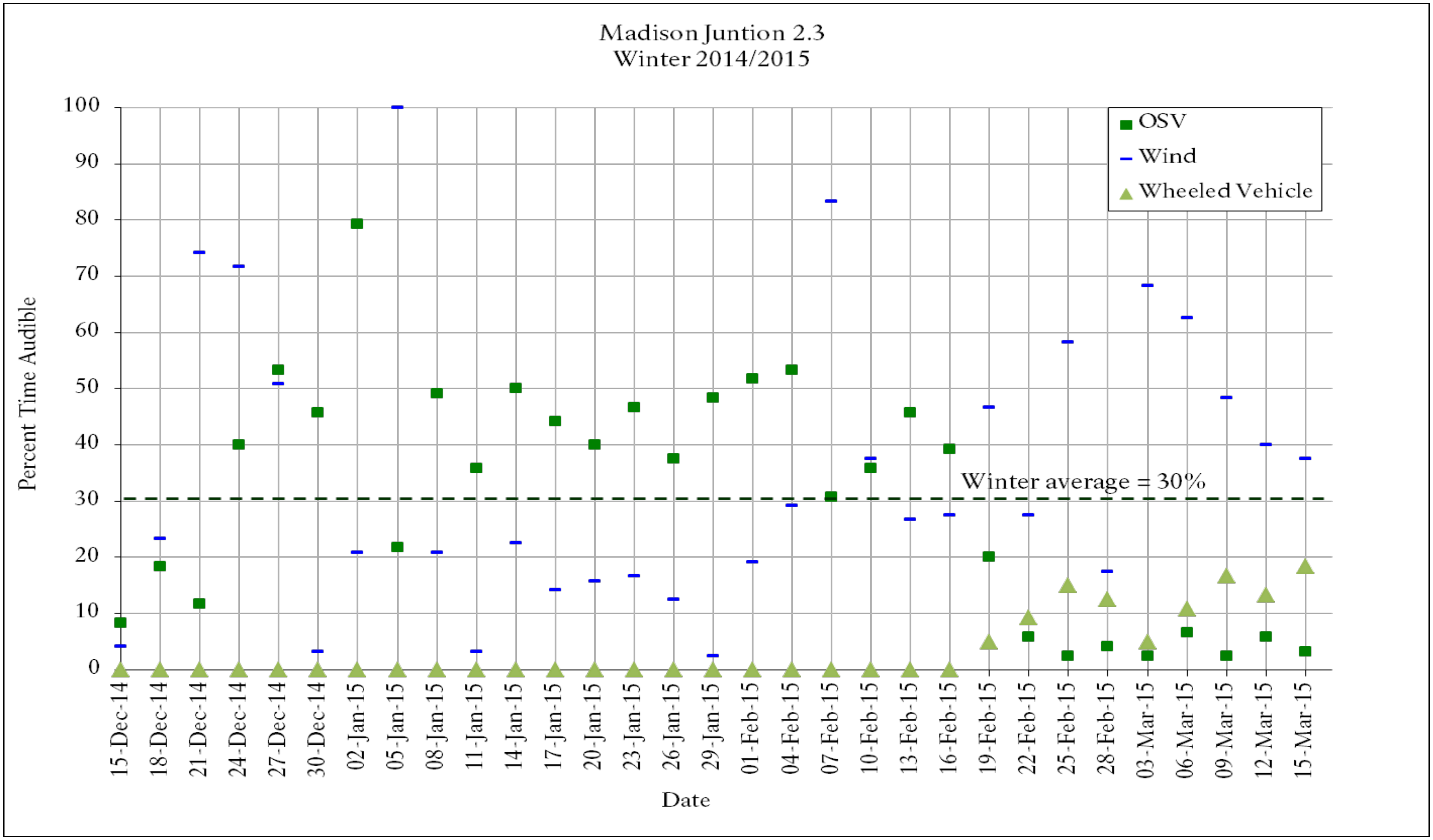

Figure 5. The average percent time audible (8 am - 4 pm) by date of snowmobiles and snowcoaches, wheeled vehicles, and wind at 2.3 miles 3.7 km) west of Madison Junction along the West Entrance Road YNP, 15 December 2014-15 March 2015.

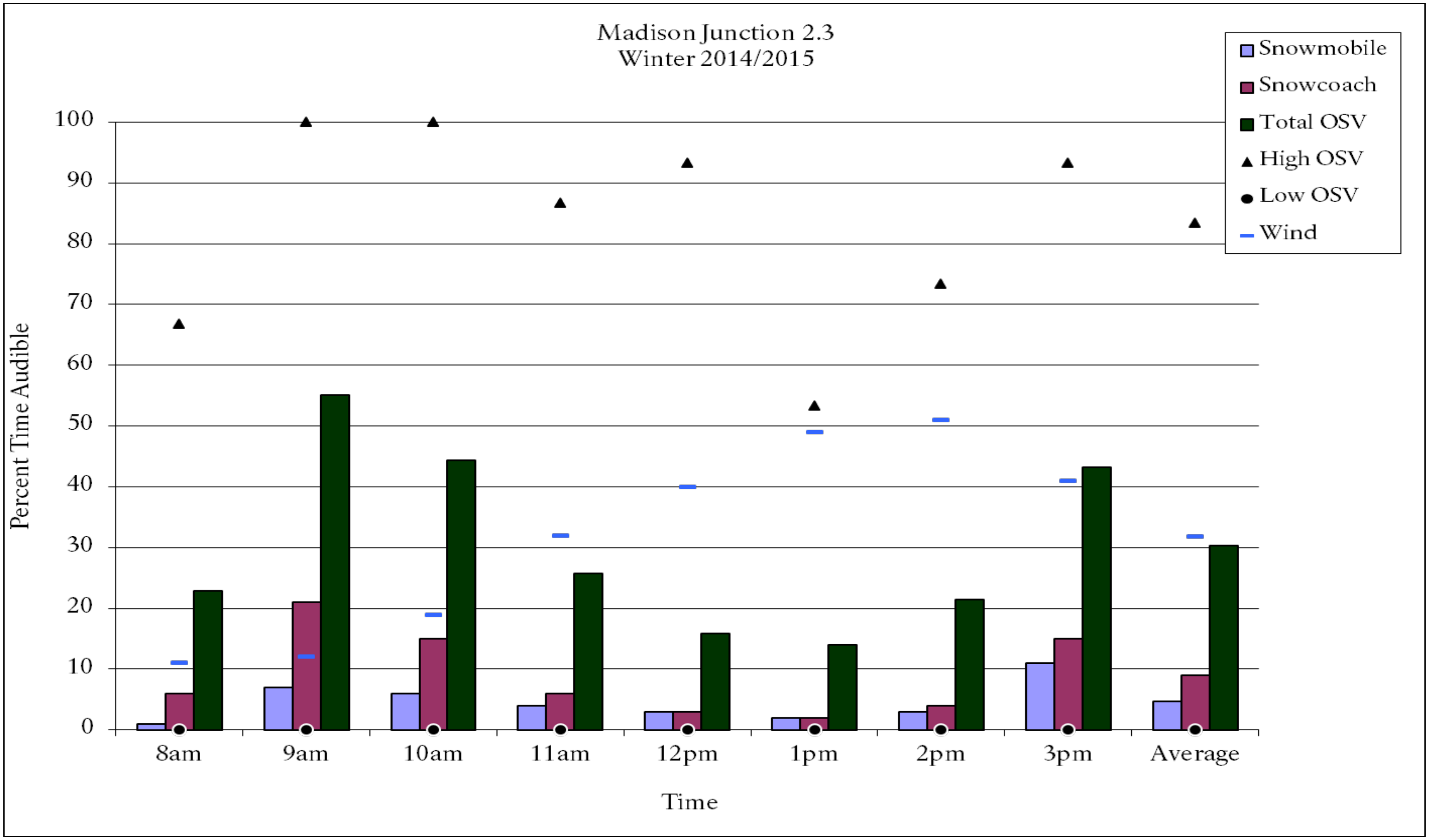

Figure 6. The average percent time audible by hour of snowmobiles and snowcoaches, and total OSVs including unidentified OSVs, wind, and the season's maximum and minimum OSV percent time audible values by hour at 2.3 miles (3.7 km) west of Madison Junction along the West Entrance Road, YNP, 15 December 2014-15 March 2015.

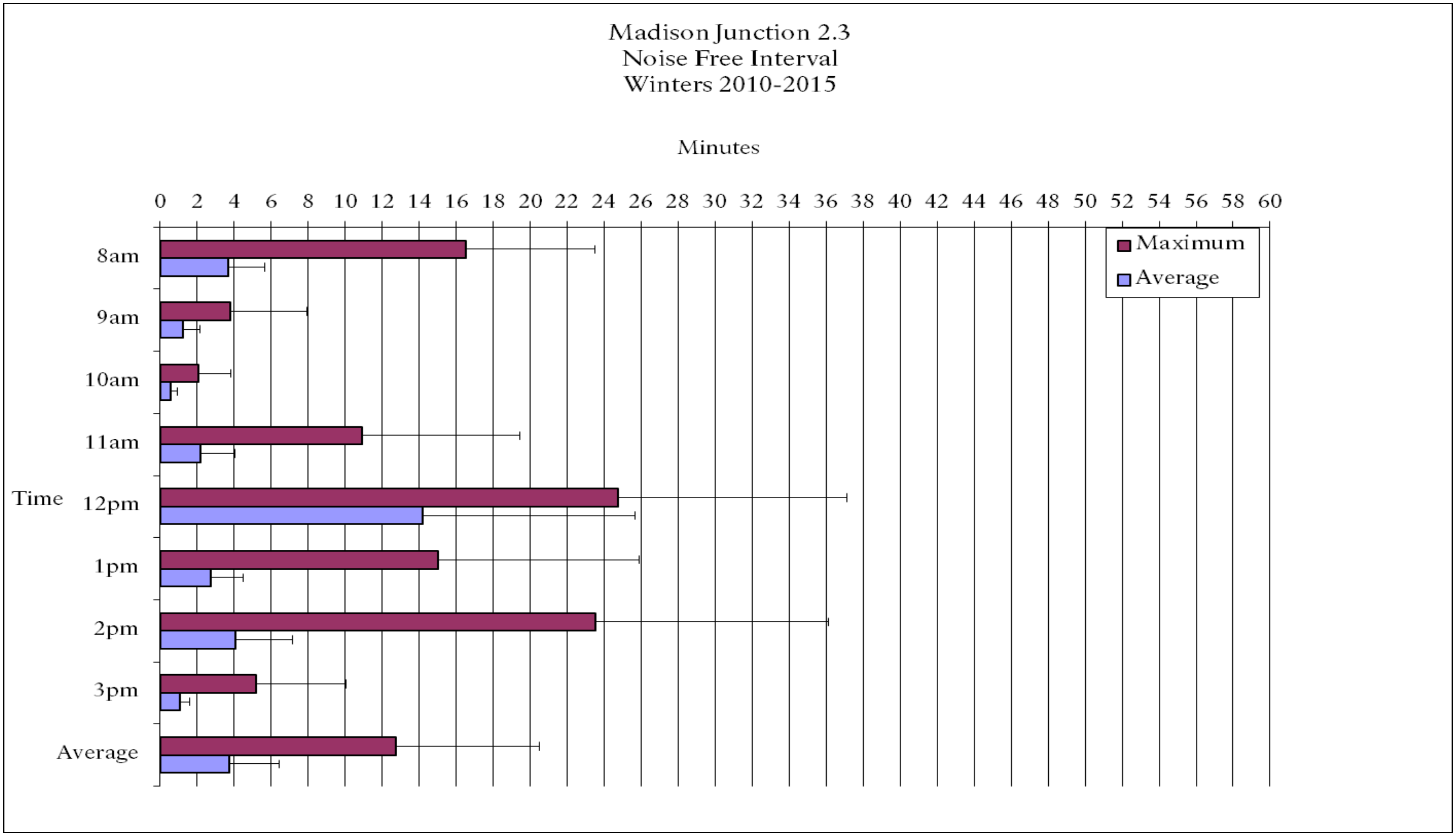

Figure 7a. Noise-free interval (and *SD*) measured at Madison Junction 2.3 during the six winters of 2010-2015, YNP. See Table 3 for dates used, and text for more details.

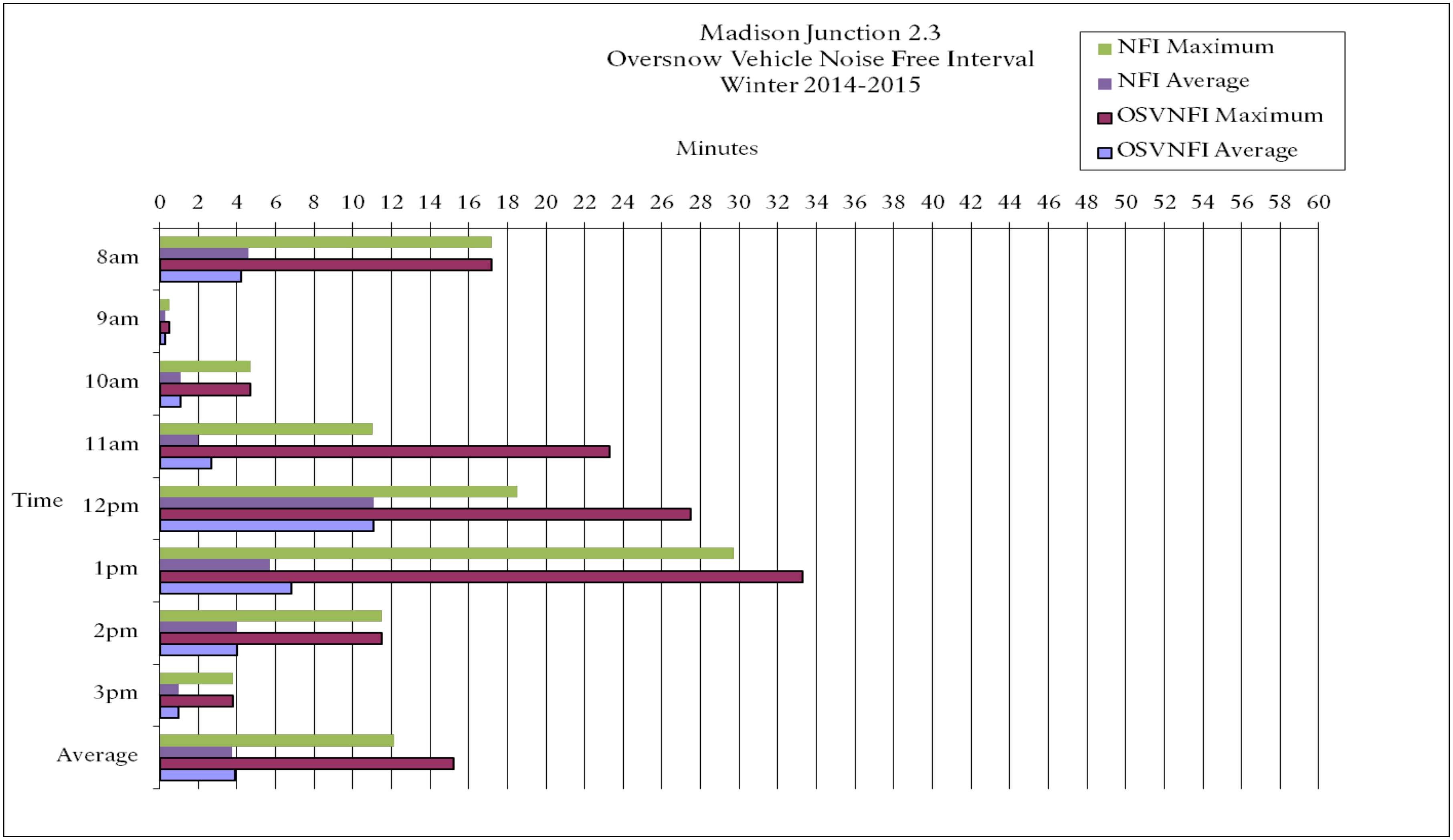

Figure 7b. Noise-free interval and oversnow vehicle noise free-interval at Madison Junction 2.3 during the winter of 2014-2015, YNP. See Table 3 for dates used, and text for more details.

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 similar monitoring occurred during the winter of 2007-2008. Woodpeckers, chickadees, nuthatches, ravens, and red squirrels were audible at this site. Wind was audible an average of 47% of the day (8 am to 4 pm) and an average of 19% of the day was silent with no sounds audible. Aircraft (a total of 16 propeller aircraft and 200 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*=10%) of the time between 8 am and 4 pm during the sampling period (Fig. 8). This compares to a daily average of 37% seven winters earlier, and 24% at last winter's sound monitoring site at South Entrance Roadside twelve miles to the south. A likely reason for this site's decrease is the use of several quieter snowcoaches with rubber tires and reduced numbers (8% lower than last winter and 25% lower than 2008) of oversnow vehicles.

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. 23). This allows faint distant OSVs to be audible.

The average noise-free interval (about 11 minutes) at Grant Village Lewis Lake is shown in Figure 10. To separate the contribution of only oversnow vehicles to the NFI, Figure 10 also shows the average oversnow vehicle noise-free interval (OSVNFI) at about 12 minutes. Additional samples would give a better representation of typical noise-free conditions because only one hour was analyzed for each of these eight hours (Table 3).

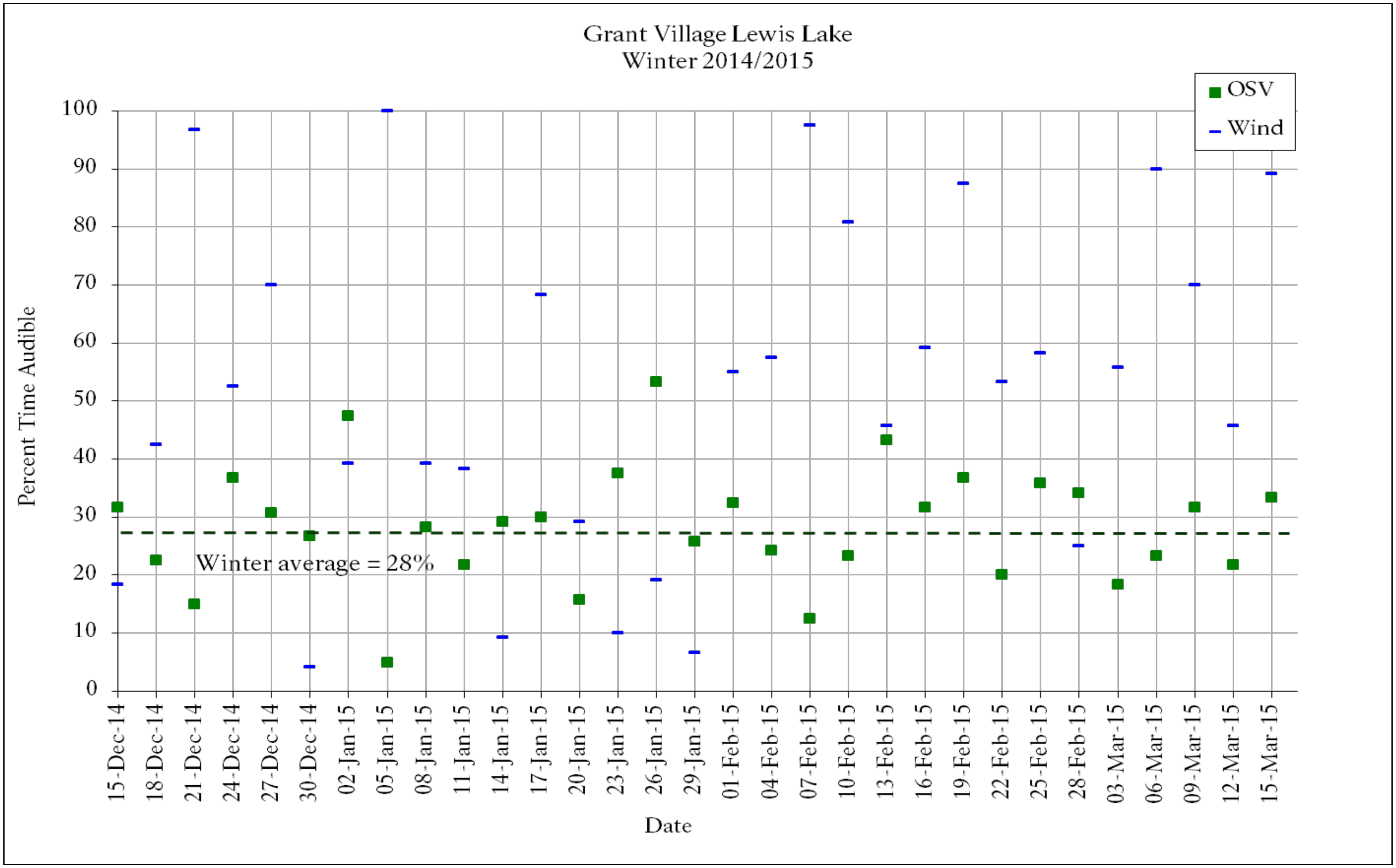

Figure 8. The average percent time audible (8 am - 4 pm) by date of oversnow vehicles, and wind at Grant Village Lewis Lake YNP, 15 December 2014 - 15 March 2015.

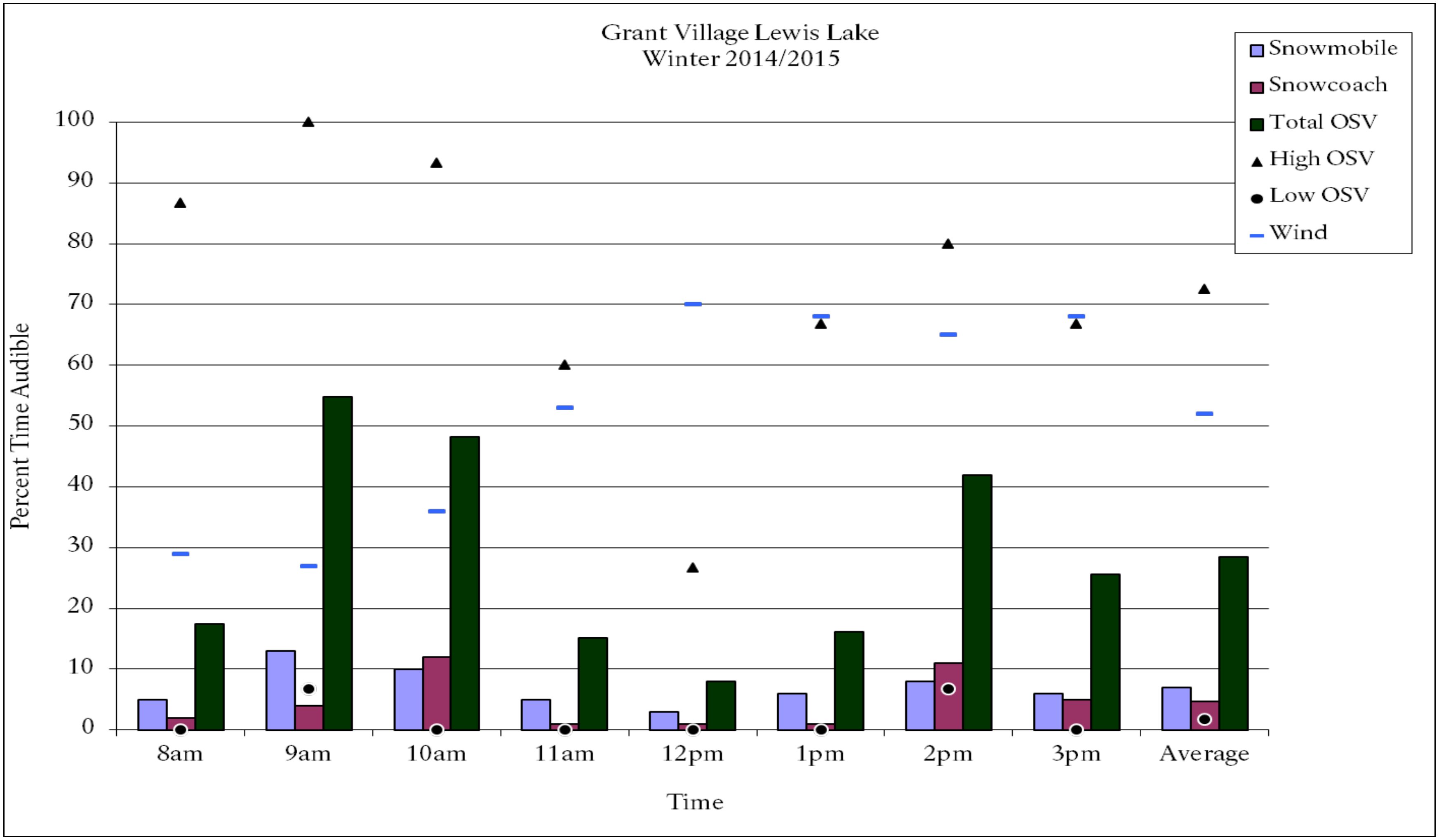

Figure 9. The average percent time audible by hour of snowmobiles, snowcoaches, wind, and the season's maximum and minimum OSV percent time audible values by hour at Grant Village Lewis Lake, YNP, 15 December 2014 - 15 March 2015.

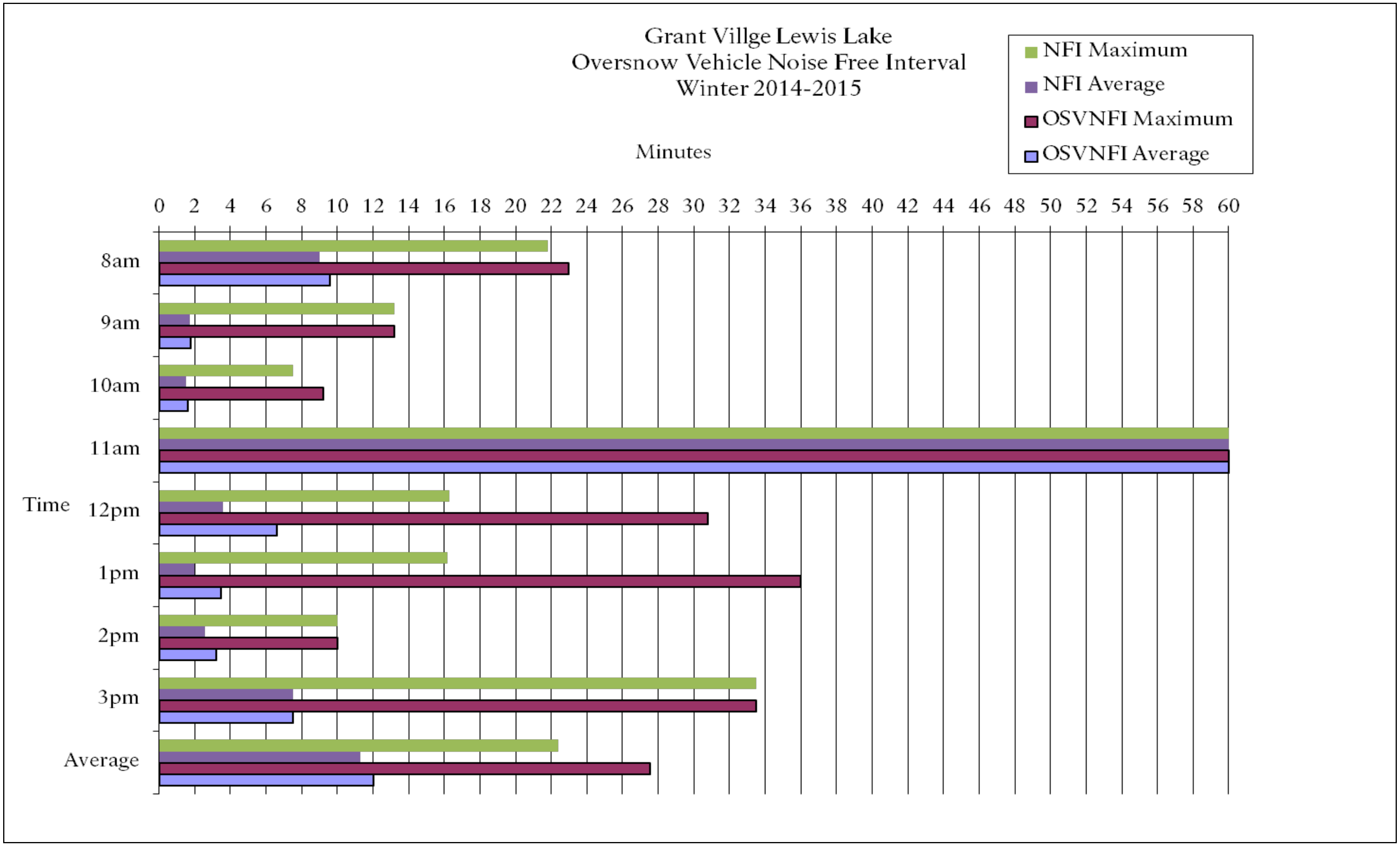

Figure 10. Noise-free interval and oversnow vehicle noise-free interval at Grant Village Lewis Lake during the winter of 2014-2015, YNP. See Table 3 for dates used and text for more details.

Audibility Trends:

Oversnow audibility is summarized for 21 locations in YNP during the past eleven 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.

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. 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 and 28% in 2015. 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 distance OSVs. And as previously discussed, fewer OSVs and quieter snowcoaches likely explains the decreased audibility over the two winters at GVLL. 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. Percent time audible (8 am - 4 pm) of OSV sounds at monitoring sites by management zone during the winters (2003-2015), YNP.

	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%								
Site Average	62%	39%	49%	55%	44%	44%	33%	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
2012-2013	185	28	229
2013-2014	195	28	233
2014-2015	154	20	188
Average	217	27	255

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 were estimated

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 over 50% of the day at Madison Junction 2.3 and Grant Village sites, but not the developed areas 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 YNP are below this noise floor (Burson 2006) so the lowest documented measurements in this report likely overestimate the actual minimum sound levels. While there is no easy solution to these limitations, the disadvantages of any one metric can be reduced by using multiple sound level metrics.

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

Table 6. Approximate decibel levels of commonly known sound sources. Note that decibels are logarithmic and a difference of 10 decibels is sometimes described as a doubling 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		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	

2014-2015 Sound Metrics by Monitoring Site

A number of sound level metrics at the three sound monitoring sites during the winter season 2014-2015 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 2014-2015. 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	20.6	27.8	32.4	39.2	42.1	74.5	585
Travel Corridor							
Madison Junction 2.3	16.0	26.8	31.0	39.2	37.0	80.9	720
Grant Village Lewis Lake	14.0	17.6	22.0	42.1	32.9	79.1	722

Old Faithful Weather Station

The median hourly sound levels from the soundscape monitoring site at Old Faithful Weather Station are shown in Figure 11 for the winter 2014-2015. 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, 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.

The lowest sound levels (about 21 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 12. Equipment malfunction caused a loss of data at the end of January and beginning of February.

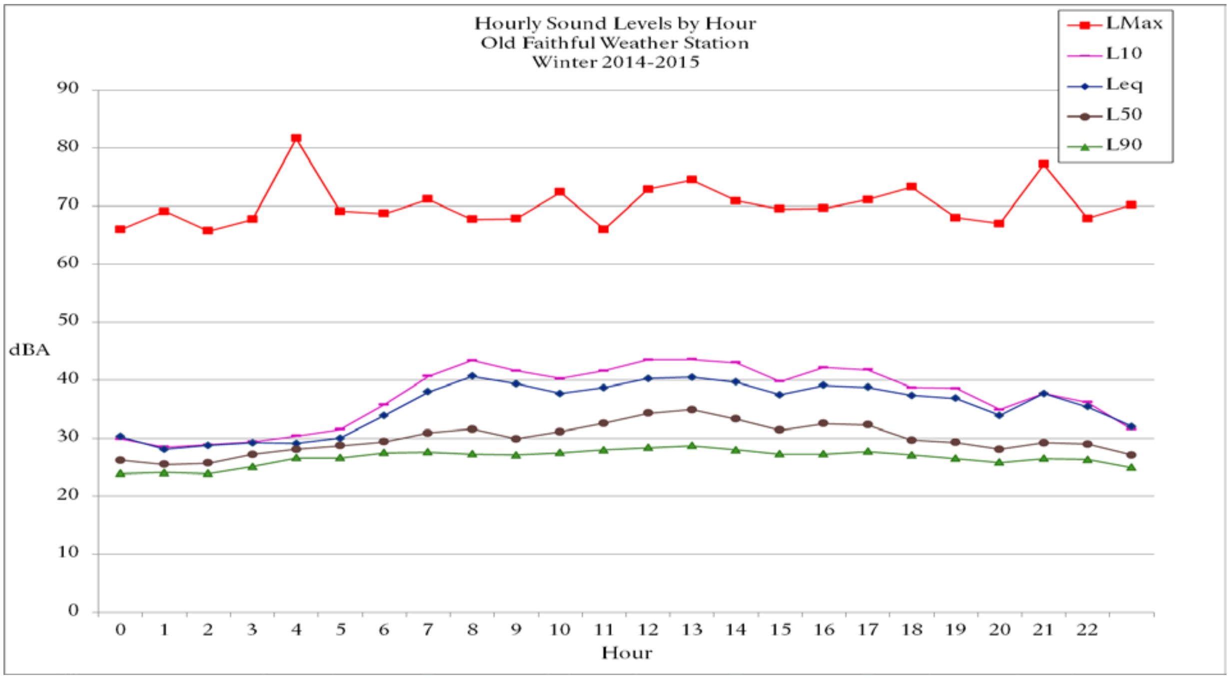

Figure 11. Median hourly sound levels for winter 2014-2015, Old Faithful Weather Station, YNP. These sound levels include all natural and non-natural sounds. L_{max} is the highest sound level measured during each hour of the winter use season. (n=1,774 hours).

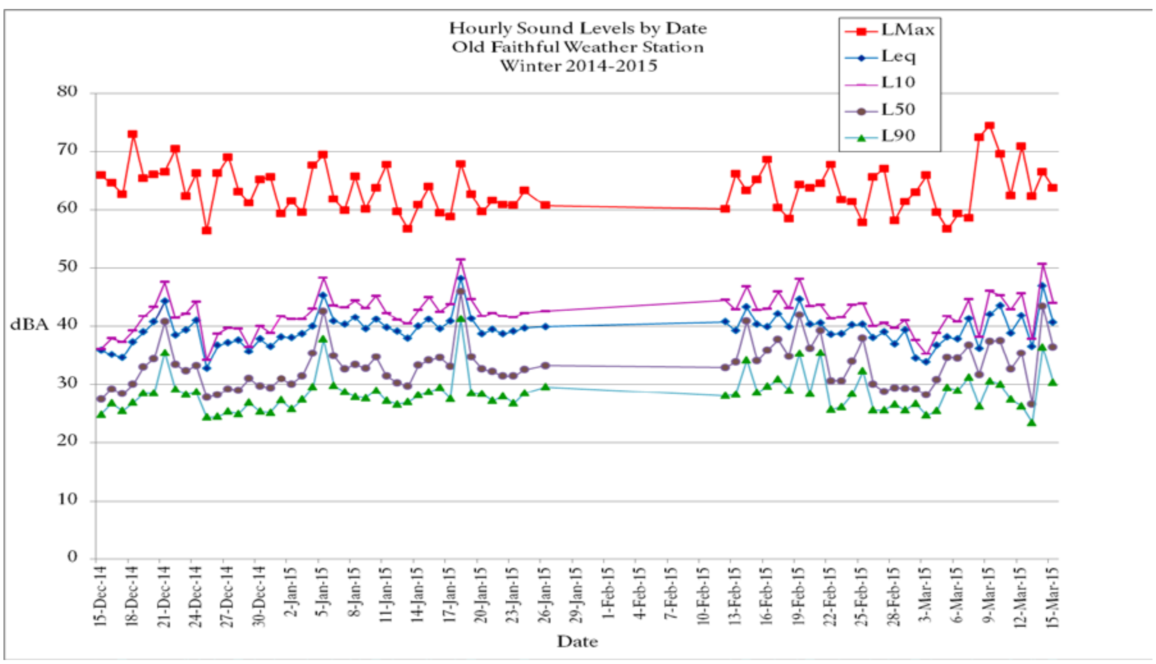

Figure 12. Median average daily (8 am – 4 pm) sound levels for winter 2014-2015, Old Faithful Weather Station, YNP. These sound levels include all natural and on-natural sounds. L_{max} is the highest sound level measured during each hour of the measurement period. (n=74 days).

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. 13). 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. 13). Wind generally increases during the afternoons and is reflected in the median hourly L_{50} and L_{90} values (Fig. 21).

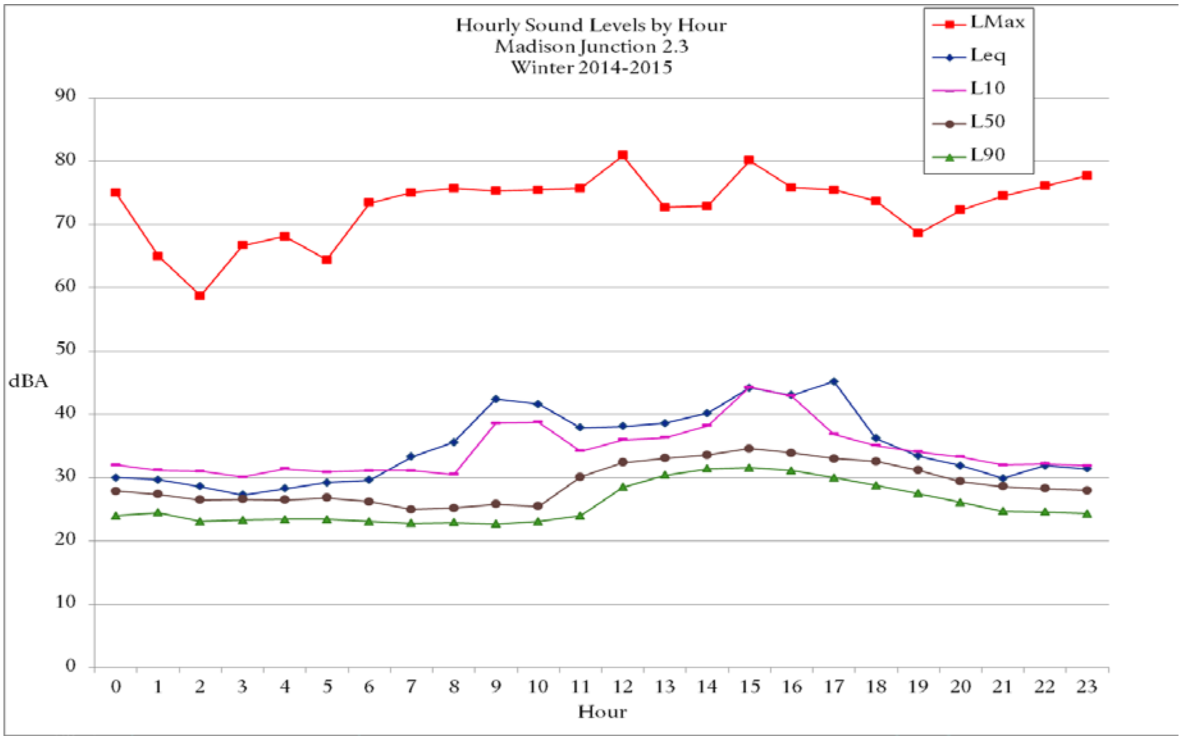

Figure 13. Median hourly sound levels for winter 2014-2015 at Madison Junction 2.3, YNP. See Fig. 19 caption for more details. (n=2,176 hours)

In addition to displaying sound levels by hour, winter-long acoustic metric summaries are shown by date in Figure 14. Especially windy days can be seen in the elevated L90 levels.

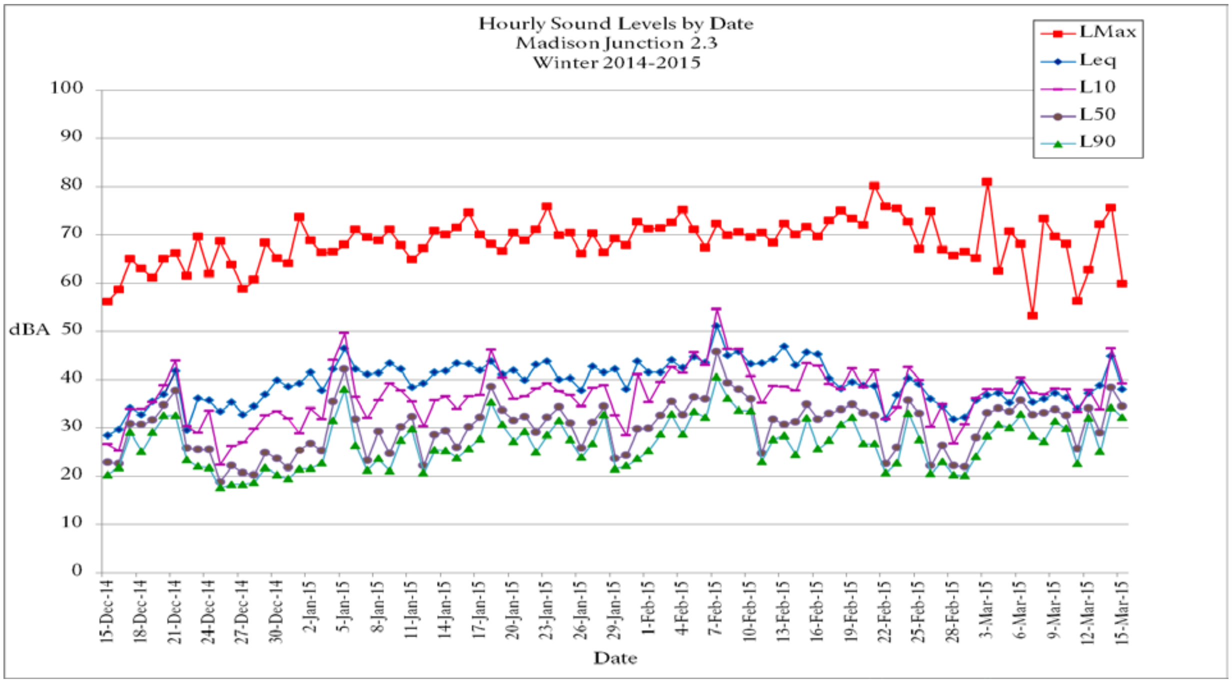

Figure 14. Median daily (8 am – 4 pm) sound levels winter 2014-2015 at Madison Junction 2.3, YNP. See Fig. 19 caption for more details. (n= 91 days)

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. The loudest sounds at this site were OSVs traveling on the road. 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 groomer schedule at about 5 pm and 8 pm (Fig. 15). 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 levels

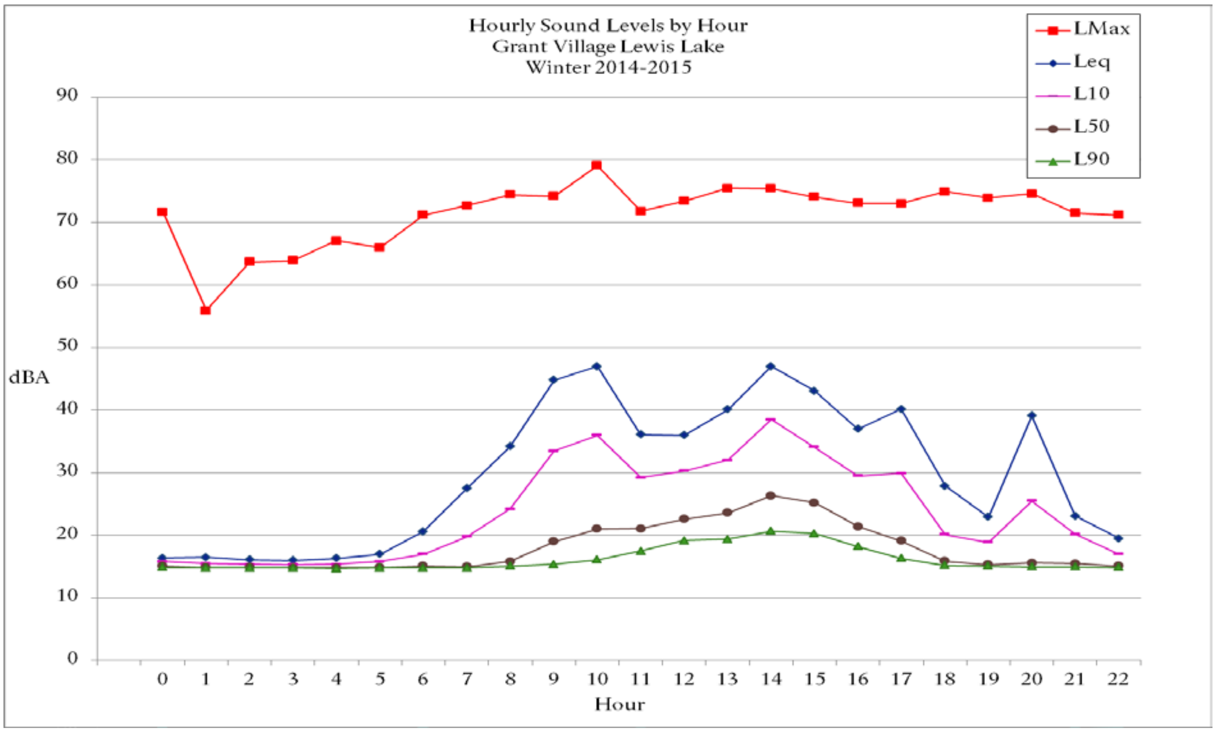

Figure 15. Median hourly sound levels for winter 2014-2015, Grant Village Lewis Lake YNP. See Fig. 11 caption for more details. (n=2,178 hours)

In addition to displaying sound levels by hour, winter-long acoustic metric summaries are shown by date in Figure 16. The days with high wind speeds, and thus elevated sound levels are shown by increased L90 values (Fig. 16).

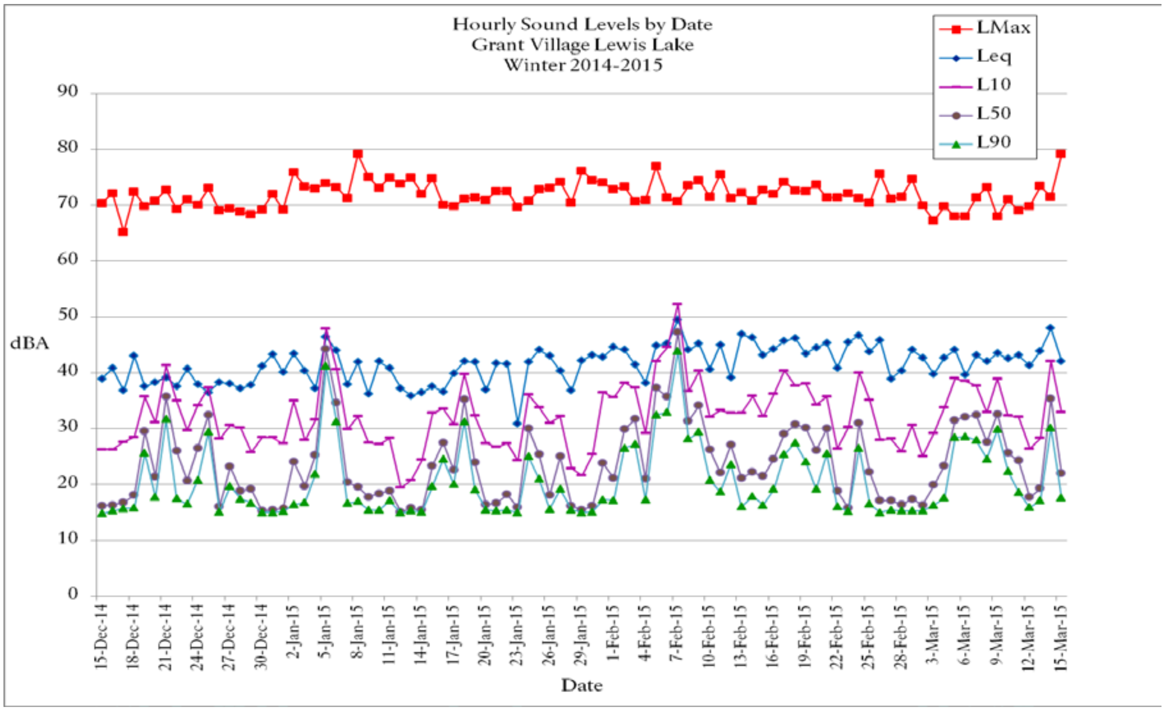

Figure 16. Median daily (8 am – 4 pm) sound levels for Grant Village Lewis Lake, winter 2014-2015, YNP. See Fig. 19 caption for more details. (n=91 days)

Acknowledgements:

Skip Ambrose (NPS Natural Sound Program-retired) developed an initial plan that led to this study. Ann Rodman provided logistical support and encouragement that was helpful. The Old Faithful Maintenance staff also provided logistical help on this project. Robin Long, through the Sandhill Company, expertly coded the digital recordings for the eleventh winter season. Her assistance continues to be invaluable. Ric Hupolo and the NPS Natural Sound Program provided computer analysis software. This report heavily relies on previous reports. John Sacklin, Denice Swanke, Mike Yochim, Skip Ambrose, Linda Franklin, Ann Rodman, Dave Hallac, and Robin Long provided valuable editorial comments on previous versions.

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, YNP, 7-9 February 2006. Unpublished Report for Yellowstone National Park. April 2006. Sandhill Company, Castle Valley, UT.

Burson, S. 2004. Natural soundscape monitoring in Yellowstone National Park December 2003-March 2004. 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. Grand Teton National Park Soundscape Program Report #200502. Moose, WY. 91 pp.

Burson, S. 2006. Natural soundscape monitoring in Yellowstone National Park December 2005-March 2006. Grand Teton National Park Soundscape Program Report #200601. Moose, WY. 116 pp.

Burson, S. 2007. Natural soundscape monitoring in Yellowstone National Park December 2006-March 2007. Grand Teton National Park Soundscape Program Report #200702. Moose, WY. 87 pp.

Burson, S. 2008. Natural soundscape monitoring in Yellowstone National Park December 2007-March 2008. Yellowstone National Park Soundscape Program Report. Moose, WY. 106 pp.

Burson, S. 2009. Natural soundscape monitoring in Yellowstone National Park December 2008-March 2009. Yellowstone National Park Soundscape Program Report. Moose, WY. 94 pp.

Burson, S. 2010. Natural soundscape monitoring in Yellowstone National Park December 2009-March 2010. Yellowstone National Park Soundscape Program Report. Moose, WY. 91 pp.

Burson, S. 2011. Natural soundscape monitoring in Yellowstone National Park December 2011-March 2012. Yellowstone National Park Soundscape Program Report. Moose, WY. 79 pp.

Burson, S. 2012. Winter acoustic monitoring in Yellowstone National Park December 2011-March 2012. Yellowstone National Park Soundscape Program Report. Moose, WY. 116 pp.

Burson, S. 2013. Winter acoustic monitoring in Yellowstone National Park December 2012-March 2013. Yellowstone National Park Soundscape Program Report. Moose, WY. 78 pp.

Burson, S. 2014. Winter acoustic monitoring in Yellowstone National Park December 2013-March 2014. Yellowstone National Park Soundscape Program Report. Moose, WY. 57 pp.

Freimund, W., Patterson, M., Bosak, K., & Saxen, S. 2009. Winter experiences of old Faithful visitors in Yellowstone National Park. Final Report. University of Montana, Missoula, Montana.

NPS (National Park Service, U.S. Department of the Interior). 2000. Winter use plans final environmental impact statement and record of decision for the Yellowstone and Grand Teton National Parks and John D. Rockefeller, Jr., Memorial Parkway.

NPS (National Park Service, U.S. Department of the Interior). 2003. Winter use plans final supplemental environmental impact statement and record of decision: Yellowstone and Grand Teton National Parks and John D. Rockefeller, Jr., Memorial Parkway.

NPS (National Park Service, U.S. Department of the Interior). 2004. Temporary winter use plans environmental assessment and finding of no significant impact for Grand Teton/ Yellowstone National Parks and John D. Rockefeller, Jr., Memorial Parkway.

NPS (National Park Service, U.S. Department of the Interior). 2006. Management Policies 2006. US Department of the Interior.

NPS (National Park Service, U.S. Department of the Interior). 2007. Winter use plans final environmental impact statement and record of decision for Yellowstone and Grand Teton National Parks and John D. Rockefeller, Jr., Memorial Parkway.

NPS (National Park Service, U.S. Department of the Interior). 2009. Temporary winter use plan environmental assessment and finding of no significant impact for Yellowstone National.

NPS (National Park Service, U.S. Department of the Interior). 2013. Winter use plan final supplemental environmental impact statement: Yellowstone National Park.

Appendix A: Spectrograms of sound levels

The NPS developed a technique for plotting the 33 one-third octave band frequency decibel 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 or wheeled vehicle signatures are narrow orange-yellow marks that extend from high to low frequency, the first occurrence for the day at 0707. The louder sounds are brighter yellow as shown in hours 0035 and 2352 (snow groomer) at Madison Junction 2.3 (Fig. A-1). At 0810, 2055, and 2255, a jet appears as a low frequency blob. The sounds of riffles on the Madison River and wind in the trees are shown as diffuse horizontal streaks during the whole day (Fig. A-1).

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). A propeller plane starts at 1420 and can be seen as the multiple horizontal lines.

Aircraft and OSVs are the main "visible" sounds at Grand Village Lewis Lake on a calm day (Fig. A-3). Jets at 2020, 2101, and 2150, and OSVs starting at 0930. The snow groomer passed by at 1730 and 2001.

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 2015 (548 snowmobiles during Saturday and Sunday). Although plotted using a different color scheme, one can readily 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.

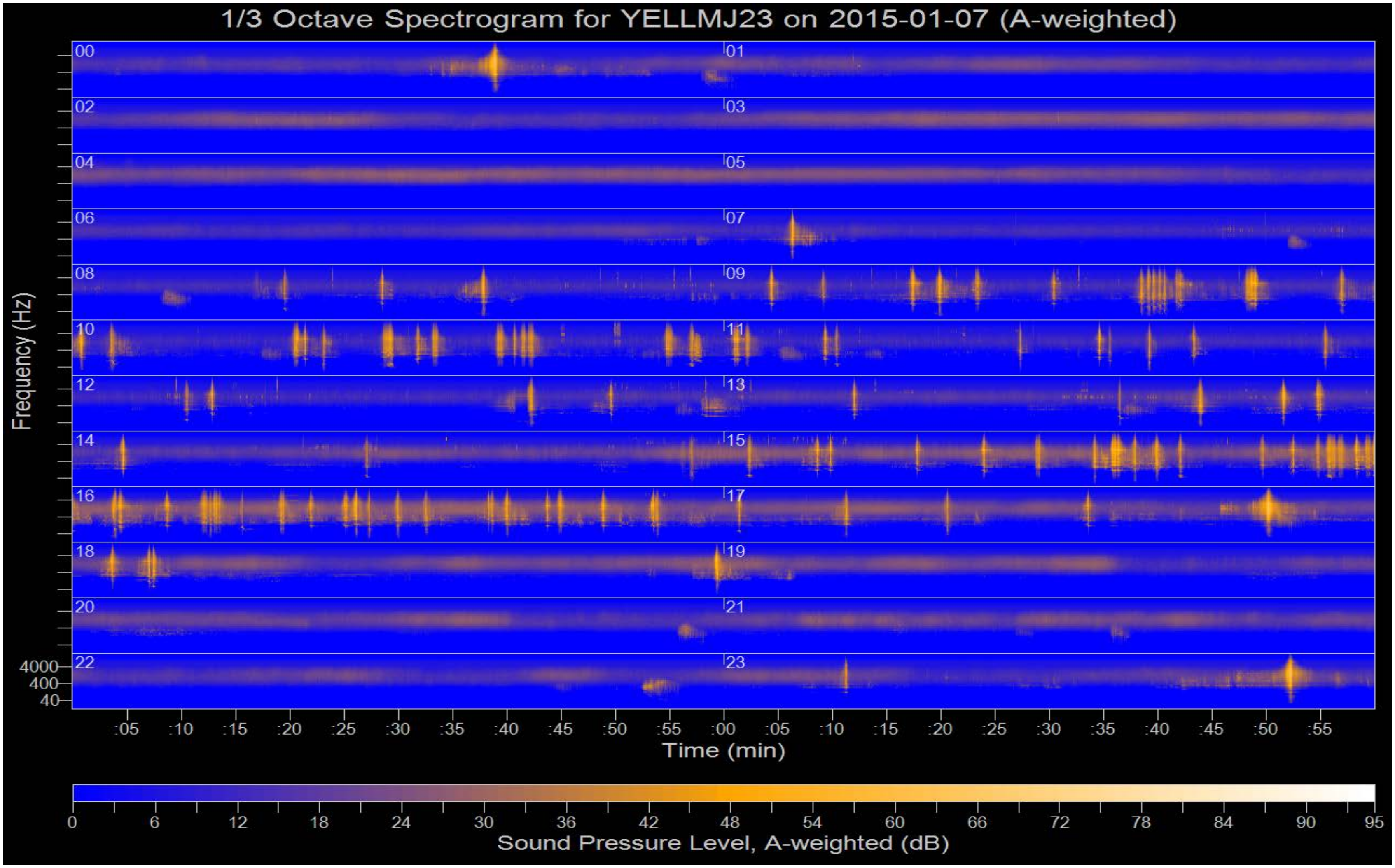

Figure A-1. Sound level spectrogram of 7 January 2015 at Madison Junction 2.3, YNP. See text for explanation.

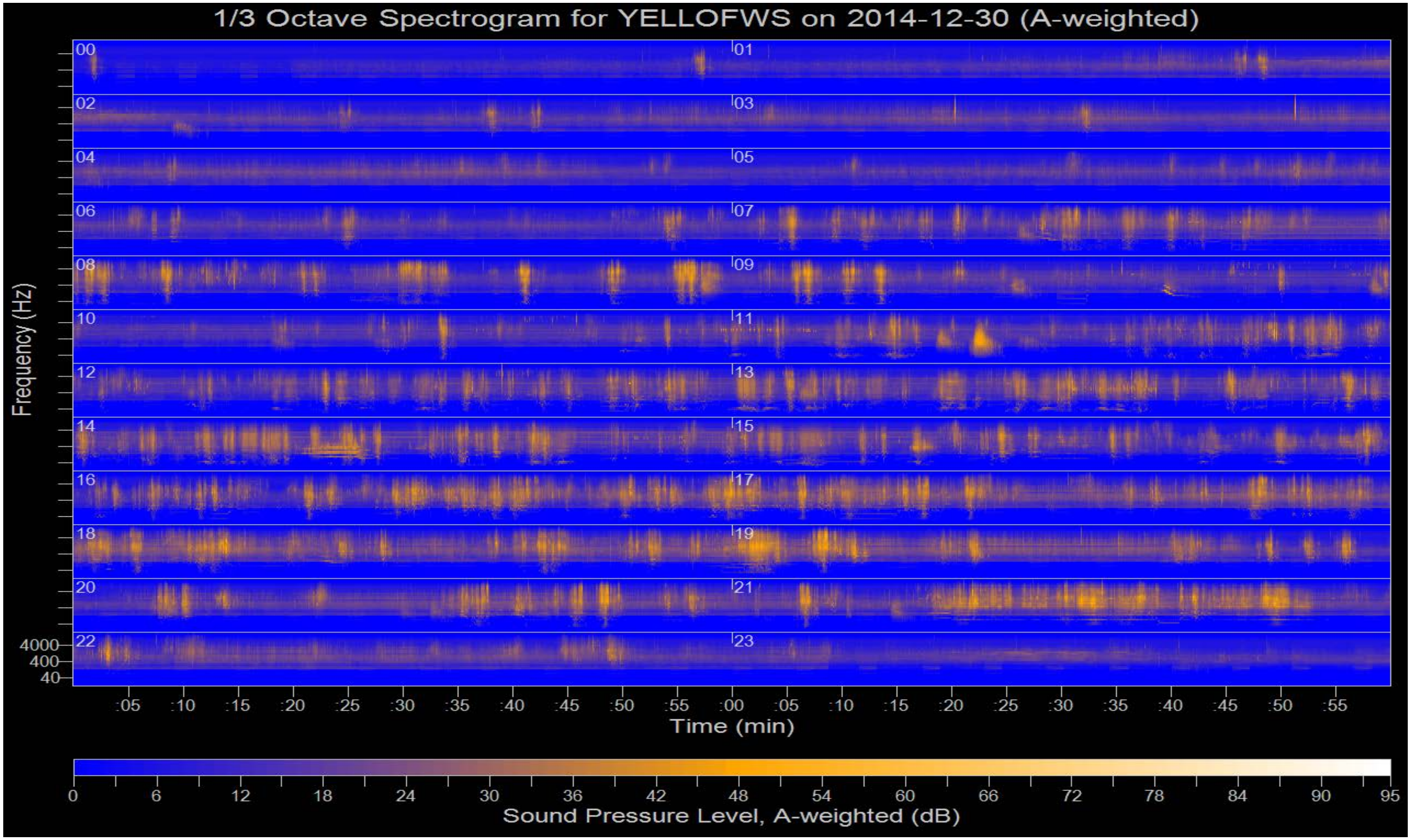

Fig A-2. Sound level spectrogram at Old Faithful Weather Station, 30 December 2014, YNP. See text for explanation.

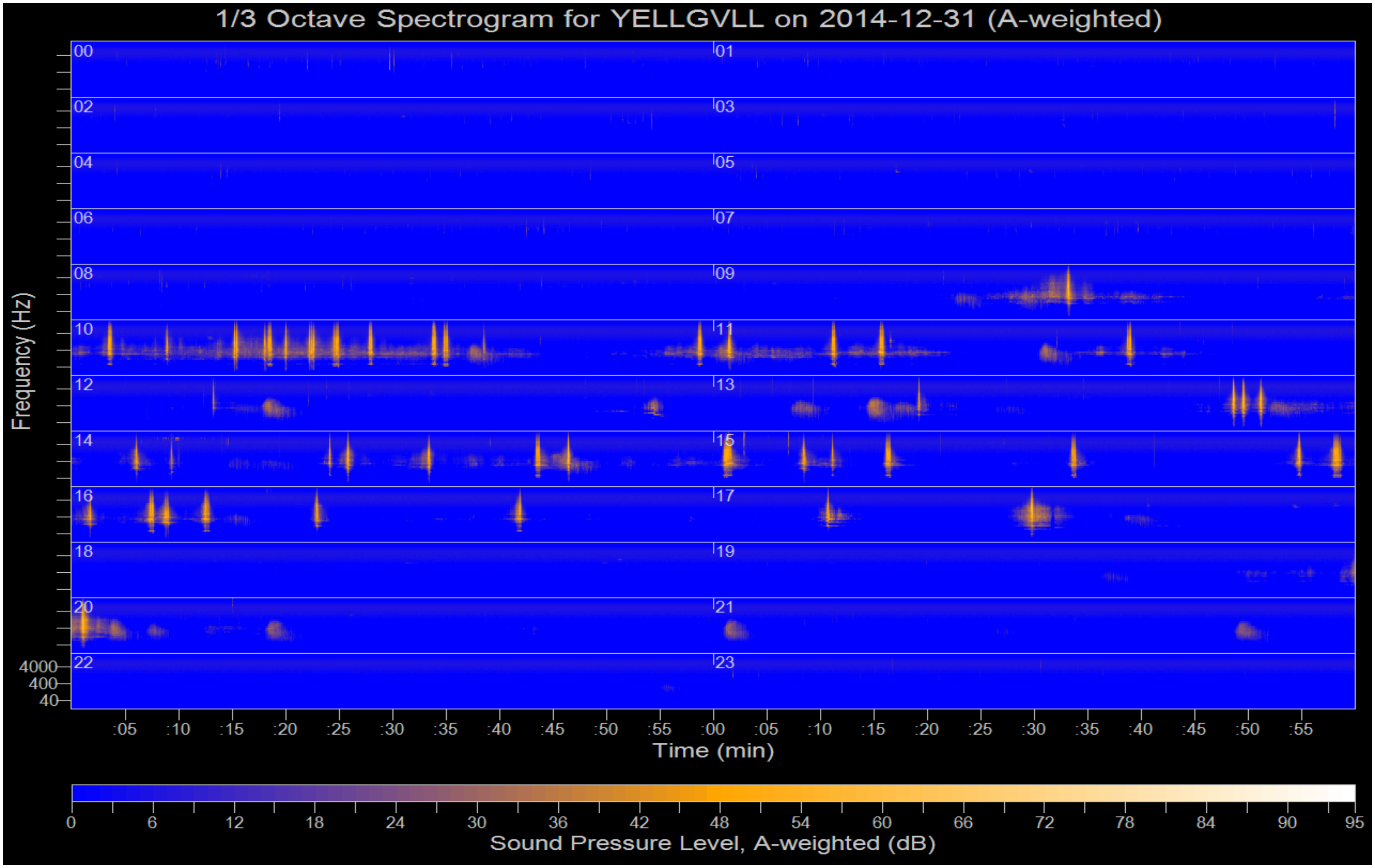

Fig A-3. Sound level spectrogram at Grant Village Lewis Lake, 31 December 2014, YNP. See text for explanation.

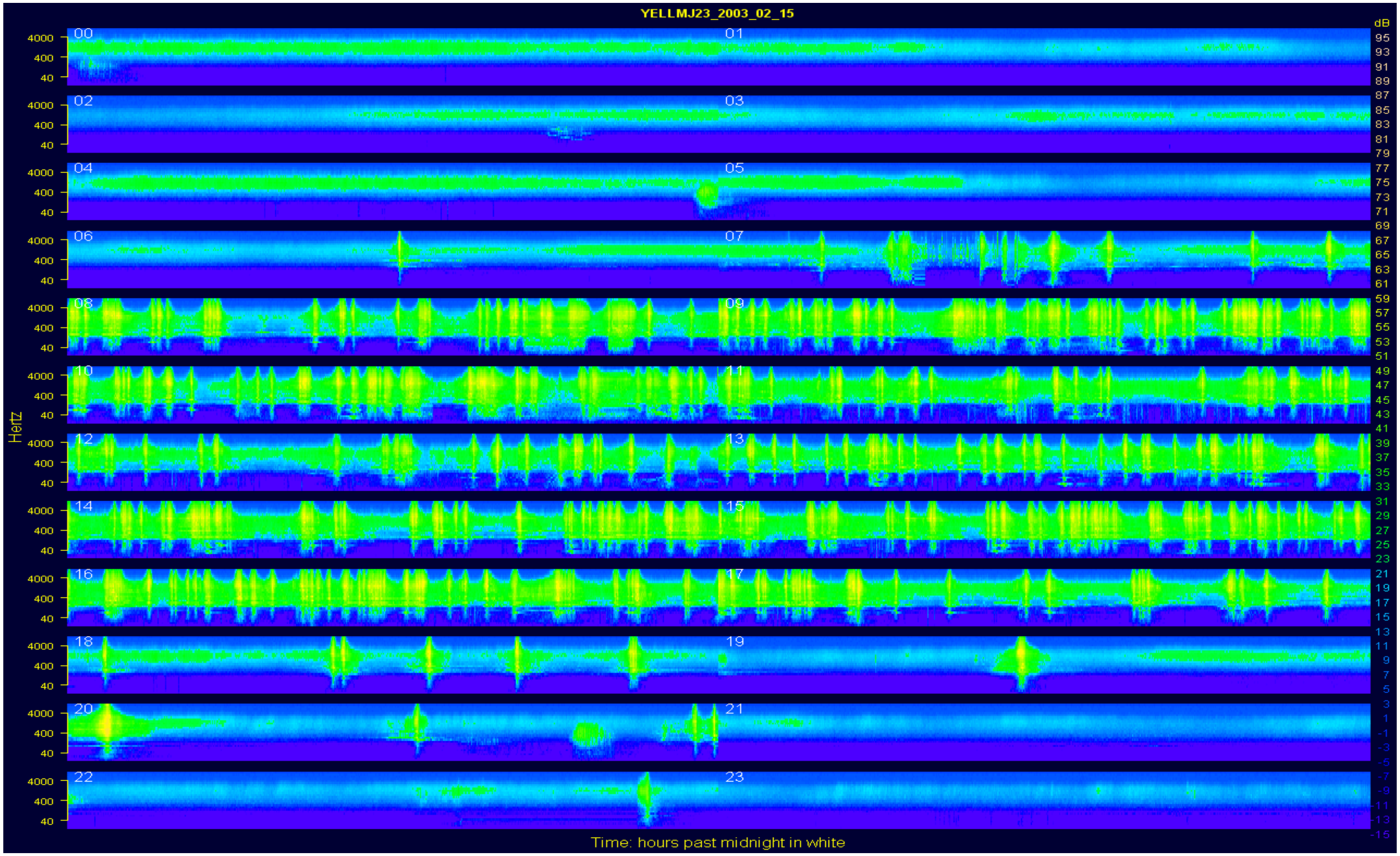

Fig A-4. A-weighted sound level spectrogram at Madison Junction 2.3 monitoring site, 15 February 2003, YNP. Compare to Fig. A-5 for number and timing of OSVs. See text for explanation.

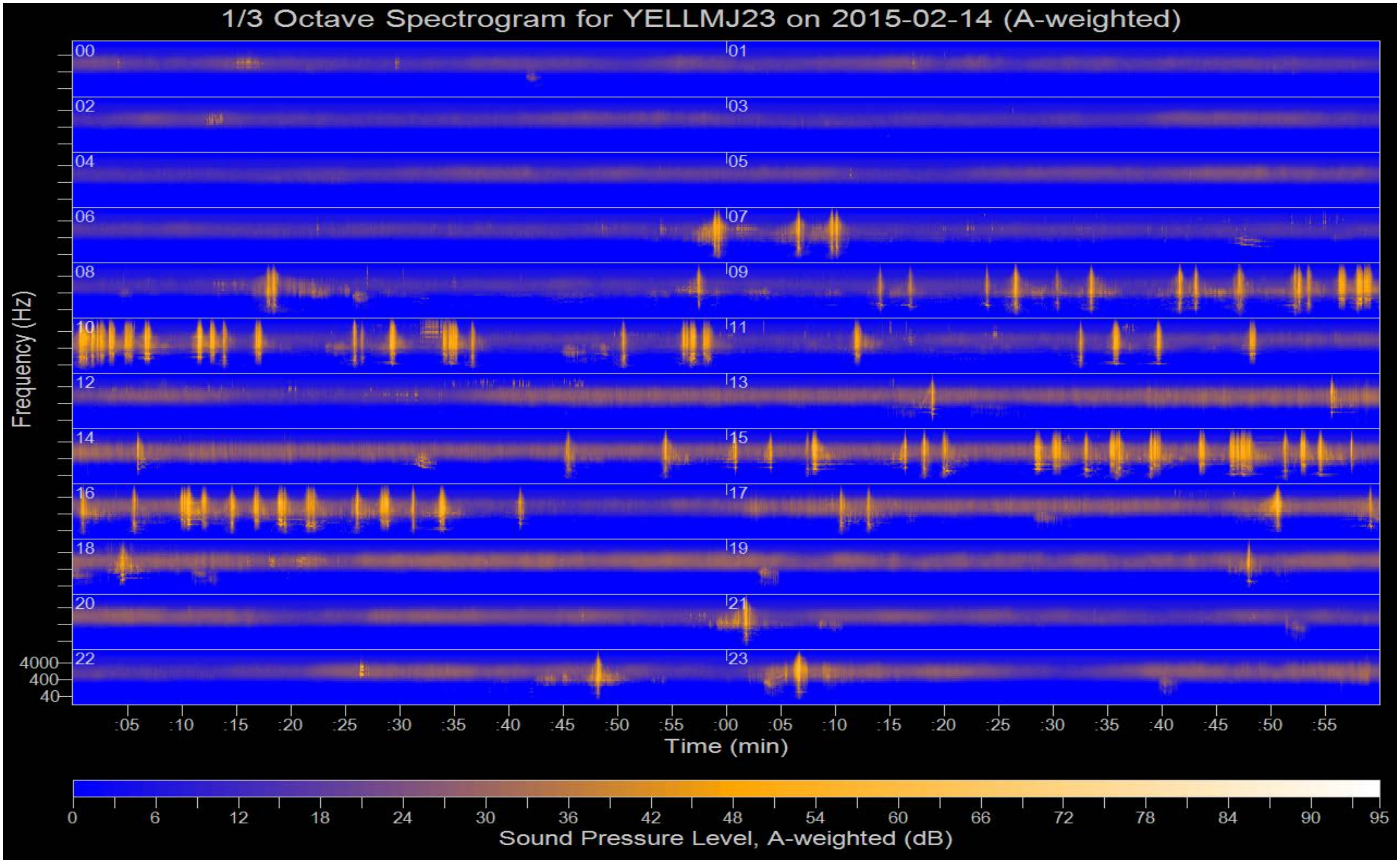

Fig A-5. A-weighted sound level spectrogram at Madison Junction 2.3 monitoring site, 15 February 2015, YNP. Compare to Fig. A-4 for number and timing of OSVs. See text for explanation.

Appendix B: OSV Comparability in a Visitor Destination Area

A new pilot study this winter was designed to address one of the three objectives of the Winter Use Adaptive Management Plan that was outlined in the Record of Decision- to gather additional data regarding the comparability of noise impacts from a group of snowmobiles versus a snowcoach. This preliminary effort was conducted at Fountain Paint Pots, a popular visitor destination.

Computer acoustic modeling has concluded that noise impacts from snowcoaches and groups of snowmobiles are comparable when assessed at a distance at which the two types can be considered a point source. Previous analyses from acoustic monitoring concluded that snowcoach and groups of snowmobiles percent time audible are comparable when taken in aggregate, that is, the averages from both types. Near-road area impacts present a different scenario. The noise impact from a snowcoach pass-by event is a single point source whereas a group of snowmobiles is numerous closely spaced point sources. The sound levels and audibility at near-road destinations may differ between the two OSV types.

Using autonomous equipment acoustic measurements were collected from 28 December 2014 to 14 February 2015. Continuous digital recordings and 1/3 octave band sound levels were collected every second. From these data the oversnow vehicle percent time audible and maximum and other sound level metrics can be calculated. On-site observational data were to be simultaneously collected, but these efforts were postponed to future winters due to other priorities. Without the observational data, comparative analyses are limited. What analyses were conducted are provided below.

Figure B-1 illustrates the location of the sound monitor 45 feet (14 m) from the boardwalk, and the groomed road was 300 feet (91 m) to the left beyond the edge of the photo. Generally, about 50% of the OSVs could be identified from the recordings of all audible OSV sounds (Fig. B-2). OSVs were audible for an average of 50% of the day, with snowcoaches audible for an average of 15% and snowmobiles for 10% of the day (Fig. B-2). Some of these OSVs were audible from activities in the parking lot rather than on the road.

The sound level metrics from this site were similar to other travel corridor sites showing bi-modal peaks in OSV sound levels during the morning and afternoon travel periods (Fig. B-3). The ambient sound levels were elevated at this site because of the bubbling mudpots, geysers, and other geothermal activity (Fig. B-3). Days with high winds can be seen in the elevated L90 values in Figure B-4.

These data and analyses, when fully implemented and analyzed, and in conjunction will simultaneous observational data, will help the NPS to determine if snowmobiles and snowcoaches have comparable noise impacts on visitors and the natural soundscape in heavily-visited roadside destination areas.

Figure B-1. Fountain Paint Pots sound monitor located in cluster of trees to the right in the photograph above, near the boardwalk surrounding the mud pots.

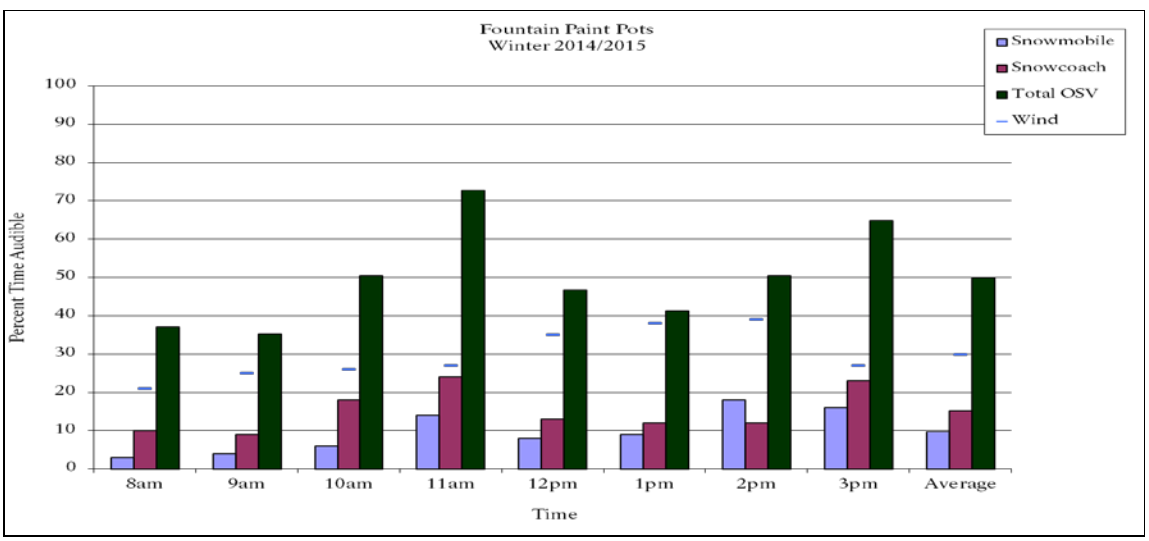

Figure B-2. Audibility of snowmobiles (left blue bar), snowcoaches (middle maroon bar) and unidentified OSVs (right green bar) at Fountain Paint Pots, 29 December 2014 to 14 February 2015.

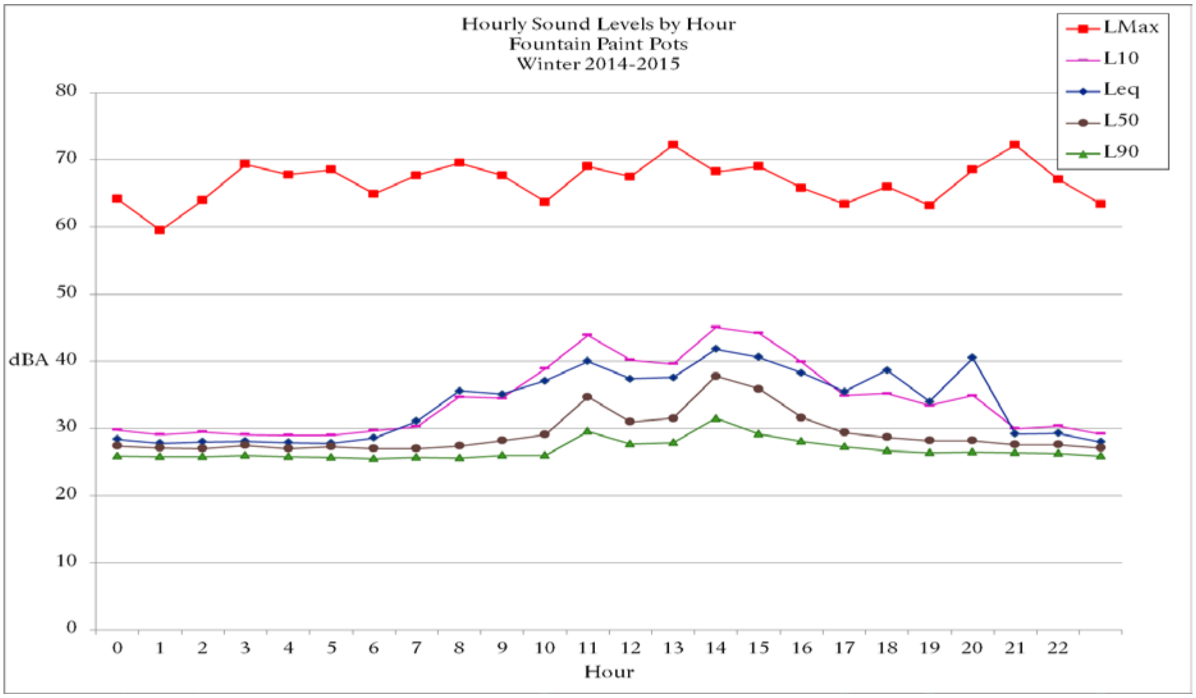

Figure B-3. Median hourly sound levels for winter 2014-2015, Fountain Paint Pots, YNP. These sound levels include all natural and non-natural sounds. L_{max} is the highest sound level measured for each hour of the day. (n=1,145 hours).

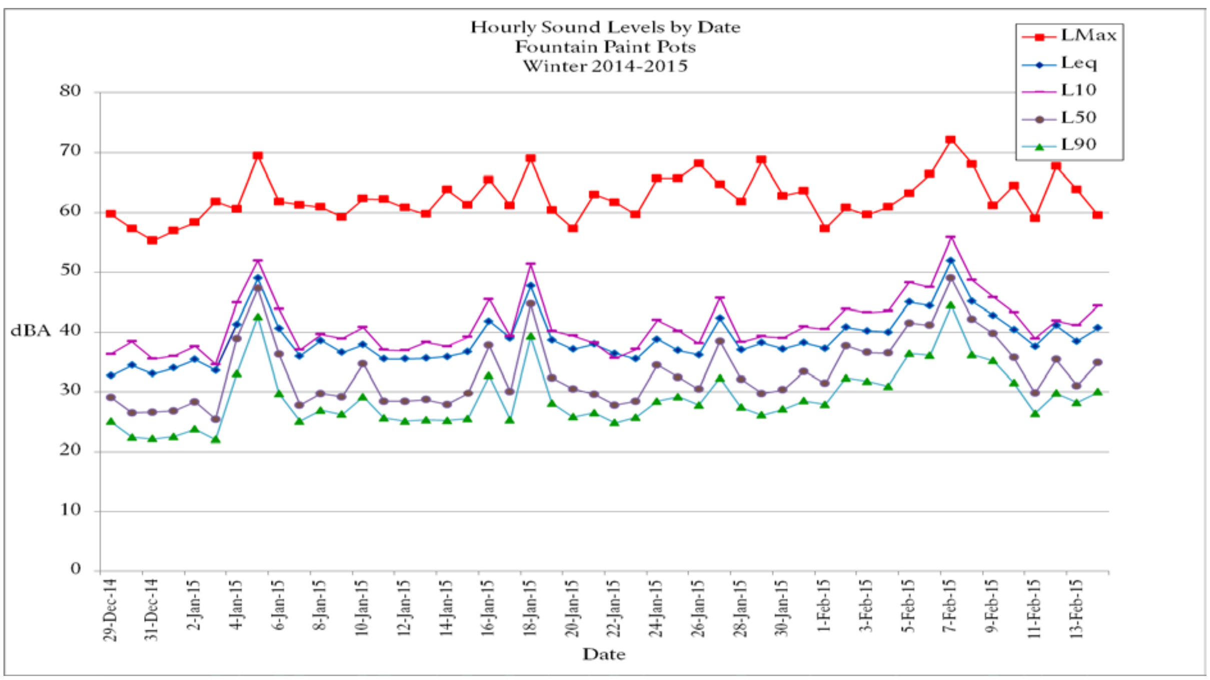

Figure B-4. Median average daily (8 am – 4 pm) sound levels for winter 2014-2015, Fountain Paint Pots, YNP. These sound levels include all natural and on-natural sounds. L_{max} is the highest sound level measured for each day of the measurement period. (n= 48 days).

Appendix C: 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 primary travel corridor monitoring site, for this study, has been Madison Junction 2.3 along the busiest travel corridor in winter. For the winter season 2014-2015, OSVs were audible 30% 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 38%. Audibility climbed to 55% during the busiest hour of the day, 9 am to 10 am, and was 16% during the noon hour. 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 C-1).

Table C-1: Oversnow audibility as a function of monitoring site and period of analysis, YNP, 15 December 2014-15 March 2015.

Site(s)	Period of Analysis	Audibility
Madison Junction	9 am to 10 am	55%
Madison Junction	noon to 1 pm	16%
Madison Junction	8 am to 4 pm	30%
Madison Junction	7 am to 9 pm	25%
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.