# Winter Acoustic Monitoring in Yellowstone National Park December 2011-March 2012

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Shan Burson/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 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 at least 50% 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. Acoustical standards and thresholds have been defined in park planning documents for the winter use season. The primary purpose of this study was to monitor the impact of oversnow vehicles on the natural soundscape. 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) along travel corridors and in destination areas. We then compared those values to the winter use plan's thresholds.

Acoustical data were collected at three winter-long sites and three shorter-term sites in Yellowstone National Park during the winter use season, 15 December 2011-15 March 2012. One of these shorter-term sites was along a plowed road section that had no oversnow vehicle traffic. That site was chosen to augment other locations that serve as a comparison of oversnow and wheeled vehicle noise impacts. This report includes, with few exceptions, only those sites sampled during the 2011-2012 winter. Results of data collected in the other eight 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 hour day (8 am to 4 pm) and dividing by the eight hour period. Each of these calculations could then be compared to the winter use management thresholds for the site's zone. For example, the season-long threshold for audibility in developed areas was 75% and 50% in travel corridors, with no more than 15% of the sampled days to exceed these thresholds. The overall winter use season average and each measured day was compared to those thresholds.

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. Noise-free intervals were not calculated for developed areas where human-caused sound was nearly constant.

The official winter use season was 92 days, but as in occasional past winters, because of poor oversnow road conditions, not all oversnow vehicles were allowed to travel all road segments for the entire winter use season. No snowmobiles or snowcoaches with skis were allowed to travel to and from the north and west entrance until 1 January 2012. Except where otherwise indicated, the summary statistics shown in this report are for the full 92-day winter use season.

The oversnow vehicles' overall winter use audibility in the most heavily-used developed area, Old Faithful, averaged 66% (*SD* = 11%). At Old Faithful, oversnow vehicles were audible over 75% of the day during six (20%) of 30 days analyzed.

Oversnow vehicles were audible for an overall average of 45% (*SD* = 17%) of the day near Madison Junction along the road corridor between Old Faithful and the West Entrance. At the Madison Junction site oversnow vehicles were audible over 50% of the day during nine (29%) of 31 days analyzed. The average noise-free interval between 8 am and 4 pm at Madison Junction was three minutes and 21 seconds, with a maximum noise-free interval of 23 minutes and 16 seconds.

Oversnow vehicles were audible for a winter use overall average of 22% (*SD* = 14%) at Cygnet Lake Roadside along the Norris to Canyon road corridor. At Cygnet Lake Roadside oversnow vehicles were audible over 50% of the day during one (5%) of 20 days analyzed. The average noise-free interval at Cygnet Lake Roadside was 3 minutes and 56 seconds, with a maximum noise-free interval of 28 minutes and 12 seconds.

Oversnow vehicles were audible for a winter use season average of 38% (*SD* = 23%) at Canyon Village Developed Area near the visitor center in Canyon. At Canyon Village Developed Area, oversnow vehicles were audible over 75% of the day for none of 14 days analyzed.

Acoustic data were also collected near the plowed roads at Canary Springs in the Mammoth Terraces. Oversnow vehicles (snowcoaches that traveled the plowed road heading to or from the park's interior) were audible for an average of 7% (*SD* = 7%) of the day at Mammoth Canary Springs. Wheeled vehicles were audible for an average of 25% (*SD* = 7%) of the day. At Mammoth Canary Springs, there were no days of the 15 analyzed when oversnow vehicles were audible over 50% of the day. The average noise-free interval at Mammoth Canary Springs was 1 minute and 14 seconds, with a maximum noise-free interval of 7 minutes and 42 seconds.

At Middle Barronette Meadow, near Barronette Peak in the northeast corner of the park, wheeled vehicles were audible for an average of 25% (*SD* = 11%) of the 11 days analyzed. The average noise-free interval was 2 minutes and 53 seconds at Middle Barronette Meadow, with a maximum noise-free interval of 19 minutes and 30 seconds.

The maximum sound levels of oversnow vehicles often exceeded 70 A-weighted decibels (dBA) along the groomed travel corridors at the Madison Junction 2.3 and Cygnet Lake Roadside 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 eight winter seasons, the sound level and the percent time oversnow vehicles were audible remained substantially lower than during the 2002-2003 winter use season. The reduced sound and audibility levels 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 are audible continues to be more closely associated with the number and distribution of groups 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. The existing winter soundscape at Yellowstone consists of both natural and non-natural sounds. Common natural sounds include bird calls, mammal vocalizations, flowing water, wind, and thermal activity. Non-natural sounds include motorized sounds of snowmobiles, snowcoaches, snow-grooming, wheeled vehicles, aircraft, and the sounds associated with facility utilities and other human activity in destination and support areas.

The 2000, 2003, and 2007 Winter Use Plans Environmental Impact Statement of YNP and Grand Teton National Parks and the John D. Rockefeller, Jr., Memorial Parkway (NPS 2000, 2003, and 2007) and the 2004 and 2009 Temporary Winter Use Plans (WUP) Environmental Assessment (NPS 2004 and 2009) concluded that historical oversnow vehicle (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 OSVs and a commercial guiding requirement. The 2009 impact definitions describing the acoustical thresholds (Table 1) can be compared to the acoustic field measurements collected in Yellowstone during the 2011-2012 winter use season. 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 (but see Appendix E). See Burson (2004-2011) for additional information on park soundscapes during the previous winters, and the Winter Use Plans (NPS 2000, 2003, 2004, 2007, and 2009) for additional details of OSV management.

Table 1. Impact definitions for the natural soundscape in the 2009 Winter Use Plan (WUP) Environmental Assessment. Also see Appendix C.

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

[1]Thresholds are calculated using the period 8 am-4 pm. Measurements are at 100 feet (30 m) from sound source in developed areas and travel corridors.
[2] Audibility is the ability of humans with normal hearing to hear a certain sound.
[3] To remain within impact category listed audibility and maximum sound level thresholds shall not be violated more than 15% of the measurement days.
[4]Typical natural soundscape sound levels on a calm winter day can range from 0-30 dBA. Snowmobile best available technology (BAT) sound level requirements of 73 dBA measured at 50 feet (15 m) is roughly equivalent to 67 dBA at 100 feet. The maximum sound level for all non- natural sounds in national parks other than OSVs and motorboats is 60 dBA **[**36 CFR (2.12) (a)(1)(i)].

## Study Area:

YNP occupies the northwest corner of Wyoming and extends over the borders into Montana and Idaho. The park is at high elevation and has extensive stands of lodgepole pine forests, grasslands, and open thermal areas. Large areas of Yellowstone are in early stages of lodgepole pine regrowth after the 1988 and subsequent fires. For the purpose of describing areas with similar natural acoustic properties, the park's two million acres were divided into two acoustic zone categories (open and forested) for habitat descriptions in this present study.

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 2011 and 15 March 2012, 14,917 guided snowmobiles and 2,406 guided snowcoaches, totaling 17,323 oversnow vehicles, entered YNP (NPS unpublished data). The majority (14,429; 96.7%) 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 seven snowmobiles/day and nine snowcoaches/day and were not included in the number of OSVs given above and, unless otherwise indicated, elsewhere in this report.

## Instrumentation and Methods:

Automated acoustic monitors (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. Calibrated Type 1 Larson Davis (Provo, Utah) 831 sound level meters, PCB PRM831 preamplifiers, and PCB 377B02 microphones (Provo, UT) with windscreens were used to collect A-weighted wideband and 33 unweighted one-third octave band frequency (12.5-20,000 Hz) sound pressure levels each second (1-second $L_{eqs}$) during the entire sampling period. Continuous digital recordings were made with Edirol R-09HR or R-05 (Bellingham, WA) mp3 recorders collecting high quality digital recordings (44.1 KHz, 16-bit). B&K (Naerum, Demark) Model 4231 and Larson Davis LD200 calibrators were used for field calibration. The sound level meters, microphone preamplifiers, microphones, and calibrators were tested and calibrated at a laboratory that conforms to and operates under the requirements of ANSI/NCSL Z540-1. During the initial deployment, the sound level meter noise floor was measured using a Larson Davis ADP005 dummy microphone. The actual system noise floor (3-7 dBA above the level measured with a dummy microphone) is the lowest sound level that the system can measure. During quiet periods the actual ambient sound level was sometimes lower than the noise floor (Burson 2006). Davis Instruments anemometers (Hayward, CA) collected wind speeds and direction.

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

The acoustic monitors, contained within weatherproof containers, were either plugged into electrical outlets (Old Faithful) or powered by 12 or 14.4 volt batteries with or without photovoltaic charging systems. The monitors could operate continuously for weeks between site visits.

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

**Acoustic Measurement Locations:**

The 2011-2012 sound monitoring locations (Fig. 1; Table 1) were chosen to include high and medium OSV use and represented two soundscape management zones (Developed and Travel Corridor). Two additional locations were chosen to represent plowed roads near and far from developed areas. Using aerial photos, habitat cover percentages listed below were calculated in a 500 meter radius of the sound monitor.

The Cygnet Lake Roadside site was located on the road segment between Norris and Canyon. The Canyon Village Developed Area site was between Canyon's visitor center and the service station.  The Mammoth Canary Springs site was along the plowed road between Mammoth and the upper terraces. The Middle Barronette Meadow site was along the plowed road six miles from the northeast entrance. These were the first monitoring sites along those three road segments.

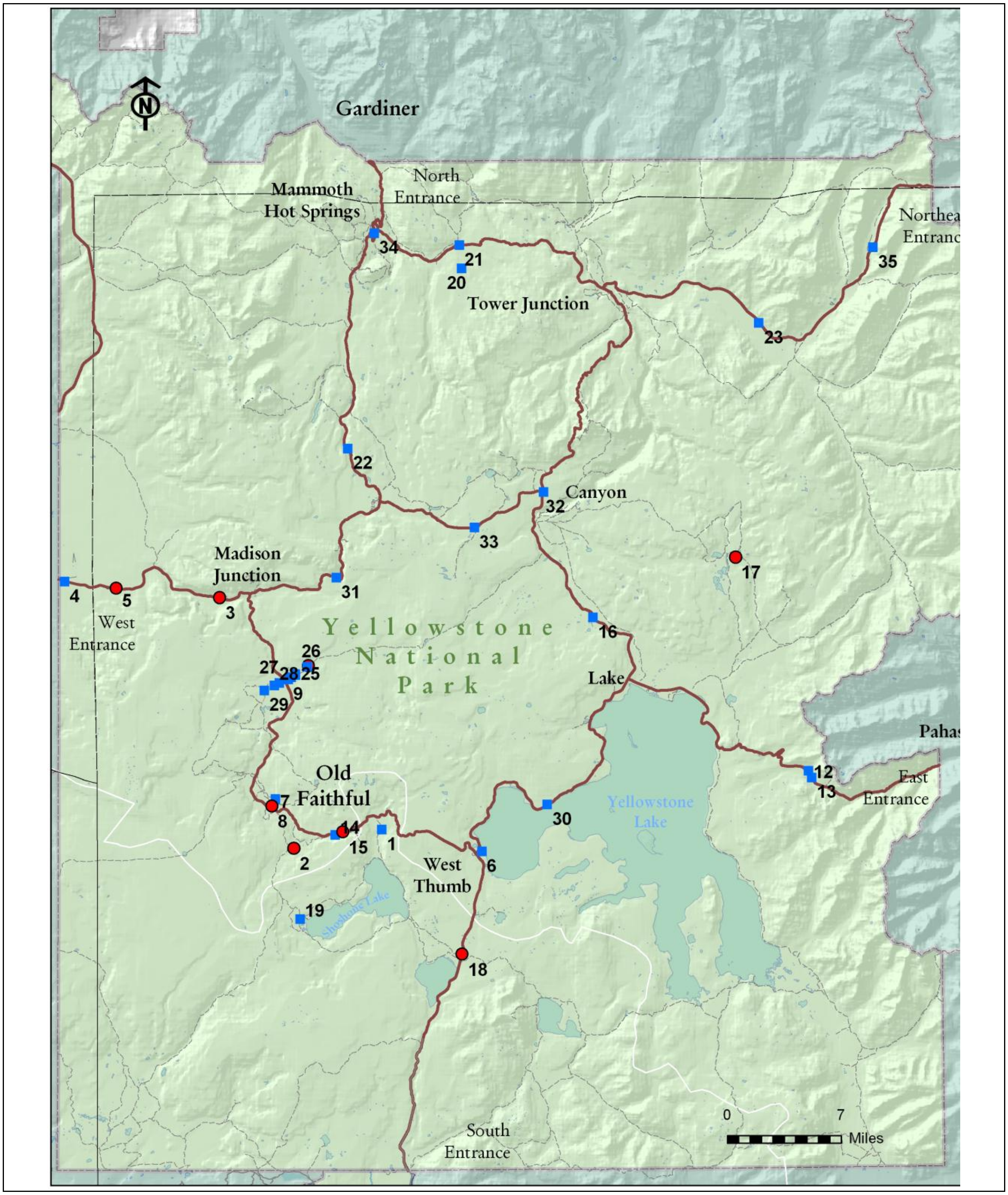


Figure 1. Locations of sound monitoring sites (red circles- multiple seasons, and blue squares- winter only) within YNP, December 2003-March 2012. See associated table for year and labels (Table 1). Only FY12 sampling locations are included in detail in this report (but see Burson [2004-2011] for previous winters' sampling results).

Table 1. Site name and years of sound monitoring locations within YNP, December 2003-March 2012. See associated map (Fig. 1) and labels.

| Label | Site Name | FY 03 | FY 04 | FY 05 | FY 06 | FY 07 | FY 08 | FY 09 | FY 10 | FY 11 | **FY 12** |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Delacy Creek | Y | | | | | Y | | | | |
| 2 | Lone Star Geyser | | Y | Y | | | | | | | |
| **3** | **Madison Junction 2.3** | **Y** | **Y** | **Y** | **Y** | **Y** | **Y** | **Y** | **Y** | **Y** | **Y** |
| 4 | West Yellowstone | Y | | | | | | | | | |
| 5 | W. Yellowstone 3.1 | | | Y | Y | | | | | | |
| 6 | West Thumb | | | Y | Y | | | | | | |
| 7 | Old Faithful Upper Basin | | | Y | Y | | | | | | |
| **8** | **Old Faithful Weather Station** | **Y** | **Y** | **Y** | **Y** | **Y** | **Y** | **Y** | **Y** | **Y** | **Y** |
| 9 | Mary Mountain Trail | | Y | | | | | | | | |
| 10 | Mary Mountain 4K | | Y | | | | | | | | |
| 11 | Mary Mountain 8K | | | Y | Y | | Y | | | | |
| 12 | Avalanche Creek | | | | Y | | | | | | |
| 13 | Sylvan Lake | | | | Y | | | | | | |
| 14 | Spring Creek | | | | Y | | | | | | |
| 15 | Spring Creek 2 | | | | | Y | | | | | |
| 16 | Mud Volcano | | | | | Y | | | | | |
| 17 | Fern Lake | | | | | Y | | | | | |
| 18 | Grant Village Lewis Lake | | | | | | Y | | | | |
| 19 | Shoshone Geyser Basin | | | | | | Y | | | | |
| 20 | Blacktail Backcountry | | | | | | | Y | | | |
| 21 | Blacktail Roadside | | | | | | | Y | | | |
| 22 | North Twin Lake | | | | | | | Y | | | |
| 23 | Lamar Valley Willow | | | | | | | | Y | | |
| 24 | Mary Mountain Transect East 1 | | | | | | | | Y | | |
| 25 | Mary Mountain Transect East 2 | | | | | | | | Y | | |
| 26 | Mary Mountain Transect East 3 | | | | | | | | Y | | |
| 27 | Mary Mountain Transect West 1 | | | | | | | | Y | | |
| 28 | Mary Mountain Transect West 2 | | | | | | | | Y | | |
| 29 | Mary Mountain Transect West 3 | | | | | | | | Y | | |
| 30 | Pumice Point Roadside | | | | | | | | | Y | |
| 31 | Caldera Rim Picnic Area | | | | | | | | | Y | |
| **32** | **Canyon Village Developed Area** | | | | | | | | | | **Y** |
| **33** | **Cygnet Lake Roadside** | | | | | | | | | | **Y** |
| **34** | **Mammoth Canary Springs** | | | | | | | | | | **Y** |
| **35** | **Middle Barronette Meadow** | | | | | | | | | | **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 (61 m) from the Ranger Station, 230 feet (70 m) from the entrance road used by oversnow traffic, 300 feet (91 m) from the large parking lot between the Ranger Station and the Visitors Center, 600 feet (183 m) from the Old Faithful Inn, and 700 feet (213 m) from the Snow Lodge. The monitor was powered by AC electricity. See Tables 2 and 3 for dates of operation.

*Madison Junction 2.3*

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

Photo 2. Madison Junction 2.3 sound monitor location.

The Madison Junction 2.3 monitor (in the center of the photo above in trees) was located 2.3 miles (3.7 km) west of Madison Junction, 100 feet (30 m) from the West Entrance-Madison Junction Road within a large area of small (4 to 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.

*Cygnet Lake Roadside*

Latitude: 44.70412

Longitude: 110.57818

Elevation: 8200 feet (2500 m)

Habitat: 1% open (road), 99% conifer forest (mostly sparse regeneration)

Management Zone: Travel Corridor

Photo 3. Cygnet Lake Roadside sound monitor location.

The Cygnet Lake Roadside monitor (in the center of the photo above) was located 100 feet (30 m) from the road between Norris and Canyon. The microphone was on the edge of a forest of regenerating conifers at the edge of a utility line corridor. The site was 575 yards (526 m) from the trailhead parking area of Cygnet Lake. The monitor was powered by batteries charged by a small solar panel. See Tables 2 and 3 for dates of operation.

*Canyon Village Developed Area*

| | |
|---|---|
| Latitude: | 44.73528 |
| Longitude: | 110.49157 |
| Elevation: | 7900 feet (2400 m) |
| Habitat: | 45% open (meadow), 6% open (pavement), 3% open (buildings), 46% conifer forest |
| Management Zone: | Developed Area |

Photo 4. Canyon Village Developed Area sound monitor location.

The Canyon Village Developed Area monitor (in the center of the photo above) was located 100 feet (30 m) from the entrance road to the Canyon Visitor Center. The microphone was within a clump of dense conifers. The site was 160 feet (49 m) north of the visitor center, and 400 feet (122 m) southeast of the Canyon Service Station. The monitor was powered by stand-alone batteries. See Tables 2 and 3 for dates of operation.

*Mammoth Canary Springs*

| | |
|---|---|
| Latitude: | 44.96624 |
| Longitude: | 110.70197 |
| Elevation: | 6400 feet (1951 m) |
| Habitat: | 67% open (sage/ dry meadow), 15% open (hot spring terraces), 2% open (pavement), 1% open (reservoir), 15% conifer forest |
| Management Zone: | Road Corridor, near Developed Area |

Photo 5. Mammoth Canary Springs sound monitor location.

The Mammoth Canary Springs monitor (in the center of the photo above) was located 170 feet (52 m) from the road between Mammoth and the Upper Terraces. The microphone was within the branches of a juniper tree. The site was 1/2 mile (0.8 km) north of the nearest buildings in the Mammoth Developed Area, and 500 feet (152 m) from the Canary Springs terrace (seen in the photo above). The monitor was powered by stand-alone batteries. See Tables 2 and 3 for dates of operation.

*Middle Barronette Meadow*

| | |
|---|---|
| Latitude: | 44.95032 |
| Longitude: | 110.07675 |
| Elevation: | 7100 feet (2164 m) |
| Habitat: | 38% open (meadow), 1% open (pavement), 1% open (river), 60% conifer forest |
| Management Zone: | Road Corridor |

Photo 6. Middle Barronette Meadow sound monitor location.

The Middle Barronette Meadow monitor (in the left center of the photo above) was located 100 feet (30 m) from the road between Tower and Cooke City. The site was 6 miles (9.7 km) west of the Northeast Entrance. The microphone was within the branches of a conifer tree. This monitor only collected digital recordings that were then post-processed to obtain sound levels. The monitor was powered by stand-alone batteries. 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 Cygnet Lake Roadside. Additional acoustic data were collected for shorter periods at Canyon Village Developed Area, Mammoth Canary Springs, and Middle Barronette Meadow, (see previous section for site details). Data collection began on 15 December 2011 and continued throughout the winter use season (15 December 2011-15 March 2012). 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 third day was analyzed at Old Faithful Weather Station, Madison Junction 2.3, and Cygnet Lake Roadside. Depending on the length of the sampling period, every other or every third day was analyzed at Canyon Village Developed Area, Mammoth Canary Springs and Middle Barronette Meadow. If a site visit fell on a day to be analyzed the day before or after 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 F). 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 vehicle percent time audible. At some monitoring locations the lowest minimum sound levels can be below the range (noise floor) of the instrumentation for many hours of the day. The actual minimum sound levels are therefore unknown. Because of this uncertainty, and other factors, the association between the number of OSVs, the natural ambient sound levels, and the distances OSVs are audible is not straightforward.

Acoustic data were collected at YNP during the past ten 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 6). Soundscapes are highly variable over time, both in minutes and seasons. All attempts to summarize long-term datasets therefore fail to describe or fully explain this inherent variability. Methods and techniques to completely address the soundscapes variability are currently unavailable. Attempts to draw tight correlations between certain actions, such as the daily number of OSVs allowed to 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 season and upon which this report is based is one of the most extensive national park winter acoustic datasets in existence and a substantial amount of useful information can be gathered from the data as collected and presented.

Audibility

Ten seconds of every four minutes of the continuous digital recordings were used and analyzed. These daily 360 10-second samples were calibrated, combined, and replayed using Adobe's Audition™ software, Sound Devices USBPre™ acoustical interface, and professional grade headphones. The Soundscape Database software (Ric Hupulo, formerly of the Natural Sounds Program, Ft. Collins, CO) was used to analyze the audibility data. The entire 24-hour period was collected and analyzed but the time period 8 am to 4 pm (120 samples totaling 20 minutes per day) is reported here as prescribed in the 2009 YNP Winter Use Plan Environmental Assessment (NPS 2009).

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

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

It was increasingly difficult to identify sound sources as distances increased from the recording location to the sound source. Therefore sound source codes are hierarchal (e.g., snowmobile; oversnow vehicle; motorized sound; non-natural sound; unknown). The most specific identification possible was used. 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 hours between 8 am and 4 pm at Madison Junction 2.3, Cygnet Lake Roadside, Mammoth Canary Springs, and Middle Barronette Meadow. At Madison Junction 2.3 these eight hours were combined with 16 hours collected the last two winters for a total of 24 hours. The days chosen to represent each hour were randomly selected. Continuous recordings were analyzed for each of these 48 hours. Noise-free intervals were not calculated for Old Faithful or Canyon Village 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.

Sound levels

Sound pressure levels (decibels) were compiled and common acoustic metrics were calculated using HourlyMetrics™ software (Ric Hupalo, formerly of the NPS Natural Sound Program, Ft. Collins, CO). Wind contamination (distortion) caused false sound levels when wind speeds exceeded the capacity of the microphone windscreens. Therefore, data collected when wind speeds exceeded 11 mph (5 meters per second) were deleted from analyses at the three winter-long sites. Strong wind is a natural phenomenon and deleting periods of time with strong winds would artificially lower estimates of natural ambient sound levels during these wind events. This potential bias was not a major concern because the number of seconds that were deleted was small compared to the total number of seconds that were measured, and estimating natural ambient sound levels was not a primary objective of this study. Acoustic data collected during visits to the monitoring site were also deleted from analyses.

This report relies on a number of common acoustical metrics for the sound level data and descriptive statistics, mostly medians, for the audibility data. The real distribution of data points is not revealed when only medians are displayed. A disadvantage of using only medians is that knowledge of these other values is often valuable for interpretation, therefore minimum and maximum values are also given. Because estimates of variability beyond the minimum and maximum values are also desirable, information about the sound levels exceeded 10, 50, and 90 percent of the time is provided.

A wealth of biological information, as well as sound level data, is contained within this study's acoustic dataset. These additional data, substantially not yet analyzed, are available for future study.

See Appendix C for acoustical standards and thresholds of the 2000, 2003, 2004, and 2007 Winter Use Plans of Yellowstone and Grand Teton National Parks and the John D. Rockefeller, Jr., Memorial Parkway. See Appendix D for a discussion and examples of a technique to visualize daily sound levels. This technique provides another avenue to understand the natural soundscape and the sound impact of oversnow vehicles. See Appendix E for the results of a multi-year observational study that estimates the proportion of usage categories for OSVs (e.g., percent of total snowmobiles driven by park visitors). See Appendix F for additional considerations of OSV percent time audible summaries. See Appendix G for results of standardized pass-by sound level measurements of several snowcoaches and snowmobiles. See Appendix H for standardized measurements of the interior sound levels of several snowcoaches.

## 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 six locations in YNP, December 2011-March 2012. Daily average number of guided snowmobiles was 162/day for the 92-day winter use season, excluding OSVs originating from Old Faithful. Total number of days analyzed, 121.

| Middle Barronette Meadow | Canyon Village Developed Area | Mammoth Canary Springs | Cygnet Lake Roadside | Old Faithful Weather Station | Madison Junction 2.3 |
|---|---|---|---|---|---|
| 11 days | 13 days | 16 days | 20 days | 30 days | 31 days |
| 8 Feb 12 | 15 Dec 11 | 25 Jan 12 | 2 Jan 12 | 15 Dec 11 | 15 Dec 11 |
| 10 Feb 12 | 18 Dec 11 | 27 Jan 12 | 5 Jan 12 | 18 Dec 11 | 18 Dec 11 |
| 12 Feb 12 | 21 Dec 11 | 29 Jan 12 | 8 Jan 12 | 21 Dec 11 | 21 Dec 11 |
| 14 Feb 12 | 24 Dec 11 | 31 Jan 12 | 11 Jan 12 | 24 Dec 11 | 24 Dec 11 |
| 16 Feb 12 | 27 Dec 11 | 2 Feb 12 | 14 Jan 12 | 27 Dec 11 | 27 Dec 11 |
| 18 Feb 12 | 2 Jan 12 | 4 Feb 12 | 17 Jan 12 | 30 Dec 11 | 30 Dec 11 |
| 20 Feb 12 | 5 Jan 12 | 5 Feb 12 | 20 Jan 12 | 2 Jan 12 | 2 Jan 12 |
| 22 Feb 12 | 8 Jan 12 | 8 Feb 12 | 24 Jan 12 | 5 Jan 12 | 5 Jan 12 |
| 24 Feb 12 | 11 Jan 12 | 10 Feb 12 | 27 Jan 12 | 8 Jan 12 | 8 Jan 12 |
| 26 Feb 12 | 14 Jan 12 | 12 Feb 12 | 30 Jan 12 | 11 Jan 12 | 11 Jan 12 |
| 28 Feb 12 | 17 Jan 12 | 16 Feb 12 | 2 Feb 12 | 14 Jan 12 | 14 Jan 12 |
| | 20 Jan 12 | 18 Feb 12 | 5 Feb 12 | 17 Jan 12 | 17 Jan 12 |
| | 22 Jan 12 | 20 Feb 12 | 8 Feb 12 | 20 Jan 12 | 20 Jan 12 |
| | | 22 Feb 12 | 11 Feb 12 | 23 Jan 12 | 24 Feb 12 |
| | | 2 Mar 12 | 14 Feb 12 | 27 Jan 12 | 27 Jan 12 |
| | | 3 Mar 12 | 17 Feb 12 | 30 Jan 12 | 30 Jan 12 |
| | | | 20 Feb 12 | 2 Feb 12 | 2 Feb 12 |
| | | | 22 Feb 12 | 4 Feb 12 | 5 Feb 12 |
| | | | 26 Feb 12 | 7 Feb 12 | 7 Feb 12 |
| | | | 29 Feb 12 | 14 Feb 12 | 10 Feb 12 |
| | | | | 16 Feb 12 | 13 Feb 12 |
| | | | | 19 Feb 12 | 16 Feb 12 |
| | | | | 22 Feb 12 | 19 Feb 12 |
| | | | | 25 Feb 12 | 22 Feb 12 |
| | | | | 28 Feb 12 | 25 Feb 12 |
| | | | | 2 Mar 12 | 28 Feb 12 |
| | | | | 5 Mar 12 | 2 Mar 12 |
| | | | | 8 Mar 12 | 5 Mar 12 |
| | | | | 11 Mar 12 | 7 Mar 12 |
| | | | | 14 Mar 12 | 11 Mar 12 |
| | | | | | 14 Mar 12 |
| NA | 118/day[1] | NA | 175/day[1] | 154/day[1] | 158/day[1] |

[1]Average daily number of guided snowmobiles that entered Yellowstone NP during sampling days. Average number of snowmobiles was calculated using all snowmobiles entering Yellowstone. Not all snowmobiles would pass by each site. Administrative OSV use was not counted in these totals. Average daily number of snowcoaches for the winter use season was 26/day.

Table 3. Hours and dates used for analysis of noise-free intervals at Madison Junction, Cygnet Lake Roadside, Mammoth Canary Springs, and Middle Barronette Meadow. Total number of days and hours analyzed, 48.

| | **Madison Junction 2.3** | **Cygnet Lake Roadside** | **Mammoth Canary Springs** | **Middle Barronette Meadow** |
|---|---|---|---|---|
| **Hour** | **Date** | **Date** | **Date** | **Date** |
| **8 am** | **12/24/09, 2/22/11, 12/25/11** | **2/13/12** | **1/25/12** | **2/26/12** |
| **9 am** | **1/4/10, 1/7/11, 1/19/12** | **1/8/12** | **1/27/12** | **2/13/12** |
| **10 am** | **1/10/10, 2/4/11, 2/27/12** | **1/24/12** | **2/9/12** | **2/8/12** |
| **11 am** | **1/15/10, 12/19/10, 1/28/12** | **1/20/12** | **1/28/12** | **2/24/12** |
| **12 pm** | **1/30/10, 2/7/11, 12/27/11** | **1/2/12** | **2/18/12** | **2/25/12** |
| **1 pm** | **2/5/10, 3/2/11, 2/2/12** | **3/1/12** | **2/20/12** | **2/27/12** |
| **2 pm** | **2/10/10, 1/21/11, 2/24/12** | **1/7/12** | **1/29/12** | **2/21/12** |
| **3 pm** | **2/20/10, 12/25/10, 1/18/12** | **2/22/12** | **2/7/12** | **2/16/12** |

Table 4. Dates used for sound level analyses at six locations in YNP, December 2011-March 2012. Total hours 8,013.

| | |
|---|---|
| Old Faithful (1,883 hours)<br>15 December 2011-15 March 2012 | Madison Junction 2.3 (2,150 hours)<br>15 December 2010-15 March 2011 |
| Cygnet Lake Roadside (1,816 hours)<br>15 December 2011-1 March 2012 | Canyon Village Developed Area (943 hours)<br>15 December 2011-23 January 2012 |
| Mammoth Canary Springs (717 hours)<br>24 January-23 February 2012 | Middle Barronette Meadow (504 hours)<br>7 February-1 March 2012 |

Audibility:

Each audible sound (snowmobile, wheeled vehicle, animal, aircraft, wind, thermal activity, etc.) was identified from the 120 10-second digital recording samples each day during 8 am-4 pm. The proportion of each sound source sample out of the possible 120 was used to calculate the percent time audible for each sound source; however, only the snowmobile, snowcoach and wind percent time audible is presented. 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 (or wheeled vehicles) at travel corridors and backcountry sites were occasional aircraft. The average number of snowcoaches entering YNP during the winter season was 26/day (range 9-54), with an additional daily average of nine snowcoaches originating from Old Faithful. The average number of guided snowmobiles entering YNP during the winter season was 162/day (range 24-251), with an additional daily average of seven guided snowmobiles originating from Old Faithful. See Table 2 for further details. The percent time audible calculations were based on days throughout the entire winter use season, however snowmobiles and snowcoaches with metal skis were prohibited from entering the park’s west and north entrances until 1 January 2012 when the snow conditions on the road had improved.

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

A related audibility issue involves an acoustical metric called the noise-free interval (NFI). NFIs measure the uninterrupted periods of time when only silence or natural sounds are audible. For the purposes of this report, NFIs were the times when no oversnow or wheeled vehicles or aircraft (on average audible 5% or less of the day) were audible. Using logic and common sense, the number and distribution of vehicles largely determine the NFI. Given the same number of vehicles, NFIs measured near travel corridors would be longer with larger rather than smaller groups (however as group size increases they would likely be heard at increasing distances). A particular percent time audible can have varying NFIs. For example, if OSVs were audible for 50% of an hour, depending on the distribution of these vehicles they could all be audible in the first 30 minutes and not audible the remaining 30 minutes. Or OSVs could be audible every other 10 minute period during the hour. The NFI of the first scenario would be 30 minutes but only 10 minutes for the second. The management requirement for groups of guided snowmobiles have increased the NFIs at YNP compared to non-grouped snowmobiles (personal observation, and Appendix D; Fig. D-7 and D-8).

Audibility depends on the sound level of and distance from the sound source as well as the presence of 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 ninth full winter (Table 6). 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. For the winter use season the average daily percent time audible for snowmobiles and snowcoaches was 66% (*SD* = 11%) within the developed area at Old Faithful, (Fig. 2). This compares to 61% (*SD* = 10%) the previous winter and 55-69% during the seven winter use seasons before that (Table 6). Figure 2 also shows lower OSV audibility in December when all snowmobiles and snowcoaches with metal skis were prohibited from entering the west and north entrances due to poor snow conditions on those groomed roads. Six (20%) of the 30 days analyzed exceeded the 2009 WUP audibility threshold of 75% for developed areas.

Oversnow vehicles traveling on the main road and within the Old Faithful developed area were audible at this site. Wind, depending on direction and speed, can increase or decrease the distance OSV sounds are audible. However, though typically OSVs are heard at greater distances during calm wind conditions, and there appears to be no strong association between days with low to moderate wind and 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 during 8 am and 9 am hours than during the mid-morning lull, but then increased as visitors arrived closer to mid-day. On average, of the OSVs that were identified, snowmobiles were audible for 25% of the day versus 18% for snowcoaches (Fig. 3). OSVs were audible on average 74% of the time during the busiest (1 pm) 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.

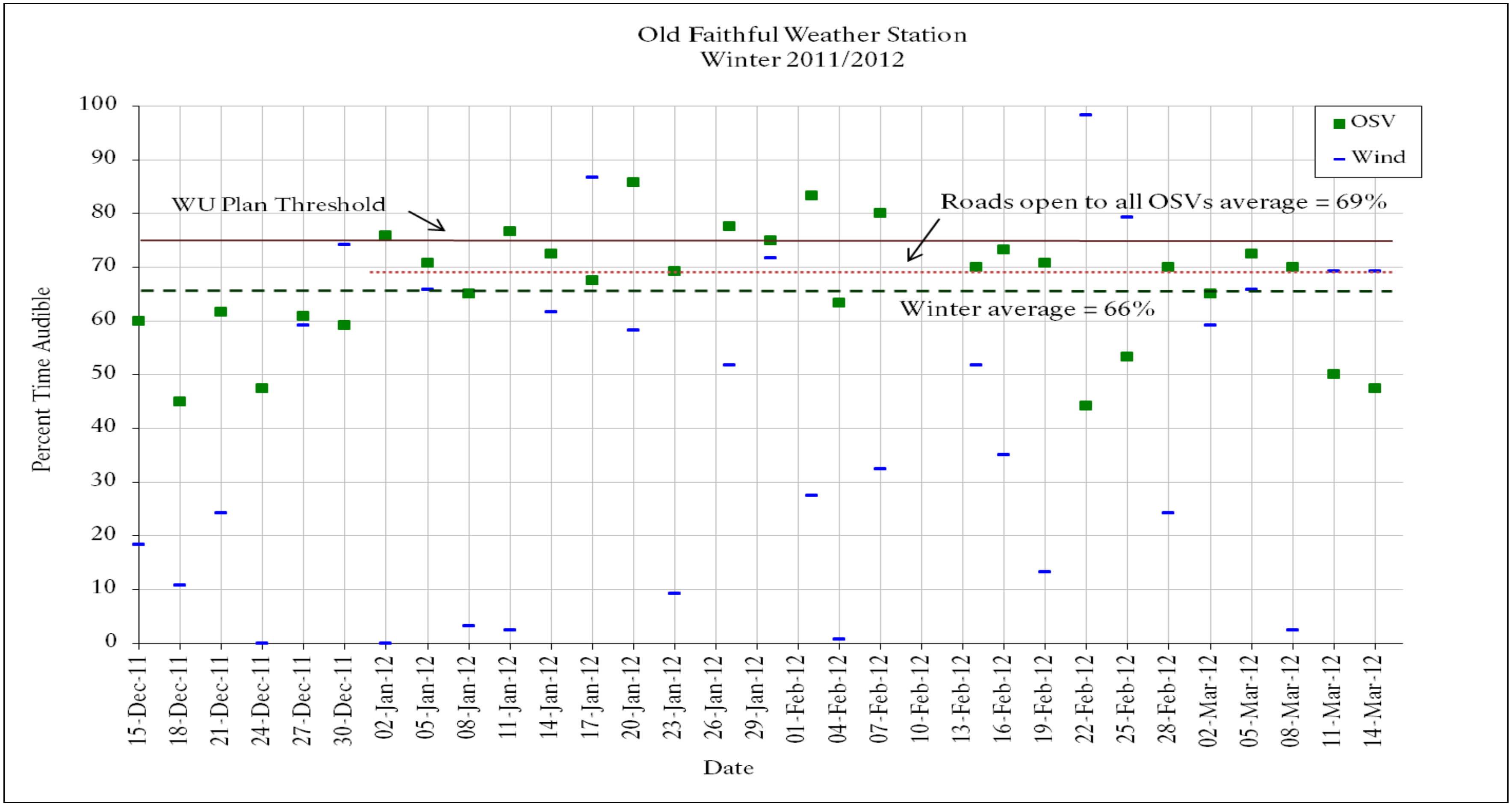


Figure 2. The percent time audible (8 am - 4 pm) for snowmobiles and snowcoaches, and wind by date at Old Faithful Weather Station, YNP, 15 December 2011-15 March 2012. The red dotted line indicates the average percent time audible excluding the time period when snowmobiles and snowcoaches with metal skis were prohibited from entering the west and north entrances due to poor snow conditions on those groomed roads. The brown solid line indicates the winter use plan threshold for percent time audible in developed areas.

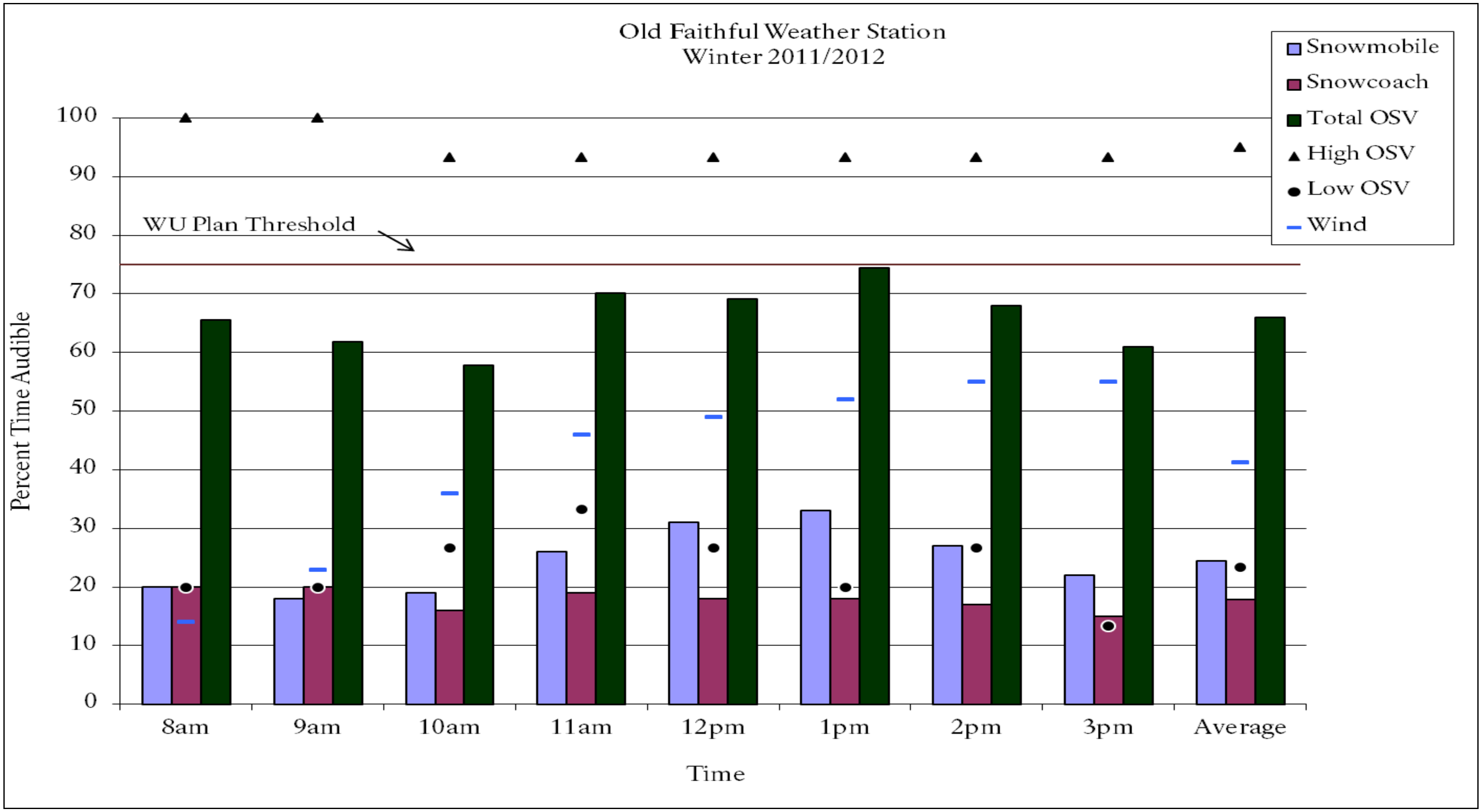


Figure 3. The season average percent time audible by hour of snowmobiles (left light blue bar), snowcoaches (middle maroon bar), and a total OSV category including unidentified OSVs (right dark green bar), and the season's maximum and minimum OSV percent time audible values by hour at Old Faithful Weather Station, YNP from 8 am - 4 pm, 15 December 2011-15 March 2012. The brown solid line indicates the winter use plan threshold for percent time audible in developed areas.

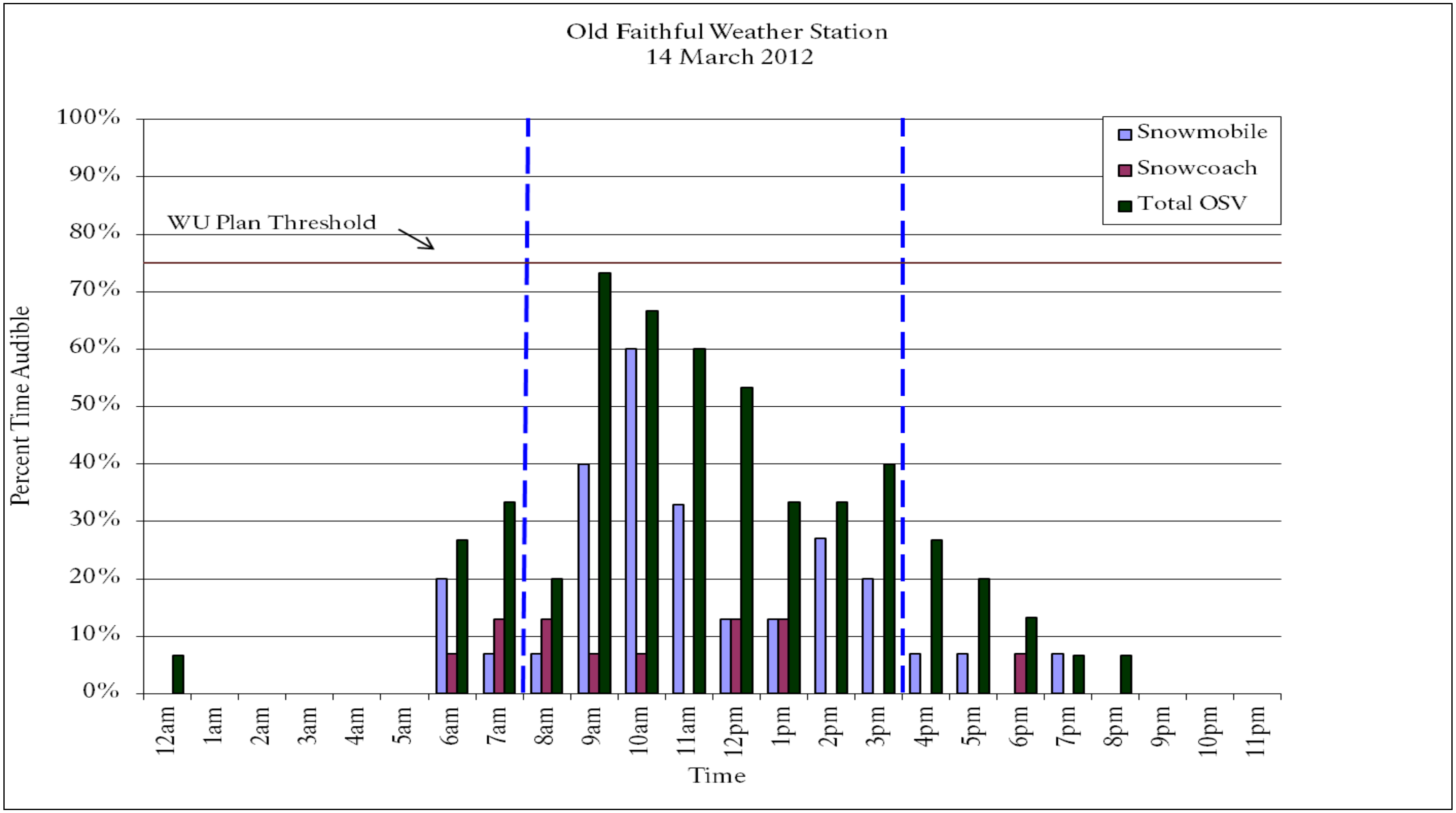


Figure 4. The percent time audible by hour of snowmobiles (left light blue bar), snowcoaches (middle maroon bar), and a total OSV category including unidentified OSVs (right dark green bar) at Old Faithful Weather Station, YNP, 14 March 2012. The winter use analysis time period is between the vertical dashed lines. The brown solid line indicates the winter use plan threshold for percent time audible in developed areas.

*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 nine winter use seasons (Table 4) 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 ravens and other birds were audible daily. Aircraft (a season total of 3 helicopters, 18 propeller aircraft, and 108 jets) were audible for a daily (8 am and 4 pm) average of 3% during the winter use season.

Snowmobiles and snowcoaches were audible for an average of 45% (*SD* = 17%) of the time during the entire winter use season (Fig. 5). The range during the previous seven full seasons was 47%-59% (Table 6). Figure 5 also shows the lower OSV percent time audible at the beginning of the winter use season due to the prohibition of snowmobiles and snowcoaches with metal skis through the west and north entrances. All entrances were open to all OSVs beginning on 1 January 2012. The OSV percent time audible exceeded 50% for nine (19%) of 31 days analyzed during the winter 2011-2012 (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. The average OSV percent time audible exceeded 50% during the hours of 9 am, 10 am, and 3 pm. 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 three winters combined, the average noise-free interval at Madison Junction 2.3 was three minutes and 21 seconds (Figure 7) during 8 am to 4 pm. Noon had the longest average noise-free interval (over 13 minutes) and longest maximum NFI (over 23 minutes), and 10 am had the shortest average NFI (30 seconds) and shortest maximum NFI (under 2 minutes) during the winter use day. Three hours were analyzed for each of these eight hours of the day. Additional samples would give a better representation of typical noise-free conditions, however, this noise-free interval analysis again reflects the pulse of OSVs traveling by the site during the morning and afternoon hours (Figure 7).

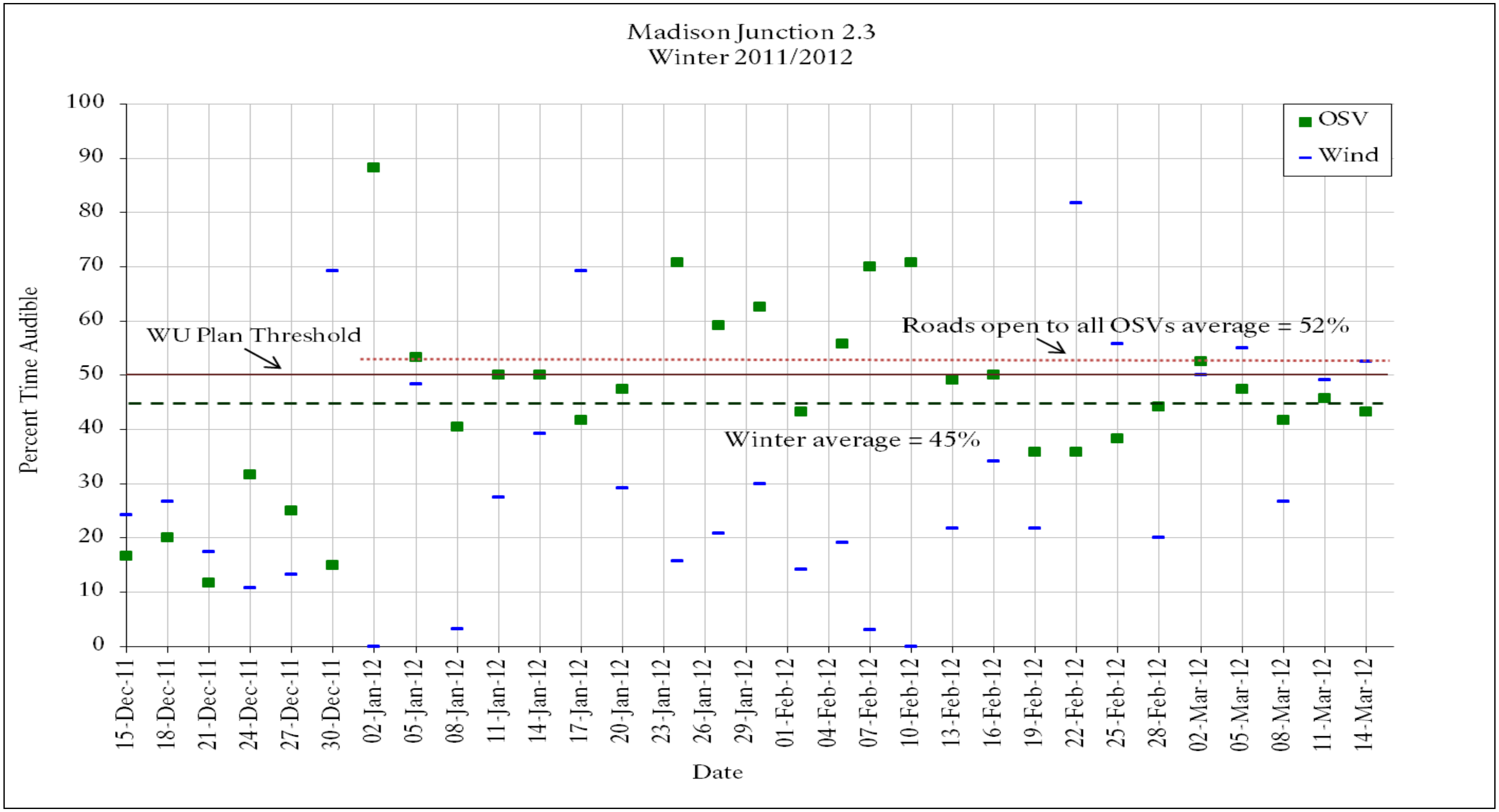


Figure 5. The average percent time audible (8 am - 4 pm) by date of snowmobiles and snowcoaches, and wind at 2.3 miles 3.7 km) west of Madison Junction along the West Entrance Road YNP, 15 December 2011-15 March 2012. The red dotted line indicates the average percent time audible excluding the time period when snowmobiles and snowcoaches with metal skis were prohibited from entering the west and north entrances due to poor snow conditions on those

groomed roads. The brown solid line indicates the winter use plan threshold for percent time audible along travel corridors.

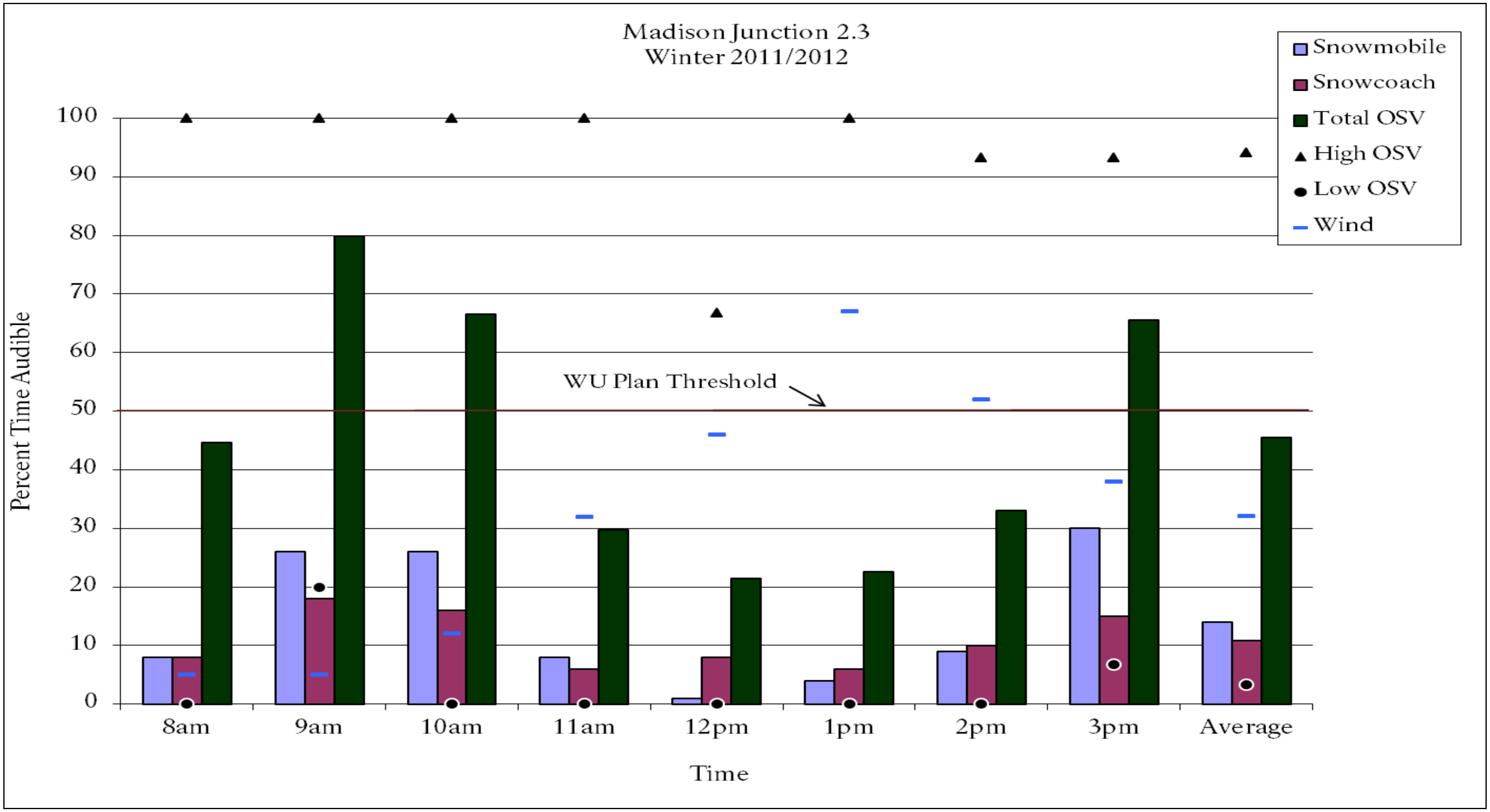


Figure 6. The average percent time audible by hour of snowmobiles and snowcoaches, and total OSVs including unidentified OSVs, and the season's maximum and minimum OSV percent time audible values by hour at 2.3 miles (3.7

km) west of Madison Junction along the West Entrance Road, YNP, 15 December 2011-15 March 2012. The brown solid line indicates the winter use plan threshold for percent time audible along travel corridors.

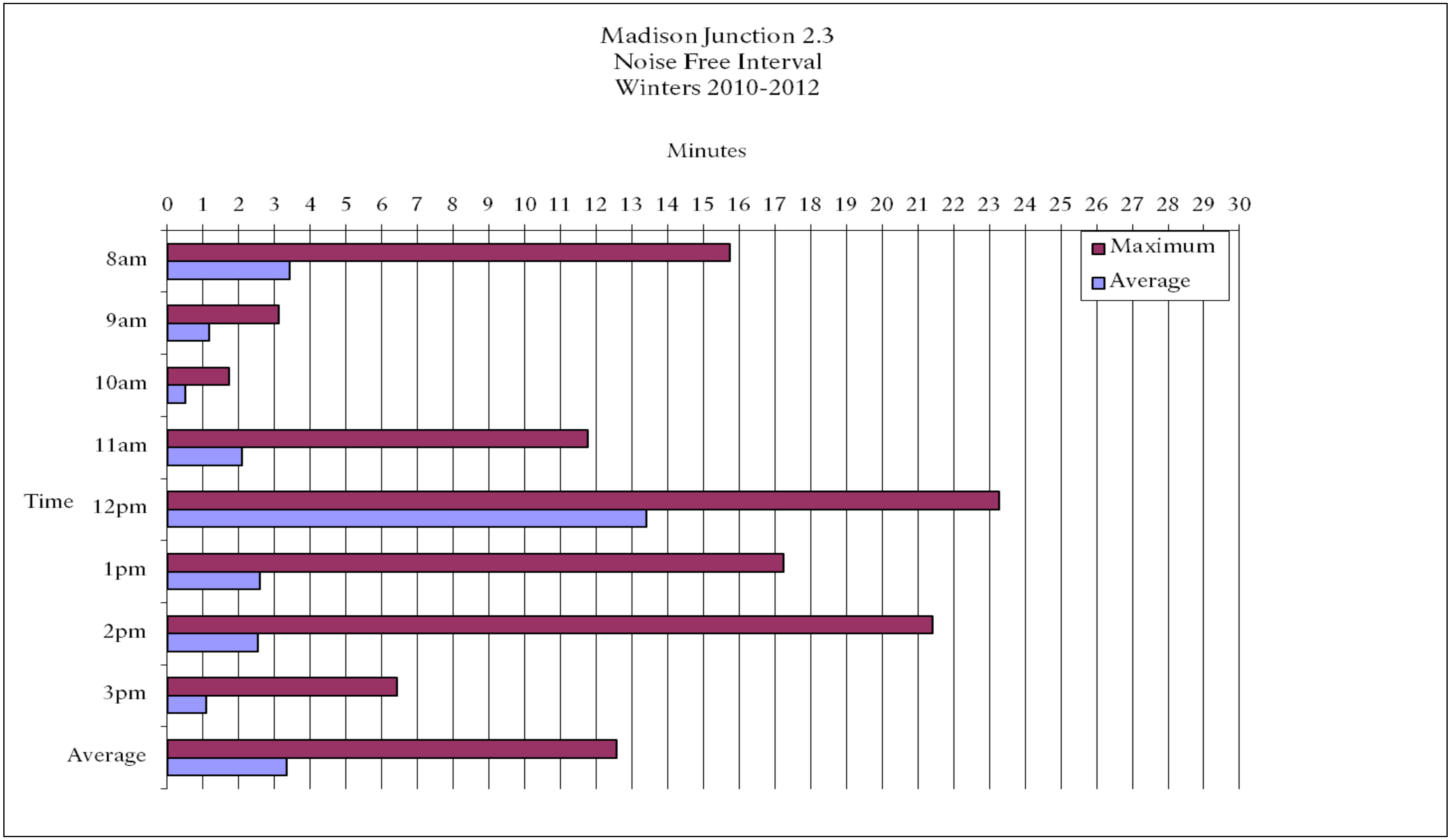

Figure 7. Noise-free interval measured at Madison Junction 2.3 during the winters of 2009-2010, 2010-2011, and 2011-2012, YNP. See Table 3 for dates used, and text for more details.

*Cygnet Lake Roadside*

Acoustic monitoring data were collected between Norris and Canyon for the first time this winter season. This location was 0.5 miles (0.8 km) west of the Cygnet Lake Trailhead, 100 feet (30 m) south of the groomed road.

Oversnow vehicles were audible an average of 22% (*SD* = 14%) of the time between 8 am and 4 pm during the sampling period (Fig. 8). Oversnow vehicles were audible over 50% of the day during one (5%) of 20 days analyzed. Strong wind off the high plateau to the south was audible on many days. Wind obscured the faint sound levels of distant vehicle sounds on most days (see 22 February 12; Fig. 8).

The 11 am hour was the only hour of the 8-hour day with average OSV audibility over 30% (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). Only the 3 pm hour had a maximum audibility of more than 80% on at least one day that was analyzed (Fig. 9). When the wind was not present, this site had very low ambient sound levels (Fig. 23). OSVs were then audible at long distances.

The average noise-free interval at Cygnet Lake Roadside was three minutes and 56 seconds (Figure 10). The 1 pm hour had the longest average NFI (9 minutes and 6 seconds) and longest maximum NFI (over 28 minutes), and the noon hour had the shortest average NFI (48 seconds) and shortest maximum NFI (4 minutes and 15 seconds). Some hours analyzed at this site had strong wind that increased the NFI compared to what would be measured when the wind was calm. 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).

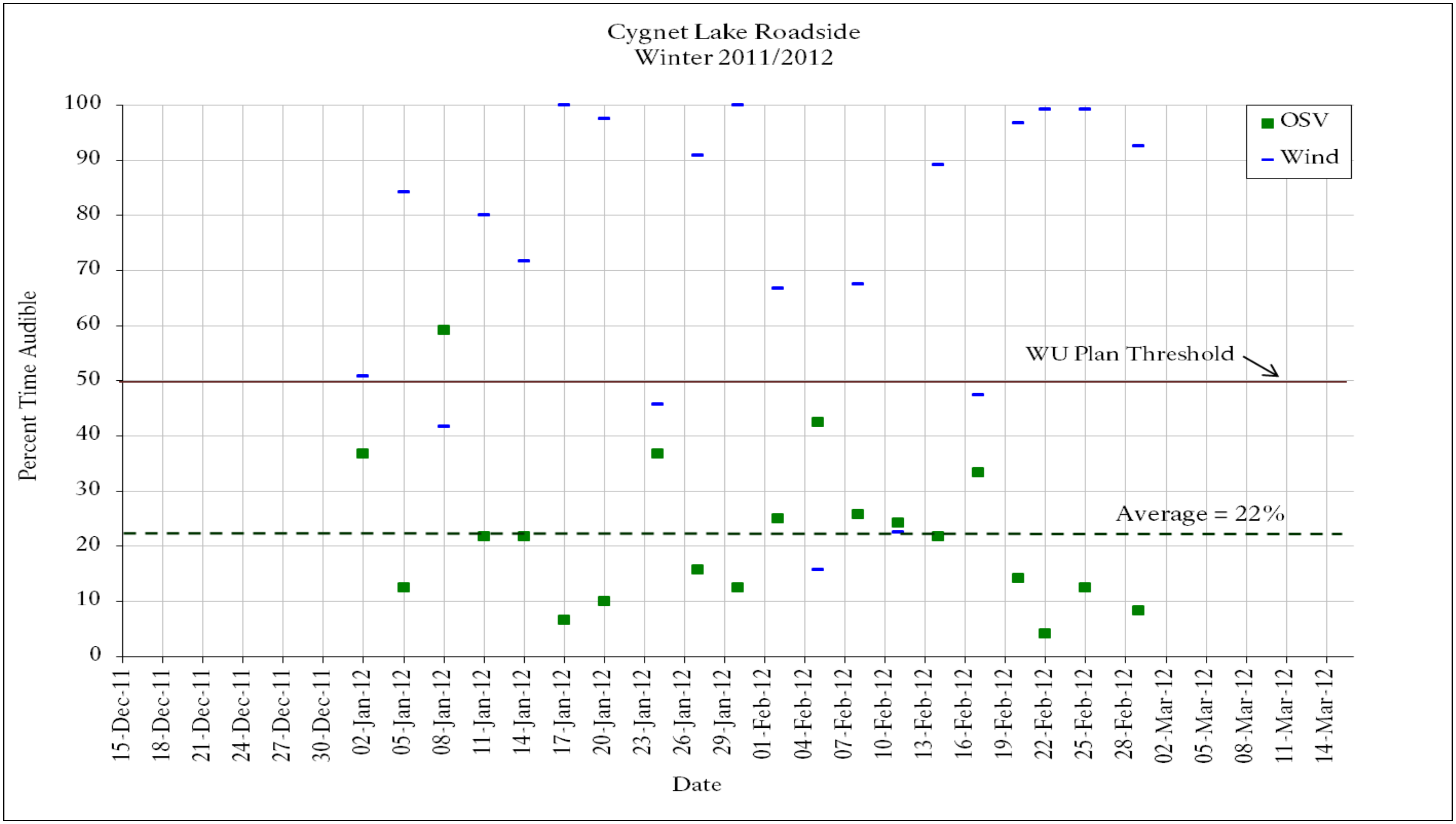

Figure 8. The average percent time audible (8 am - 4 pm) by date of oversnow vehicles, and wind at Cygnet Lake Roadside, YNP, 1 January-1 March 2012. The brown solid line indicates the winter use plan threshold for percent time audible along travel corridors.

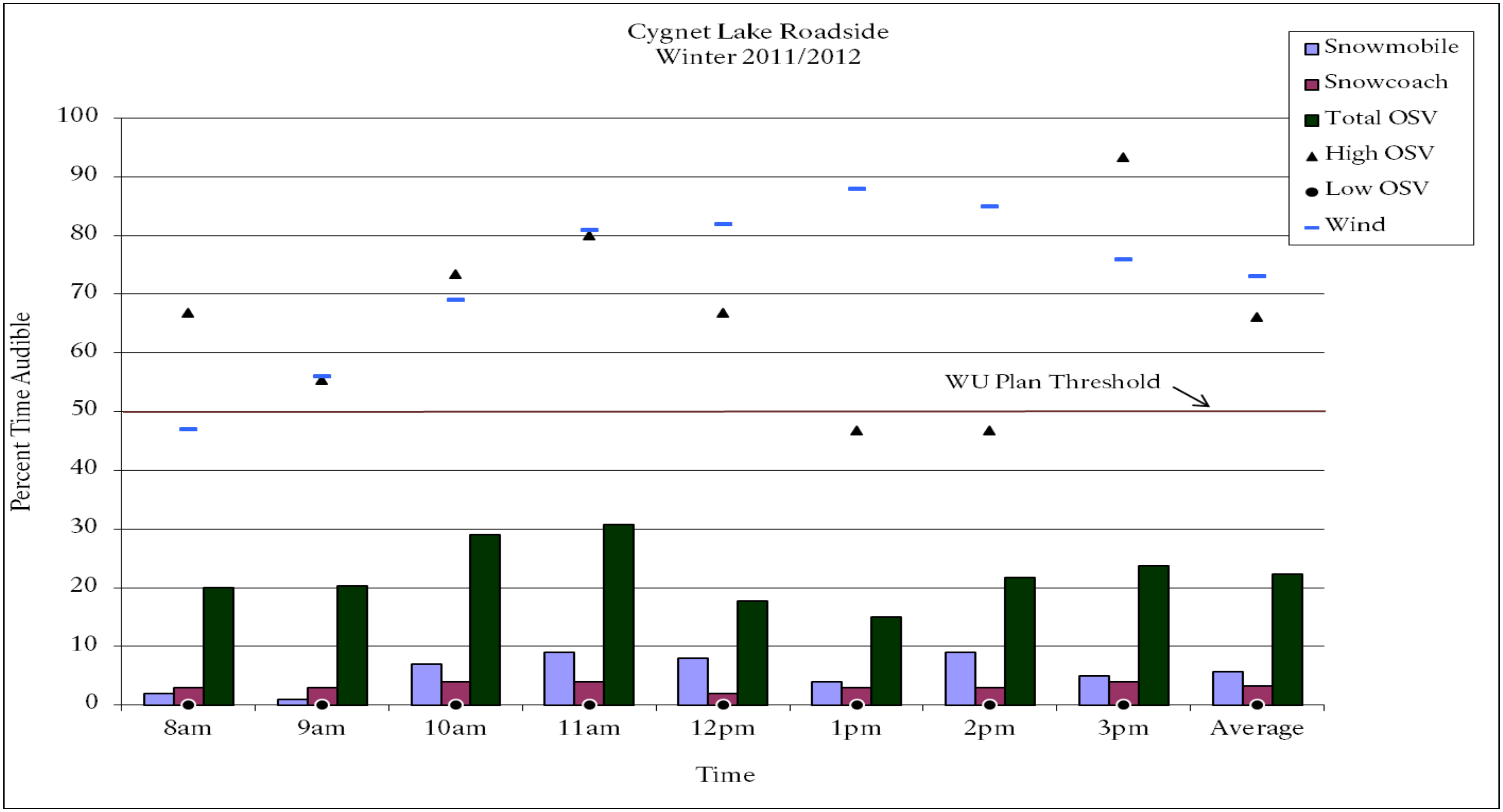


Figure 9. The average percent time audible by hour of snowmobiles, snowcoaches, and total OSVs including unidentified OSVs, and the season's maximum and minimum OSV percent time audible values by hour at Cygnet Lake Roadside, YNP, 1 January-1 March 2012. The brown solid line indicates the winter use plan threshold for percent time audible along travel corridors.

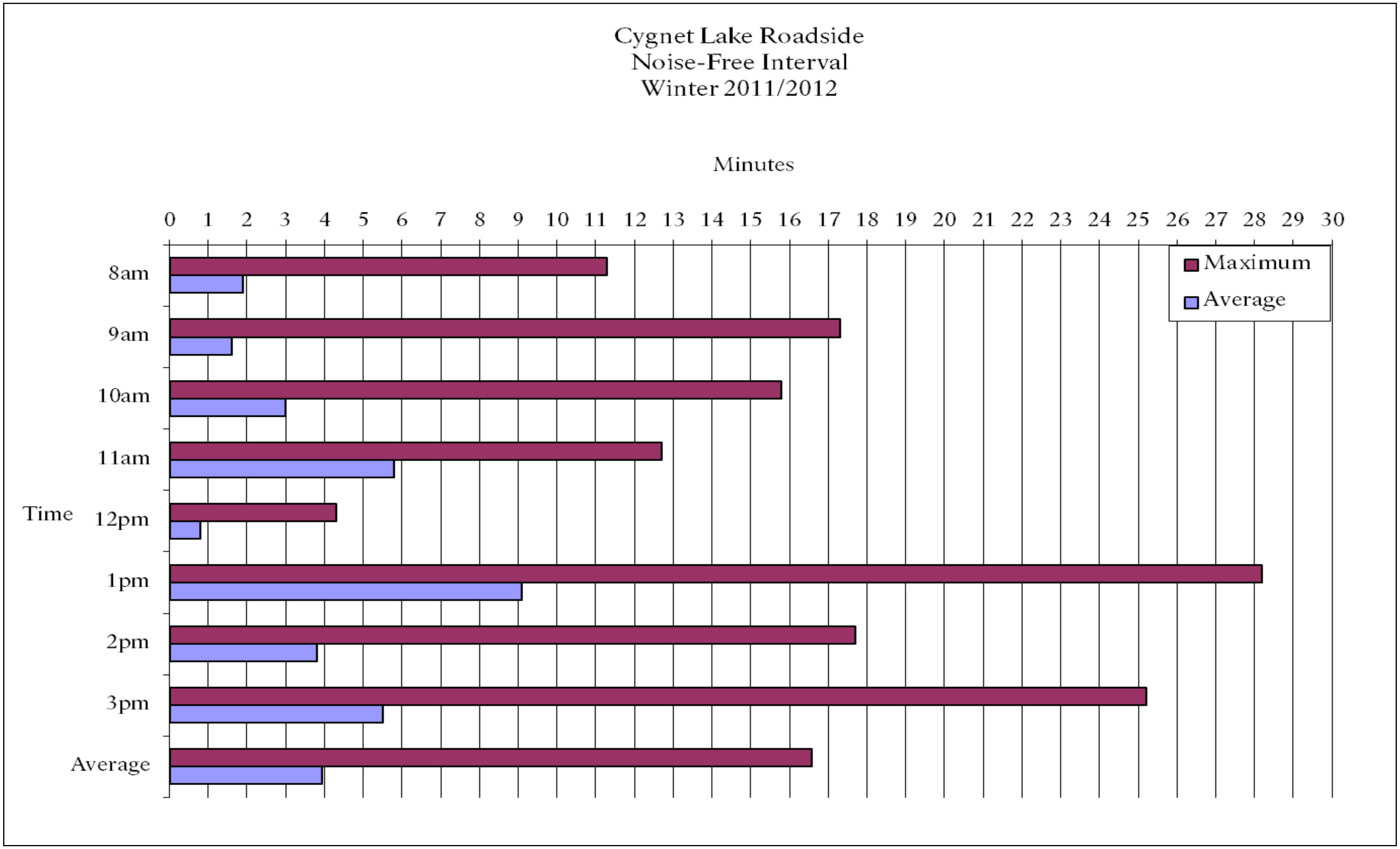


Figure 10. Noise-free interval at Cygnet Lake Roadside during the winter of 2011-2012, YNP. See Table 3 for dates used and text for more details.

*Canyon Village Developed Area*

Acoustic monitoring data were collected near the Canyon Visitor Center for the first time this winter season. This site was between the Visitor Center and the four-way stop Canyon intersection.

Oversnow vehicles were audible an average of 38% (*SD* = 23%) of the time between 8 am and 4 pm during the 14 days analyzed in December and January (Fig. 11). This site shows the obvious change in OSV traffic once the park's west and north entrances were open for visitor snowmobiles and snowcoaches with metal skis on 1 January. The percent time OSVs were audible climbed to 56% for the eight days analyzed after 1 January.  Zero of 14 days (0%) had OSV audibility over the WUP developed area threshold of 75%.

The hourly average OSV audibility had neither the bi-modal distribution common on travel corridors near the park entrances nor a pronounced midday peak that is often shown at Old Faithful. The peak in average OSV audibility was at 11 am, and the lowest at 9 am (Fig. 12). In addition to average audibility, Figure 12 shows the range of OSV audibility for each hour of the day for the entire sampling period (labeled high and low OSV).

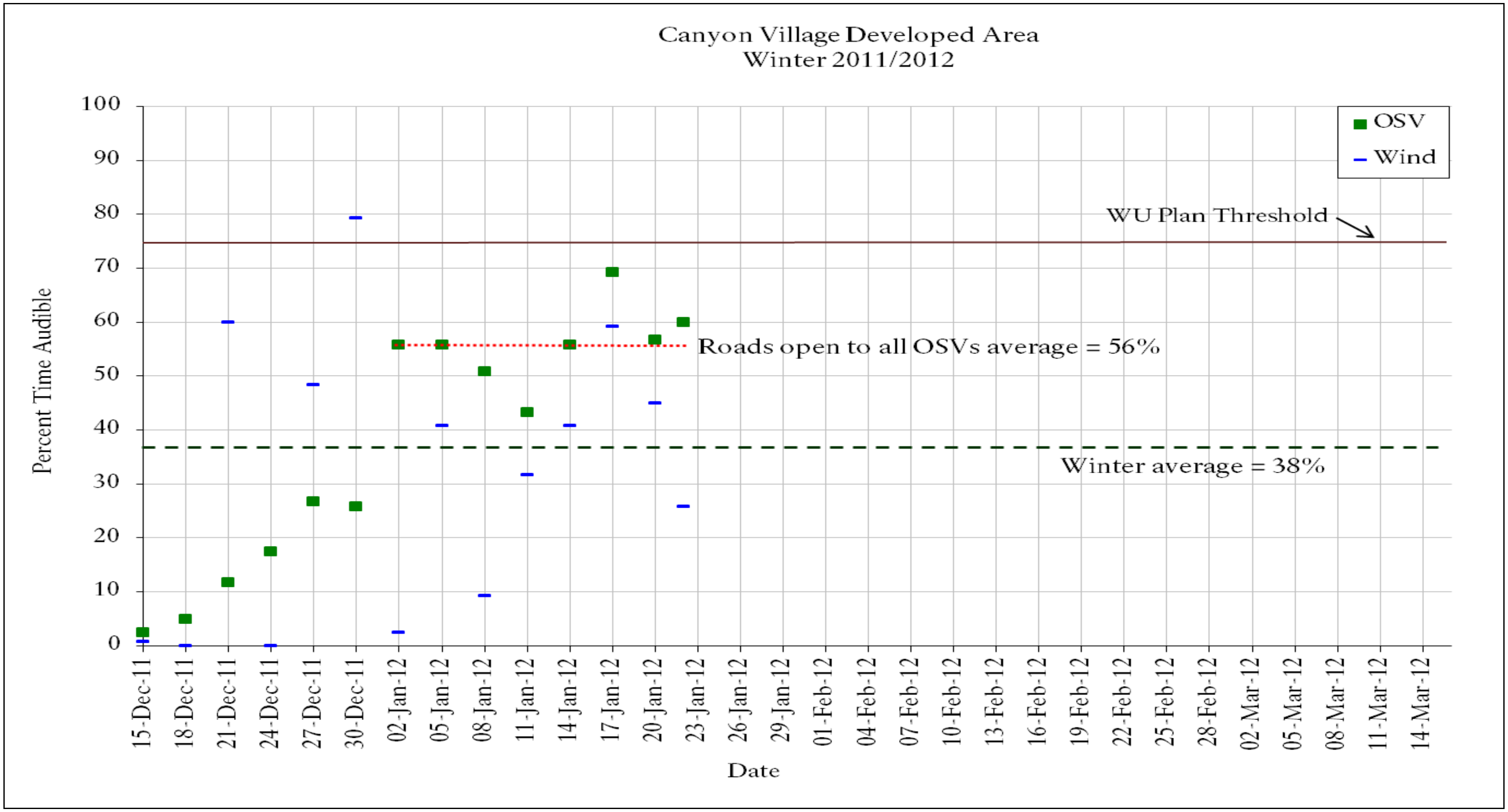


Figure 11. The average percent time audible (8 am - 4 pm) by date of oversnow vehicles, and wind at Canyon Village Developed Area, YNP, 15 December 2011- 22 January 2012. The red dotted line indicates the average percent time audible excluding the time period when snowmobiles and snowcoaches with metal skis were prohibited from entering the west and north entrances due to poor snow conditions on those groomed roads. The brown solid line indicates the winter use plan threshold for percent time audible along travel corridors.

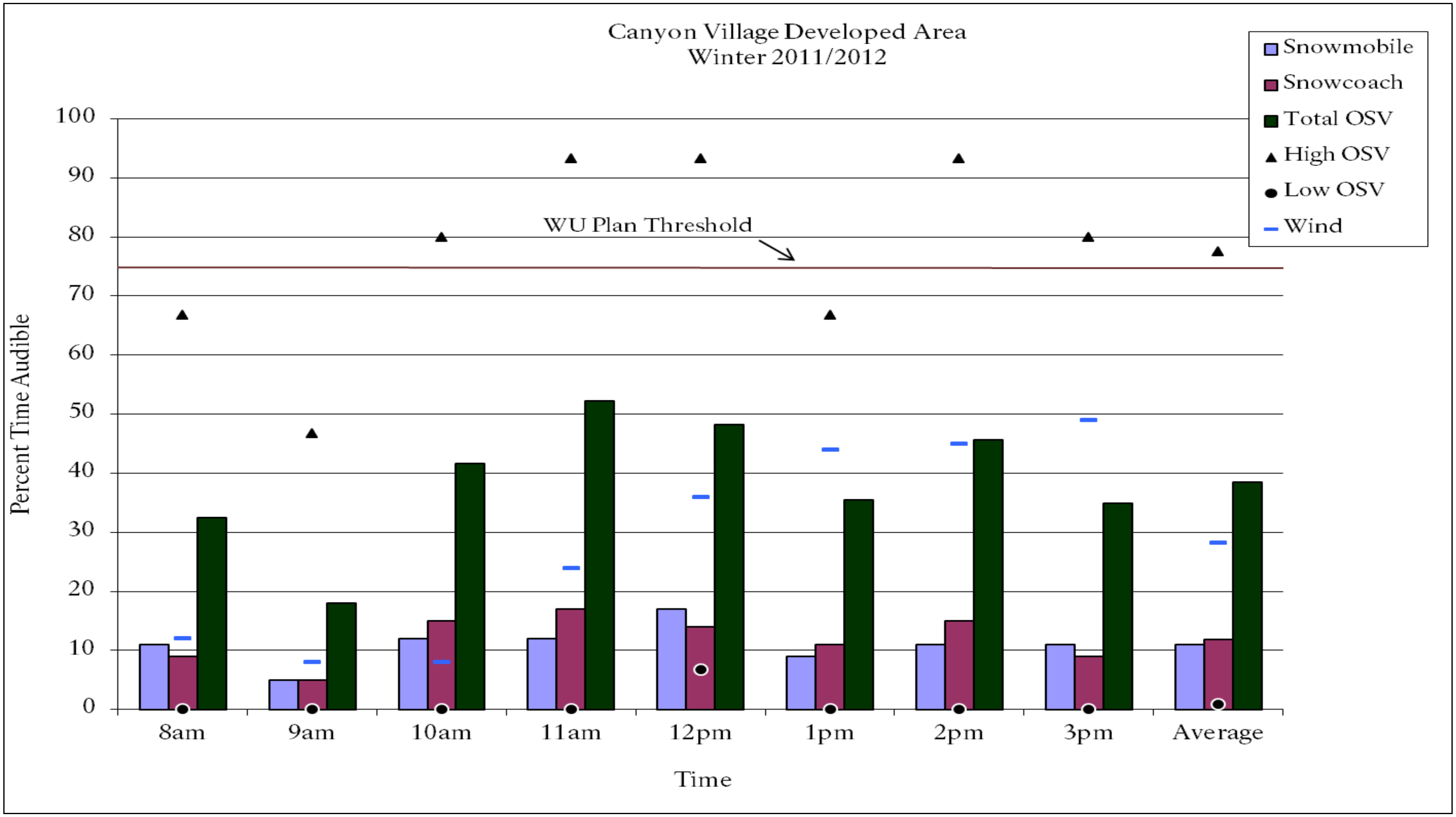


Figure 12. The average percent time audible by hour of snowmobiles, snowcoaches, and total OSVs including unidentified OSVs, and the season's maximum and minimum OSV percent time audible values by hour at Canyon Village Developed Area, YNP, 15 December 2011- 22 January 2012. The brown solid line indicates the winter use plan threshold for percent time audible along travel corridors.

Mammoth Canary Springs

Acoustic data were collected 175 feet (53 m) from the plowed road near Canary Springs between the Mammoth visitor service developed area and the park's maintenance area for the first time this winter season. This site was unusual because both snowcoaches and wheeled vehicles used the adjacent road. Snowcoaches without skis drove by this site en route between Mammoth and the groomed snow roads in the interior of the park. Wheeled vehicles also passed this site en route to the park's maintenance area and to the Mammoth Upper Terraces.

Oversnow vehicles were audible an average of 7% (*SD* = 7%) of the time between 8 am and 4 pm during the 15 days analyzed in January and February (Fig. 13). Wheeled vehicles were audible an average of 25% (*SD* = 7%) of the time between 8 am and 4 pm. Wind was audible on many days.

Snowcoach audibility peaked at 15% during the 8 am hour and remained below 10% for the rest of the eight hour analysis period (Fig. 14).

The average noise-free interval at Mammoth Canary Springs was 1 minute and 14 seconds (Figure 15). Only the 10 am hour had an average NFI more than two minutes (2 minutes and 42 seconds), and had the longest maximum NFI (less than 8 minutes). The 8 am hour had the shortest average noise-free intervals of 42 seconds, and the shortest maximum NFI (2 minutes and 30 seconds). Additional samples would give a better representation of typical noise-free intervals because only one hour was analyzed for each of these eight hours (Table 3).

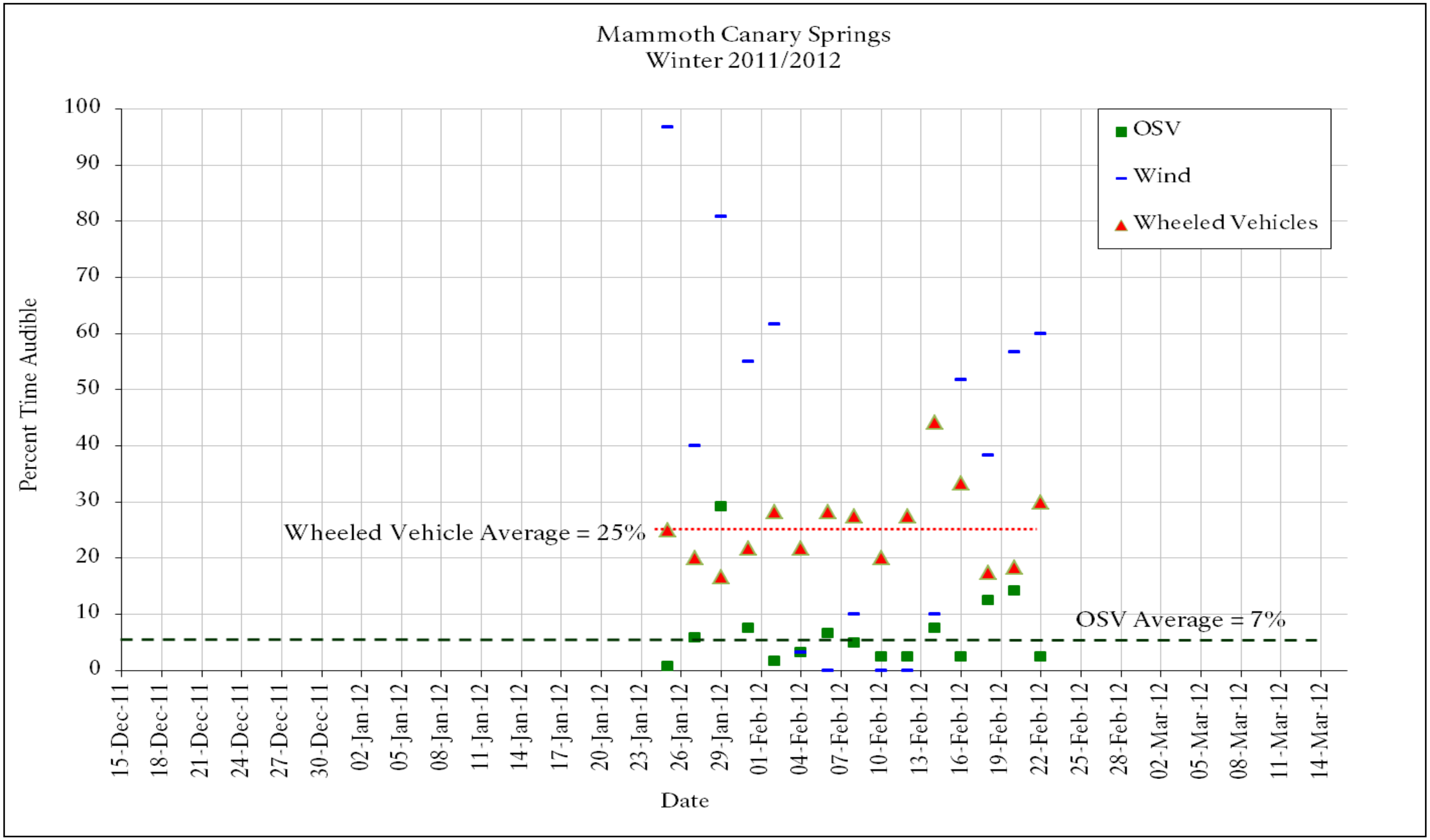

Figure 13. The average percent time audible (8 am - 4 pm) by date of oversnow vehicles, wheeled vehicles, and wind at Mammoth Canary Springs, YNP, 25 January – 22 February 2012.

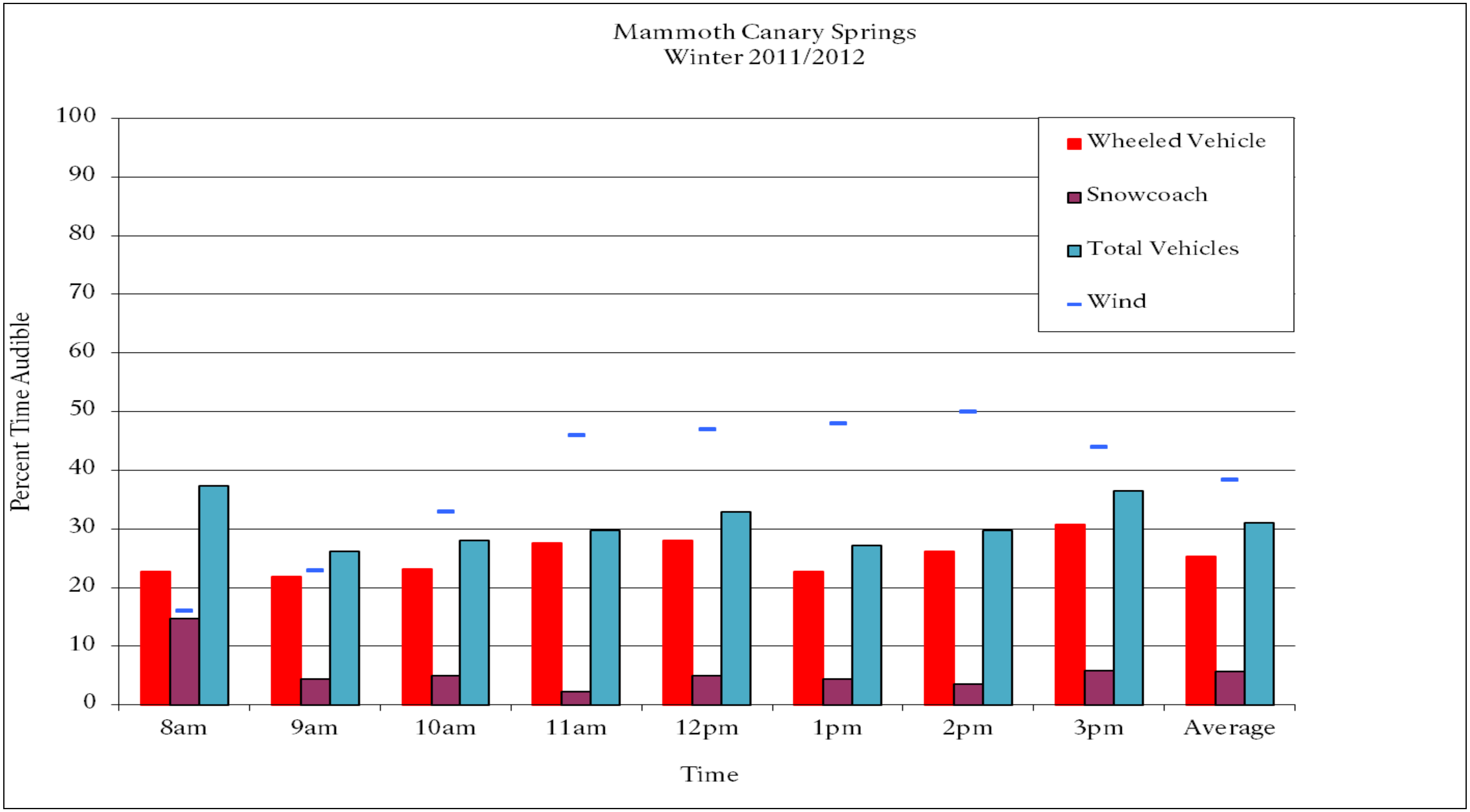


Figure 14. The average percent time audible (8 am - 4 pm) by hour of oversnow vehicles, wheeled vehicles, and wind (bars left to right) at Mammoth Canary Springs, YNP, 25 January – 22 February 2012.

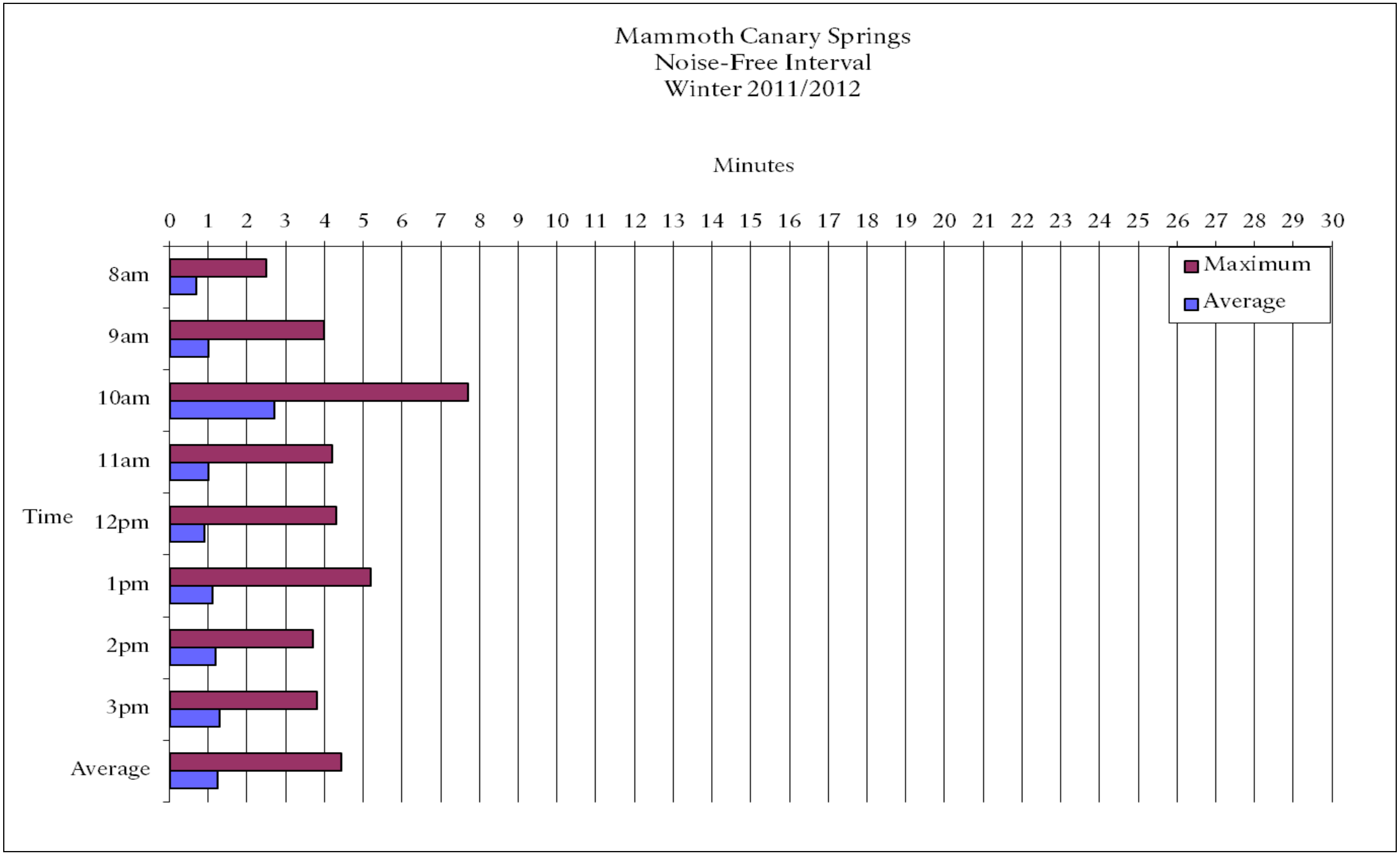


Figure 15. Noise-free interval as measured at Mammoth Canary Springs during the winter of 2011-2012, YNP. See Table 3 for dates used and text for more details.

*Middle Barronette Meadows*

Acoustic data were collected 100 feet (31 m) from the plowed road between Lamar Valley and the park's Northeast Entrance for the first time this winter season. The monitoring site was 6 miles west of the northeast entrance near Barronette Peak.

Wheeled vehicles were audible an average of 25% (*SD* = 11%) of the time between 8 am and 4 pm during the 11 days analyzed in February (Fig. 16). Wind was audible on many days and influenced the percent time audible of wheeled vehicles.

There was a slight bimodal distribution of wheeled vehicle audibility in the morning and afternoon (Fig. 17), similar to OSV audibility patterns near the park entrances.

The average noise-free interval at Middle Barronette Meadows was two minutes and 53 seconds (Figure 18). The 8 am hour had the longest average NFI (5 minutes and 42 seconds). The longest maximum NFI (19 ½ minutes) was during the noon hour. The 10 am hour had the shortest average NFI (1 minute). The shortest maximum NFI (3 minutes) was during the 3 pm hour. Additional samples would give a better representation of typical noise-free intervals because only one hour was analyzed for each of these eight hours (Table 3).

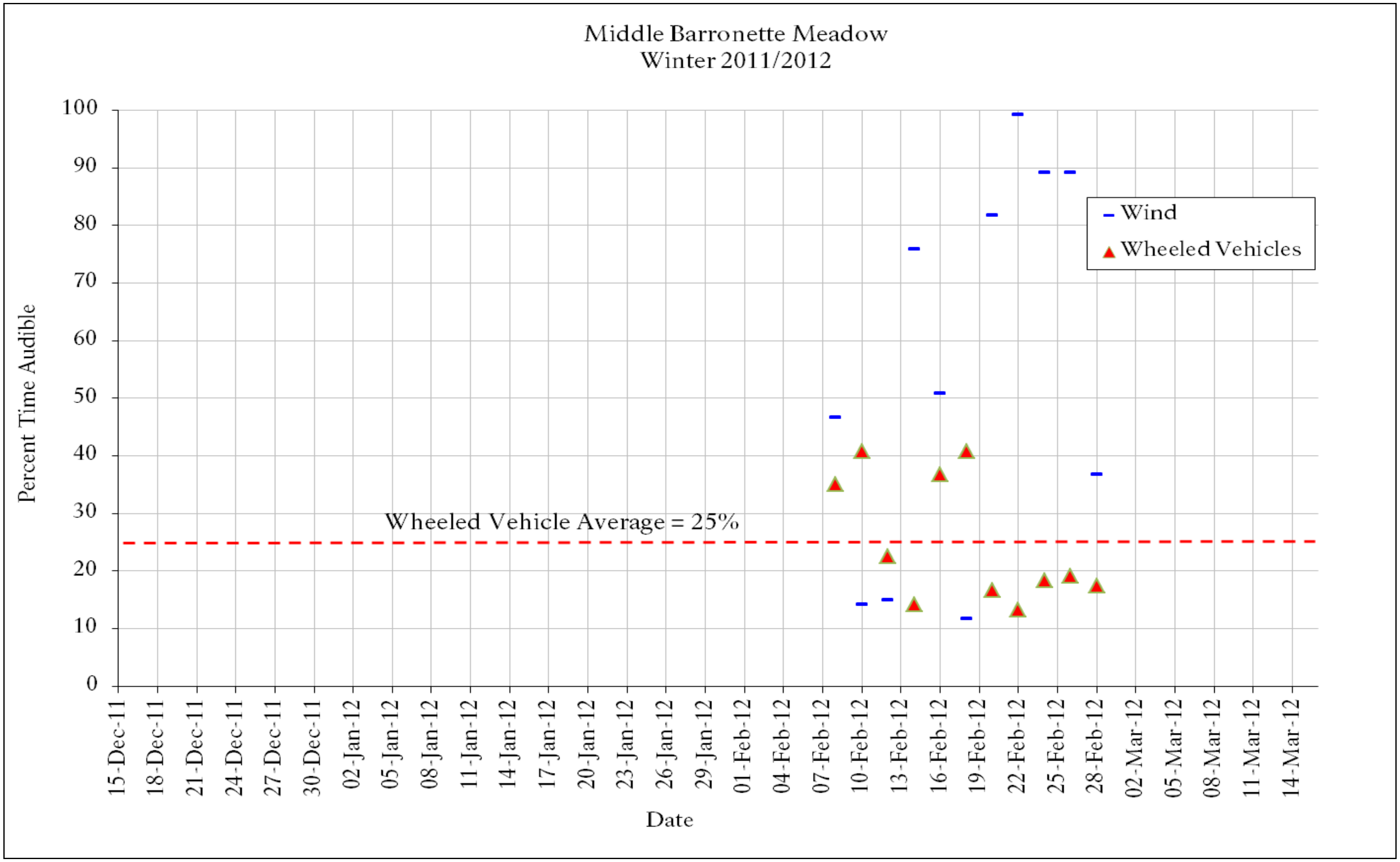

Figure 16. The average percent time audible (8 am - 4 pm) by date of oversnow vehicles, wheeled vehicles, and wind at Middle Barronette Meadow, YNP, 8 - 28 February 2012.

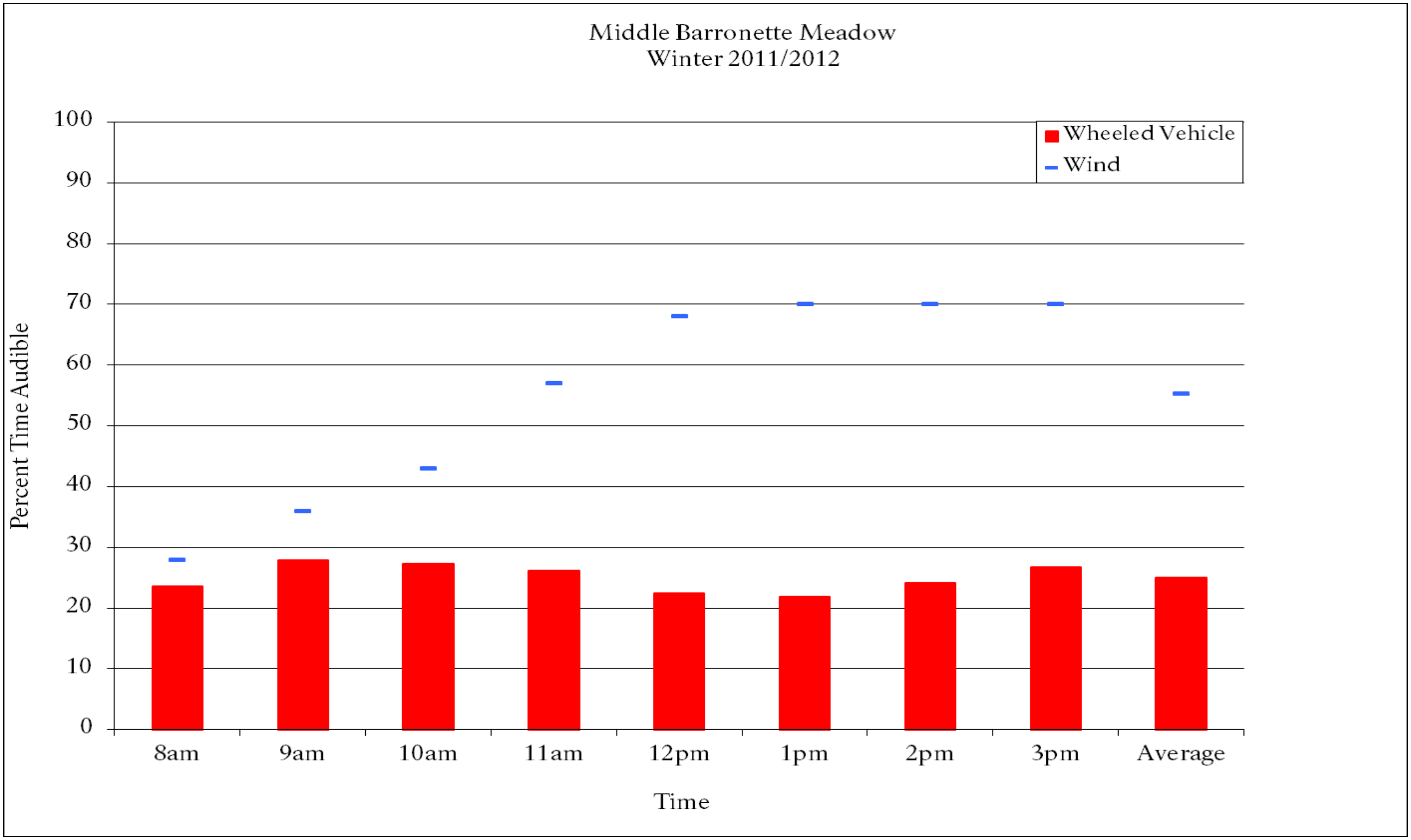

Figure 17. The average percent time audible (8 am - 4 pm) by hour of wheeled vehicles and wind at Middle Barronette Meadow, YNP, 8 - 28 February 2012.

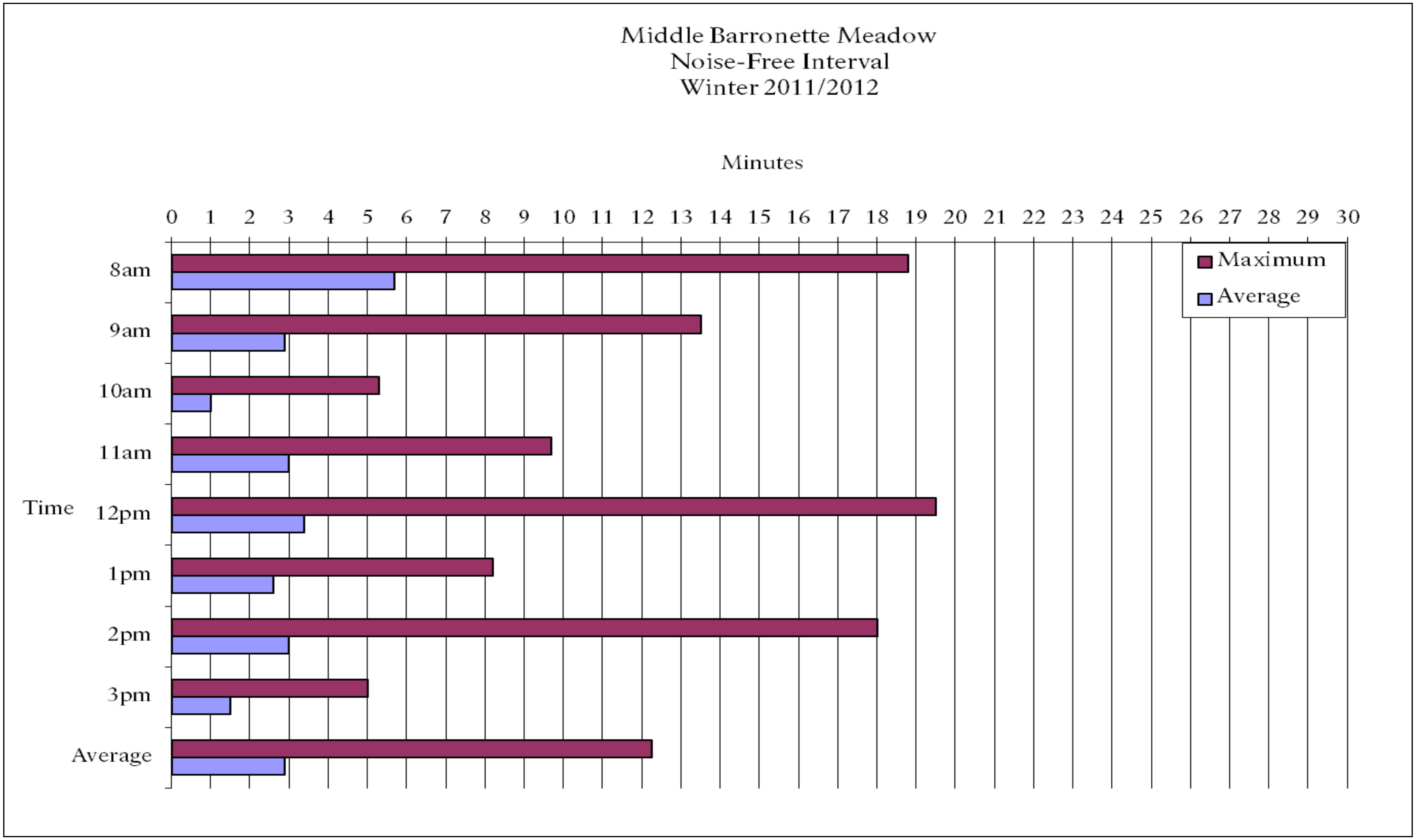

Figure 18. Noise-free interval as measured at Middle Barronette Meadows during the winter of 2011-2012, YNP. See Table 3 for dates used and text for more details.

*Management Thresholds for OSV Audibility:*

For each site with OSV activity the audibility results were compared to the 2009 Winter Use Plan adaptive management thresholds (Table 5.) The overall, season-long, average audibility for all sites was under the thresholds, but two sites (at Old Faithful and near Madison Junction) exceeded the number of days with audibility above the threshold. Both sites were within the busiest OSV corridor in the park.

Table 5. Percent time OSVs were audible at five sites in YNP in 2011-2012 compared to winter use plan management thresholds for developed areas and travel corridors. The overall and the percent of the days above threshold in red italics exceed threshold; values in green are below threshold.

| Audibility | | |
|---|---|---|
| Location | Overall % | % of Days above Threshold |
| | | |
| **Developed Area Threshold** | **75** | **15** |
| Old Faithful Weather Station | 66 | ***20*** |
| Canyon Village Developed Area | 38 | 0 |
| | | |
| **Travel Corridor Threshold** | **75** | **15** |
| Madison Junction 2.3 | 45 | ***29*** |
| Cygnet Lake Roadside | 22 | 5 |
| Mammoth Canary Spring | 7 | 0 |

*Audibility Trends:*

Oversnow audibility is summarized for 21 locations in YNP during the past nine winters (Table 6). These locations include the four winter use plan management zones (developed, travel corridors, transition and backcountry). The monitoring sites in Table 6 are ordered left to right from most busy (closer to OSV activity or busier road corridor) to most distant to OSV activity. Interpret sites with small sample sizes, those with seven or fewer days of data, with caution. Acoustic conditions vary widely due to wind and other atmospheric conditions, and depend on the daily number of OSVs; therefore small sample sizes may 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 52% for developed areas, 36% for travel corridors, 20% for transition zone, and 15% for backcountry areas. Sites that had more than seven days of analysis had relatively consistent audibility values when monitored in multiple years. Sites along the same segment of road (WY31 and MJ23) had similar OSV audibility. OSVs operating outside YNP were often audible at WY31, three miles from the park boundary. Backcountry sites ranged from just over one and a half 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 two Spring Creek sites (SPCR and SPC2) were 100 feet from this same road. The monitor at Lone Star Geyser (LSGY) was also along this route one mile from the road. Topography and frequent prolonged geyser activity were likely the reasons that OSVs were less audible at Lone Star Geyser than at Shoshone Geyser Basin more than four miles farther from the road.

Table 6. Percent time audible (8 am - 4 pm) of OSV sounds at monitoring sites by management zone during nine winters (2003-2012), YNP.

| | Management Zone: Sites[1] | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Developed[2] | | | Road Corridor[2] | | | | | | | | | | Transition[3] | | | | | Backcountry[3] | | |
| Year | OFWS | CVDA | WETH | MJ23 | WY31 | SPCR | SPC2 | CRPA | GVLL | MUVO | NTLA | CLRS | PPRD | MMTR | OFUB | MM4K | DLCR | LSGY | MM8K | SHGB | FLBC |
| 2003-2004 | 61% | | | 25%[4] | | | | | | | | | | 32% | | 13% | | 3% | | | |
| 2004-2005 | 69% | | 47% | 61% | 55% | | | | | | | | | | 29% | | | 4% | 26% | | |
| 2005-2006 | 67% | | 62% | 55% | | 34% | | | | | | | | | 35% | | | | | | |
| 2006-2007 | 68% | | | 59% | | | 44% | | | 26% | | | | | | | | | | | 0% |
| 2007-2008 | 68% | | | 53% | | | | | 37% | | | | | | | | 20% | | 26% | 18% | |
| 2008-2009 | 55% | | | 47% | | | | | | | 24% | | | | | | | | | | |
| 2009-2010 | 55% | | | 54% | | | | | | | | | | | | | | | | | |
| 2010-2011 | 61% | | | 51% | | | | 44% | | | | | 22% | | | | | | | | |
| 2011-2012 | 66% | 39% | | 45% | | | | | | | | 22% | | | | | | | | | |
| **Site Average** | **63%** | **39%** | **55%** | **53%** | **55%** | **34%** | **44%** | **44%** | **37%** | **26%** | **24%** | **22%** | **22%** | **32%** | **32%** | **13%** | **20%** | **4%** | **26%** | **18%** | **0%** |
| **Management Zone Average** | | | **52%** | | | | | | | | | | **36%** | | | | | **20%** | | | **15%** |

| | # of Oversnow Vehicles (OSVs)/day | | |
|---|---|---|---|
| | Snowmobile | Snowcoach | OSVs incl. OF[5] |
| 2003-2004 | 254 | 23 | 281 |
| 2004-2005 | 206 | 25 | 236 |
| 2005-2006 | 267 | 30 | 302 |
| 2006-2007 | 299 | 30 | 336 |
| 2007-2008 | 290 | 32 | 338 |
| 2008-2009 | 196 | 29 | 234 |
| 2009-2010 | 181 | 28 | 221 |
| 2010-2011 | 214 | 30 | 261 |
| 2011-2012 | 162 | 26 | 204 |
| **Average** | **230** | **28** | **276** |

1 OFWS-Old Faithful Weather Station; CVDA-Canyon Village Developed Area; WETH-West Thumb Geyser Basin; MJ23-Madison Junction 2.3; WY31-West Yellowstone 3.1; SPRC-Spring Creek; SPC2-Spring Creek 2; CRPA-Caldera Rim Picnic Area; GVLL-Grant Village Lewis Lake; MUVO-Mud Volcano; NTLA-North Twin Lake; CLRS-Cygnet Lake Roadside; PPRD-Pumice Point Roadside; MMTR-Mary Mountain Trail; OFUB-Old Faithful Upper Basin; MM4K-Mary Mountain 4K; DLCR-Delacy Creek Trail; LSGY-Lone Star Geyser Basin; MM8K-Mary Mountain 8K; SHGB-Shoshone Geyser Basin; FLBC-Fern Lake Backcountry

2 Sites ordered from left to right, busiest to less busy

3 Sites ordered from left to right, closest to motorized route to most distant

4 Red underlined indicates 7 or fewer days analyzed; Double red underlined indicates 1 or 2 days only

5 Number of OSVs originating at Old Faithful prior to 2006-2007 were estimated

Sound Levels:

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 four of the six sites (but not the developed areas of Old Faithful or Canyon Village). Each site's acoustic metrics, including the $L_{eq}$, $L_{50}$ (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 WUP adaptive management thresholds apply only to OSVs. Therefore the sound levels for OSVs should be separated from other sounds before evaluating them against sound level thresholds. Unfortunately there is yet no automated process for separating different sound sources from the sound level data and the manual separation of 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, but as distance increased from these motorized areas natural sounds were sometimes louder than OSV sounds. 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 and in some locations. Sound levels (decibels) of some common sound sources are shown in Table 6.

The 2009 Winter Use Plan (NPS 2009) defined major adverse maximum sound level thresholds for OSVs for three acoustic management zones. These thresholds are 70 dBA in developed areas and along travel corridors, and 45 dBA in backcountry areas, with no more than 15% of the sampled days to exceed these thresholds (Table 1 and see Table 8). See Appendix C to compare to previous winter use plans' standards and thresholds.

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

$L_{eq}$ is the level (in decibels) of a constant sound over a specific time period that has the same sound energy as the actual (unsteady) sound over the same period. $L_{eq}$ depends heavily on the loudest periods of a time-varying sound. $L_{eq}$ of an intruding source, though, is inadequate to fully characterize the intrusiveness of the source. The effects of intrusions in park environments depend not only upon the amplitude of the intrusion, but also upon the 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 $L_{10}$, $L_{50}$, 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 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. 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 | |

*2011-2012 Sound Metrics by Monitoring Site*

A number of sound level metrics at the six sound monitoring sites during the winter season 2011-2012 are compared in Table 7. These sites are individually discussed on the following pages.

Table 7. Sound level metrics (dBA) for six sites and two soundscape management areas in YNP, 8 am - 4 pm, winter 2011-2012. $L_{90}$, $L_{50}$, $L_{eq}$ are median values from hourly calculations.

| Site | $L_{min}$ | $L_{90}$ | $L_{50}$ | $L_{eq}$ | $L_{max}$ | Hours |
|---|---|---|---|---|---|---|
| *Developed Area* | | | | | | |
| Old Faithful Weather Station | 19.3 | 29.1 | 34.4 | 40.3 | 90.3 | 632 |
| Canyon Village Developed Area | 15.1 | 22.1 | 26.6 | 34.2 | 76.2 | 314 |
| *Travel Corridor* | | | | | | |
| Madison Junction 2.3 | 15.5 | 28.2 | 31.8 | 42.5 | 80.8 | 709 |
| Cygnet Lake Roadside | 13.8 | 18.7 | 25.7 | 37.5 | 82.3 | 598 |
| *Plowed Road* | | | | | | |
| Mammoth Canary Springs | 34.0 | 41.5 | 42.8 | 46.9 | 84.3 | 237 |
| *Middle Barronette Meadow*[1] | *19*[1] | *22*[1] | *26*[1] | *39*[1] | *81*[1] | *167* |

[1] Sound levels at Middle Barronette Meadow were not collected using a Type 1 sound level meter. Digital recordings were post-processed to derive approximate sound levels. See methods for details.

*Old Faithful Weather Station*

The median hourly sound levels from the soundscape monitoring site at Old Faithful Weather Station are shown in Figure 19 for the winter 2011-2012. The Old Faithful monitor was 230 feet (70 m) from the entrance/exit road used by oversnow vehicles. The 2009 WUP soundscape thresholds assume at a distance of 100 feet (30 m) from the sound source in developed areas. In a free-field, sound levels decrease by approximately 6 dBA for every doubling of the distance from a point source to the receiver. Therefore to compensate for the additional distance from the sound monitor using the reasonable assumption that, 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 20 dBA, Table 7)) and the $L_{90}$ were largely determined by the nearly constant utility sounds (exhaust and heating fans) from the Snow Lodge and Old Faithful Ranger Station (Fig. 19).

In addition to displaying sound levels by hour, winter-long acoustic metric summaries are shown by date in Figure 20.

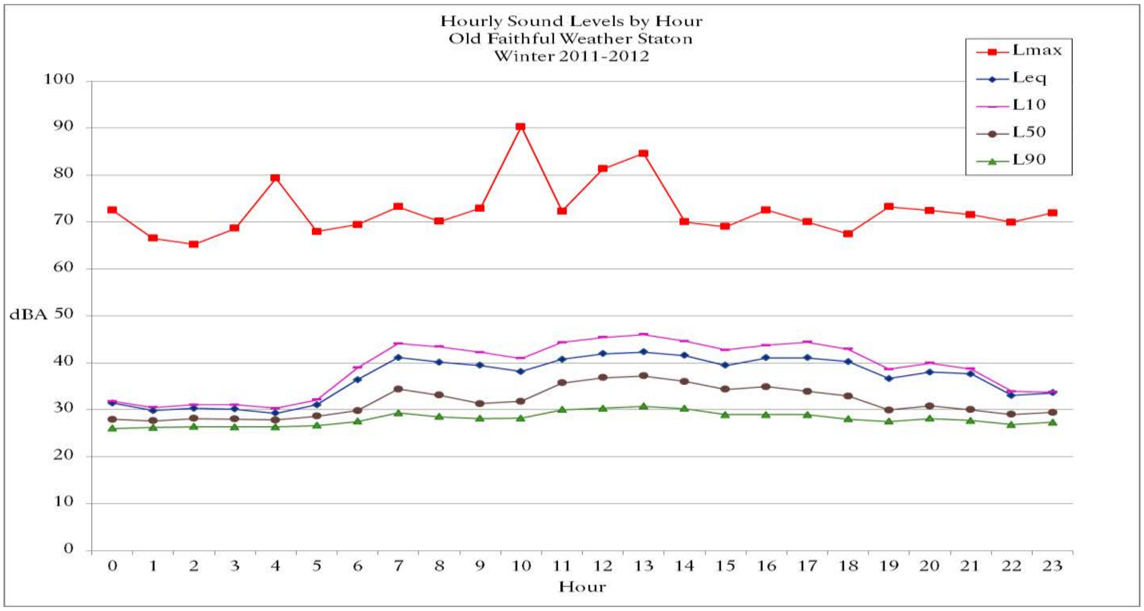


Figure 19. Median hourly sound levels for winter 2011-2012, Old Faithful Weather Station, YNP. These sound levels include all natural and non-natural sounds. $L_{max}$ is the highest sound level measured during each hour of the winter use season. (n=1,883 hours)

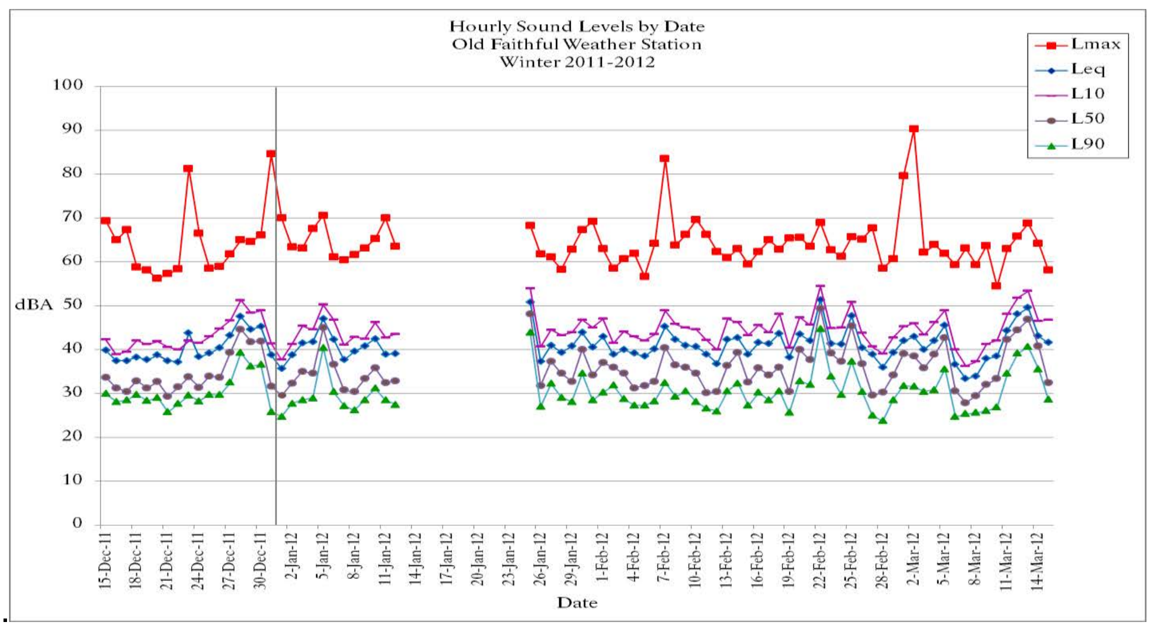


Figure 20. Median average daily (8 am – 4 pm) sound levels for winter 2011-2012, Old Faithful Weather Station, YNP. These sound levels include all natural and non-natural sounds. $L_{max}$ is the highest sound level measured during each hour of the measurement period. The vertical gray line indicates when the west and north entrances were opened to snowmobiles and snowcoaches with metal skis. (n=80 days)

*Madison Junction 2.3*

Consistent with previous seasons, the maximum hourly sound levels from OSVs at Madison Junction 2.3 exceeded the 2009 WUP maximum sound level threshold (70 dBA) during most measurement days (8 am - 4 pm) in 2011-2012 (Fig. 21). 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. 21). The maximum sound levels ($L_{max}$) were generally caused by snow groomers at night and snowcoaches during the day. However, the maximum sound level during the 5 am hour (and the loudest sound measured during the winter) was the yipping of a coyote near the microphone. The lowest median hourly $L_{90}$ values are constrained by riffles of the nearby Madison River (Fig. 21). Wind generally increases during the afternoons and is reflected in the median hourly $L_{50}$ and $L_{90}$ values (Fig. 21).

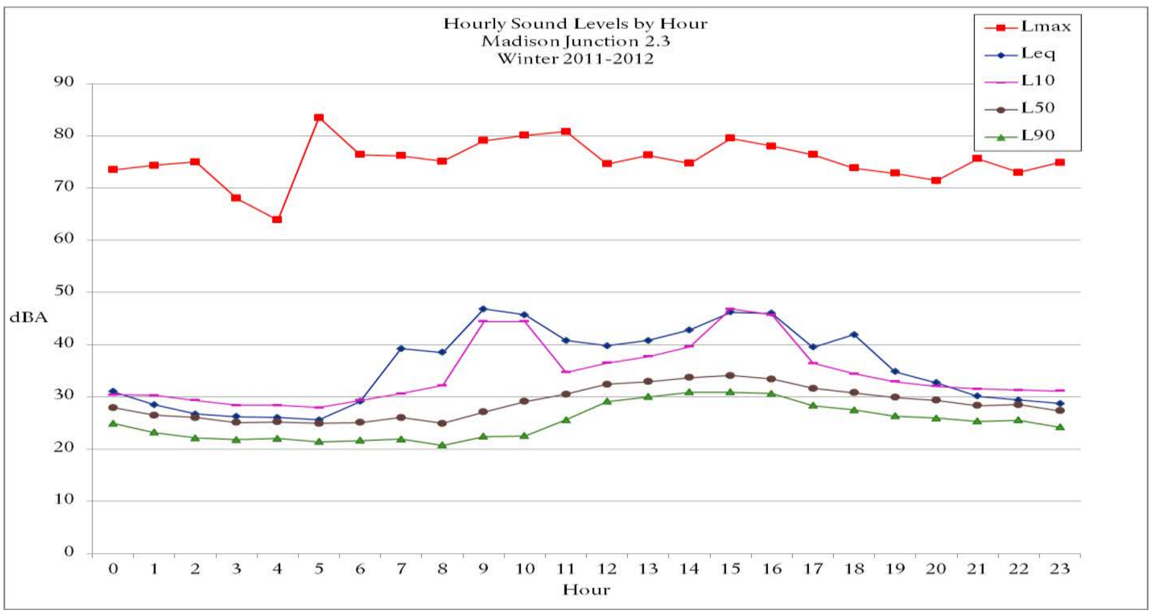


Figure 21. Median hourly sound levels for winter 2011-2012 at Madison Junction 2.3, YNP. See Fig. 19 caption for more details. (n=2,150 hours)

In addition to displaying sound levels by hour, winter-long acoustic metric summaries are shown by date in Figure 22. Especially windy days can be seen in the elevated L90 levels.

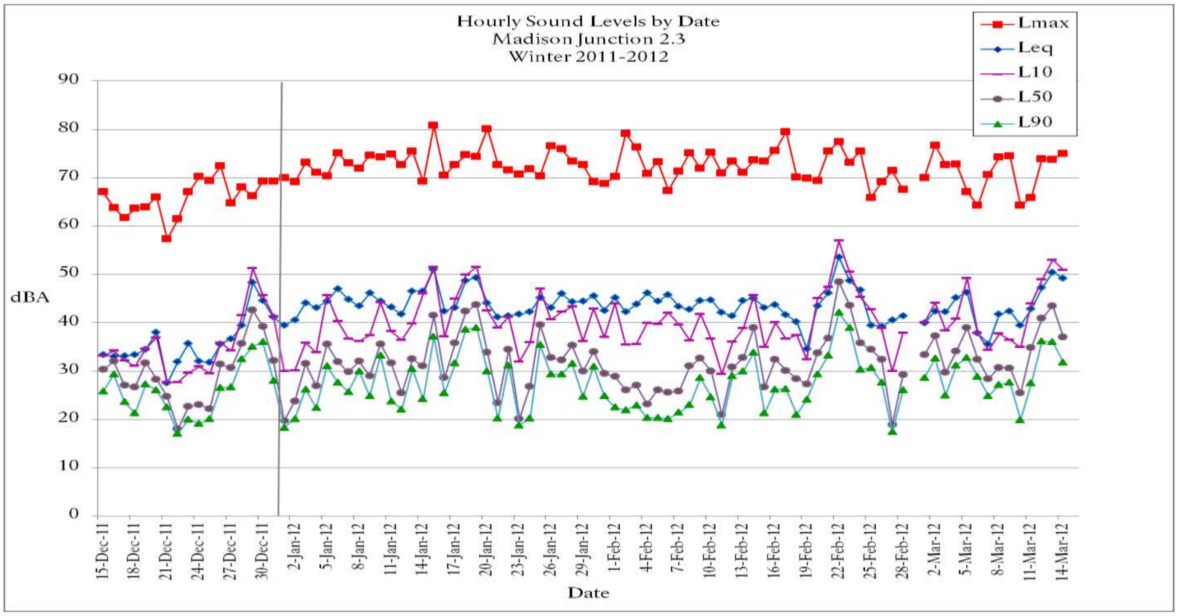

Figure 22. Median daily (8 am – 4 pm) sound levels winter 2010-2011 at Madison Junction 2.3, YNP. See Fig. 19 caption for more details. The vertical gray line indicates when the west and north entrances were opened to snowmobiles and snowcoaches with metal skis. (n=91 days)

*Cygnet Lake Roadside*

This sound monitoring site was 100 feet (30 m) from the groomed road between Norris and Canyon. There were frequent daytime strong winds off the high plateau to the south of this location (Fig. 23). The loudest sounds at this site were the OSVs traveling on the road. The peak maximum sound level during the 10 am hour (and the loudest measured sound during the winter at this site) was a 2-stroke snowmobile on 26 February (Fig. 23 and 24). Aircraft sounds were sometimes present and at levels above the natural ambient. Distant motorized sounds were present at the quietest times originating from perhaps the Norris to Mammoth road or the Canyon to Lake road. The very low sound levels were a result of no wind and no nearby streams, rivers, or human development.

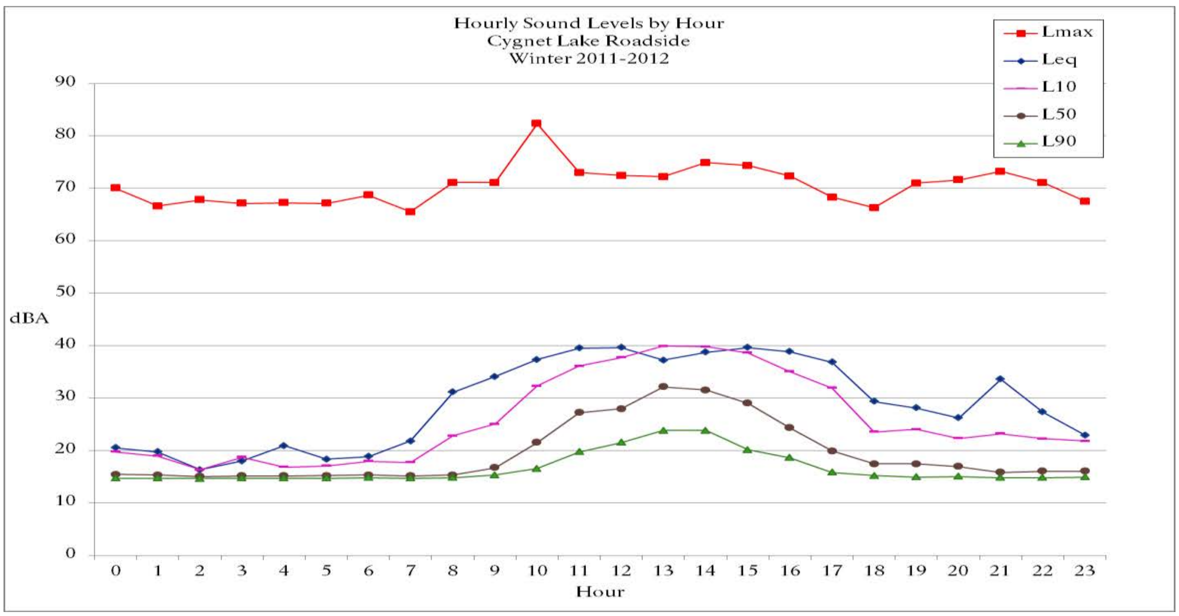


Figure 23. Median hourly sound levels for winter 2011-2012, Cygnet Lake Roadside, YNP. See Fig. 19 caption for more details. (n=1,816 hours)

In addition to displaying sound levels by hour, winter-long acoustic metric summaries are shown by date in Figure 24. The days with high wind speeds, and thus elevated sound levels are shown by increased L90 values (Fig. 24).

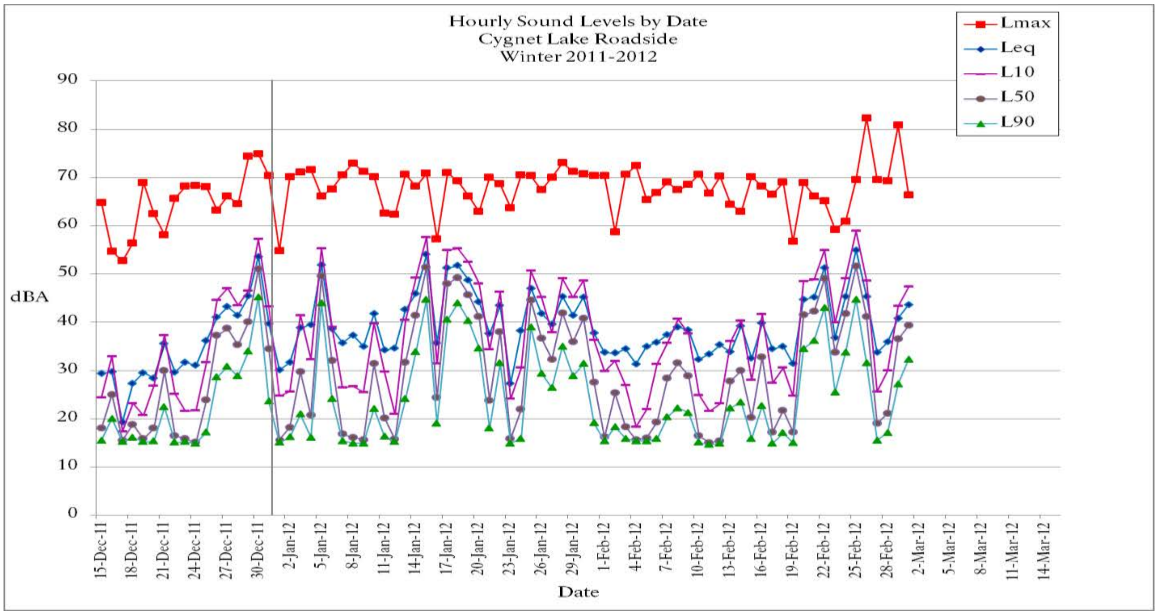

Figure 24. Median daily (8 am – 4 pm) sound levels for Cygnet Lake Roadside, winter 2011-2012, YNP. See Fig. 19 caption for more details. The vertical gray line indicates when the west and north entrances were opened to snowmobiles and snowcoaches with metal skis. (n=78 days)

*Canyon Village Developed Area*

This site was located 100 feet (30m) from the entrance road to the Canyon Visitor Center. Although utility sounds from the visitor center were regularly audible, they were at low sound levels (Fig. 25). The $L_{eq}$, $L_{10}$, $L_{50}$ and $L_{90}$ sound levels metrics all increase during the day when OSVs were present (Fig. 25) peaking around noon. The daily sound level pattern is consistent with a destination area, but at a lower level than the more visited Old Faithful. The peak maximum sound level was caused by a low flying helicopter on 4 January, during the 2 pm hour (Fig. 25 and 26).

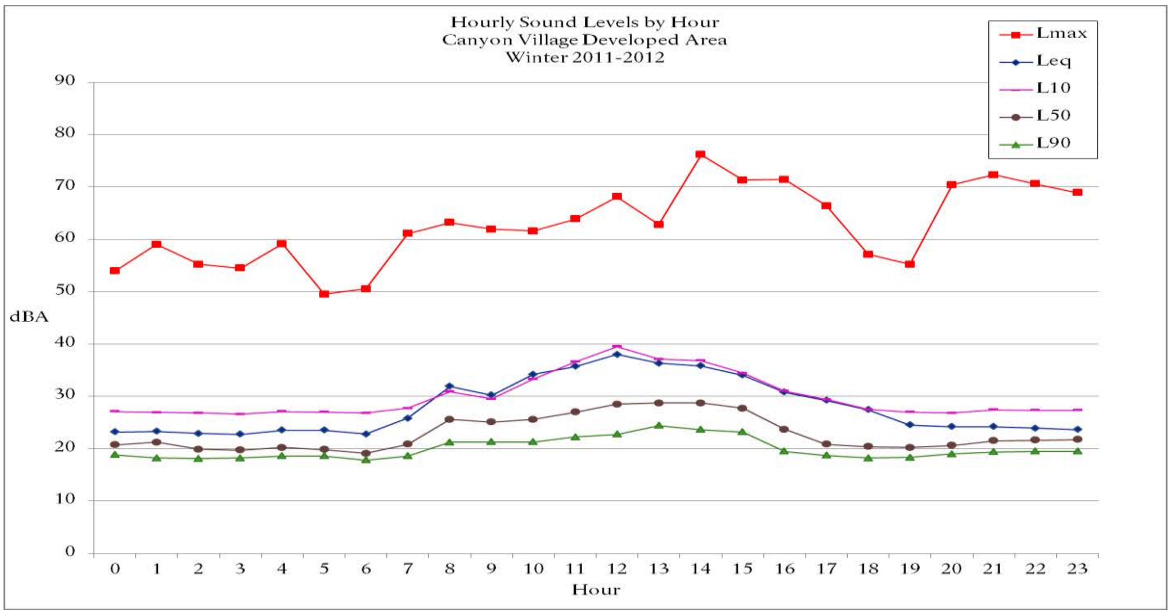

Fig. 25. Median hourly sound levels, winter 2011-2012, Canyon Village Developed Area, YNP. See Fig. 19 caption for more details. (n=943 hours).

In addition to displaying sound levels by hour, winter-long acoustic metric summaries are shown by date in Figure 26. 15 January was an especially windy day as shown by high $L_{90}$ values (Fig. 26).

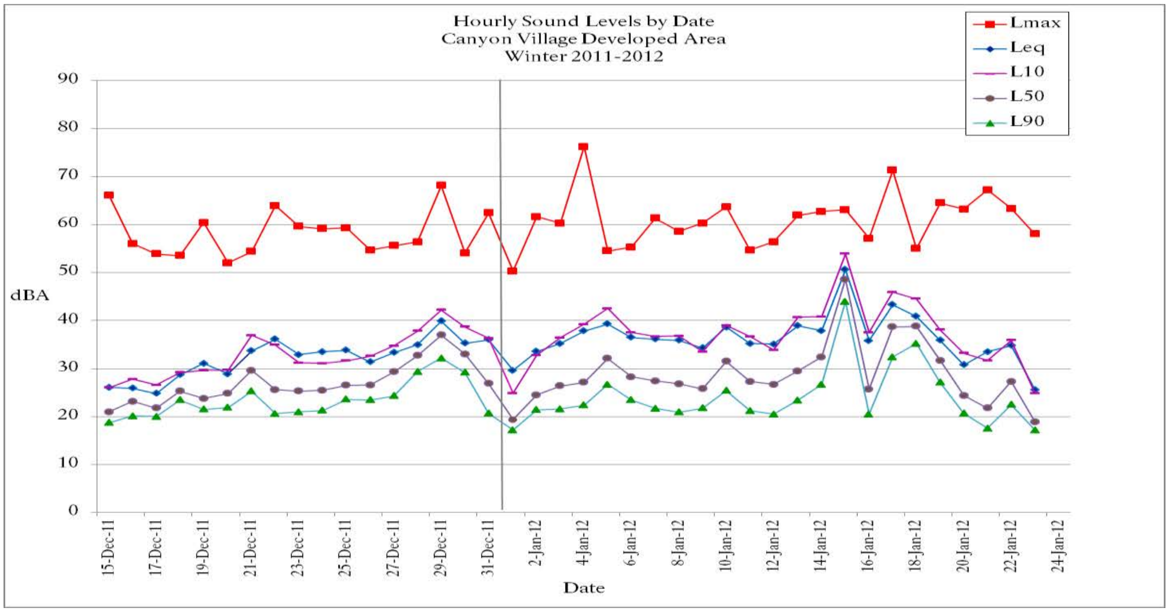


Fig. 26. Median daily (8 am – 4 pm) sound levels, winter 2011-2012, Canyon Village Developed Area, YNP. See Fig. 19 caption for more details. The vertical gray line indicates when the west and north entrances were opened to snowmobiles and snowcoaches with metal skis. (n=40 days).

*Mammoth Canary Springs*

This site was located 175 feet (53 m) from the plowed road between Mammoth developed area and the Upper Terraces. Both snowcoaches and wheeled vehicles used the road. Other than the variable hourly Lmax values the most notable thing from this site is the constant relatively high sound levels (about 42 dBA) caused by Canary Spring itself (Fig. 27). The $L_{eq}$ and $L_{10}$ show a bimodal pattern of increased traffic during the morning and afternoon.

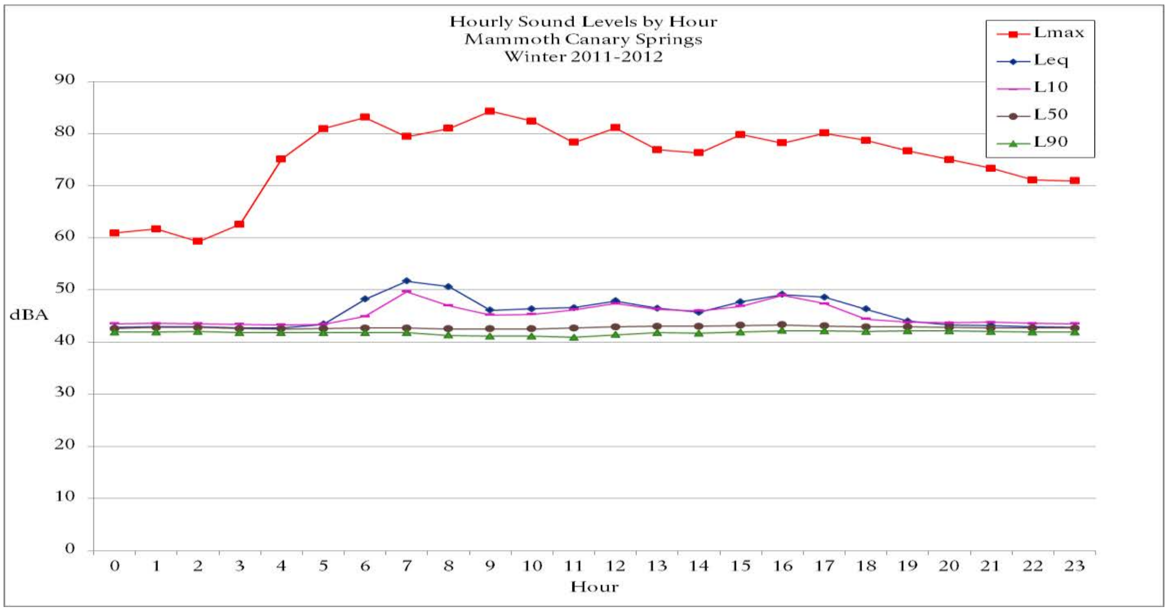


Fig. 27. Median hourly sound levels, winter 2011-2012, Mammoth Canary Springs, YNP. See Fig. 19 caption for more details. (n=717 hours).

In addition to displaying sound levels by hour, winter-long acoustic metric summaries are shown by date in Figure 28.

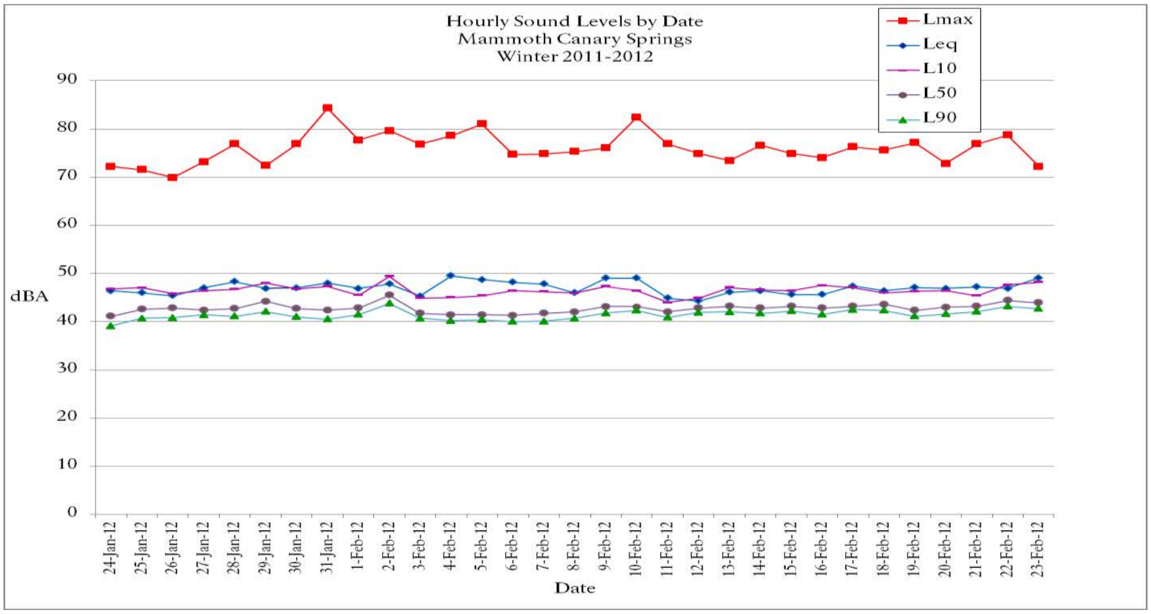


Fig. 28. Median daily (8 am – 4 pm) sound levels, winter 2011-2012, Mammoth Canary Springs, YNP. See Fig. 19 caption for more details. (n=31 days).

*Middle Barronette Meadow*

This site was located 100 feet from the plowed road between Lamar Valley and the park's Northeast Entrance. The sound levels at this site were not collected directly, but derived by post-processing digital recordings. This post-processing result in sound levels that are within a few decibels of the true levels but they do introduce a small amount of uncertainty. The hourly patterns of $L_{90}$ and $L_{50}$ (Fig. 29) reflect increased wind during the afternoon. The highest hourly sound levels were caused by a snowplow on the road during the 1 pm hour on 14 February (81 dBA; Fig. 29 and 30).


Fig. 29. Median hourly sound levels, winter 2011-2012, Middle Barronette Meadow, YNP. These sound levels were not collected directly, but derived by post-processing digital recordings. See Fig. 19 caption for more details. (n=504 hours).

In addition to displaying sound levels by hour, winter-long acoustic metric summaries are shown by date in Figure 30.

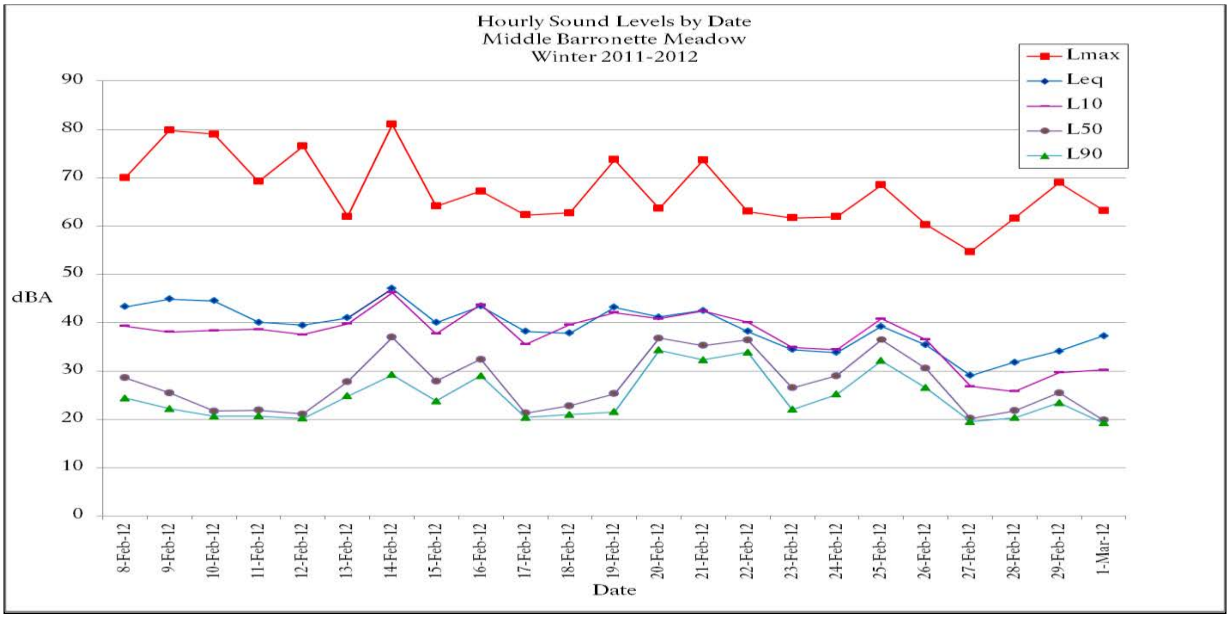

Fig. 30. Median daily (8 am – 4 pm) sound levels, winter 2011-2012, Middle Barronette Meadow, YNP. These sound levels were not collected directly, but derived by post-processing digital recordings. See Fig. 19 caption for more details. (n=23 days).

*Management Thresholds for OSV Sound Levels:*

OSV maximum sound levels between 8 am and 4 pm at four sites were compared to the 2009 Winter Use Plan adaptive management thresholds (Table 8.) Both travel corridor sites (Madison Junction and Cygnet Lake Roadside) exceeded the number of days with the maximum OSV sound level above the threshold. Two-thirds of the days at Madison Junction 2.3 exceeded the 70 dBA threshold. Xanterra Bombardier snowcoaches comprised most of the exceedances at both sites. At the Cygnet Lake site, Xanterra Bombardiers snowcoaches exceeded 70 dBA on 21 (88%) of the 24 days; two-stroke snowmobiles were responsible for two days, and an unknown OSV for the remaining day. Modified oversnow vehicles hauling construction supplies joined with Xanterra Bombardier snowcoaches for the loudest OSV passing the Madison Junction site between 8 am and 4 pm.

Table 8. Maximum sound levels of OSVs (8 am to 4 pm) at four sites in YNP in 2011-2012 compared to winter use plan management thresholds for developed areas and travel corridors. The percent of the days above threshold are in red italics; values in green are below threshold.

| Sound Levels | | |
|---|---|---|
| Location | % of Days above Threshold | Sampled Days |
| | | |
| **Developed Area Threshold** | 70 dBA | |
| Old Faithful Weather Station | 3 | 80 |
| Canyon Village Developed Area | 0 | 40 |
| | | |
| **Travel Corridor Threshold** | 70 dBA | |
| Madison Junction 2.3 | 67 | 91 |
| Cygnet Lake Roadside | 30 | 78 |

Recommendations:

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

Although substantial reductions to the impacts on the natural soundscape were made by the switch from 2-stroke to 4-stroke snowmobiles and by the grouping that resulted from the guiding requirement, the WUP maximum sound levels are still being exceeded along travel corridors. Reduced sound levels of OSVs would also reduce their audibility. Improvements to snowcoach sound emissions should be made, especially to the older and louder Bombardier snowcoaches. Phasing out the loudest snowcoaches and choosing the quietest snowmobile models would reduce the sound levels and audibility of those user types. Minimizing and grouping administrative OSV use at all times would minimize impacts to the natural soundscape. Because most travel at night is administrative use, reductions in administrative night-time OSV use would have an especially large reduction of the noise impacts on the natural soundscape.

Sound levels and audibility from motorized OSVs also can be reduced by lowering travel speeds. With reduced speed, visitors would experience lower OSV sound levels and percent time audible, especially in popular areas such as near thermal features and around Old Faithful. Decreasing the speed limit on all roads would reduce OSV impacts on the natural soundscape and would have the added benefit of promoting sightseeing while traveling. Reducing unnecessary idling and rapid acceleration, and instituting other driver behavior modifications would also minimize sound impacts from oversnow vehicles. Reducing the total number and number of single OSVs operating on YNP roads would also minimize their impact to natural soundscapes. Soundscape awareness training should be presented to operators of oversnow vehicles. The NPS should work with manufacturers, equipment operators, and concessionaires to reduce further sound levels of oversnow vehicles.

2- Continue to conduct acoustical studies to fill in information gaps to understand better the impacts of OSVs on the natural soundscape.

YNP can better manage the impacts of OSVs on the natural soundscape with data to answer to specific questions such as 1) how group size and type of OSV affects sound levels and audibility, 2) the distance to limits of audibility in different habitat types (acoustic zones) and weather conditions, 3) the effects of road surface on sound levels and audibility, and 4) how speed influences percent time audible and sound levels. Acoustic computer modeling can begin to answer some of these questions but needs to be validated by actual field data collection. Studies are ongoing that provide information to understand better the relationship between OSV numbers and their impact on the natural soundscape.

3- Continue to augment the number of sampling locations and sample duration, and continue sampling beyond the winter season.

The acoustical dataset will improve as the number of sampling locations is increased within and among management zones. A full range of locations provides a more comprehensive evaluation of YNP's natural soundscape and the impacts from oversnow vehicles. Because of the soundscape's inherent variability, it is usually preferable to gather multiple weeks (at least 25 days) of data at one location rather than shorter duration periods at multiple locations. Data collected during non-winter seasons allow comparisons to the winter season and provides additional information of YNP's natural and non-natural soundscapes for resource inventory and monitoring and for future planning efforts (including Air Tour Management and Soundscape Management planning). Year-round data collection started during the spring of 2005 and should be continued.

4- Continue to monitor both audibility and sound levels and include measurement and reporting of noise-free intervals.

The combination of sound level and audibility data gathered for this study provides useful acoustical information about YNP's soundscapes and the level of impact from oversnow vehicles. Collecting audibility data and identifying sources of sounds is important to characterize natural soundscapes and the non-natural acoustical impacts. Evaluating oversnow impacts on the natural soundscape requires sound source identification. In addition to information on audibility, the sound level of intruding non-natural sounds is an important aspect of soundscape monitoring. Ongoing collection of 1/3 octave band frequency sound levels allows all standard acoustical metrics to be calculated and provides input data for computer modeling. Acoustic monitoring results allow for comparisons to computer acoustical modeling results. Monitoring measurements now include continuous recordings and provide the opportunity to measure and report noise-free intervals. These data are an important complement to audibility analyses for describing OSV impacts on the park's natural soundscape and on visitor experience.

5- Audibility and sound level metrics standards and thresholds should be used for impact definitions in planning documents.

The ability to determine if the acoustic impacts of winter oversnow use are meeting the management objectives require defined quantitative acoustical standards and thresholds. Acoustical monitoring and the understanding of natural soundscapes in parks are both improving. The requirements for specific impact definitions and associated standards parallel these changes. It is useful to use easily understood, and more importantly, measurable and meaningful standards and thresholds.

**Acknowledgements:**

Skip Ambrose (NPS Natural Sound Program-retired) developed an initial study plan that led to this project. John Klaptosky collected thirty-one additional hours of OSV logging data over the course of the winter- no small feat. Roy Renkin provided logistical support and encouragement that was helpful. The Old Faithful Maintenance staff, especially Roy Jenkins, also provided logistical help on this project. Robin Long, through the Sandhill Company, expertly coded most of the digital recordings for the eighth winter season. Her assistance continues to be invaluable. Mike Donaldson and the NPS Natural Sound Program provided computer software. This report heavily relies on previous 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.

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## Appendix A: Instrumentation and Setup Protocol

AC Output Weighting
For digital recordings using the AC output of the SLM, the AC output weighting shall be set to Flat, with appropriate gain setting for SLM or recording device in use

Attended Data Logging
Observers will conduct attended data logging approximately 50 m (150 feet) from the sound level meter, microphone, and/or tape recorder to ensure that field personnel can move about and conduct whispered conversations without influencing the measured sound. Observations during attended logging will be recorded on a standardized NPS data sheet.

Bird Spike
Spikes made of wire or hard plastic which prevents birds from perching on microphones and windscreens shall be used.

Cables and Wiring
All cables and wiring shall be secured to prevent any sound which might be created in windy conditions (due to wiring hitting other objects).

Calibrator
A calibrator whose performance is essentially independent of off-reference atmospheric conditions (such as the B & K Model 4231) is to be used.

Instrument Clocks
All clocks associated with the sound measurement effort shall be coordinated with GPS (Global Positioning System) time. This includes sound level meters, data loggers (notebook computer, Personal Digital Assistant-PDA), and all digital watches used during data logging. For long-term measurements, all clocks will be synchronized with GPS time at the beginning of the measurement period, and time differences with GPS time will be noted at the end of the measurement period. Acoustic data collected during the measurement period will be adjusted to correspond with GPS time.

Microphone type
A Type 1 random incidence microphone is recommended for acoustic measurements in wilderness settings. Microphones can be either polarized or pre-polarized.

Monitor Location
The microphone/pre-amplifier/windscreen shall be placed in a location representative of the habitat/acoustic zone under study. The microphone diaphragm should be placed 1.1 m to 1.5 m above the ground surface and

oriented vertically (microphone grid facing the sky).

Solar Panels
All solar panels should be placed in a location with as little shading as possible and at least .3 m (12 inches) above the ground.

Sound Level Meter
Sound level meters shall be Type I or better and should perform true numeric integration and averaging in accordance with ANSI S1.4-1983.

Time Weighting
Sound level meters shall be set to fast exponential time weighting.

Windscreen
Windscreens which are effectively acoustically transparent (less than +/- 0.5 dB effect over the frequency span of interest) shall be used.

## Appendix B: Glossary of Acoustic Terms

**Acoustics**
The science of sound.

**Ambient Sound, Existing**
All sounds in a given area (includes all natural and all non-natural (human-caused) sounds).

**Ambient Sound, Natural**
The natural sound conditions found in a given area, including all sounds of nature. The natural ambient sound level of a park is comprised of the natural sound conditions which exist in the absence of mechanical, electrical, and other non-natural sounds. Some generally unobtrusive non-natural sounds (talking quietly, walking) may be part of the natural soundscape, but not those generated by mechanical, electrical, or motorized means. Natural ambient sounds are actually composed of many natural sounds, near and far, which often are heard as a composite, not individually. In an acoustic environment subjected to high levels of non-natural sounds, natural sounds may be masked. Natural ambient sound is considered synonymous with the term "natural quiet," although "natural ambient sound is more appropriate because nature is not always quiet.

**Ambient Sound, Non-natural**
Ambient sounds attributable to non-natural sources (mechanical, electrical, and other non-natural sources). In a national park setting, these sounds may be associated with activities that are essential to the park's purpose, they may be a by-product of park management activities, or they may come from outside the park.

**Appropriate Sounds**
Sound conditions defined as appropriate for an area in national parks, such as a specific management zone. Other appropriate sounds, not natural in origin, are those types of sounds which are generated by activities directly related to the purposes of a park, including resource protection, maintenance, and visitor services. Natural sounds are not only appropriate, but are part of the park's resource base to be protected and enjoyed by the visiting public.

**Appropriate Sound Level**
Appropriate sound levels in a given area of a park are determined based on mandates in the Organic Act, establishment legislation, or other laws pertinent to the specific purposes and values associated with the park. This determination takes the form of management zone objectives for soundscape, as well as measurable indicators and standards for sound.

**Attenuation**
The reduction of sound intensity by various means (e.g., air, humidity and porous materials).

**Area of Audibility**
The area within which a specific sound or sounds is audible.

**Audibility**
Audibility is the ability of animals with normal hearing, including humans, to hear a given sound. Audibility is affected by the hearing ability of the animal, other simultaneous interfering sounds or stimuli, and by the frequency content and amplitude of the sound.

**Decibel**
A logarithmic measure of any measured physical quantity and commonly used in the measurement of sound. The decibel provides the possibility of representing a large span of signal levels in a simple manner as opposed to using the basic unit Pascal. The difference between the sound pressure for silence versus a loud sound is a factor of 1,000,000:1 or more, therefore it is less cumbersome to use a small range of equivalent values: 0 to 130 decibels. See also, Sound Level.

Doubling of Sound Pressure = 6 dB
Doubling of Sound Power = 3 dB
Doubling of Perceived Sound Level = 10 dB (approximately)

**Doppler Effect (or Shift)**
The apparent upward shift in frequency of a sound as a noise source approaches the receiver or the apparent downward shift when the noise source recedes.

**Energy Equivalent Sound Level ($L_{eq}$)**
The level of a constant sound over a specific time period that has the same sound energy as the actual (unsteady) sound over the same period. $L_{eq}$ depends heavily on the loudest periods of a time-varying sound. $L_{eq}$ of an intruding source by itself, though, is inadequate for fully characterizing the intrusiveness of the source. Research has shown that judgments of the effects of intrusions in park environments depend not only upon the amplitude of the intrusion, but also upon the sound level of the “background,” in this case, the sound level of the non-intruding sources, usually the natural ambient sound levels. $L_{eq}$ must be used carefully in quantifying natural ambient sound levels because occasional loud sound levels (gusts of wind, birds, insects) may heavily influence (increase) its value, even though the sound levels are typically lower.

**Frequency**
The number of times per second that the sine wave of sound repeats itself. It can be expressed in cycles per second, or Hertz (Hz). Frequency equals Speed of Sound / Wavelength.

**Hearing Range (human)**
An average healthy young person can hear frequencies from approximately 20 Hz to 20000 Hz, and sound pressure levels from 0 dB to 130 dB or more (threshold of pain). The smallest perceptible change is 1 dB.

**Impact**
For environmental analysis, an impact is defined as a change at a receptor that is caused by a stimulus, or an action. In accordance with the CEQ regulations (40 CFR 1500-1508), direct and indirect impacts (environmental consequences) are to be described in an environmental document by assessing their type, magnitude, intensity, and duration. The significance of an impact is to be determined specifically in view of criteria provided in 40 CFR 1508.27, based on the outcome of these assessments. An assessment will take account of the short or long term nature of the impact, the extent to which it is either beneficial or adverse, whether it is irreversible or irretrievable, and, finally, its geographic and societal extent. Lastly, a resource impact is put in the context of all other past, present or reasonably foreseeable actions which affect the same resource, and its contribution to the total cumulative effect is to be disclosed. Under CEQ regulations, the term “impact” is synonymous with “effect” (40 CFR 1508.8).

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

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

**Noise**
Noise is defined as unwanted or extraneous sound.

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

**Octave**
The interval between two frequencies having a ration of 2 to 1. For acoustic measurements, the octaves start a 1000 Hz center frequency and go up or down

from that point, at the 2:1 ratio. From 1000 Hz, the next filter's center frequency is 2000 Hz, the next is 4000 Hz, etc., or 500 Hz, 250 Hz, etc. Octave filtering is usually referred to as the class of octave filters typically 1, 3 or 12, thus creating full octaves, one-third octaves, or one-twelve octaves.

**Octave Band**
The segment of the frequency spectrum centered on an octave center frequency bounded by the midpoint between the next lower and higher octave.

**Percent Exceedance ($L_x$)**
These metrics are the sound levels (L), in decibels, exceeded *x* percent of the time. The $L_{10}$ value represents the sound level exceeding 10 percent of the time; the loudest sounds. The $L_{50}$ value represents the sound level exceed 50 percent of the measurement period. $L_{50}$ is the same as the median. The $L_{90}$ value represents the sound level exceeded 90 percent of the time during the measurement period. $L_{50}$ and $L_{90}$ are useful measures of the natural sounds because in park situations, away from developed areas, they are less likely to be affected by non-natural sounds. Put another way, non-natural sounds in many park areas are likely to affect the measured sound levels for less than 50% of the time, and almost certainly for less than 90% of the time. $L_{50}$ is used when there is high probability that no non-natural sounds affect the measurements. $L_{90}$ is used when human-produced sounds are present much of the time during measurements. Common sounds that could be present for more than 50% of the time include road traffic sounds and, in some areas, high altitude jet aircraft.

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

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

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

**Sound**
A wave motion in air, water, or other media. It is the rapid oscillatory compressional changes in a medium that propagate to distant points. It is characterized by changes in density, pressure, motion, and temperature as well as other physical properties. Not all rapid changes in the medium are sound (such as wind distortion on a microphone diaphragm).

**Sound Impacts**
Sound impacts are effects on a receptor caused by the physical attributes of sound emissions. In national parks, non-natural sounds cause physical changes in the soundscape that can be detected and measured. The fact that a sound can be measured does not equate immediately to whether the impact of that sound is adverse, inconsequential, or beneficial, or whether there are adverse secondary impacts on wildlife, cultural values, or visitors. Levels of impact and impact significance are policy determinations.

**Soundscape**
Soundscape refers to the total acoustic environment associated with a given area. In a national park setting, soundscapes can be composed of natural sounds, or it can be composed of both natural and non-natural sounds.

**Soundscape, Natural**
Natural soundscapes consist of sounds associated with nature: wind, water flow, rain, surf, wildlife, thermal activity, lava flows, or other sounds not generated by non-natural means.

**Sound Level**
The *weighted* sound pressure level obtained by frequency weighting, generally A-weighting (dBA).

**Sound Level Floor (Noise Floor)**
The lowest amplitude measurable by sound monitoring equipment. Most commercially available sound level meters and microphones can detect sound levels down to about 15 to 20 dBA; however, there are microphones capable of measuring sound levels below 0 dBA.

**Sound Pressure Level (SPL)**
The logarithmic form of sound pressure. In air, 20 times the logarithm (to the base 10) of the ratio of the actual sound pressure to a reference sound pressure (which is 20 micropascals, and by convention has been selected to be equal to the assumed threshold of human hearing). It is also expressed by attachment of the word decibel to the number.

**Windscreen**

A porous device used to cover the microphone of a sound level measurement system. Windscreens are designed to minimize the effects of wind disturbance on the sound levels being measured while minimizing the attenuation of the signal.

These definitions were derived from several sources, including:

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## Appendix C: Acoustic standards and thresholds in previous winter use plans

**Table C-1**. Management zones and soundscape thresholds in 2000 YNP and Grand Teton National Parks and the John D. Rockefeller, Jr. Memorial Parkway Final Environmental Impact Statement Winter Use Plan.

| Zone | Management Zone | Maximum Audibility[1] of motorized sound during the hours of 8 am-4 pm |
|---|---|---|
| 1 | Destination or Support Area | Audibility: NTE 50% (anywhere within area boundary) |
| 2 | Plowed Road (within 100 feet (30 m) either side of road) | Audibility: NTE 50% at 100 feet (30 m) |
| 3 | Groomed Motorized Route Clean and Quiet (within 100 feet (30 m) either side route) | Audibility: NTE 50% at 100 feet (30 m) |
| 4 | Groomed Motorized Route (within 100 feet (30 m) either side route) | Audibility: NTE 50% at 100 feet (30 m) |
| 5 | Groomed Motorized Trail Clean and Quiet (within 100 feet (30 m) either side of trail) | Audibility: NTE 25% at 100 feet (30 m) |
| 6 | Groomed Motorized Trail (within 100 feet (30 m) either side of trail) | Audibility: NTE 25% at 100 feet (30 m) |
| 7 | Ungroomed Motorized Trail (within 100 feet (30 m) either side of trail) | Audibility: NTE 25% at 100 feet (30 m) |
| 8 | Groomed Non-motorized Trail | Audibility: NTE 10% at 500 feet (152 m) |
| 9 | Ungroomed Non-motorized Trail or Area | Audibility: NTE 10% at 500 feet (152 m) |
| 10 | Backcountry non-motor trail or area | Audibility: NTE 10% at 500 feet (152 m)<br>Audibility: NTE 0% at 1000 feet (305 m) |

[1] Audibility- the ability of a person with normal hearing to hear a given sound

**Table C-2**. Management zones and soundscape thresholds in 2003 YNP and Grand Teton National Parks and the John D. Rockefeller, Jr. Memorial Parkway Final Supplemental Environmental Impact Statement Winter Use Plan.

| Zone | Management Zone | Maximum Audibility[1], Max. dBA[2], and Hourly $L_{eq}$ [3] of OSV sounds during hours of 8 am-4 pm |
|---|---|---|
| 1 | Destination or Support Area (anywhere within area boundary) | Audibility: NTE[4] 50%<br>dBA: NTE 70 dBA<br>$L_{eq}$: NTE 45dBA |
| 2 | Plowed Road (within 100 feet (30 m) either side of road) | Audibility: NTE 50%<br>dBA: NTE 70 dBA<br>$L_{eq}$: NTE 45 dBA |
| 3 | Groomed Motorized Route (within 100 feet (30 m) either side route) | Audibility: NTE 50%<br>dBA: NTE 70 dBA<br>$L_{eq}$: NTE 45 dBA |
| 4 | Groomed Motorized Trail (within 100 feet (30 m) either side route) | Audibility: NTE 50%<br>dBA: NTE 70 dBA<br>$L_{eq}$: NTE 45 dBA |
| 5 | Ungroomed Motorized Trail or Area (within 100 feet (30 m) either side of trail) | Audibility: NTE 50%<br>dBA: NTE 70 dBA<br>$L_{eq}$: NTE 45 dBA |
| 6 | Groomed Non-motorized Trail (within 100 feet (30 m) either side of trail) | Audibility: NTE 25%<br>dBA: NTE 70 dBA<br>$L_{eq}$: NTE 45 dBA |
| 7 | Ungroomed Nonmotorized Trail or Area (within 100 feet (30 m) either side of trail) | Audibility: NTE 20%<br>dBA: NTE Lnat[5] - 6 dBA<br>$L_{eq}$: NTE to Lnat |
| 8 | Backcountry Nonmotorized Area (anywhere within area >1,000 feet (301 m) from motorized area) | Audibility: NTE 20%<br>dBA: NTE Lnat - 6 dBA<br>$L_{eq}$: NTE to Lnat |
| 9 | Sensitive Area (no winter use) | |

[1] Audibility- the ability of a person with normal hearing to hear a given sound
[2] dBA- weighted sound level in decibels
[3] $L_{eq}$ - The level of a constant sound over a specific time period that has the same sound energy as the actual (unsteady) sound over the same period.
[4] NTE- not to exceed
[5] Lnat- The natural sound conditions found in a given area, including only sounds of nature.

Table C-3. . Impact definitions for the natural soundscape in the 2004 YNP Winter Use Plans (WUP) Environmental Assessment.

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

[1]Thresholds are calculated using the period 8 am-4 pm. Measurements are at 100 feet (30 m) from sound source in developed areas and travel corridors.
[2] Audibility is the ability of humans with normal hearing to hear a certain sound.
[3] To remain within impact category listed audibility and maximum sound level thresholds shall not be violated more than 15% of the measurement days.
[4]Typical natural soundscape sound levels on a calm winter day can range from 0-30 dBA. Snowmobile best available technology (BAT) sound level requirements of 73 dBA measured at 50 feet (15 m) is roughly equivalent to 67 dBA at 100 feet. The maximum sound level for all non-natural sounds in national parks other than OSVs and motorboats is 60 dBA **[**36 CFR (2.12)(a)(1)(i)].

Table C-4. Management zones and adaptive management soundscape thresholds in the 2007 YNP Winter Use Plans (WUP) Final Environmental Impact

Statement and Record of Decision. Measured period is during daytime hours of park operations 8 am-4 pm.

| Management Zone | Percent Time Audible | Sound Level Threshold |
|---|---|---|
| Developed Area | Not to exceed 75% | Not to exceed 70 dBA |
| Road Corridor | Not to exceed 50% | Not to exceed 70 dBA |
| Transition Zone | Not to exceed 25% | Not to exceed 65 dBA |
| Backcountry | Not to exceed 10% | Not to exceed Natural Ambient Sound Level |

## Appendix D: Spectrographs of sound levels

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

Figures D-1 to D-8 show example days from six monitoring sites. Determining the common sound sources signatures from the 1/3 octave band frequencies is not difficult, but takes a bit of experience. A brief introduction follows. Oversnow or wheeled vehicle signatures are narrow orange-yellow marks that extend from high to low frequency. The louder sounds are brighter yellow as shown in hours 00 and 22 (snow groomer) at Madison Junction 2.3 (Fig. D-1). At 1930, a jet appears as a low frequency blob (Fig. D-1). A propeller plane is visible at 0737 (Fig. D-1) The sounds of riffles on the Madison River are shown as diffuse horizontal streaks especially during the early morning and late evening hours (Fig. D-1).

Building utility sounds and wind create the extensive and horizontal light yellow lines at Old Faithful Weather Station (Fig. D-2). Aircraft and OSVs are the main “visible” sounds at Cygnet Lake Roadside on a calm day (Fig. D-3). There were nearly half as many jets as there were OSVs on this day (Fig. D-3). The visitor center heating cycles can easily be seen along with OSVs at Canyon Village Developed Area (Fig. D-4). Snow groomers can be seen during the 1600 hour.

The rushing water sounds of Canary Spring near Mammoth dominate the soundscape at that site (Fig. D-5). Road traffic can also be seen throughout the day. One can more easily see the signatures of the many passing road vehicles nearing the park’s northeast entrance at Middle Barronette Meadow sound monitoring site (Fig. D-6).

Figures D-7 and D-8 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 2012 (440 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 beginning earlier in the day in 2003 and with shorter time intervals between OSVs. This comparison illustrates the difference in noise-free interval, sound level, distribution, and number of OSVs between years. See Figure D-1 for another example of OSV activity at this site during the most recent winter season.

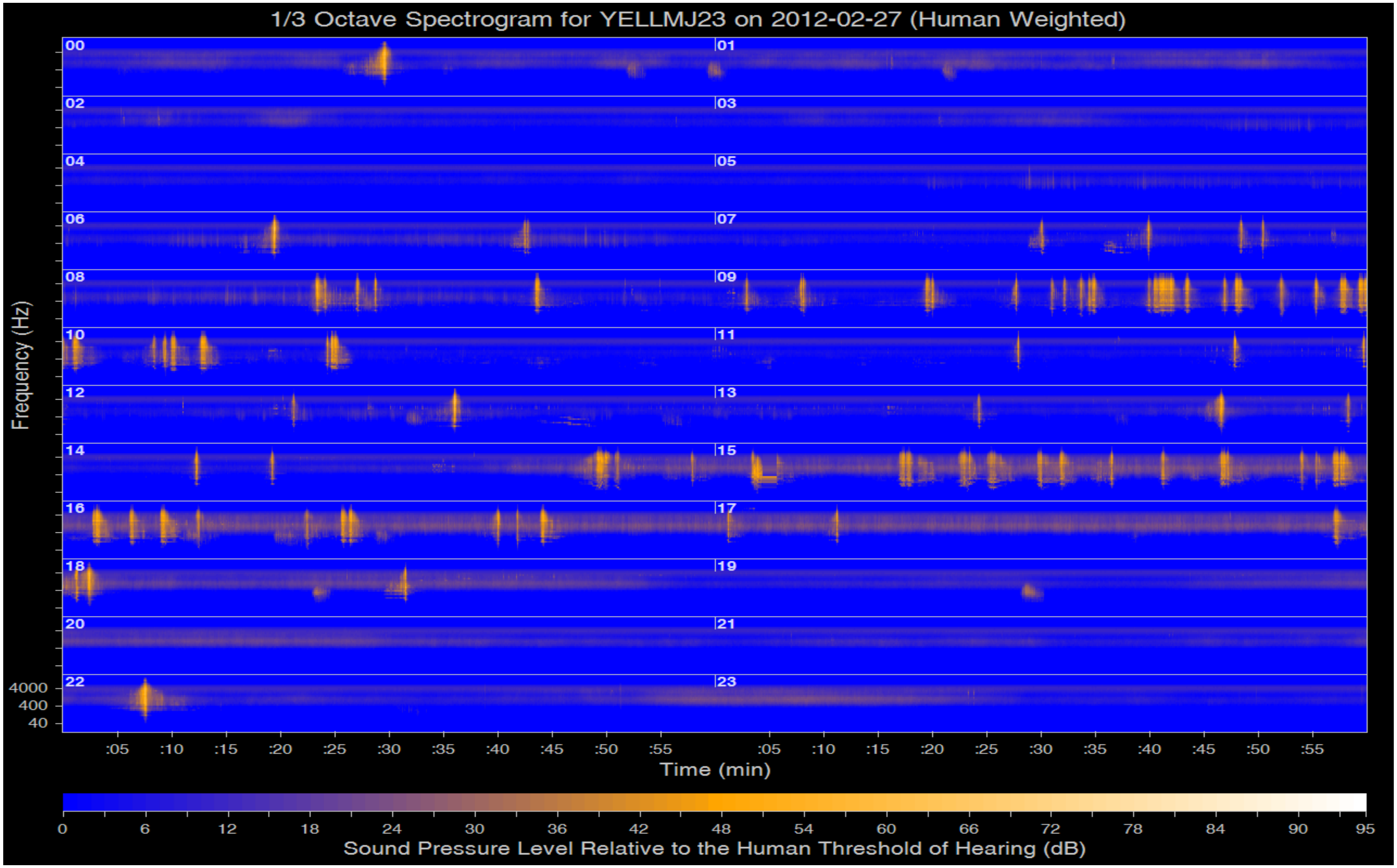

Figure D-1. Sound level spectrograph of 27 February 2012 at Madison Junction 2.3, YNP. See text for explanation.

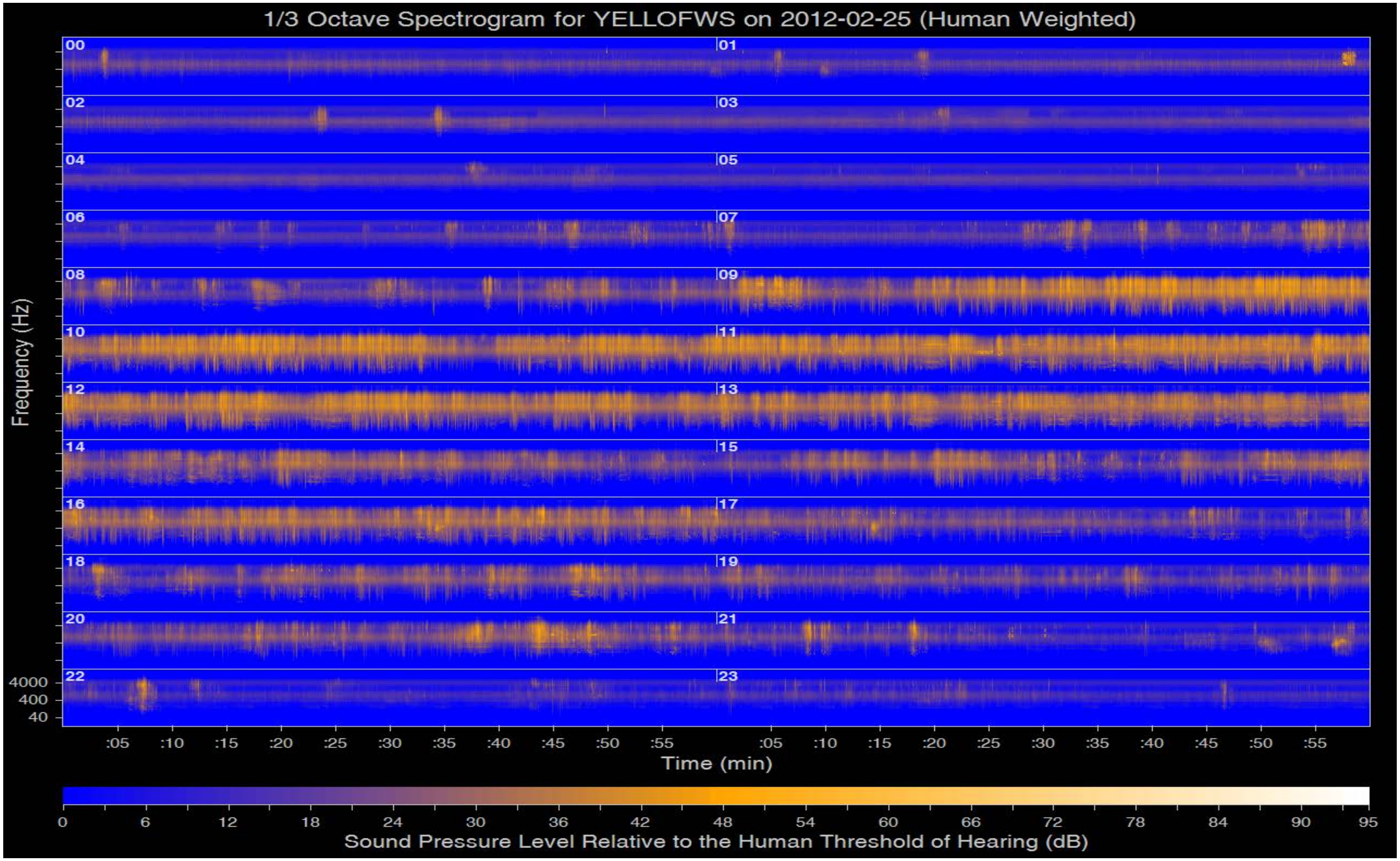


Fig D-2. Sound levels at Old Faithful Weather Station, 25 February 2012, YNP. See text for explanation.

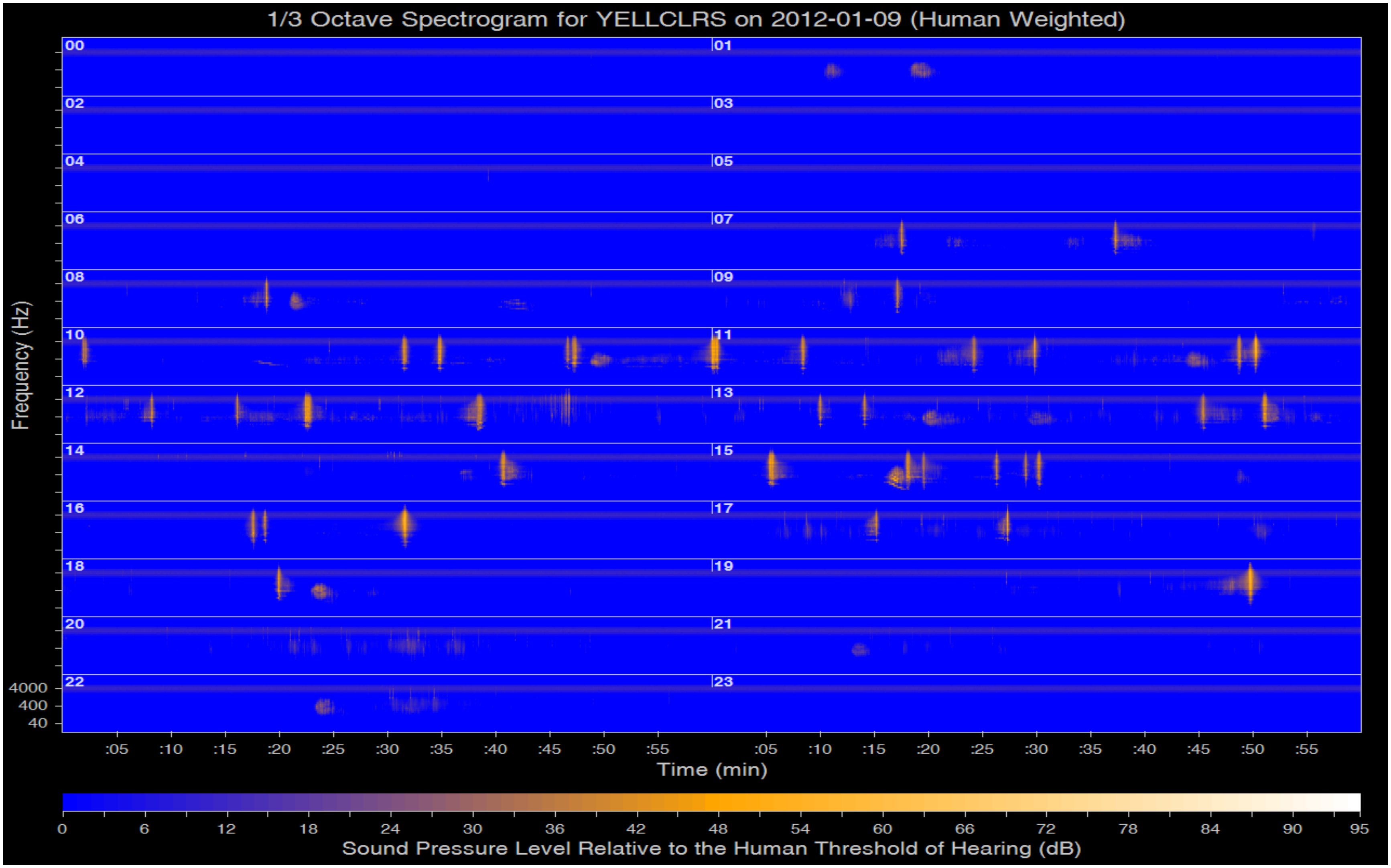

Fig D-3. Sound levels at Cygnet Lake Roadside, 9 January 2012, YNP, on a calm day. See text for explanation.

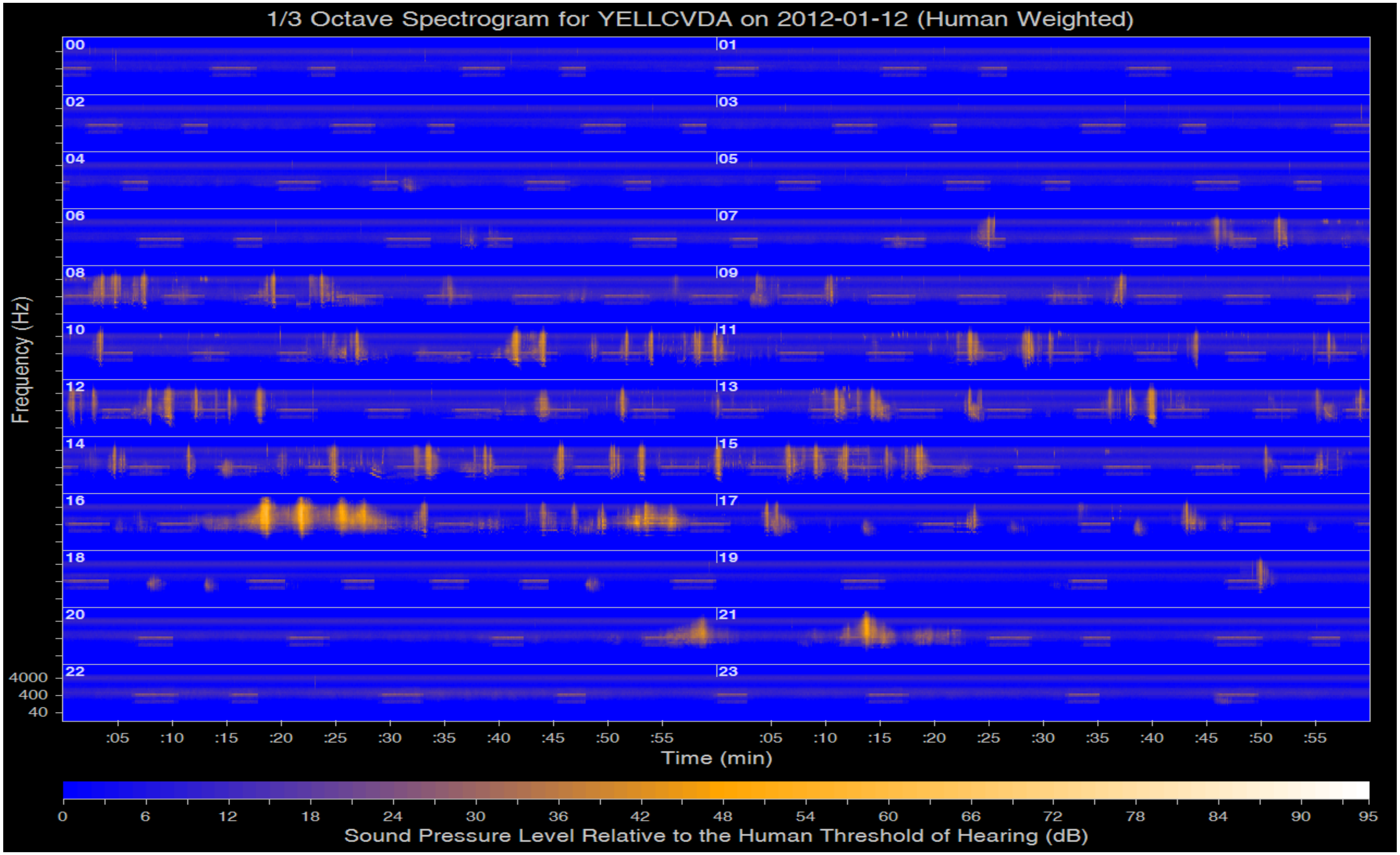


Fig D-4. Sound levels at Canyon Village Developed Area, 12 January 2012, YNP, on a calm day. See text for explanation.

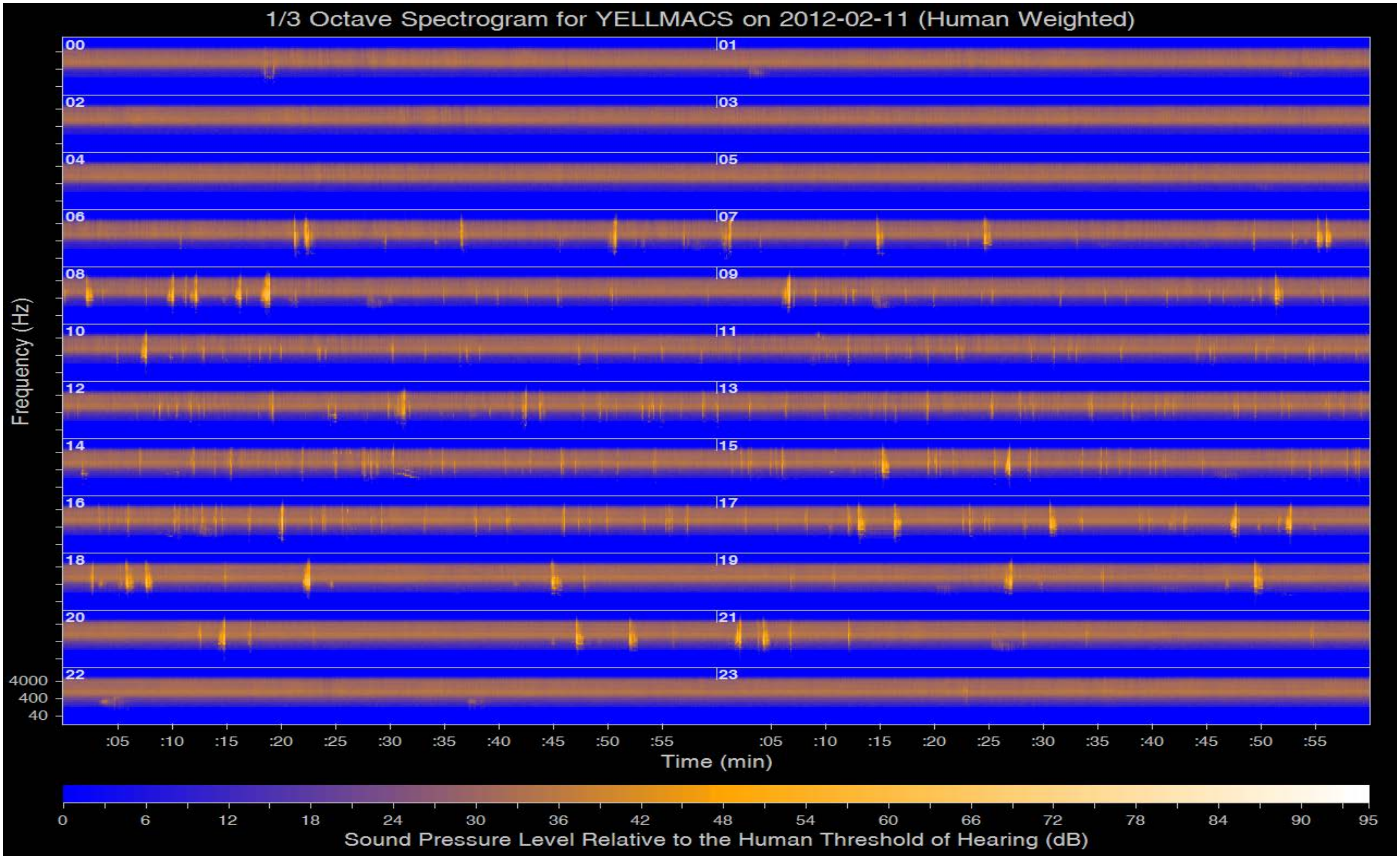

Fig D-5. Sound levels at Mammoth Canary Springs, 11 February 2012, YNP, on a calm day. See text for explanation.

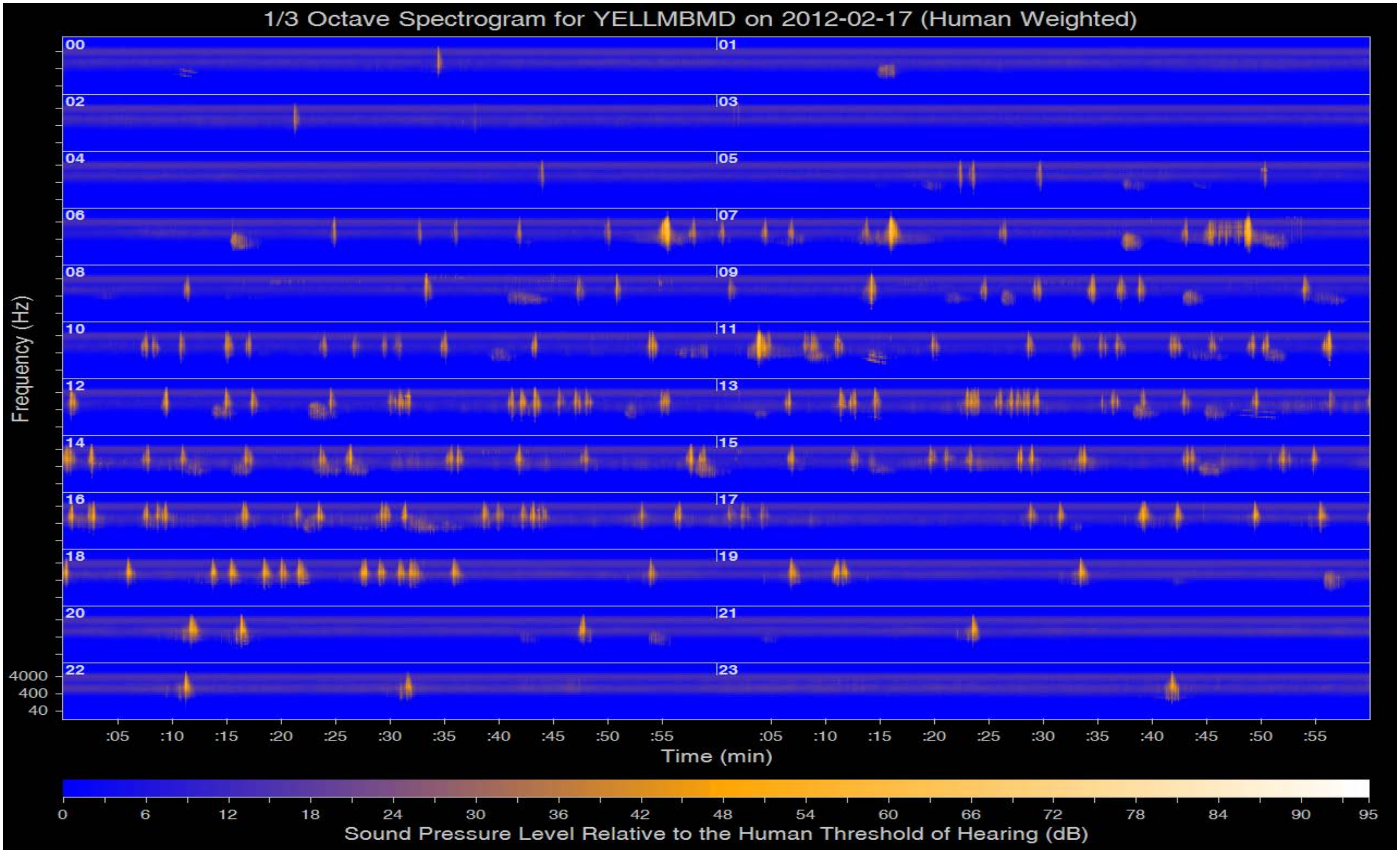


Fig D-6. Sound levels at Middle Barronette Meadow, 17 February 2012, YNP, on a calm day. See text for explanation.

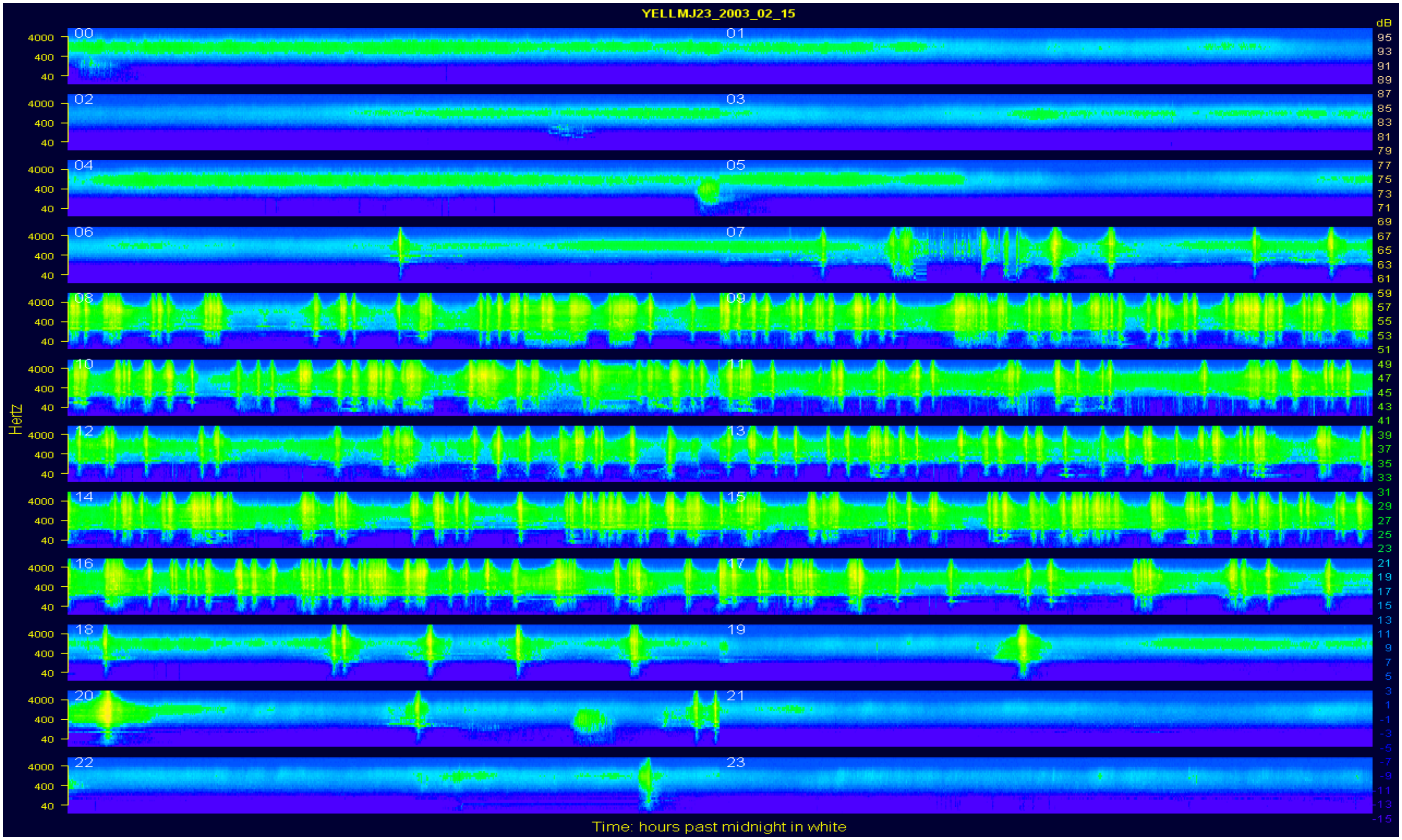


Fig D-7. A-weighted sound levels at Madison Junction 2.3 monitoring site, 15 February 2003, YNP. Compare to Fig. D-6 for number and timing of OSVs. See text for explanation.

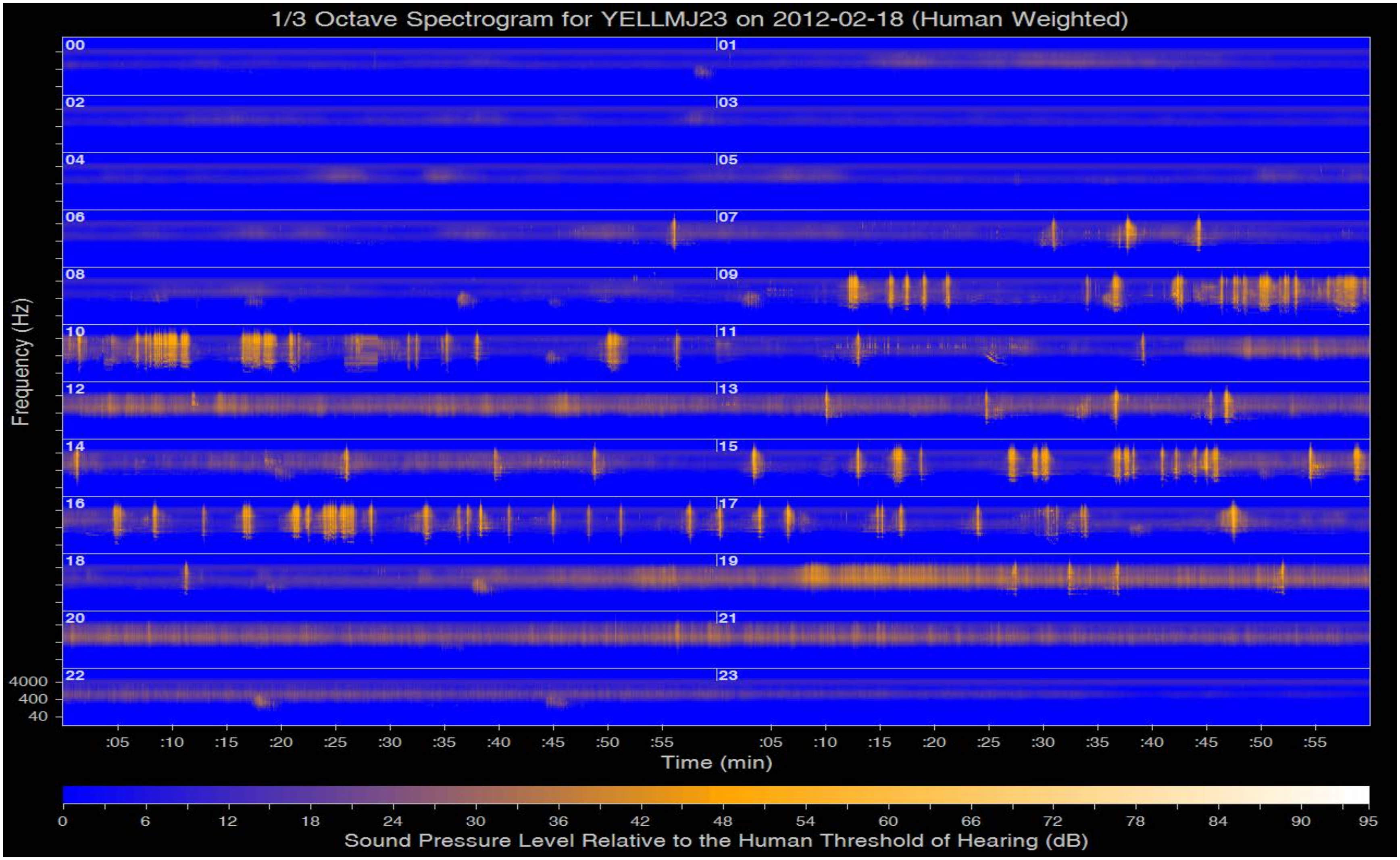

Fig D-8. A-weighted sound levels at Madison Junction 2.3 monitoring site, 18 February 2012, YNP. Compare to Fig. D-7 for number and timing of OSVs. See text for explanation.

## Appendix E: Observational study of oversnow vehicle usage

The audibility analysis using unattended sound monitoring equipment estimated the percent time all sounds were audible at those locations. Unfortunately, that technique was not able to provide the identity of the user type of oversnow vehicles. To determine the type and proportion of OSV usage a separate observational study was conducted during the eight winters of 2005-2012 (Table E-1). Observers were positioned within view of travel routes at key locations and documented the time audible and type of usage for each OSV observed. The data were collected during 253 logging periods at locations within developed areas and along the travel corridors mainly between Lewis Lake and West Yellowstone and Bridge Bay and Cygnet Lake (Table E-2). The total observer logging time was 338 hours 12 minutes 38 seconds, 7 am to 5 pm, split between morning and afternoon.

Table E-1. Dates of observational study of oversnow usage patterns during winters 2005-2012 in YNP.

| | |
|---|---|
| 17 February-5 March 2005 | 12 January-25 February 2009 |
| 20 January-9 March 2006 | 22 December 2009-11 March 2010 |
| 26 December 2006-5 March 2007 | 5 January-13 March 2011 |
| 8 January-5 March 2008 | 9 January- 22 February 2012 |

Table E-2. Locations used and percent of sampling effort for observational study of oversnow usage type during winters 2005-2012 in YNP.

| Developed Area | % Sampling Time | Travel Corridor | % Sampling Time |
|---|---|---|---|
| Old Faithful | 13.7 | Kepler Cascades Pullout | 1.5 |
| Canyon Junction | 9.4 | Daisy Trailhead | 2.1 |
| | | Indian Creek | 0.9 |
| | | Mallard Lake Trailhead | 0.6 |
| | | Midway Geyser Basin | 0.9 |
| | | Mary Mountain Trailhead | 4.6 |
| | | Madison Junction 2.3 | 10.5 |
| | | West Yellowstone 3.1 | 3.8 |
| | | Bridge Bay Area | 7.9 |
| | | Talus Slopes | 0.6 |
| | | Tuff Cliff Pullout | 8.5 |
| | | Cygnet Lake Trailhead | 9.6 |
| | | Hayden Valley | 4.7 |
| | | Grant Village Lewis Lake | 6.1 |
| | | North Twin Lake | 5.8 |
| | | Spring Creek | 7.4 |
| | | Caldera Rim Picnic Area | 1.3 |

Oversnow usage types included guided visitors, NPS administrative use, contractors, and Xanterra administrative use, (see sample data sheet Table E-3).

These data were then transferred to an MS Access™ database for summary and analysis. Tables E-4 to E-7 present these summary analyses. OSVs that were not seen, but only heard, were not included in Tables E-4 to E-6 because the user group could not be determined.

The number and proportion of snowmobiles was analyzed by group (Table E-4) and by individual machine (Table E-5). The developed area, travel corridor, and combined totals are summarized in both tables. To understand snowmobile usage patterns within YNP it is necessary to assess both group and individual patterns. A total of 3,484 groups of OSVs were documented, including 2,198 groups of snowmobile (Table E-4). Guided group size ranged from 1-31 (the highest counts were presumably from multiple groups that had merged together). Average size for all snowmobile groups was just over four snowmobiles per group; just over seven snowmobiles per guided group; and one and a quarter snowmobiles per administrative group. A total of 10,498 individual OSVs were tallied, including 9,212 snowmobiles (Tables E-5 and E-6).

Of all individual snowmobiles observed, guided visitors (recreational use) accounted for 92% along travel corridors and 79% in developed areas (Table E-5). Guided visitors comprised 66% of all groups documented along travel corridors and 38% in developed areas (Table E-4). As would be expected, more administrative travel occurred in developed areas than along travel corridors between developed areas (Tables E-4 and E-5). Contractors working on the Old Faithful Inn and the Old Faithful Visitor Center comprised 6% of all groups of snowmobiles documented in developed areas (Table E-4). All administrative travel totaled 56% of the total number of groups observed in developed areas (Table E-4).

The same analysis was done with snowcoach use in developed areas and travel corridors (Table E-6). Administrative travel is mostly by snowmobile but the NPS and concessions do travel by snowcoach, especially between locations in developed areas. Guided snowcoaches with park visitors comprised 94% of snowcoaches observed along travel corridors and 88% of snowcoaches within developed areas (Table E-6). Of the 1,286 snowcoaches observed, 9 out of 10 were guided (Table E-6).

Guided snowmobiles comprised 55% of all audible snowmobiles and 53% of all audible motorized vehicles were snowmobiles (Table E-7). Guided snowcoaches comprised 29% of all audible motorized vehicles (Table E-7). All OSVs were audible for 48% of the study period and comprised 90% of the motorized sounds audible (Table E-7). Visitor and administrative snowmobiles were audible for 97 hours 6 minute and 51 seconds (29%), and snowcoaches were audible for 52 hours 34 minutes and 47 seconds (16%) of the 338 hours 12 minutes and 38 second study period (Table E-7). No motorized sounds were audible for 46% of the time during the study period (Table E-7).

Table E-3. Field data sheet for logging oversnow usage type in YNP, during the winters of 2005-2012.

| | | |
|---|---|---|
| Date: | Time: Start/End | Page of |
| Name, Address, Telephone: | Shan Burson Grand Teton National Park 307 739 3584 | |
| Location Description: | Latitude: | |
| | Longitude: | |
| | Elevation (ASL, feet): | |
| Habitat types (up to three, include percentage) and Terrain within .5 km: | | |
| Weather | Temperature (F): | Cloud cover (%): |
| | Wind (MPH/from): | Precipitation: |

| Time Start: | Source*: | Time Stopped: | Location: | Remarks: |
|---|---|---|---|---|
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| | | | | |
| 10:41:05 | 4.2 | 10:46:08 | Eastbound | Yellow Bombardier |
| 10:45:12 | 4.1 | 10:48:50 | Out headed south | 8 in guided group leaving OF |

24 hr. time. Include exact Obs.Time Start and End

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

Table E-4. Number and proportion of snowmobile groups by usage type traveling within YNP, winters 2005-2012.

| Location | Guided Snowmobiles | Contractor | NPS Maintenance | Ranger | Research | NPS Other/Unknown | Concession Admin | Unknown Admin | Xanterra Admin | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Developed Area | 387 | 63 | 68 | 109 | 10 | 125 | 18 | 64 | 188 | 1032 |
| | 38% | 6% | 7% | 11% | 1% | 12% | 2% | 6% | 18% | 100% |
| | | | | NPS-All[a] | 312 | | | | | |
| | | | | | 30% | | | | | |
| | | | | Admin-All[b] | 582 | | | | | |
| | | | | | 56% | | | | | |
| | | | | | | | | | | |
| Travel Corridor | 769 | 17 | 20 | 71 | 55 | 162 | 17 | 28 | 27 | 1166 |
| | 66% | 1% | 2% | 6% | 5% | 14% | 1% | 2% | 2% | 100% |
| | | | | NPS-All | 308 | | | | | |
| | | | | | 26% | | | | | |
| | | | | Admin-All | 380 | | | | | |
| | | | | | 33% | | | | | |
| | | | | | | | | | | |
| All Areas | 1156 | 80 | 88 | 180 | 65 | 287 | 35 | 92 | 215 | 2198 |
| | 53% | 4% | 4% | 8% | 3% | 13% | 2% | 4% | 10% | 100% |
| | | | | NPS-All | 620 | | | | | |
| | | | | | 28% | | | | | |
| | | | | Admin-All | 962 | | | | | |
| | | | | | 44% | | | | | |
| | | | | | | | | | | |
| [a]NPS-All | Includes maintenance, rangers, research and NPS others/unknown | | | | | | | | | |
| [b]Admin-All | Includes all but guided snowmobiles and contractors | | | | | | | | | |

Table E-5. Number and proportion of individual snowmobiles by usage type traveling within YNP, winters 2005-2012.

| Location | Guided Snowmobiles | Contractor | NPS Maintenance | Ranger | NPS Research | NPS Other/Unknown | Concession Admin | Unknown Admin | Xanterra Admin | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| Developed Area | 2636 | 96 | 80 | 110 | 13 | 136 | 20 | 66 | 194 | 3351 |
| | 79% | 3% | 2% | 3% | 0% | 4% | 1% | 2% | 6% | 100% |
| | | | | NPS-All[a] | 339 | | | | | |
| | | | | | 10% | | | | | |
| | | | | Admin-All[b] | 619 | | | | | |
| | | | | | 18% | | | | | |
| | | | | | | | | | | |
| Travel Corridor | 5367 | 31 | 24 | 78 | 71 | 201 | 26 | 32 | 31 | 5861 |
| | 92% | 1% | 0% | 1% | 1% | 3% | 0% | 1% | 1% | 100% |
| | | | | NPS-All[a] | 374 | | | | | |
| | | | | | 6% | | | | | |
| | | | | Admin-All[b] | 463 | | | | | |
| | | | | | 8% | | | | | |
| | | | | | | | | | | |
| All Areas | 8003 | 127 | 104 | 188 | 84 | 337 | 46 | 98 | 225 | 9212 |
| | 87% | 1% | 1% | 2% | 1% | 4% | 0% | 1% | 2% | 100% |
| | | | | NPS-All[a] | 713 | | | | | |
| | | | | | 8% | | | | | |
| | | | | Admin-All[b] | 1082 | | | | | |
| | | | | | 12% | | | | | |

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

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

Table E-6. Number and proportion of individual snowcoaches by usage type traveling within YNP, winters 2005-2012.

| Location | Guided Snowcoach | Contractor | NPS Maintenance | NPS Ranger | NPS Other/Unknown | Concession Admin | Unknown Admin | Xanterra Admin | Total |
|---|---|---|---|---|---|---|---|---|---|
| Developed Area | 564 | 5 | 2 | 2 | 1 | 3 | 4 | 62 | 643 |
| | 88% | 1% | 0% | 0% | 0% | 0% | 1% | 10% | 100% |
| | | | | NPS-All[a] | 5 | | | | |
| | | | | | 1% | | | | |
| | | | | Admin-All[b] | 74 | | | | |
| | | | | | 12% | | | | |
| Travel Corridor | 603 | 0 | 0 | 1 | 9 | 8 | 2 | 20 | 643 |
| | 94% | 0% | 0% | 0% | 1% | 1% | 0% | 3% | 100% |
| | | | | NPS-All | 10 | | | | |
| | | | | | 2% | | | | |
| | | | | Admin-All | 40 | | | | |
| | | | | | 6% | | | | |
| All Areas | 1167 | 5 | 2 | 3 | 10 | 11 | 6 | 82 | 1286 |
| | 91% | 0% | 0% | 0% | 1% | 1% | 0% | 6% | 100% |
| | | | | NPS-All | 15 | | | | |
| | | | | | 1% | | | | |
| | | | | Admin-All | 114 | | | | |
| | | | | | 9% | | | | |

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

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

Table E-7. Elapsed time (hours:minutes:seconds) and percentages for motorized vehicles during an observational study, winters 2005-2012, YNP. Percentage totals may not appear correct due to rounding errors.

| User Group | Elapsed Time | Percentage | Combined Total |
|---|---|---|---|
| Snowmobiles Only | | | |
| Guided Snowmobile | 53:45:33 | 55% | 55% |
| | | | |
| Contractor | 1:27:04 | 1% | 1% |
| | | | |
| NPS-Maintenance | 2:38:41 | 3% | |
| NPS-Ranger | 4:19:32 | 4% | |
| NPS-Research | 1:54:20 | 2% | |
| NPS-Other/Unknown | 9:59:23 | 10% | 19% |
| | | | |
| Admin-Concession | 0:40:15 | 1% | |
| Administrative-Xanterra | 4:25:32 | 5% | |
| Administrative-Unknown | 2:22:06 | 2% | 8% |
| | | | |
| Unknown Snowmobile User | 15:34:25 | 16% | 16% |
| | **97:06:51** | | |
| | | | |
| Snowcoaches Only | | | |
| Guided Snowcoach | 45:55:17 | 87% | 87% |
| | | | |
| Contractor | 0:04:02 | 0% | 0% |
| | | | |
| NPS-Maintenance | 0:02:31 | 0% | |
| NPS-Ranger | 0:05:02 | 0% | |
| NPS-Research | 0:00:00 | 0% | |
| NPS-Other/Unknown | 0:27:55 | 1% | 1% |
| | | | |
| Admin-Concession | 0:17:37 | 1% | |
| Administrative-Xanterra | 2:33:27 | 5% | |
| Administrative-Unknown | 0:08:50 | 0% | 6% |
| | | | |
| Unknown Snowcoach User | 3:00:06 | 6% | 6% |
| | **52:34:47** | | |

**Table E-7 continued.** Elapsed time (hours:minutes:seconds) and percentages for motorized vehicles during an observational study, winters 2005-2012, YNP. Percentage totals may not appear correct due to rounding errors.

| User Group | Elapsed Time | Percentage | Combined Total |
|---|---|---|---|
| | | | |
| All Motorized Sounds | | | |
| Jets | 9:21:43 | 5% | |
| Props | 2:58:52 | 2% | |
| Helicopters | 0:32:43 | 0% | 7% |
| | | | |
| Snowmobile | 97:06:51 | 53% | |
| Snowcoach | 52:34:47 | 29% | |
| Snowmobile or Snowcoach | 7:46:55 | 4% | |
| Unknown Oversnow Vehicle | 6:30:01 | 4% | 90% |
| | | | |
| Groomer | 3:38:10 | 2% | 2% |
| | | | |
| Unknown/Other Motorized | 2:18:16 | 1% | 1% |
| | **182:48:18** | | |
| | | | |
| | | | |
| Total Observation Time | 338:12:38 | | |
| | | | |
| Motorized Sounds | 182:48:18 | 54% | |
| Oversnow Vehicles | 163:58:34 | 48% | |
| Snowmobiles | 97:06:51 | 29% | |
| Snowcoaches | 52:34:47 | 16% | |
| No Motorized Sounds | 155:24:20 | 46% | |

## Appendix F: Additional percent time audible considerations

As was discussed in the Results and Discussion section, the percent time OSVs were audible at any one point depended on several variables. For the last several winter use plans, audibility was measured by the percent of time between 8 am and 4 pm that OSVs were audible at a given point. The primary travel corridor monitoring site, for this study, has been Madison Junction 2.3 along the busiest travel corridor in winter. For the winter season 2011-2012, OSVs were audible 45% 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 80% during the busiest hour of the day, 9 am to 10 am, and was 22% during the noon hour. The average OSV audibility for all days analyzed of all travel corridor monitoring sites was 36% for 8 am to 4 pm. The time period and location of data collection and analysis can greatly influence the percent time audible results (Table F-1).

Table F-1: Oversnow audibility as a function of monitoring site and period of analysis, YNP, 15 December 2011-15 March 2012.

| Site(s) | Period of Analysis | Audibility |
|---|---|---|
| Madison Junction | 9 am to 10 am | 80% |
| Madison Junction | noon to 1 pm | 22% |
| Madison Junction | 8 am to 4 pm | 45% |
| Madison Junction | 7 am to 9 pm | 38% |
| All travel corridor monitoring sites in YNP all years | 8 am to 4 pm | 36% |

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

**Appendix G: Pass-by Measurements**

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

Acoustic pass-by measurements were collected during the winter of 2011-2012 on two days. Several newer model snowcoaches were measured to supplement previous snowcoach acoustic measurements performed by the John A. Volpe National Transportation Systems Center's Environmental Measurement and Modeling Division (Scarpone 2010) and the NPS (Burson 2009). Two recent model snowmobiles were also tested.

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

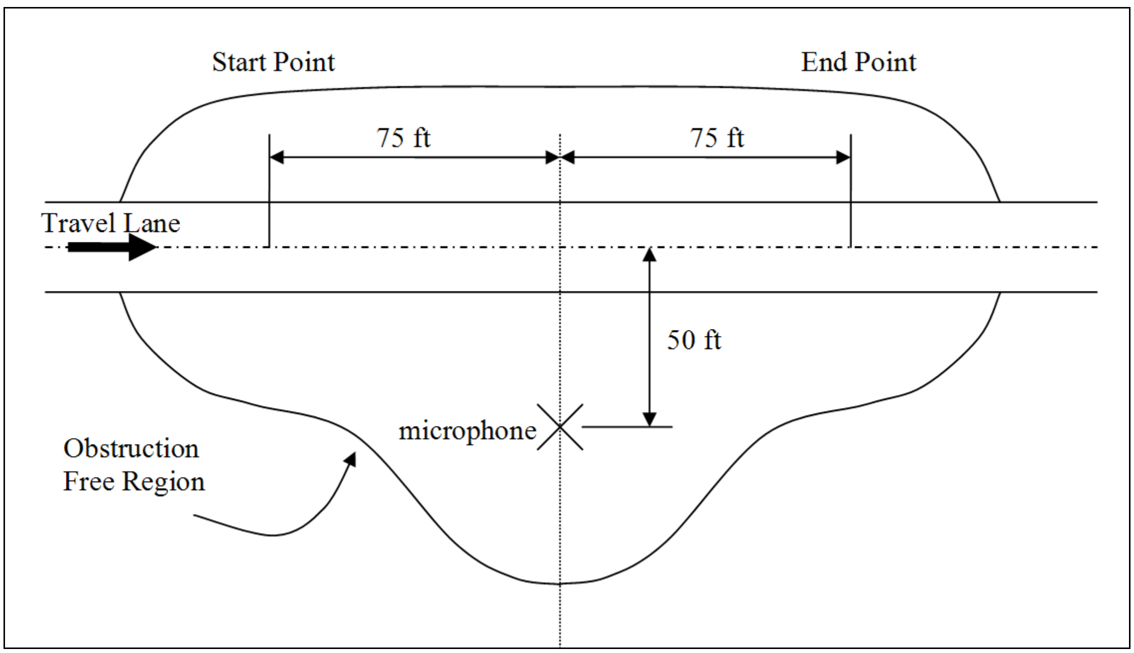


Figure G-1. SAE J1161 area layout.

The OSV measurements were conducted on 17 February and 4 March 2012 at Yellowstone's 7-Mile Bridge Pass-by measurement site. Table G-1a and b contains the details of the measurement instruments and weather conditions.

Table G-1a. Datasheet containing instrument specifications and site weather.

| | | | |
|---|---|---|---|
| Date | 24-Feb-12 | | |
| | | | |
| | | | |
| Location: 7-Mile Bridge Pass-by Location, Yellowstone NP | Latitude: 44.881942 | Longitude: 110.732869 | |
| | | | |
| | Type | Serial # | |
| SLM microphone | GRAS40AE | 36931 | |
| SLM preamp | LDPRM902 | 3116 | |
| Sound Level Meter | LD 824 | 824A2979 | |
| | | | |
| Elevation | 6750 | 2057 | |
| Weather | Clear | | |
| Temperature | 20-30 F | -7 to -1C | |
| Wind speed/direction | 0-11mph/SW | 0-18kmh | |
| Precipitation | 0 | | |
| Humidity | 45% | | |
| Barometric pressure | 22.585 in-hg | 764.8mb | calculated from Weatherunderground.com data |
| | | | |
| Snow conditions | Depth | | |
| On road | 7+ in | 18+ cm | |
| Between road and microphone | 30"" | 76 cm | |
| | | | |
| Ambient sound level | <25 dBA | | |
| | | | |
| GPS time at start of recording/data logging: | 0900 | | |

Table G-1b. Datasheet containing instrument specifications and site weather.

| | | | |
|---|---|---|---|
| Date | 08-Mar-12 | | |
| | | | |
| | | | |
| Location: 7-Mile Bridge Pass-by Location, Yellowstone NP | Latitude: 44.881942 | Longitude: 110.732869 | |
| | | | |
| | Type | Serial # | |
| SLM microphone | GRAS40AE | 36931 | |
| SLM preamp | LDPRM902 | 3116 | |
| Sound Level Meter | LD 824 | 824A2979 | |
| | | | |
| Elevation | 6750 | 2057 | |
| Weather | Clear | | |
| Temperature | 0-25 F | -18 to -4 C | |
| Wind speed/direction | 0-7mph/SW | 0-18kmh | |
| Precipitation | 0 | | |
| Humidity | na | | |
| Barometric pressure | na | | |
| | | | |
| Snow conditions | Depth | | |
| On road | 7+ in | 18+ cm | |
| Between road and microphone | 30"" | 76 cm | |
| | | | |
| Ambient sound level | <25 dBA | | |
| | | | |
| GPS time at start of recording/data logging: | 0830 | | |

The field measurements of the tested snowcoaches and snowmobiles are shown in Table G-2 through G-6. The standard pass-by speeds of 15 mph and cruising speeds were augmented by an idle measurement. Following SAE J1161 protocol the standard pass-bys were continued until three sound level readings from each side of the vehicle were within 2 dBA. Those three values were then arithmetically averaged and the side with the highest average level is reported at the bottom of each table. Table G-7 summarizes the data.

Table G-2. Field measurements of a 2012 SnoGrizz snowcoach, YNP, 24 February 2012.

| SnowGrizz-gas | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Time (hh:mm:ss) | Vehicle Side | | | 150 ft | |
| Trial # | Speed (mph) | Start | Driver | Passenger | Lmax (dBA) | SEL (dBA) | Comments |
| 1 | 16 | 0920 | x | | 72.2 | nd | SAE J1161 |
| 2 | 15 | 092430 | | x | 68.1 | nd | SAE J1161 |
| 3 | 15 | 092712 | x | | 68.1 | nd | SAE J1161 |
| 4 | 15 | 0932 | | x | 67.3 | nd | SAE J1161 |
| 5 | 15 | 0935 | x | | 71.4 | nd | SAE J1161 |
| 6 | 15 | 093959 | | x | 67.8 | nd | SAE J1161 |
| 7 | 15 | 094650 | x | | 69.2 | nd | SAE J1161 |
| 8 | 15 | 0959 | x | | 69.8 | nd | SAE J1161 |
| 9 | 25 | 0957 | | x | 75.9 | nd | crusing speed |
| 10 | 25 | 1003 | | x | 75.9 | nd | crusing speed |
| 11 | 27 | 1007 | x | | 78.3 | nd | crusing speed |
| 12 | 25 | 1010 | | x | 74.7 | nd | crusing speed |
| 13 | 26 | 1013 | x | | 73.9 | nd | crusing speed |
| 14 | 26 | 1022 | x | | 78.3 | nd | crusing speed |
| 15 | 25 | 1027 | x | | 79.3 | nd | crusing speed |
| 16 | Idle | | x | | 49.4 | 66.2 | 1-min Leq |
| 17 | Idle | | | x | 47.5 | 64.3 | 1-min Leq |
| 18 | | | | | | | |

| Summary | Speed | Drivers | Passenger | Test Result |
|---|---|---|---|---|
| | SAE J1161 | 69.0 | 67.7 | **69** |
| | Cruising | 78.9 | 75.5 | **79** |
| | Idle | 49.4 | 47.5 | **49** |

Table G-3. Field measurements of a 2011 Arctic Cat TZ2 snowmobile, YNP, 24 February 2012.

| 2010 Arctic Cat TZ1 | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Time (hh:mm:ss) | Vehicle Side | | | 150 ft | |
| Trial # | Speed (mph) | Start | Westbound | Eastbound | Lmax (dBA) | SEL (dBA) | Comments |
| 1 | 14 | 1117 | | x | 65.3 | nd | SAE J1161 |
| 2 | 15 | | x | | 65.6 | nd | SAE J1161 |
| 3 | 15 | 111910 | | x | 66.3 | nd | SAE J1161 |
| 4 | 15 | 1120 | x | | 65.2 | nd | SAE J1161 |
| 5 | 15 | 1121 | | x | 65.8 | nd | SAE J1161 |
| 6 | 15 | 1122 | x | | 65.7 | nd | SAE J1161 |
| 7 | 34 | 1123 | | x | 72.7 | nd | 35 mph |
| 8 | 34 | 1124 | x | | 72.5 | nd | 35 mph |
| 9 | 35 | 1125 | | x | 73.4 | nd | 35 mph |
| 10 | 35 | 1126 | x | | 73.2 | nd | 35 mph |
| 11 | 36 | 1126 | | x | 73.3 | nd | 35 mph |
| 12 | 35 | 1127 | x | | 72.6 | nd | 35 mph |
| 13 | 43 | 1128 | | x | 76.9 | nd | 45 mph |
| 14 | 45 | 1129 | x | | 78.5 | nd | 45 mph |
| 15 | 43 | 1130 | | x | 76.1 | nd | 45 mph |
| 16 | 46 | 1131 | x | | 78.2 | nd | 45 mph |
| 17 | 44 | 113150 | | x | 77.0 | nd | 45 mph |
| 18 | 45 | 113230 | x | | 77.8 | nd | 45 mph |
| 19 | Idle | | | x | 52.8 | 66.9 | 1-min Leq |
| 20 | Idle | | x | | 50.3 | 64.6 | 1-min Leq |

| Summary | Speed | Westbound | Eastbound | **Test Result** |
|---|---|---|---|---|
| | SAE J1161 | 65.5 | 65.8 | **66** |
| | 35 | 72.8 | 73.1 | **73** |
| | 45 | 78.2 | 76.7 | **78** |
| | Idle | 50.3 | 52.8 | **53** |

Table G-4. Field measurements of a 2012 Skidoo Expedition Sport snowmobile, YNP, 24 February 2012.

| 2012 Skidoo Expedition Sport | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Time (hh:mm:ss) | Vehicle Side | | | 150 ft | |
| Trial# | Speed (mph) | Start | Westbound | Eastbound | Lmax (dBA) | SEL (dBA) | Comments |
| 1 | 16 | 103630 | x | | 63.2 | 67.6 | SAE J1161 |
| 2 | 15 | 1039 | | x | 62.1 | 67.5 | SAE J1161 |
| 3 | 15 | 104040 | x | | 62.2 | 67.4 | SAE J1161 |
| 4 | 15 | 104340 | | x | 61.8 | 67.1 | SAE J1161 |
| 5 | 15 | 104440 | x | | 61.9 | 67.4 | SAE J1161 |
| 6 | 15 | 1045 | | x | 61.3 | 67.0 | SAE J1161 |
| 7 | 35 | 1048 | x | | 69.2 | 72.3 | 35 mph |
| 8 | 34 | 1048 | | x | 69.7 | 72.0 | 35 mph |
| 9 | 34 | 1049 | x | | 68.3 | 71.0 | 35 mph |
| 10 | 34 | 1050 | | x | 71.0 | 72.1 | 35 mph |
| 11 | 34 | 1051 | x | | 68.8 | 71.1 | 35 mph |
| 12 | 34 | nd | | x | 70.1 | 72.5 | 35 mph |
| 13 | 42 | 1108 | x | | 75.0 | 76.0 | 45 mph |
| 14 | 43 | 1109 | | x | 76.7 | 76.5 | 45 mph |
| 15 | 44 | 1110 | x | | 74.6 | 75.3 | 45 mph |
| 16 | 46 | 1111 | | x | 76.9 | 76.5 | 45 mph |
| 17 | 46 | 1112 | x | | 74.8 | 75.3 | 45 mph |
| 18 | 45 | 1113 | | x | 75.3 | 75.5 | 45 mph |
| 19 | Idle | | x | | 40.7 | nd | 1-min Leq |
| 20 | Idle | | | x | 40.5 | nd | 1-min Leq |

| Summary | Speed | Westbound | Eastbound | Test Result |
|---|---|---|---|---|
| | SAE J1161 | 62.4 | 61.7 | **62** |
| | 35 | 68.8 | 70.3 | **70** |
| | 45 | 74.8 | 76.1 | **76** |
| | Idle | 40.7 | 40.5 | **41** |

Table G-5. Field measurements of a 2011 Ford F550, YNP, 8 March 2012.

| Bus #8 - Diesel, with driver and passenger | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | Time (hh:mm:ss) | Vehicle Side | | | 150 ft | |
| Trial # | Speed (mph) | Start | Driver | Passenger | Lmax (dBA) | SEL (dBA) | Comments |
| 1 | 15 | 0853 | | x | 67.6 | 71.0 | SAE J1161 |
| 2 | 15 | 0854 | x | | 63.2 | 69.3 | SAE J1161 |
| 3 | 15 | 0900 | | x | 64.6 | 70.4 | SAE J1161 |
| 4 | 15 | 0904 | x | | 63.3 | 68.8 | SAE J1161 |
| 5 | 15 | nd | | x | 64.6 | 70.2 | SAE J1161 |
| 6 | 15 | 0914 | x | | 63.9 | 69.3 | SAE J1161 |
| 7 | 15 | 0921 | | x | 66.3 | 70.4 | SAE J1161 |
| 8 | 21 | 0926 | x | | 67.1 | 71.3 | crusing speed |
| 9 | 22 | 0932 | | x | 66.0 | 70.5 | crusing speed |
| 10 | 21 | 0934 | x | | 67.6 | 71.6 | crusing speed |
| 11 | 21 | 0940 | | x | 66.8 | 71.0 | crusing speed |
| 12 | 21 | 0941 | x | | 66.8 | nd | crusing speed |
| 13 | 21 | 0947 | | x | 66.9 | 70.5 | crusing speed |
| 14 | Idle | | x | | 45.1 | nd | 1-min Leq |
| 15 | Idle | | | x | 42.3 | nd | 1-min Leq |
| 16 | | | | | | | |
| 17 | | | | | | | |
| 18 | | | | | | | |

| Summary | Speed | Drivers | Passenger | Test Result |
|---|---|---|---|---|
| | SAE J1161 | 63.5 | 65.2 | **65** |
| | Cruising | 67.2 | 66.6 | **67** |
| | Idle | 45.1 | 42.3 | **45** |

Table G-6. Field measurements of a 2011 Ford Vanterra, YNP, 8 March 2012.

Buffalo Bus #3-Gas, with 1250 pounds of cargo including people

| | | Time (hh:mm:ss) | Vehicle Side | | | 150 ft | |
|---|---|---|---|---|---|---|---|
| Trial # | Speed (mph) | Start | Driver | Passenger | Lmax (dBA) | SEL (dBA) | Comments |
| 1 | 15 | 1024 | x | | 66.0 | 70.7 | SAE J1161 |
| 2 | 15 | 1026 | | x | 65.5 | 71.4 | SAE J1161 |
| 3 | 15 | 1028 | x | | 64.2 | 69.7 | SAE J1161 |
| 4 | 15 | 1030 | | x | 65.5 | 71.1 | SAE J1161 |
| 5 | 15 | 1032 | x | | 63.4 | 69.3 | SAE J1161 |
| 6 | 15 | 1034 | | x | 65.7 | 71.1 | SAE J1161 |
| 7 | 15 | 1036 | x | | 64.8 | 70.1 | SAE J1161 |
| 8 | 21 | 1038 | | x | 69.0 | 73.3 | crusing speed |
| 9 | 22 | 1040 | x | | 69.7 | 74.3 | crusing speed |
| 10 | 21 | 1042 | | x | 69.4 | 73.8 | crusing speed |
| 11 | 21 | 1043 | x | | 69.0 | 73.3 | crusing speed |
| 12 | 21 | 1045 | | x | 70.0 | 73.8 | crusing speed |
| 13 | 21 | 1047 | x | | 70.5 | nd | crusing speed |
| 14 | Idle | 1020 | | x | 36.8 | nd | 1-min Leq |
| 15 | Idle | 1016 | x | | 36.9 | nd | 1-min Leq |
| 16 | | | | | | | |
| 17 | | | | | | | |
| 18 | | | | | | | |

| Summary | Speed | Drivers | Passenger | Test Result |
|---|---|---|---|---|
| | SAE J1161 | 65.0 | 65.6 | **66** |
| | Cruising | 69.7 | 69.5 | **70** |
| | Idle | 36.9 | 36.8 | **37** |

Table G-7. Comparison of exterior sound levels in snowcoaches and snowmobiles measured during standardized pass-by testing, YNP, winter 2012.

| Exterior Noise Levels | | | | | | |
|---|---|---|---|---|---|---|
| Speed | MPH | **Test Result (Maximum dBA)** | | | | |
| | | Snowcoach | | | Snowmobile | |
| | | **Snow Grizz** | 2011 Ford Vanterra | 2011 Ford F550 | Skidoo 600Ace | Arctic Cat TZ1 |
| SAE J1161 | 15 | **69** | **66** | **65** | **62** | **66** |
| Cruising | 21.2 | | **70** | **67** | | |
| Cruising | 25.6 | **79** | | | | |
| Cruising | 34.2 | | | | **70** | |
| Cruising | 34.8 | | | | | **73** |
| Cruising | 44.3 | | | | **76** | **78** |
| Idle | 0 | **49** | **37** | **45** | **41** | **53** |

## Appendix H: Snowcoach Interior Sound Level Measurements

Snowcoach interior sound levels were measured to understand better the acoustic conditions experienced by passengers riding in snowcoaches. Sound levels were measured in the interior of six different snowcoaches operating at idle and at typical cruising speeds of approximately 20 to 25 mph on snow-covered groomed roads in the interior of YNP (Table H-1).

These six vehicles ranged from a repowered and retrofitted Bombardier with skis and long tracks to a 32-passenger bus. These vehicles were selected because they represent a cross-section of late model snowcoaches currently in operation in the park. The exception was the SnoGrizz that was tested as a prototype snowcoach. Sound levels inside snowcoach cabins were measured using a calibrated Larson Davis Type 1 sound level meter and microphone. One-minute $L_{eq}$ measurements were taken in the front seat and the back seat of each snowcoach at approximate ear level as the snowcoach traveled at typical cruising speed. Measurements were taken over a three-day period during the week of March 5, 2012.

Table H-1. Interior sound levels of six snowcoaches in YNP, March 2012.

| Interior Noise Levels | | | | | |
|---|---|---|---|---|---|
| Snowcoach | Test Result (1-min Leq (dBA)) | | | | Notes |
| | Idle | Front Seat | Backseat | Cruising Speed | |
| 2011 Ford F550 | 51.5 | 69.7 | 71.1 | 22 | |
| Snow Grizz | nd | see note | 89.2 | 23 | similar noise levels throughout the interior |
| 2011 Ford Vanterra | 41.6 | 75.4 | 73.0 | 24 | |
| 2008 Chevy Express Van | 43.3 | 77.3 | 75.9 | 24 | |
| 1956 Bombardier | 49.0 | 86.0 | 79.6 | 26 | |
| 2011 Glavel | 47.2 | 82.0 | 79.6 | 27 | |