Sound Levels at Greater Sage-grouse Leks in the Pinedale Anticline Project Area, WY, April, 2013─2020

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Executive Summary

The Bureau of Land Management's Pinedale Anticline Project Area Supplemental Environmental Impact Statement developed a "Wildlife Monitoring and Mitigation Matrix" that identifies specific species to be monitored as well as criteria to be monitored. Greater Sage-grouse were identified as a species to be monitored, and one criterion for this species was sound levels at leks. The objective of this project was to monitor sound levels at Greater Sage-grouse leks in the Pinedale Anticline Project Area (PAPA) south of Pinedale, WY, and determine if sound levels exceeded 10 dB over background sound levels. This is the eighth year of monitoring sound levels at Greater Sage-grouse leks in the PAPA.

A total of 4,216 hours of acoustic data were collected at 19 leks in the PAPA in 2020 (1 of the 20 leks was not accessible due to snow). Average sound levels in 2020 for all hours for all leks were L_{Aeq} = 28.1 dB, L_{A10} = 29.7 dB, L_{A50} = 24.8 dB, and L_{A90} = 21.4 dB. Average sound levels for lekking hours (1800-0800) were L_{Aeq} = 26.5 dB, L_{A10} = 28.2 dB, L_{A50} = 24.1 dB, and L_{A90} = 21.2 dB. From 2013–2020, 21,623 hours of acoustic data were collected at 20 leks in the PAPA. Average sound levels for all leks for all years for all hours were L_{Aeq} = 29.8 dB, L_{A10} = 31.4 dB, L_{A50} = 26.1 dB, and L_{A90} = 22.6 dB. Sound levels at leks were influenced by the distance from the lek to the nearest well pad. At leks <1560 m from a well pad, the mean L_{A50} = 28.9 dB, and at leks ≥1560 m from a well pad, the mean L_{A50} = 22.4 dB. At the 10 leks <1560 m from a well pad, all were unoccupied or had declining trends.

The 2008 BLM Record of Decision used 39 dBA as the background sound level (L_{A90}) in the PAPA, based on a 1971 EPA study that found L_{A90} = 39 dB in a California farm valley. Of the 21,623 hours of acoustic data collected at 20 leks in the PAPA from 2013–2020, 7 hours (0.03%) exceeded 49 dBA (10 dBA over background of 39). Based on recent studies in Wyoming in undeveloped sagebrush habitats, a more accurate background sound level is 14.0 dB. Of all 21,623 hours of data in the PAPA, 13,785 hours (63%) had L_{A50} levels > 24 dB. Of the 20 leks monitored in the PAPA from 2013–2020, 13 had L_{A50} >24 dB (11 of these had declining trends), and 7 had L_{A50} <24 dB (1 of these had declining trends). Analysis of acoustic and lek count data in the PAPA suggests that when sound levels (L_{A50}) at leks exceed 26 dB (or L_{Aeq} exceeds 31 dB), grouse populations decline. 26 dB is 12 dB over a background of 14 dB in rural, sagebrush Wyoming.

The long-term lek counts in the PAPA, in conjunction with these long-term sound level studies, have allowed to us better understand the relationships between Greater Sage-grouse trends and the sounds of gas field operations.

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Introduction

Greater Sage-grouse (*Centrocercus urophasianus*) use elaborate audio and visual display behaviors to attract and select mates, and depend on audio communication between females and chicks during brood rearing. A potential threat to Greater Sage-grouse is anthropogenic sounds associated with human activity, including sounds from oil and gas development and production (Holloran 2005, BLM 2008, Patricelli et al. 2013).

The Bureau of Land Management's Pinedale Anticline Project Area Supplemental Environmental Impact Statement (BLM 2008) developed a "Wildlife Monitoring and Mitigation Matrix" that identified specific species to be monitored as well as criteria to be measured and changes that will be monitored. Greater Sage-grouse were identified as a species to be monitored, and one criterion for this species was sound levels at leks. This is the eighth year of monitoring sound levels at leks in the Pinedale Anticline Project Area (PAPA).

Appendix B of the Record of Decision (ROD) of the Final Supplemental Environmental Impact Statement for the Pinedale Anticline Oil and Gas Exploration and Development Project (BLM 2008) lists the following specific change in noise levels that will require mitigation: Decibel levels at the lek more than 10 dBA above background measured from the edge of the lek, and a concurrent average of 30% decline in peak numbers of male birds over 2 years vs. reference area. BLM's 2008 ROD for the PAPA used 39 dBA as the background sound level (L_{A90}) in the PAPA, based on a 1971 EPA study that found an L_{A90} of 39 dB in a California farm valley (BLM 2008, EPA 1971).

Objective

The objective of this project was to monitor sound levels at Greater Sage-grouse leks in the Pinedale Anticline Project Area (PAPA) south of Pinedale, WY, and document leks where sound levels exceeded 10 dB over background sound level.

Study Area

The study area was south of Pinedale, WY, in the Pinedale Anticline Project Area. The leks studied were in or near the Mesa, Duke's Triangle, and Yellowpoint complexes.

Methods

Definitions

Definitions of common acoustic terms are provided in Appendix I.

Measurement Protocol

We followed protocols developed specifically for sound level measurements relative to Greater Sage-grouse (Appendix II), and "Procedures for Outdoor Measurement of Sound Pressure Level" (ANSI 1994) and). ANSI procedures recommend microphone heights of 1.2 m to 1.8 m to assess noise impacts on humans, stating that "other heights may be used if they prove to be more practicable or if they are specified in other pertinent standards" (ANSI 1994, Section 7.3.2.4). Several authors recommend that in wildlife acoustic studies microphones be placed such that sound level measurements accurately reflect sound stimulus to which the target animal is exposed (Grubb et al. 1998, Pater et al. 2009, Delaney et al. 2011, Patricelli et al. 2013). The approximate ear height of Greater Sage-grouse is 0.3 m (12”); therefore, microphones were placed 0.3 m above the ground (Figures 1 and 2). Standardizing microphone height at 0.3 m for acoustic studies relative to Greater Sage-grouse is consistent with flexibility and guidance provided by ANSI (1994, Section 7.3.2.4).

Acoustic equipment was placed at the perimeter of the lek in sagebrush vegetation typical of that surrounding the lek and not visible to grouse (Figures 1 and 2). Locations were selected to minimize potential influence on grouse behavior while capturing sound levels that grouse experience. The average distance from the center of the lek to the microphone in 2020 was 60 m.

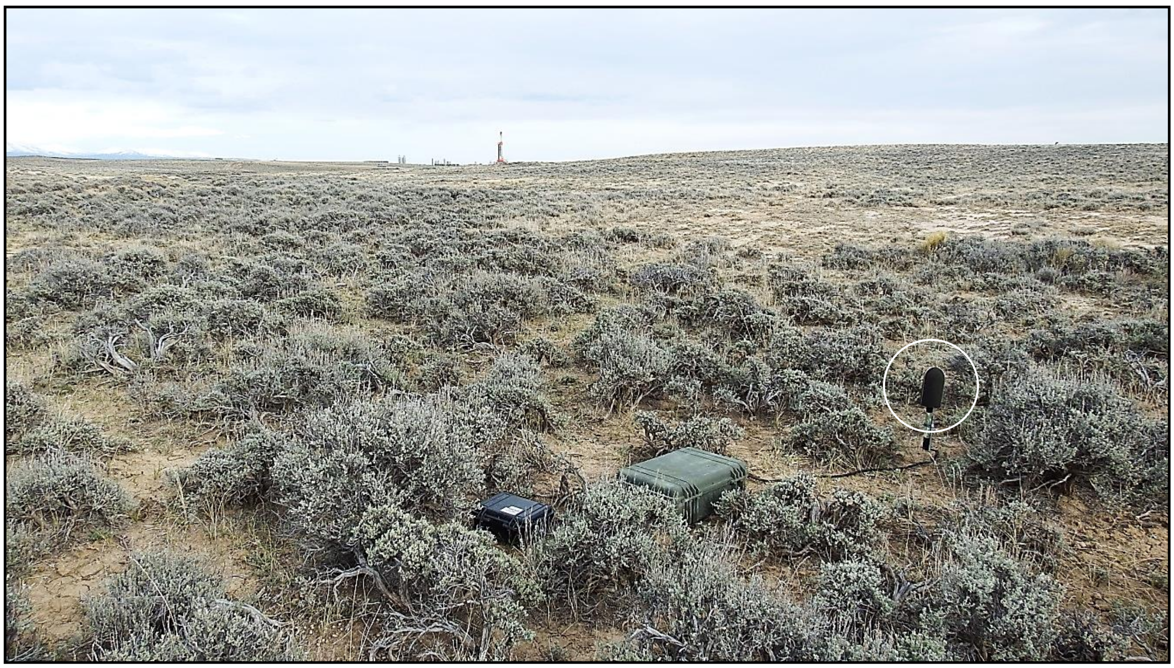

Figure 1. Typical equipment deployment near lek, showing case (sound level meter, digital recorder, battery) and microphone with foam windscreen and bird spike (in circle) at 0.3 m above ground. Lek is open area in background.

Figure 2. Microphone, with foam windscreen and bird spike, 0.3 m above ground.

Instrumentation

We used Larson-Davis 831 sound level meters with PRM831 preamplifiers, PCB 377B20 microphones, and Larson-Davis EPS2106 Environmental Shrouds (foam windscreen and bird spike). All acoustic equipment used for data collection (sound level meters, microphones, and preamplifiers) met or exceeded ANSI S1.4-1983 Type 1 standards. Sound level analyzers (capable of one-third octave band and broadband measurements) met ANSI S1.11-2004 and ANSI S1.42-2001, respectively. All acoustic equipment and field calibrators were calibrated to meet ANSI S1.40-2006 prior to deployment. All systems and calibrators were factory calibrated as recommended by the manufacturer, and all systems were field calibrated at the beginning and end of each measurement period at each location using a field calibrator that met ANSI S1.40-1984 standards. All system components (SLM and digital recorder) were synchronized with GPS time, and differences at the end of the measurement period noted. We used a Bruel and Kjaer (B&K) Acoustic Calibrator Type 4231 for field calibration.

Correcting Sound Levels for the Influence of Instrument Electrical Self-noise

Sound levels in sagebrush habitats in undeveloped areas of the west are typically low, especially during evening and early morning hours when lekking occurs (1800-0800). The

Larson Davis 831 SLMs used in this study have noise floors of 13-15 dBA with settings of +20 dB gain and 1/3 OB low range. Sound level meters have inherent electrical noise in the system components, such as that introduced by the microphone, preamplifier, and power supply. This is often referred to as the "noise floor," suggesting (not quite accurately) the lower measurement limit of that SLM. More expensive SLMs tend to have better (more sensitive) microphones than lower quality models. When sound levels are within 10 dB of the SLM noise floor, the electrical noise of the instrument influences decibel readings of the SLM. When this occurs, actual environmental sound levels are lower than the level reported by the SLM due to the fact that the measured signal is combined with the device self-noise in an additive fashion. Many of our readings, particularly at leks far from gas field activity, were within 10 dBA of the SLM noise floor, which means actual sound levels were lower than the SLMs reported. When sound levels were within 10 dB of the SLM noise floor, we corrected levels using decibel subtractions (see Appendix III).

Sound Level Metrics

Sound level meters were set to collect continuous, 1-second data for the following: unweighted 1/3 octave bands, 12.5-20,000 Hz, and dBA, dBC, and dBF, for the entire measurement period. From these 1-second data, we computed the following 1-hour summary dBA metrics for each hour for each site: L_{min}, L_{max}, logarithmic mean for L_{eq}, and percentile metrics L_{10}, L_{50}, and L_{90}. From these 1-hour summaries, we computed average sound levels for specific daily time periods, all hours (0000-2400), daytime hours (0800-1800), and Greater Sage-grouse lekking hours (1800-0800). The time period 1800-0800 is specified in Wyoming's Governor's Executive Order 2019-3 (Gordon 2019) and is used in other state's Greater Sage-grouse management (NDOW 2018).We computed these time specific levels by taking the arithmetic means of all hours in that specific time period. Only hours that have 75% of all 3600 seconds (>2700 seconds) were analyzed.

We collected continuous digital recordings at all measurement locations, recording quality at 16-bit, 44.1 kHz, MP3, 128 kbps. We used Roland R05 and R07 digital recorders, and used the microphone output from the sound level meters for input to the recorder. Recordings were used to review unusual sound events and to determine sound sources and the percent time that various sound sources were audible.

Measurement Locations

We collected acoustic data at 19 Greater Sage-grouse leks in the PAPA in 2020 (one lek was not accessible due to snow). Lek names and numbers are provided in Table 1. Exact measurement locations are not provided in this report due to security concerns regarding lek locations.

Existing Sound Level and Background Sound Level

Describing the *existing sound level* at any given location is straightforward; it is the sound level averaged over many hours or many days (or for any specific time period, such grouse lekking hours, 1800-0800). Two metrics commonly used to describe existing sound levels are the L_{50} and the L_{eq}. The L_{50} is a percentile value (the sound level exceeded 50% of the time, or the median) and the L_{eq} is an energy-averaged sound level, or a logarithmic mean. High sound levels with short duration can greatly influence the L_{eq}, but have little effect on L_{50} when measured over several hours or days. For this reason, the utility of each metric often depends on the acoustic situation. For example, in an acoustic environment with more or less steady, constant sounds, both the L_{50} and L_{eq} can be used with similar results. In an acoustic environment with periods of more or less steady, constant sounds but with occasional short, loud sounds, the L_{eq} may be more appropriate because such events would not be obvious in L_{50} levels. L_{50} is most commonly used to describe *existing sound level* because it is not influenced by short, loud sounds, and is usually more representative of "typical" sound levels than the L_{eq}.

Describing the *background sound level*, the sound level without the influence anthropogenic sounds, is more difficult due to the many natural and non-natural sound sources in the environment. The most commonly used method to describe *background sound level* is to use the L_{90} metric, the sound level exceeded 90% of the time, or the quietest 10% of sampled data (EPA 1971, ANSI 1988, BSI 1997). It is important to note that ANSI (1988, 1994) standards consider *background sound* as the "sound associated with a given environment without contributions from the source of interest" and *background noise* as "the total acoustical and electrical noise from all sources in a measurement system." Background noise is the SLM electrical self-noise or noise floor and can significantly influence levels reported by the SLM when environmental sound levels are within 10 dB of the SLM electrical self-noise. When SLM reported sound levels are within 10 dB of the SLM electrical self-noise level, actual sound levels are less than reported.

The L_{A90} metric is commonly used to establish baseline or background sound level, and the method used to determine this level is critical because it is this level against which potential project sounds are evaluated. ANSI (1994) is clear in how to establish the L_{A90} level, stating: "Background sound is the total of all sounds produced by sources other than the source of interest. The background sound pressure level shall be determined by shutting down, quieting, or removing from the site, the source of interest. Alternatively, a measurement in a similar environment without the source of may be used as an estimate of the background sound pressure level" (ANSI 1994). In other words, if an accurate baseline sound level cannot be determined due to ongoing project activity, measurements should be made in a similar environment without the source of interest.

Wyoming's Executive Order 2019-3 (2019), and associated Wyoming Game and Fish Department (2019) protocols for measuring sound levels at Greater Sage-grouse leks specifies that the L_{A50} metric shall be used to measure new project sound levels at each lek's perimeter, and that the L_{A90} metric shall be used to establish baseline (background) sound level at each lek's perimeter.

BLM's 2008 Record of Decision for the PAPA used 39 dBA as the background sound level (L_{A90}) in the PAPA, based on a 1971 EPA study that found an L_{A90} of 39 dB in a California farm valley (BLM 2008, EPA 1971). In 2014, the Wyoming Game and Fish Department contracted us to measure sound levels at leks and locations in sagebrush habitat far from gas field developments. The purpose of the project was to establish background and existing sound levels without the influence of gas field sounds. In total, sound levels were measured at 6 locations. The report for that project, Ambrose et al. 2014, reported levels as collected by the sound level meters. Since many of the hours were within 10 dB of the SLM noise floors, actual sound levels were lower than reported. The levels reported in that paper were subsequently post-processed and corrected for noise floor influence. At the six locations studied, the average L_{A50} = 19.4 dB (*existing sound level*), and the average L_{A90} = 14.0 dB (*background sound level*).

Statistical Analysis
We used NCSS 12 statistical software (Kaysville, UT). We examined relationships between trends and covariates using Pearson product moment correlation (r). We used a piecewise, two-segment, nonlinear regression to test relationships between dependent and independent variables (such as L_{A50} and distance from lek to well pad), and to estimate breakpoints between the two segments of the data.

Results

Sound Levels at PAPA Leks, 2020
Acoustic data were collected at 19 Greater Sage-grouse leks in the PAPA in 2020 (4,216 hours at 19 leks, one lek was not accessible due to snow). From 2013-2020, a total of 21,623 hours of acoustic data were collected at 20 leks in the PAPA. The number of hours of data collected by lek and by year is shown in Table 1. Sound levels (corrected for noise floor influence) at 19 leks in the PAPA in 2020 are shown in Table 2, and mean sound levels for all leks and all years are shown in Table 2.

Sound levels varied according to the distance to the nearest gas field activity, and were significantly correlated with distance from lek to nearest well pad (L_{A50}: r = -0.766, P < 0.001; L_{Aeq}: r = -0.732, P < 0.001) (Figures 3 and 4). At distances over about 3300 m, sound levels of standard gas field operations generally attenuated to sound levels in areas without gas field development, L_{A50} = 19 dB and L_{Aeq} = 26 dB (excluding short-term drilling sounds, which are louder than normal gas field sounds). L_{A50} and L_{Aeq} sound levels were correlated with lek count binary trends (L_{A50}: r = -0.688, P < 0.05; L_{Aeq}: r = -0.671; P < 0.05) (Figures 5 and 6). Using non-linear regression, we identified threshold sound levels of L_{A50} = 26 dB and L_{Aeq} = 31 dB, above which lek count trends tended to be declining.

Table 1. Hours of acoustic data collected at each lek by year, PAPA, April 2013-2020.

Site/Year	**Lek Name**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**Total**
PAPA001	Big Fred	47	43	48	170	157	190	123	217	995
PAPA002	Little Fred	47	45	25	167	171	191	121	289	1056
PAPA003	Lower Sand Springs Dr.	50	48	193	168	122	190	110	200	1081
PAPA004	Two Buttes	75	46	169	171	151	163	116	193	1084
PAPA005	Mesa Spring	75	68	68	236	151	100	117	231	1046
PAPA006	Lovatt Draw Res.	59	42	48	128	144	146	118	193	878
PAPA007	Shelter Cabin Res.	49	43	188	212	169	186	184	219	1250
PAPA008	The Rocks	50	98	48	148	144	190	186	197	1061
PAPA009	South Rocks	50	61	191	157	160	191	185	230	1225
PAPA010	Stud Horse Butte	49	98	48	167	165	190	185	222	1124
PAPA011	Little Saddle	47	18	167	172	124	171	95	274	1068
PAPA012	Alkali Draw	46	68	189	216	120	189	185	248	1261
PAPA013	Sand Draw Res.	46	68	96	176	157	189	116	294	1142
PAPA014	Lovatt West	75	43	64	239	126	240	116	229	1132
PAPA015	Cat	49	44	50	172	126	166	122	0	729
PAPA016	Tyler Draw North	46	108	167	247	149	165	187	200	1269
PAPA017	Oil Road Fork	46	59	194	245	175	164	187	226	1296
PAPA018	Mesa Road 3	47	46	164	242	150	119	116	127	1011
PAPA019	Bloom Res. Sat.	46	46	163	241	149	162	188	198	1193
PAPA025	Luman Allotment Res.	0	0	0	0	149	163	181	229	722
Total Hrs.		999	1092	2280	3674	2959	3465	2938	4216	21623

Table 2. Mean sound levels, corrected for noise floor influence, at 20 leks in the PAPA, April 2020.

Site	L_{Aeq}	L_{A10}	L_{A50}	L_{A90}	L_{Amin}	L_{Amax}
PAPA001	31.0	33.0	29.1	26.4	14.1	62.3
PAPA002	31.9	33.0	28.2	24.7	10.1	75.0
PAPA003	30.1	32.4	27.5	24.0	12.4	64.2
PAPA004	25.9	27.9	22.6	18.8	11.4	81.3
PAPA005	25.3	26.5	22.0	19.1	9.2	69.7
PAPA006	28.2	29.8	26.4	23.9	10.4	70.4
PAPA007	29.5	31.6	26.6	23.3	15.1	74.1
PAPA008	32.1	34.2	30.4	27.6	15.4	72.7
PAPA009	30.8	32.0	27.9	24.9	12.1	73.4
PAPA010	28.4	30.1	26.1	23.2	10.9	72.5
PAPA011	24.4	25.9	21.4	18.1	9.5	65.7
PAPA012	29.0	31.3	25.2	21.0	11.2	69.3
PAPA013	26.9	29.0	24.9	22.2	11.4	61.8
PAPA014	28.8	29.9	25.9	23.2	11.9	85.1
PAPA015	NA	NA	NA	NA	NA	NA
PAPA016	32.9	35.1	26.2	19.7	7.1	109.1
PAPA017	22.6	24.0	19.5	16.7	10.9	64.0
PAPA018	23.3	25.2	20.4	17.3	11.7	73.0
PAPA019	25.8	26.9	20.9	16.7	9.5	70.0
PAPA025	27.7	26.1	19.9	15.9	9.5	79.7

Table 3. Mean sound levels, corrected for noise floor influence, at 20 leks in the PAPA, April 2013-2020.

Site	L_{Aeq}	L_{A10}	L_{A50}	L_{A90}	L_{Amin}	L_{Amax}
PAPA001	33.7	35.3	31.3	28.6	13.4	85.8
PAPA002	31.3	32.6	27.9	24.9	10.1	81.3
PAPA003	30.6	32.3	27.7	24.5	10.9	83.8
PAPA004	27.5	29.2	23.5	19.9	7.1	81.3
PAPA005	30.2	31.8	26.7	23.4	9.2	94.0
PAPA006	31.7	33.2	29.1	26.5	10.4	88.0
PAPA007	31.8	33.8	29.1	25.7	12.4	81.4
PAPA008	32.7	34.6	30.5	27.6	11.7	105.2
PAPA009	32.1	34.1	29.4	26.0	11.2	94.7
PAPA010	31.5	33.2	28.8	25.8	10.9	93.8
PAPA011	28.0	29.0	23.0	19.1	9.2	99.4
PAPA012	29.3	31.2	25.1	20.9	8.0	87.9
PAPA013	31.7	33.7	29.0	25.6	8.4	87.6
PAPA014	32.0	33.3	28.5	25.4	11.7	90.5
PAPA015	25.5	27.1	20.5	16.4	0.0	80.3
PAPA016	29.0	30.9	24.1	19.4	5.4	109.1
PAPA017	27.7	29.1	23.9	20.4	4.7	81.0
PAPA018	26.0	27.6	21.3	17.4	3.9	83.7
PAPA019	26.7	28.0	21.5	17.2	2.8	89.3
PAPA025	27.7	28.3	21.7	17.5	4.7	87.6

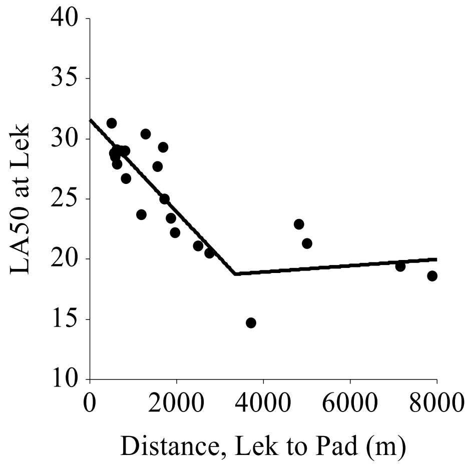

Figure 3. L_{A50} at 20 leks in PAPA relative to distance to nearest well pad (non-linear threshold = 3345 m).

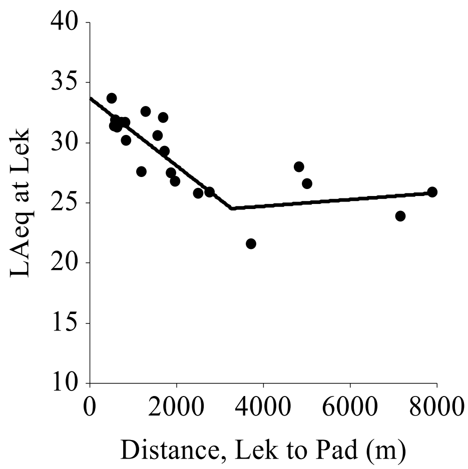

Figure 4. L_{Aeq} at 20 leks in PAPA relative to distance to nearest well pad (non-linear threshold = 3265 m).

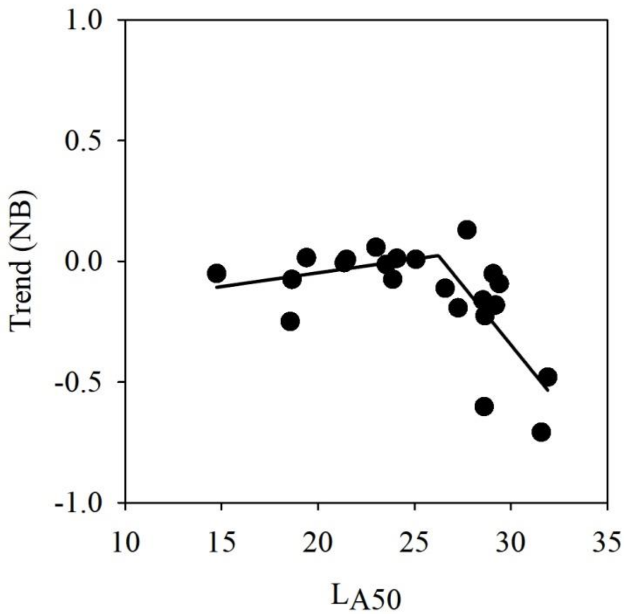

Figure 5. Lek count trends (negative binomial) relative to L_{A50} sound levels (non-linear threshold = 23.4 dBA)

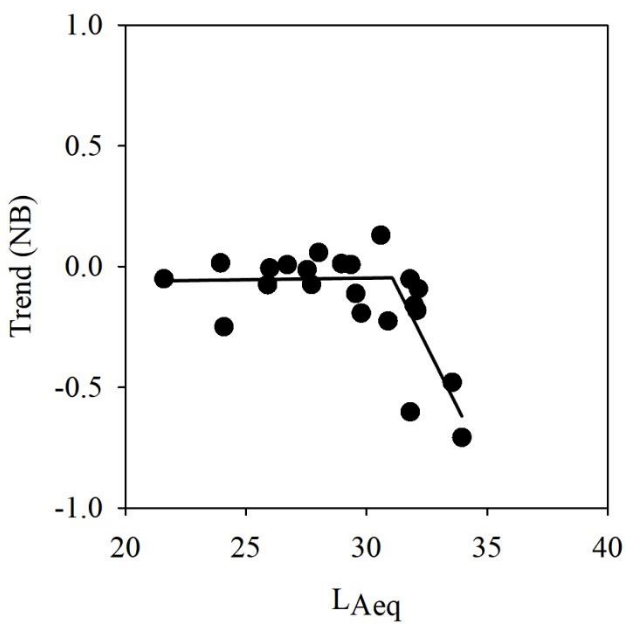

Figure 6. Lek count trends (negative binomial) relative to L_{Aeq} sound levels (non-linear threshold = 31 dBA)

Grouse Display Sounds by Hour
We analyzed 105 days of digital recordings at four leks far from gas field sounds to assess the primary hours of grouse display activity. In the morning hours, grouse were most active during the 0500-0800 hours, and in the evening, during the 2000 hour (all hours Mountain Daylight Time; standard times would be one hour earlier). Sound levels at the leks on days of the recordings are also shown in Figure 5. Elevated levels during the 0600 hour were likely due to grouse display sounds.

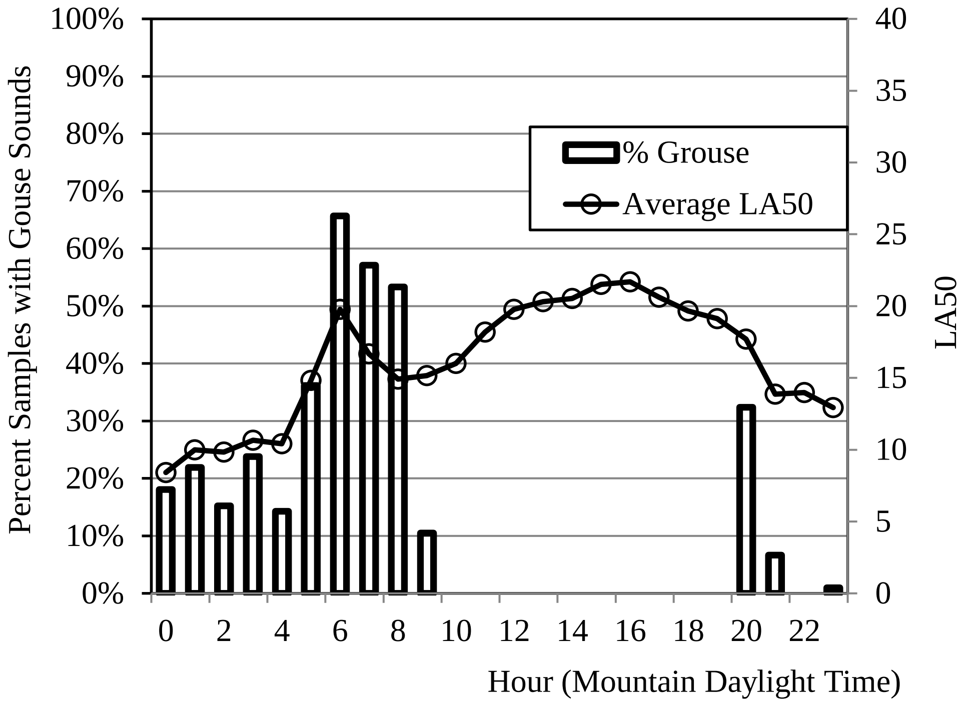

Figure 7. Percent of audio samples with grouse display sounds, and L_{A50} sound levels by hour at selected leks in the PAPA (elevated levels between 0400-0800 were due to grouse display sounds).

Hours Exceeding Background Sound Level by 10 dB
Of the 21,623 hours of acoustic data collected at 20 leks in the PAPA from 2013–2020, 7 hours (0.03%) exceeded 49 dB (L_{A50}) (10 dBA over background of 39 dBA). None of the leks in any year exceeded, on average, 49 dBA, the 2008 ROD wildlife matrix criteria requiring mitigation (along with concurrent average decline of 30% decline in peak numbers of male birds). However, based on recent studies in Wyoming sagebrush habitats, a more accurate *background sound level* in sagebrush habitats in rural, undeveloped Wyoming is 14.0 dB. Of all 21,623 hours of data in the PAPA from 2013-2020, 13,785 (63%) had L_{A50} levels > 24 dB. Of the 20 leks observed in the PAPA from 2013–2020, 13 had L_{A50} >24 dB (11 of these had declining trends), and 7 had L_{A50} <24 dB (1 of these had declining trends). Analyses of acoustic and lek count data in the PAPA suggests that when gas field sound levels (L_{A50}) exceed 26 dB, grouse populations

decline; 26 dB is 12 dB over a background of 14 dB in rural, sagebrush habitats in Wyoming.

Discussion

Sound Levels at PAPA Leks, 2013-2020

Sound levels at each lek in the PAPA were generally similar for all years, except when nearby gas field operations changed significantly. The mean standard deviation for L_{A50} at 20 leks from 2013-2020 was 2.29 dBA (range 0.8–4.1).

Sound Levels, Distance to Pad, and Number of Pads within 3 km

Sound levels at each lek varied due to the distance from the lek to the nearest well pad, number of well pads near the lek, and the type of activity at each pad. Attenuation rates around each well pad and each lek varied due to terrain differences and possibly other variables, but regardless of the different attenuation influences, L_{A50} sound levels (mean for all years), distance to nearest well pad and number of well pads within 3 km were highly correlated (sound level at lek and distance to well pad: $r = -0.766$, $P < 0.001$; sound level at lek and number of well pads within 3 km: $r = 0.767$, $P < 0.001$).

Sound Levels and Lek Count Trends

Both L_{A50} and L_{Aeq} sound levels were strongly correlated with lek count trends. Threshold levels of $L_{A50} = 26$ dB and $L_{Aeq} = 31$ dB were identified as levels above which lek count trends tended to be negative, and below which lek count trends tended to be stable or increasing. It is difficult to ascertain the importance of noise on grouse trends relative to all other variables associated with gas field activity because all variables are inter-related; however, noise appears to be one of the more important factors relative to lek count trends.

Barber et al. (2011) reviewed four studies that provided traffic volumes and distances at which different species were negatively impacted by anthropogenic sounds. These four studies did not measure sound levels, but using traffic volume and distance data from those studies, Barber et al. (2011) calculated sound levels at which species were negatively impacted. The sound level threshold for frogs in Ontario was $L_{Aeq} = 43.6$ dB, and for grassland birds in Massachusetts $L_{Aeq} = 38.3$ dB. In the Netherlands, thresholds levels for woodland birds was $L_{Aeq} = 42\text{-}52$ dB and for grassland birds, $L_{Aeq} = 47$ dB. Background sound levels (L_{A90}) were not provided for those studies, thus threshold levels above background sound levels are not know. Barber et al. (2011) did not calculate 24 hour L_{Aeq} levels as we did. He used a 24-hour L_{Aeq}, while we used 1-hour L_{Aeq} levels and averaged those 1-hour levels to get a daily average L_{Aeq}. Our approach followed recommendations by Plotkin (2001), who recommended using the 1-hour approach in order to describe hour to hour and day to day variations. In addition, activities of many wildlife species are associated with specific hours of the day, and computing sound level metrics based on hour of day allows analysis of sound levels on an hourly basis. If we used the same approach to calculate L_{Aeq} as Barber et al. (2011), the threshold level for Greater Sage-grouse would be $L_{Aeq} = 36.0$ dB. This threshold for Greater Sage-grouse would make the species one of the most sensitive studied. The 24-hour L_{Aeq} levels at leks in the PAPA (as calculated by Barber et al. 2011) were not correlated with lek count trends, while averaging 1-hour L_{Aeq} levels were strongly correlated with lek count trends. The daily logarithmic average approach of Barber et al. (2011) results in a higher L_{Aeq} level.

Background Sound Level

The 2008 Record of Decision for the PAPA gas field development used L_{A50} = 39 dB as background sound level, the level against which sound levels at leks are compared (BLM 2008). This 39 dB level was used based on an EPA study in California in 1971 (EPA 1971) and before any information on sound levels in WY was available. Several recent research projects have demonstrated that this level is not accurate. At six locations in sagebrush habitats in rural, undeveloped Wyoming, the background sound level was L_{A90} = 14.0 dB (Ambrose et al., In Prep.). Analyses of sound level and lek counts in the PAPA suggest that when gas field sound levels (L_{A50}) exceed 26 dB, grouse populations decline; 26 dB is 12 dB over a background of 14 dB in rural, sagebrush habitat in Wyoming. These analyses also indicate that the approach currently used to manage acoustic impacts to Greater Sage-grouse, that is, using 10 dB over background, is reasonable and appropriate as long as an accurate background sound level is used. Our best current understanding is that L_{A90} = 14 dB is an accurate background sound level and should be used for impact assessment.

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Literature Cited

Ambrose, S., and C. Florian. 2014. Sound Levels at Greater Sage-grouse Leks, Pinedale Anticline Project Area, Wyoming, April 2013. Unpublished report to Wyoming Department of Game and Fish, Cheyenne, WY.

Ambrose, S., C. Florian, and J. MacDonald. 2014. Ambient sound levels in sage habitats in Wyoming, April 2014. Unpublished report to Wyoming Department of Game and Fish, Cheyenne, WY.

Ambrose, S, C. Florian, J. MacDonald, T. Hartman, and J. Olnes. In Prep. Sound Levels in Sagebrush Habitats in Wyoming, and the Influence of Gas Field Sounds on Greater Sage-grouse. Manuscript in preparation.

American National Standard (ANSI). 1994. Procedures for Outdoor Measurement of Sound Pressure Level. American National Standards, Inc. New York, NY. Reaffirmed by ANSI 6/23/2004.

Barber, J. R., C. L. Burdett, S. E. Reed, K. A. Warner, C. Formichella, K. R. Crooks, D. M. Theobald, and K. M. Fristrup. 2011. Anthropogenic noise exposure in protected natural areas: estimating the scale of ecological consequences. Landscape Ecol. DOI 10.1007/s10980-011-9646-7.

Blickley, J. L., and G. L. Patricelli. 2012. Potential acoustic masking of greater sage-grouse (*Centrocercus urophasianus*) display components by chronic industrial noise. Ornithological Monographs Volume (2012), No. 74, 23–35.

Blickley, J. L, and G. L. Patricelli. 2013. Noise monitoring recommendations for Greater Sage Grouse habitat in Wyoming. Prepared for the PAPA, Pinedale, WY.

Bureau of Land Management (BLM). 2008. Final Supplemental Environmental Impact Statement for the Pinedale Anticline Oil and Gas Exploration and Development Project, Sublette County, Wyoming. US Department of the Interior, Bureau of Land Management, Cheyenne, Wyoming.

Delaney, D. K., T. G. Grubb, P. Beier, L. L. Pater, and M. H. Reiser. 1999. Effects of helicopter noise on Mexican spotted owls. Journal of Wildlife Management 63:60–76.

Delaney, D. K., L. L. Pater, L. D. Carlile, E. W. Spadgenske, T. A. Beaty, and R. H. Melton. 2011. Responses of red-cockaded woodpeckers to military training operations. Wildlife Monographs, No. 177, 1-38.

Environmental Protection Agency (EPA). 1971. Community Noise. U.S. Environmental Protection Agency, Office of Noise Abatement and Control, Washington, D.C. 20460.

Gordon, M. 2019. State of Wyoming Executive Order 2019-3, Greater Sage-grouse Core Area Protection. Cheyenne, WY.

Grubb, T. G., L. L. Pater, and D. K. Delaney. 1998. Logging truck noise near nesting northern goshawks. U.S. Forest Service Research Note RM-RMRSRN-3, Rocky Mountain Research Station, Ft. Collins, Colorado, USA.

Holloran, M. J. 2005. Greater sage-grouse (*Centrocercus urophasianus*) population response to natural gas field development in western Wyoming. Department of Zoology and Physiology, University of Wyoming, Laramie.

Nevada Division of Wildlife (NDOW). 2018. Acoustic Impacts and Greater Sage-grouse: A Review of Current Science, Sound Measurement Protocols, and Management Recommendations. Habitat Division, Nevada Department of Wildlife, Reno, NV.

Pater, L. L., T. G. Grubb, and D. K. Delaney. 2009. Recommendations for Improved Assessment of Noise Impacts on Wildlife. J. Wildlife Management 73(5):788-795.

Plotkin, K. J. 2001. Review of Technical Acoustical Issues Regarding Noise Measurements in National Parks. Wyle Report WR-01-20. Wyle Laboratories, Arlington, VA.

Appendix I. Definitions of Common Acoustic Terms.

American National Standards Institute (ANSI): ANSI has established accuracy and stability standards for different types of acoustic sound level meters (Type 0, 1, 2). For Type 1 meters, the maximum change within one hour of operation is 0.3 dB (Type 0 = 0.2 dB, Type 2 = 0.5 dB). Maximum deviation of free-field relative response level varies by frequency, with lower frequencies having tighter standards, 1.0 dB at 31.5–2000 Hz for Type 1 meters (Type 0 = 0.5 dB, Type 2 = 2.0 dB).

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 (dB): A logarithmic measure 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 pressure unit Pascal. The difference between the sound pressure of 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.

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.

Frequency Weighting: Frequency filters (weighting) are used to adjust the amplitude of all parts of the frequency spectrum for specific purposes. A-Weighting (dBA) is used to account for differences in human hearing sensitivity as a function of frequency. A-weighting de-emphasizes the high (6.3 kHz and above) and low (below 1 kHz) frequencies, and emphasizes the frequencies between 1 kHz and 6.3 kHz, in an effort to simulate the relative response of human hearing. Other weighting options include C-Weighting (dBC), which emphasizes low frequencies, and unweighted (dBF), which does not filter any frequency.

L_{eq} (Equivalent Sound Level): The logarithmic average (i.e., on an energy basis) of sound pressure levels over a specific time period. “Energy averaged” sound levels are logarithmic values, and as such are generally higher than arithmetic averages. L_{eq} values are typically calculated for a specific time period (1-hour and 12-hour time periods are often used). L_{eq} values are computed from all of the 1-second L_{eq} values for the specific time period. L_{eq} must be used carefully in quantifying sound levels because occasional loud sound levels may heavily influence (increase) the L_{eq} value, even though sound levels for that period of time are typically lower.

L_{min} and *L_{max}*: The minimum and maximum 1-second L_{eq} sound level over a specific time period, generally 1 hour.

L_x (Exceedance Percentile): This metric is the sound pressure level (L), in decibels, exceeded *x* percent of the time for the specified measurement period. L_{10} is the sound level exceeded 10% of the time, or the loudest 10%. L_{50} is the sound level exceeded 50 percent of the time (L_{50} is the same as the median, half above and half below). L_{90} is the sound level exceeded 90% of the time, or the quietest 10% of the time.

Noise Floor (*Instrument Self-noise)*: The inherent electrical noise of all components of a sound level meter (meter, microphone, and preamplifier). The "noise floor" is often described as the lower measurement limit of a sound level meter; however, all sound levels within 10 dB of the SLM noise floor are influenced by the SLM self-noise, and thus not accurate unless corrected for noise floor influence.

Noise Floor Correction (NFC): The process of using decibel subtraction to correct sound levels that are within 10 dB of the SLM noise floor.

Noise Level, Background: The total acoustical and electrical noise, from all sources in a measurement system, that may interfere with the production, transmission, time averaging, measurement, or recording of an acoustical signal. "Background noise" differs from "background sound" in that background noise is typically electrical noise in the measurement system while background sound is the sound level in a given environment without the specific sound source of interest.

Octave: The interval between two frequencies having a ratio of 2 to 1. The *octave* is an important frequency interval relative to human hearing, and octave band analysis is a standard for acoustic analysis. The frequency resolution in octave band analysis is relatively poor; hence finer frequency resolution is often used in acoustic analysis. Generally, *one-third-octave band* analysis is used. Three one-third octave bands are in one octave, so the resolution of such a spectrum is three times better than the octave band spectrum.

Sound Level, Background: The sound level in a given location including all sounds of nature without contributions from the source or sources of interest (ANSI 1994). L_{90} is the sound pressure level exceeded 90 percent of the time, and is commonly used to establish the background (also often referred to as baseline or residual) sound level (EPA 1971, ANSI 1988, BSI 2019).

Sound Level, Existing: The sound level of all sounds in a given area, including all natural sounds as well as all mechanical, electrical and other human-caused sounds. The existing sound level is generally characterized by the L_{50} metric (i.e., the median) (EPA 1971).

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

Sound Pressure Level (SPL): The logarithmic form of sound pressure. Generally, sound pressure level refers to unweighted sound pressure levels of one-third octave bands.

Time Weighting: The response speed of a sound level meter. Fast and slow time response were developed primarily to slow needle movement in analog meters so investigators could read and record sound levels. This is not needed with modern digital sound level meters. Both fast and slow time response add a decay factor. Decay factors can induce some error, although over time there is little difference in fast, slow, or actual sound levels (Plotkin 2001).

Appendix II. Protocols for Sound Level Measurements for Greater Sage-grouse.

Sound level measurements in western states relative to Greater Sage-grouse are controversial due to potential conflicts with development activities. ANSI Type 1 equipment should be used. Although ANSI procedures do not so state, it is assumed that the sensitivity of the equipment will be appropriate for the acoustic conditions in the study area. In some situations, this may require a system that measures down to 0 dBA. We use the protocol below for this study.

Protocol for Sound Level Measurements

Use the L_{A90} metric for all hours of the day to determine *background sound level*, measured at the perimeter of the lek.

Use the L_{A50} metric for all hours of the day to determine *existing sound level* and to determine new project sound level, as measured at the perimeter of the lek.

Sound level meters should meet ANSI Type 1 standards.

Sound level meters should be capable of measuring the full acoustic environment of the study area. In parts of undeveloped, rural Wyoming, sound levels in sagebrush are occasionally near 0 dBA. If it is not possible to use sound level meters with a noise floor of 0 dBA, the noise floors of the SLMs used should be documented and sound levels within 10 dB of the SLM corrected for noise floor influence through decibel subtraction. At a minimum, SLMs with a noise floor of <10 dBA should be used.

Data analysis: Hourly metrics (L_{min}, L_{max}, and L_{Aeq}, L_{A10}, L_{A50}, and L_{A90}) should be calculated for each hour. Summary site metrics (many hours or many days) can be calculated for any time period (0000-2400, 1800-0800, etc.) and should be calculated using the arithmetic mean of all hours in that time period. Unweighted one-third octave band metrics, including L_{min}, L_{max}, L_{eq}, L_{10}, L_{50}, and L_{90}, should be reported for all hours of the day as well as those hours important to lekking Greater Sage-grouse. Only hours with >75% of 1-second data should be used. Decibel data should be collected continuously, at 1-second intervals, with sound level meter set to “fast” time response.

Sound level data collected should include dBA, dBC, dBF, and unweighted one-third octave band frequency data, 20-20,000 Hz.

Microphone height should be 0.3 m (12”), approximate ear height of Greater Sage-grouse.

Measurement duration should be sufficient to ensure natural variation in sound levels and meteorological conditions are covered. We recommend a minimum of

10 days during the March-May lekking period, based on reviews of year-long studies in national parks (Iyer 2005); however, more study is needed on this topic.

Continuous digital recordings should be collected at all measurement locations. These recordings can be used to review any unusual sound sources and sound levels, and also can be used to determine common sound sources and percent time that each is audible at a given location. At a minimum, recordings should be sampled at a rate of 10 seconds every 4 minutes (which results in a one hour file), audible sources identified and logged into a spreadsheet, and presented in a table with the percent time that each source is audible by hour of day. For a 7-day measurement period, at least two days should be logged and reported; these two days should include a week day and a weekend day, selected randomly. Days with unusual weather (very high wind, rain) should not be used. In addition to providing the ability to review and identify all sound sources (natural and non-natural), digital recordings collected near leks can provide biologists information regarding presence or absence and relative abundance of grouse at the site. Recording quality should be at a minimum MP3, 16-bit, 128 kbps (uncompressed .wav, 16-bit, 44,100 kHz preferred).

In most acoustic studies, wind speed data are necessary to assess influence of wind pressure on dB data. This is especially true when microphone height is 1.5 m or higher. However, in sagebrush >0.3 m high, wind speed rarely exceeds 5 m/s at 0.3 m (on average <0.02%), and wind induced equipment noise is rare. Therefore, wind speed data are not required if the microphone height of 0.3 meters is used and microphones are placed in sagebrush vegetation > 0.3 m. If meteorological data are needed for modeling efforts, anemometers should be 1.5–2.0 m high. In such case, equipment must be sufficient distance from lek to not influence grouse attendance or behavior.

Microphone/equipment placement: Equipment should be placed at the perimeter of the lek in such a way that attendance and behavior of Greater Sage-grouse are not influenced by the equipment. This can be achieved by placing the equipment in sage vegetation so that it is not visible to grouse at the lek (see above exception for anemometers at 1.5 m).

Acoustics is a complex science. Measurements, analysis, and reporting should be done by experienced personnel.

Appendix III. Correcting Sound Levels for the Influence of Instrument Self-noise.

Sound level meters have inherent electronic and microphone self-noise in the system components, such as that introduced by the microphone, preamplifier, and power supply. This is often referred to as the “noise floor,” suggesting (not quite accurately) the lower measurement limit of that SLM. High quality (and more costly) SLMs tend to have better (more sensitive) microphones than lower quality models. When sound levels are within 10 dB of the SLM noise floor, the electrical noise of the instrument influences decibel readings of the SLM. When this occurs, actual environmental sound levels are lower than the level reported by the SLM due to the fact that the measured signal is combined with the device self-noise in an additive fashion. When this occurs, researchers can either report levels as “<xx dBA” or attempt to mathematically correct the levels for the influence of instrument self-noise. This can be done by logarithmic subtraction of the self-noise from the total measured signal.

The sound pressure level displayed by the SLM is actually the addition of two electrical signals: instrument noise floor level (electrical self-noise) plus the actual environmental sound level. Two sound levels of equal magnitude, when added together, produce a level 3 dB greater than the sound level from one of these sources because of logarithmic addition [$10*\log_{10}(2) = 3$]. For example, if the self-noise (noise floor) of the sound level meter is 13.0 dBA, and the actual sound level is 13.0 dBA, the reading on the meter will be 16.0 dBA (13 dBA + 13 dBA = 16 dBA). When two sound levels that are 10 dB or more different from each other are added together, there is little added influence from the lower value (for example, 13.0 dB + 23.0 dB = 23.4 dB). Thus, the closer actual sound levels are to the SLM noise floor, the greater the influence of instrument self-noise on the SLM reading. Figure 4 illustrates this influence.

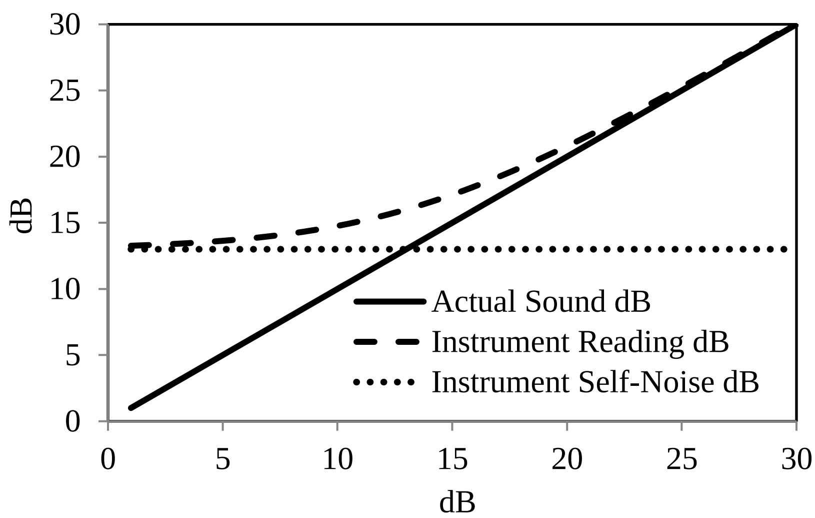

Figure 8. Influence of instrument self-noise (13 dBA in this example) on sound level readings.

Plotkin (2001) recommended decibel subtraction be used to correct dB data when reported sound levels were within 10 dB of the instrument noise floor. Decibel subtraction is a process which allows correction of sound levels influenced by the SLM noise floor. In this approach, the SLM noise floor is subtracted from the sound level reported by the SLM and the result is an improved estimate of the actual environmental sound level. For example, if the SLM noise floor is 13.0 dBA, and the SLM reported sound level is 14.5 dBA, one can calculate the actual environmental sound level as follows: 14.5 dBA – 13.0 dBA = 9.2 dBA, or 10log10[antilog(14.5)-antilog(13)] = 9.2 dB. Although the SLM reported the sound level as 14.5 dBA, correcting for the influence of the SLM noise floor reveals the actual sound level is 9.2 dBA. The closer the actual sound level is to the SLM noise floor, the greater the correction (Table 4).

It is important that the SLM noise floor be well documented when applying such corrections. Plotkin (2001) recommended that instrument noise floor be determined via long-term field measurements and not just pre-test in the laboratory. Most manufacturers provide total instrument noise for different SLM, preamp, and microphone combinations, but because components may vary slightly in electronic and total noise, manufacturers generally provide "typical" instrument noise levels. The Larson-Davis SLM Model 831, with PRM831 preamp and PCB 377B02/B20 microphone, using +20 dB gain and low range OB, has a typical noise floor 15 dBA, according to Larson Davis documentation. In over 50 long-term measurements (>10 days) with several different systems with this same combination (LD831, PRM831, 377B02/B20), noise floors were between 13-15 dBA. In order to be conservative in this correction approach and to prevent over-correction, we used a noise floor level of 13 dBA when correcting for noise floor influence when using this SLM/preamp/microphone combination.

This noise floor correction approach was tested by comparing data collected with a standard ½" microphone (noise floor = 13.0 dBA) with data collected simultaneously by a GRAS 1" very low-noise microphone (noise floor = 0 dBA). We corrected levels of the ½" microphone using the method described above, and compared all three data sets (Figure 5). Noise floor corrected levels were close to levels of the GRAS 1" microphone system. For the five days of simultaneous measurement, ½" microphone L_{A90} = 18.7 dB, noise floor corrected ½" L_{A90} = 15.3 dB, and the 1" system L_{A90} = 14.1 dB (Ambrose, unpublished data). While noise floor corrected levels may not meet ANSI Type I standards (specifically, sound levels may not be ±1 dB of actual levels), corrected levels are more accurate than uncorrected levels and should be reported when levels are near the SLM noise floor. Ideally, measurements should be made using meters sensitive enough for the acoustic situation and prevent the need for noise floor correction; however, if very low-noise meters are not available, noise floor correction should be used.

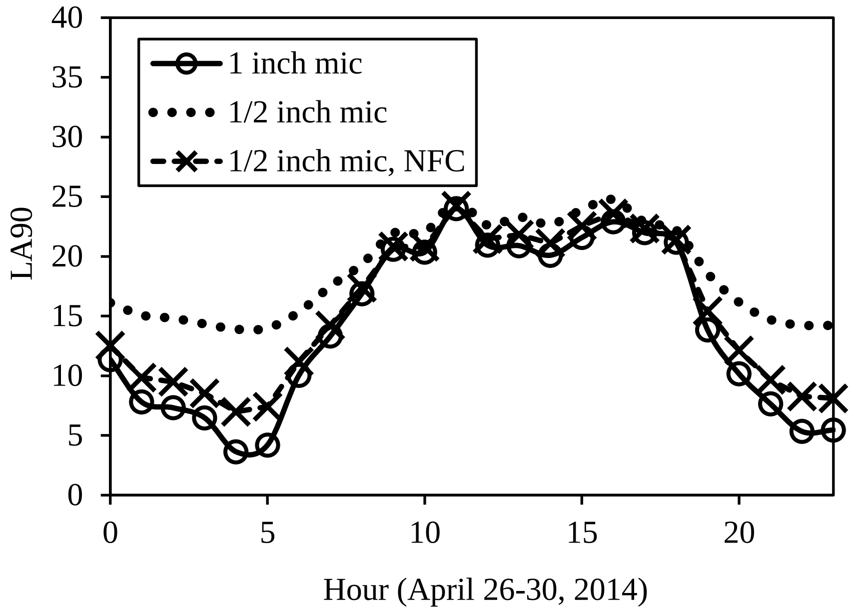

Figure 9. Example of SLM reported L_{A90} hourly levels from 1” low noise mic (NF = 0 dBA), ½” standard mic (NF = 13.0 dBA), and ½” standard mic corrected for noise floor influence (April 26-30, 2014, lek near Pinedale, WY).

Table 4. Example of SLM reported dBA sound levels and noise floor corrected dBA sound levels, using a SLM with a noise floor of 13 dBA.

Noise Floor	**SLM Reported**	**Noise Floor Corrected**	**Difference, SLM v NFC**
13.0	13.1	-3.3	16.4
13.0	13.5	3.9	9.6
13.0	14.0	7.1	6.9
13.0	15.0	10.7	4.3
13.0	16.0	13.0	3.0
13.0	17.0	14.8	2.2
13.0	18.0	16.3	1.7
13.0	19.0	17.7	1.3
13.0	20.0	19.0	1.0
13.0	21.0	20.3	0.7
13.0	22.0	21.4	0.6
13.0	23.0	22.5	0.5
13.0	24.0	23.6	0.4

Noise floor-corrected sound levels are important for Greater Sage-grouse management for two reasons. First, noise floor corrected sound levels are more accurate than non-corrected levels when levels are near the instrument noise floor (as shown in Figure 5), and second, the alternative to not applying such corrections is to report sound levels within 10 dB of instrument noise floor as "<xx dBA" which generally is not helpful in Greater Sage-grouse management. Reporting sound levels near the SLM noise floor without acknowledging such influence is misleading, although common, and doing so has led to considerable confusion among federal and state agencies, wildlife biologists, industry representatives, and politicians regarding sound levels and sage-grouse management. Of 22 sound level studies relative to Greater Sage-grouse in WY conducted prior to 2014, only one researcher acknowledged the potential for noise floor influence on reported levels, and most of these studies reported levels within 10 dB of their SLM's noise floor (Ambrose, unpublished data). It is proper engineering practice that researchers report the limitations of their data, and it is important to sage-grouse management that such limitations are understood.

When digital recordings are post-processed to provide decibel data, the same influences of inherent electronic noise occur and need to be addressed. The recorder, power supply, preamplifier, and microphone all have the potential to introduce electronic noise in the recordings and subsequent post-processing. When recordings are post-processed to provide decibel data, the same method of correcting for noise floor influence described above for SLM data can be used. However, digital recorders and associated components generally are not certified as rigorously as sound level meters, and for this reason, each recording system should be tested individually to determine noise floors. As with sound level meters, the best method of determining noise floors is long-term field measurements (Plotkin 2001).