ACOUSTIC SOUNDSCAPES IN THE GUNNISON BASIN AND EFFECTS OF ANTHROPOGENIC NOISE ON GUNNISON SAGE-GROUSE (*CENTROCERCUS MINIMUS*) IN THE GUNNISON BASIN, COLORADO

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FINAL REPORT
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Abstract: *A broad range of research has documented that noise disturbances can contribute to changes in behavior, breeding success, density, and community structure among a variety of wildlife species. Anthropogenic noise has been shown to negatively impact Greater Sage-grouse lekking activities. The Gunnison Sage-grouse Rangewide Conservation Plan (RCP) recommends that continuous noise sources in the proximity of sage-grouse leks be limited to 10 dBA above ambient; however ambient levels have not been determined. Using a Type I sound level meter and an acoustic recorder we measured soundscapes at Gunnison Sage-grouse leks in the Gunnison Basin during the springs of 2012 and 2013. The average ambient noise level on Gunnison sage-grouse leks was 17.2 dBA. We also quantified the mean, median, absolute minimum, absolute maximum and other noise amplitude variables. Further, we determined sources of anthropogenic noise, quantified number of noise events, duration of noise events, and quantified amplitude and frequency of anthropogenic noise on twelve Gunnison Sage-grouse leks in 2012 and eleven leks in 2013. Primary anthropogenic noise around Gunnison sage-grouse leks is produced by three sources: automobile traffic on roads and highways, jet airplanes, and propeller airplanes. Aircraft noise was louder than automobile noise, and was independent of proximity of leks to roads. The mean amplitude for all leks and all noise sources was approximately 15 dBA in excess of ambient conditions. Absolute peak amplitudes of 80 dBA were measured and associated with low flying propeller airplanes. Analyzing data for all leks combined, we found a significant reduction in grouse vocalizations during and after noise events caused by passing aircraft and nearby vehicle traffic (highways from 0.3 - 4.3 miles from leks). We used a mixed effects model (Program R Studio) which showed a statistically significant reduction in Gunnison sage-grouse vocalizations for all leks combined and for all anthropogenic noise sources. These results provide baseline data representing ambient acoustic habitats in the Gunnison Basin for studies of anthropogenic noise levels. Further, our data suggest that short-term intermittent noise events disrupt sage-grouse lekking behaviors. These sources of noise are not currently addressed in RCP recommendations which focus more on limiting continuous sources of noise.*

INTRODUCTION

Anthropogenic sources of noise have introduced unique sound features to the acoustic environment and have become a dominant component of many soundscapes (Francis et al. 2009, Francis et al. 2011a). No geographical location in the U.S. is free from anthropogenic noise (Barber et al. 2011) and it has been characterized as a "burgeoning pollutant" (Francis and Barber 2013). Mounting evidence suggests that anthropogenic noise may negatively affect wildlife populations causing declines in occupancy and/or density, physiological stress, changes in distribution, impairment of communication, reduced immune response, increased predation risk, damaged hearing, changes in behavior, and reduced reproductive success (Bowles 1995, Larkin et al. 1996, Patricelli and Blickley 2006, Warren et al. 2006, Slabbekoorn and Ripmeester 2008, Barber et al. 2009, Francis et al. 2009, Pater et al. 2009, Francis et al 2011b, Francis and Barber 2013). Noise impacts occur along a continuum from intermittent noises that illicit a startle response to continuous noises that mask signaling among individuals (Francis and Barber 2013). The effect of noise on wildlife varies by species and depends on noise amplitude, frequency, duration and daily/seasonal patterns (Blickley and Patricelli 2010, Blickley et al. 2012). Noises with low predictability in timing and sudden onset, high intensity (amplitude) above ambient, and with frequencies that overlap considerably with the species' hearing ability have the greatest impact on wildlife (Francis and Barber 2013). High amplitude noises at frequencies near vocalization and hearing thresholds potentially mask communication (Weisenberger 1996, Lohr 2003). Larger birds tend to have lower frequency vocalizations and tend to be most negatively affected by anthropogenic noise (Dooling et al. 2000, Francis et al. 2011c). Anthropogenic noises are generally low frequency and therefore travel relatively longer distances. Highway/road noise and aircraft overflights carry far beyond their physical boundaries and may impact landscapes that are mostly uninhabited such as wilderness areas and national parks (Blickley and Patricelli 2010).

Increased energy development throughout the west and especially in sagebrush habitats has led to decreased lek attendance in greater sage-grouse (Centrocercus urophasianus) (Holloran 2005, Walker et al. 2007, Doherty et al. 2008). Greater sage-grouse also altered their diurnal activity patterns by avoiding natural gas wells (Dzialak et al. 2012). Blickley et al. (2012) demonstrated an immediate and sustained response to experimental noise introduced into the acoustic soundscape of greater sage-grouse. Natural gas drill rig noise and road noise were recorded and played at experimental leks causing a decline in peak male attendance by 29% with natural gas drill rig noise and 79% with road noise (Blickley et al. 2012). Intermittent road noise had a stronger negative impact on lek attendance than continuous drilling noise (Blickley et al. 2012). The likely mechanism for the noise effect on lek attendance was displacement of birds (Blickley et al. 2012).

Limiting anthropogenic sources of noise in sage-grouse habitats may be necessary to minimize impacts on sage-grouse (Braun et al. 2002, Hunt 2004, Crompton and Mitchell 2005, Holloran 2005, Patricelli et al. 2013). For greater sage-grouse, ambient acoustic amplitude was recently quantified at 16 - 20 dBA in pre-development habitats and noise amplitude of 10 dBA above ambient is considered non-disruptive (Patricelli et al. 2013). Noises in excess of 10 dBA above ambient are managed as disruptive activities not only around leks, but also in proximity to nesting, brood rearing, and foraging sites (Patricelli et al. 2013). The Gunnison Sage-grouse Rangewide Conservation Plan (RCP) also recommends that continuous noise sources be limited to 10 dBA above ambient in all seasonal habitats (RCP 2005). However, baseline ambient noise levels have yet to be established. A study was initiated in 2012 by Western State Colorado University and Colorado Parks and Wildlife to measure ambient noise levels around Gunnison sage-grouse (Centrocercus minimus) leks and to inventory sources of noise in geographic locations relatively close to and farther away from anthropogenic sources of noise (i.e., roads).

Summary of 2012 Research Project

We measured ambient noise levels in the Gunnison Basin during the spring of 2012. Sources of noise and amplitudes were quantified at twelve leks, half of which were located relatively close to roads and highways (within 1.5 - 2.0 miles from major highways and roads) and the other half were farther away from anthropogenic noise sources (outside the 1.5 - 2.0 mile boundary). On average, leks closer to roads were 7 - 10 dBF (2 - 3 times) louder than leks outside the road/noise buffers. A 10 dB difference is perceived by the recipient as a sound that is 3.16 times louder (Pater et al. 2009), and a 6 dB increase represents a doubling of sound pressure or amplitude (Patricelli et al. 2013). Due to an error in the settings on the sound level meter (SLM), we were unable to quantify the complete noise spectrum and all noises at amplitudes below 45 dB were not recorded. Therefore, we did not obtain ambient noise data for the two lek classifications. However, we classified noises into four categories including jet aircraft, propellor planes, highway/road traffic and other unkown noise sources. Jet aircraft events had an average amplitude of 63 dBF, with a max event of 98 dBF. There were also many jet aircraft events that fell below 50 dBF. Noise amplitude is a function of distance from the noise source, so we expected wide variation in measured amplitudes of specific noises.

High variation in noise was found to be the general rule and each of the twelve leks we measured in the Gunnison Basin had its own unique soundscape. In addition to proximity to roads, the specific geographical location and topography of a lek influenced local acoustic characteristics. For example, two leks that were both inside the 1.5 - 2.0 mile boundary differed substantially in their acoustic environments. The Miller lek, had a mean amplitude of 55 dBF for an entire day, whereas the Stevens Creek lek had a mean amplitude of 73 dBF on one day (nearly four times louder than the mean at the Miller lek). The weather was similar on the two measurement days, but the Stevens Creek lek was acoustically open with a more direct line of site to U.S. Highway 50 and the Miller lek had a topographic barrier influencing sound travel from the county road which also had less traffic than U.S. Highway 50. Further, variation in lek noise levels is dependent on aircraft overflights. Depending on air traffic volume and patterns of aircraft movement, noise pollution at leks may be independent of road locations and even remote leks may experience relatively high levels of noise.

The highest number of male Gunnison sage-grouse displayed from 0400 – 0600 h, corresponding with a 9 dBF difference in mean noise amplitude between leks close to roads and leks farther away from roads (70 dBF vs. 61 dBF, respectively). After 0700 h, highway and airplane traffic increased and led to an overall increase in noise amplitude (75 dBF close to roads and 66 dBF farther from roads). During the loudest time periods in the mornings, no sage-grouse vocalizations were recorded. This increase in noise amplitude with the increase in human activity beginning at 0700 h, may suggest that grouse are altering their displays to avoid louder environments and noise may be masking their vocal displays. Much more research is needed to determine causality.

Gunnison sage-grouse leks located closer to roads had lower high male counts (HMC). The leks inside the road boundary had a 15-year average of 13 ± 2 HMCs, whereas the leks outside the road boundary had an average of 20 ± 6 HMCs. We have not demonstrated a causative relationship between increased anthropogenic noise in proximity to roads and decreased lek attendance. However this correlation is interesting and deserves further study.

The 2012 research served as a pilot study in which methods were refined and additional questions resulted from our data and interpretations. Colorado Parks and Wildlife biologists were eager to repeat the study using refined methods and allowing for clear definition of ambient noise levels in the Gunnison Basin. Therefore, in 2013 the project evolved to address our shortcomings in 2012 and a few new questions.

Objectives for 2013 study:

1) Measure ambient noise levels around Gunnison sage-grouse leks and compare leks close to roads (and anthropogenic noise sources) to those more remotely located in the landscape.

2) Identify the major sources of noise pollution observed at Gunnison sage-grouse leks. Measure the number of noise events, the duration of noise events, and the frequency and amplitude of noises.

3) Determine whether Gunnison sage-grouse vocalizations are being masked by anthropogenic noise sources.

4) Evaluate the relationship between noise level and Gunnison sage-grouse lek attendance. We analyzed trends in lek attendance at each lek in relation to the acoustic signature of the lek and in relation to the acoustic properties of leks close to roads and leks further from roads.

5) Determine changes in traffic volume over time on major roadways in the Gunnison Basin using Colorado Department of Transportation data and relate traffic volume data to noise levels and sage-grouse lek attendance.

6) Determine the effect of anthropogenic noise on the frequency of occurrence of Gunnison sage-grouse vocal displays.

7) Model anthropogenic noise propagation across the landscape using the System for the Prediction of Acoustic Delectability (SPreAD) model developed by Sarah Reed from Colorado State University: http://warnercnr.colostate.edu/~sereed/research/SPreAD-GIS.html. This objective is primarily be the responsibility of Brian Magee, CPW, in collaboration with Western State Colorado University, and is not discussed in this report.

Methods

Study Area

The research was conducted in the Gunnison Basin during the 2013 lekking season (28 March – 15 May). The Gunnison Basin is located in the central mountains of Colorado at an elevation of 7,700 feet (2,350 m). The floor of the valley is riparian and is immediately surrounded by pasture and hay meadow. Beyond riparian habitats and pasture lie broad sagebrush steppe lands extending up to aspen and coniferous forest. The Gunnison Basin is relatively dry with an average precipitation of approximately 11 in/year (28 cm/year). The basin lacks oil and gas development and is generally a rural landscape. The Gunnison Basin supports 88% of the rangewide population of Gunnison sage-grouse and nearly two-thirds (63%) of occupied habitat.

Study sites consisted of active Gunnison sage-grouse leks (mating areas) chosen based on distance from anthropogenic noise sources. Sound attenuates as the distance from the source increases (Dooling and Popper 2007). Colorado Parks and Wildlife (CPW) Geographic Information System (GIS) specialists in Fort Collins conducted a landscape analysis of leks based on lek size, topography, and location relative to roads and highways. The GIS model predicts distances sound moves across the landscape which allowed us to better define leks that might be less affected by anthropogenic noise sources to be used as control groups. The GIS modeling created 2 mile (3.2 km) boundaries around major U.S. and Colorado state highways and 1.5 mile (2.4 km) boundaries around major county roads to indicate the primary landscape impacted by anthropogenic noise (Fig. 1). Local forest access roads and tiger roads (two-track) were not considered as they were closed for the lekking season (March 15th – May 15th) by Gunnison County, the USDA Forest Service and the Bureau of Land Management (BLM). Leks located within the 1.5 and 2 mile boundary were defined as more disturbed and are referred to as "inside" throughout this paper as they were closer to anthropogenic noise sources. Leks that were further away from anthropogenic noise sources (outside the boundary) were defined as less disturbed and are referred to as "outside" (Table 1).

Study leks were located on a mix of public, private, and land trust properties. We obtained permission to access leks on private land and to access public lands where roads were seasonally closed. All sites and other research protocols were developed and finalized in close cooperation with CPW Gunnison office and Southwest regional staff to minimize potential disturbance to sage-grouse.

An additional 2 day sample of the Knorr lek in Middle Park, Colorado was performed with the goal of establishing a baseline acoustic signature for that area. No greater sage-grouse were present during this sample period. This sample was used for baseline data only and although we compare the two areas, the Knorr lek data was not used in the analysis of the Gunnison study. Refer to Appendix I for a brief summary of that study.

Experimental Design and Data Collection

Eleven leks were monitored from 28 March to 15 May 2013 between 0000 h and 1000 h, coinciding with times Gunnison sage-grouse most likely occupied leks. To measure noise level amplitude we placed a Type I sound level meter (SLM), a 755-Sound Pro Data Logging Real Time Frequency Analyzer by Quest Technologies, within 25 meters of an active lek. Protocols for placement of monitoring equipment emphasize the minimization of disturbance to the grouse during their mating rituals (Figs. 2 and 3). The SLM is capable of measuring amplitudes down to the level of 12 dBA (the noise floor). The recording settings of the SLM are summarized in Table 2.

In addition, we placed an acoustic recorder adjacent to the SLM. We used an SM-2 Acoustic Monitor by Wildlife Acoustics, Inc. (Table 3) in order to record grouse vocalizations, environmental sounds, and anthropogenic noise events while the grouse occupied the lek (Figs. 2 and 3). The monitors were placed for three consecutive days at each lek site. The meters were installed at each lek after 1200 h to minimize disturbance to mating activity. The microphones were placed no higher than the sagebrush and the base units were concealed using both manmade (camouflage paint and duct tape) and natural disguises. GPS readings of each site were taken and programmed into both units. Lek topography, weather, and visual lines of sight to anthropogenic noise sources were noted.

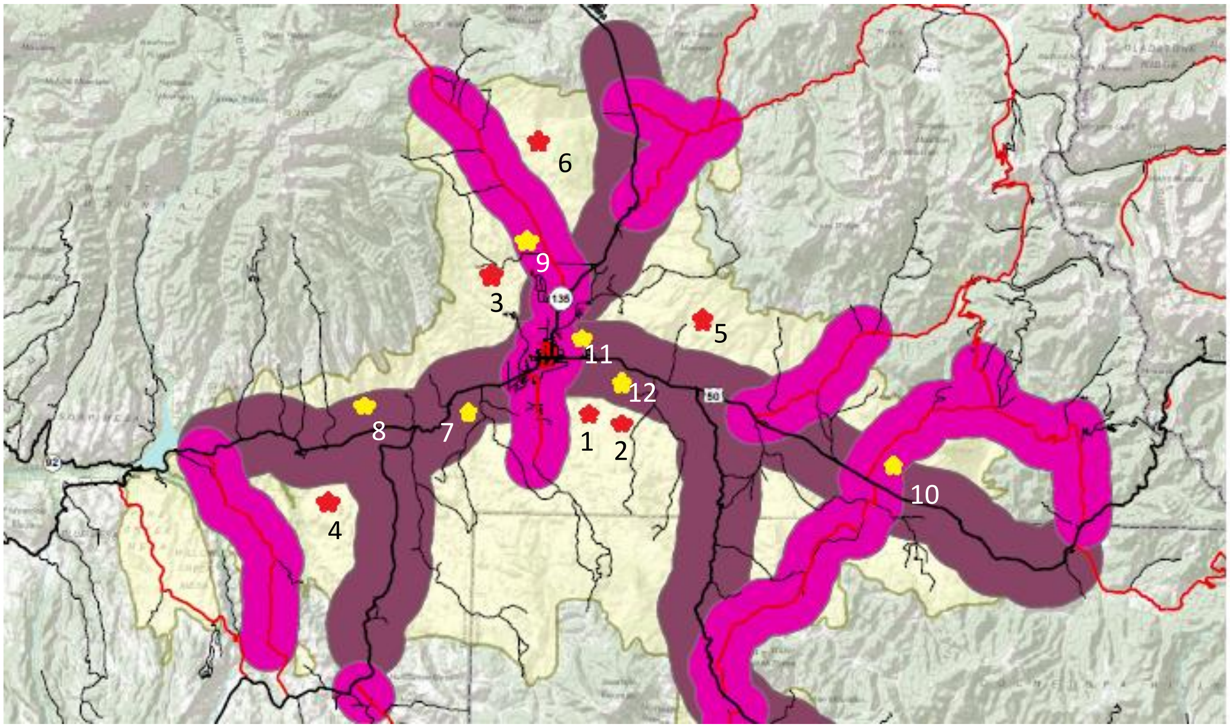

Fig. 1. Soundscape boundaries around highways and major roads within the Gunnison Basin. Pink represents the 1.5 mile boundary around local roads and the purple a 2 mile boundary around state and federal highways. The approximate location of leks inside the road boundary is represented with yellow dots and leks outside the boundary with red. Numbers correspond with lek names presented in Table 1.

Table 1. Lek sites that were used for measurement of ambient noise and anthropogenic noise within the Gunnison Basin, Colorado 2013. *No data were collected for Kezar Basin lek due to equipment malfunction.

Outside leks	**Inside leks**
1 - Chance	7 - McCabes Lane
2 - Chance E	8 - Stevens Creek
3 - Hartmans Gulch	9 - Miller Ranch
4 - *Kezar Basin North/Hupp*	10 - Waunita
5 - Sewell	11 - Signal Peak West
6 - Tailas	12 - Meyers

Fig. 2. Sound level meter (SLM, on left) and audio recorder (SM-2 Wildlife Acoustics, on right) deployed in field on a Gunnison sage-grouse lek, in the Gunnison Basin, Colorado, spring 2013.

Fig. 3. Dan Piquette sets up SLM (left) and audio recorder (right) at Gunnison sage-grouse lek in the Gunnison Basin, Colorado, spring 2013.

Table 2. Sound Level Meter settings used during spring 2013, in the Gunnison Basin, Colorado.

SOUND LEVEL METER 755-SOUND PRO DATA LOGGING REAL TIME FREQUENCY ANALYZER	
Meter 1 parameters	**On**
Weighting	dBA
Response	Fast
Octave	1/3
Projected time	10 hours (0000-1000 h)
Logging Interval	1 second
Noise Floor	12 dBA
Meter 2 parameters	**On**
Weighting	dBF
Response	Fast
Octave	1/3
Projected time	10 hours (0000-1000 h)
Logging Interval	1 second

Table 3. Summary of acoustic recorder settings used during 2013 in the Gunnison Basin, Colorado.

SM-2 by Wildlife Acoustics Settings	
Sample Rate	8,000 Hz
Gain	0
Channel	Stereo
Schedule	0000 - 1000

Data Analysis

Although our experimental design provided for a comparison of six leks relatively close to roads and six leks farther from roads, the SLM malfunctioned at the end of the study period and no data were collected at the Kezar Basin lek which is outside the 2 mile boundary.

Anthropogenic Noise Amplitude at Gunnison Sage-grouse Leks

The SLM has two meters that independently record amplitude (Table 2). Meter 1 measured amplitude with A weighting (dBA), or adjusts to frequencies within the range of human hearing (human hearing threshold = 20 Hz). Meter 2 recorded with F weighting (dBF) which assumes that all frequencies are heard at the same amplitude. Each of the two SLM meters sample sound pressure level 23 times per second, measuring 33 distinct 1/3-octave bands in each sample (center frequencies 12.5 Hz – 20 kHz). Sound amplitude data were downloaded from the SLM in the field to a laptop using Quest software. These measurements, logged every second were then used to calculate a variety of descriptive statistics for amplitude measurements (Table 4). We used LEQ to report the average amplitude over the 10 hour recording period. L50 was used to report the median amplitude, LMIN and LMAX were used to report the minimum and maximum amplitudes recorded during the 10 hour session, and the L90, meaning 90% of the amplitudes recorded were greater than this value, to identify the ambient noise level of each lek according to industry standards (Patricelli et al. 2013; ANSI S12.9P1 2003).

Table 4. Sound amplitude summary statistics generated by SLM Quest software.

Amplitude Descriptive Variable	Amplitude Symbol	Definition
Ambient	L_{90}	Quietest 10% of measurements, 90% of sound level measurements exceed ambient, also called residual noise level. This value excludes most non-continuous sound and noise
Median Amplitude	L_{50}	Middle point of data, 50% of sound level measurements exceed median, this metric less influenced than mean amplitude by occasional loud noises
Mean Amplitude	L_{EQ}	Amplitude averaged over a certain time period, called equivalent continuous sound level, appropriate for quantifying continuous noises and will be higher than L_{50} in soundscapes with occasional loud noises
Minimum Amplitude	L_{MIN}	Lowest amplitude recorded over a specific time period or for a specific sound event
Maximum Amplitude	L_{MAX}	Highest amplitude recorded over a specified time period or for a specific sound event
Peak Amplitude	L_{PEAK}	Highest absolute instantaneous amplitude recorded

Each lek was categorized as inside (closer to anthropogenic sources of noise) or outside (farther from anthropogenic sources of noise) based on the GIS road analysis. We tested the null hypothesis that there was no difference in sound amplitude for leks close to roads and leks farther from roads with a standard t-test using Program R Studio ($\alpha = 0.05$).

Sources and Amplitudes of Anthropogenic Noises at Gunnison Sage-grouse Leks

The SM-2 acoustic recordings were downloaded into the Cornell Lab of Ornithology's Raven Pro software for analysis. The sound analysis software allows for visual representation of sound data using spectrograms (frequency of sound over time) and waveforms (sound pressure or amplitude over time). Raven Pro represents amplitude in sound pressure units, whereas analysis of SLM data presents amplitude in decibels. We aurally and visually inspected the sound data recorded at the eleven leks to determine types of noise disturbances and to determine the number and duration of noise events. By listening to noise events and simultaneously examining the visual representation, noise event signatures can quickly be visually identified on spectrograms. Every noise event recorded from 0000 - 1000 h on each day at the eleven leks was identified on spectrograms. We matched (using time and date) the amplitude data from the SLM with the spectrograms to quantify noise amplitude for each event and noise frequency. Once an anthropogenic event was visually identified within the Raven Pro software, the time of the event was recorded. We then found the event's time signature in the SLM 3M detection management software where we quantified the maximum single amplitude of that event. For example, if noise from a jet lasted three minutes, only the highest dBA sample was recorded from that event. If inclement weather occurred, the event was not measured to avoid skewing the amplitude. If the event could not be isolated (multiple noises occurring at the same time), the event was not used. Duration of each event was recorded. Each noise event was classified in one of three categories: automobile traffic associated with roads/highways, propeller airplanes, and jet airplanes. The null hypothesis that there was no difference in amplitude generated from anthropogenic noise between leks located inside and outside the established boundary was tested using a t-test ($\alpha = 0.05$) in software program R Studio

Gunnison Sage-grouse Vocal Masking by Anthropogenic Noise

We recorded the amplitude and frequencies of Gunnison sage-grouse at a known distance (10 meters). The amplitude and frequencies of automobiles were recorded at each of the leks with a known distance to the SLM meter. Aircraft noise was also recorded however distances were not established. The frequencies produced by the Gunnison sage-grouse vocalizations were established and measured using spectrograms in Raven Pro and the frequencies produced by the anthropogenic events were also quantified using Raven Pro and overlap was determined by compassion of spectrograms. Similarly, amplitudes of Gunnison sage-grouse vocal displays measured at 10 meters were determined from Raven Pro waveforms and compared to amplitudes produced from the anthropogenic events (unknown distance to birds). We determined whether amplitudes of anthropogenic events were greater than those produced by Gunnison sage-grouse

Gunnison Sage-grouse Male High Counts in Relation to Anthropogenic Road Noise Sources

Gunnison sage-grouse male high count (MHC) data (from 1998 to 2013) obtained from Colorado Parks and Wildlife were averaged across the study leks that occurred inside and outside the road boundary. Annual means and a 16-year average were calculated for leks inside and outside the road boundary. We tested the null hypothesis that there was no difference in MHCs on inside (more disturbed) and outside (less disturbed) leks using a t-test (α = 0.05) in software program R Studio.

Relationship Between Traffic Volume and Gunnison Sage-grouse Lek Attendance

We conducted a preliminary analysis of traffic volume at one location where Colorado Department of Transportation data were available. Traffic volume counts were taken from the State of Colorado Department of Transportation yearly monitoring statistics for the month of April from the OTIS U.S. Highway 50 station number 102270 near Doyleville, CO located approximately 20 miles east of Gunnison, Colorado. Traffic volume was correlated with the Waunita lek counts as this site is 1.2 miles from the lek. We tested the null hypothesis that traffic patterns did not affect sage-grouse attendance using correlation analysis in software program R Studio.

Effects of Anthropogenic Noises on Gunnison Sage-grouse Vocal Communications

We assessed the effect of anthropogenic noise on Gunnison sage-grouse vocalizations by quantifying vocal display intensity at a lek (counting the air sac "pops") before, during, and after an anthropogenic event. Anthropogenic events were identified in the Raven Pro software visually and by ear. For analysis, distinct noise events were separated by at least 2 minutes. The beginning of a noise event was identified visually in the spectrogram as a unique frequency signature (See Results, Figure 12) and by the presence of increasing amplitude in the waveform. The end of the event was characterized using the disappearance of the disturbance in the same spectrogram and a return of the waveform to previous amplitudes. Because we could not distinguish "pops" of individual birds on the spectrogram, we counted all "pops" for one minute prior to the beginning of an anthropogenic event. To quantify "pops" during noise events, we divided noise events into 10-second intervals and we randomly selected one of the intervals as the start time and quantified "pops" for one minute. For example, if the event was 3 minutes in duration, the possible start times would be 10, 20, 30… 110 seconds in to the event. If the random start time was 80 seconds into the event, we would count the "pops" during the interval between 80 – 140 seconds (one minute). We would then count the "pops" for one minute after the anthropogenic event was completed. We used the "NLME" package in R Studio to develop two mixed effects models. The first was a non-paired model analyzing before, during, and after as a group (similar to an ANOVA), and the second was a paired model comparing before with during and before with after. The random effects for both models were individual leks and dates of the counts. The fixed effects for both models were noise sources: jet aircraft, propeller aircraft, and automobile noise. All leks, dates, and events were tested individually and reported as models with random leks and dates. We tested the null hypothesis that there would be no reduction in Gunnison sage-grouse vocalizations in response to anthropogenic events using a t-test (α = 0.05). Variability within the random effects was reported as 95% confidence intervals (CI).

RESULTS

Anthropogenic Noise Amplitude on Gunnison Sage-grouse Leks

The amplitude of anthropogenic noises varied temporally within all leks (Table 4). Each lek demonstrated a unique soundscape attributed to its location within the basin and topographical features (Table 4). Amplitude of noises at leks inside and outside the boundary typically increased beginning around 0730 h. In 2012, the mean amplitude (LEQ) inside was 69 + 6 dBF and outside mean amplitude was 62 + 5dBF, however, in 2013 there was less difference between the two classifications. Inside had a mean amplitude of 62 + 3 dBF and the mean amplitude of outside leks was 63 + 7 dBF (Fig. 4). With A weighting the inside lek mean amplitude was 32.3 + 0.5 dBA and the outside lek mean amplitude was 31.1 + 0.7 dBA (Fig. 5).

Table 4. Sound amplitude measurements for each of 11 Gunnison sage-grouse leks averaged over 2 or 3 day periods during spring 2013 in the Gunnison Basin. Sound data were recorded from midnight to 10 am (0000 – 1000 h) using a Type I SLM. All units are dBA unless specified. Measurements recorded using fast response, 1/3 octave, settings on SLM. HMC is Gunnison sage-grouse high male count.

Lek	Dates	L_{EQ} dBA	L_{EQ} dBF	L_{50}	L_{90}	2013 HMC
Leks Outside the 2 mile boundary						
Chance	8, 9 April	30.3	73.1	22.5	18.1	17
Chance E	1, 2, 3 April	32.1	61.9	18.5	16.6	14
Hartmans	15, 16, 17 April	31.5	68.3	17.6	17.7	43
Sewell	23, 24, 25 April	31.5	58	17.7	16.1	13
Taila	29, 30 April, 1 May	30.1	70	19.9	17.1	11
Kezar	No SLM Data	-	-	-	-	30
Mean Out		31.1	66.3	19.2	17.1	21
Leks inside the 2 mile boundary						
Stevens	2, 3, 4 May	28.9	61.7	18.8	16.4	9
Meyer	5, 6, 7 April	36.6	61.8	18.7	16.6	10
Waunita	12, 13, 14 April	38.7	64.3	21.4	17.6	11
Signal	20, 21 April	29.1	58.9	25.3	17.7	10
McCabes	26, 27, 28 April	31.8	58.8	20.3	17.5	2
Miller	29, 30, 31 March	28.9	63.6	21.3	18.2	31
Mean In		32.3	61.5	20.9	17.3	12

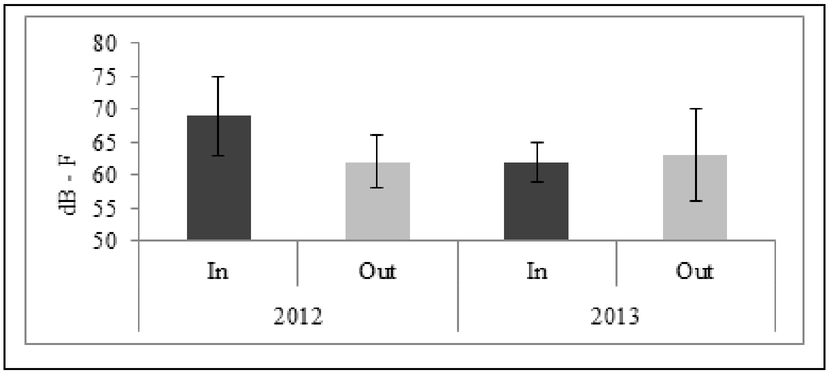

Fig. 4. Comparison of mean anthropogenic noise amplitudes in dBF at six Gunnison sage-grouse leks relatively close to roads and five (2013) or six(2012) leks farther from roads between the 2012 and 2013 study seasons in the Gunnison Basin. Error bars represent standard deviation.

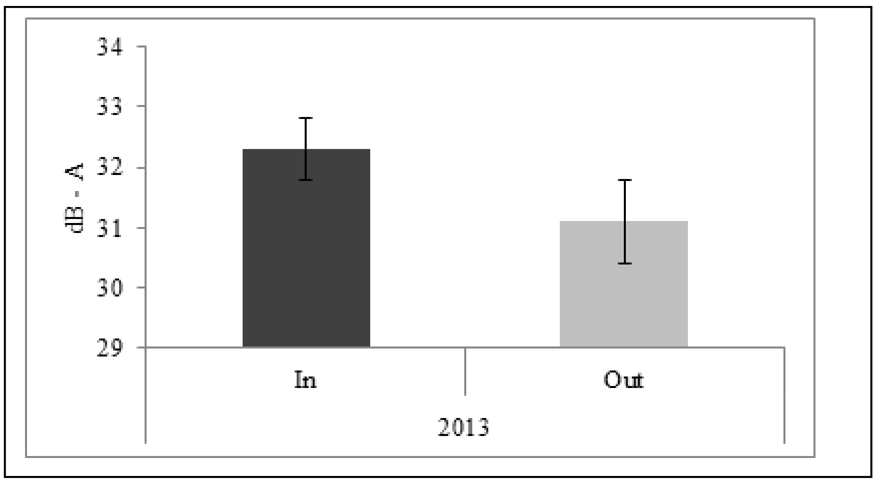

Fig. 5. Comparison of mean anthropogenic noise amplitudes in dBA at six Gunnison Sage-grouse leks relatively close to roads and five leks further from roads during spring 2013 in the Gunnison Basin. Error bars represent standard deviation.

In this study we identified the ambient noise level (natural soundscape) of eleven Gunnison basin leks. The inside leks had almost identical L_{90} findings as outside leks; 17.3 dBA to 17.1 dBA, respectively (Table 4). In addition the L_{50} findings were also similar, 20.9 dBA inside and 19.2 dBA outside. Overall for all leks ambient noise level was 17.2 dBA and L_{50} was 20.1 dBA. See Appendix I for acoustic signature of the Knorr greater sage-grouse lek located near Kremmling, CO.

Sources and Amplitudes of Anthropogenic Noises on Gunnison Sage-grouse Leks

The three main sources of anthropogenic noise on Gunnison sage-grouse leks included jet airplanes (large planes), propeller planes (small planes), and automobile traffic on roads and highways. The mean number of jets was 21.2 on leks inside the road boundary and 22 on leks outside the road boundary, and the mean number of propeller planes was 5.8 inside and 4.3 outside. For either type of aircraft, no statistical difference was determined for leks close to and further away from roads ($p = 0.221$ for jets; $p = 0.11$ for props). The mean number of highway noise events was significantly higher for leks inside the boundary (19.9 events) than outside the boundary (7 events) ($p < 0.001$) ($n = 16$ days inside and $n = 14$ days outside) (Figs. 6 and 7). No difference occurred in mean number of anthropogenic events between 2012 and 2013.

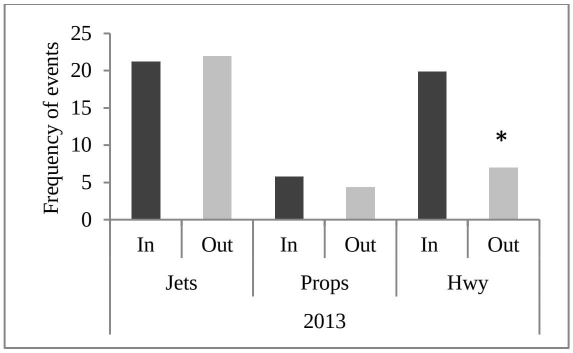

Fig. 6. Mean number of anthropogenic events around leks inside and outside the road boundary, spring 2013. * represents significantly different means ($p < 0.05$).

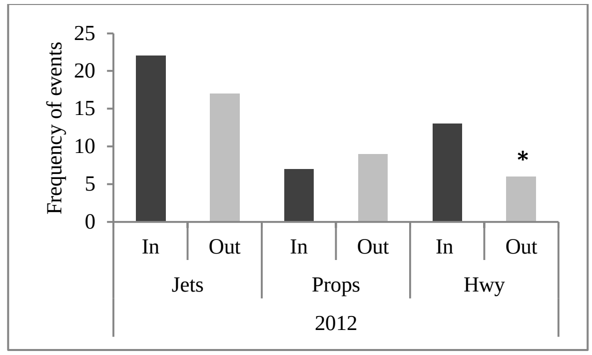

Fig. 7. Mean number of anthropogenic events around leks inside and outside the road boundary, spring 2012. * represents significantly different means ($p < 0.05$).

The amplitudes of anthropogenic noises between 2012 and 2013 cannot be compared as the peak amplitudes in 2012 were weighted in dBF and dBA in 2013. Average peak amplitudes in 2013 did not differ significantly for jets -- inside L_{PK} was 66.7 dBA and outside L_{PK} was 68.8 dBA ($p = 0.09$), or for propeller planes – inside L_{PK} was 74.7 dBA and outside L_{PK} was 74.2 dBA ($p = 0.34$). In contrast, the highway maximum amplitudes differed significantly ($p < 0.001$) with inside L_{PK} at 59.2 dBA and outside L_{PK} at 51.1 dBA (Fig 8).

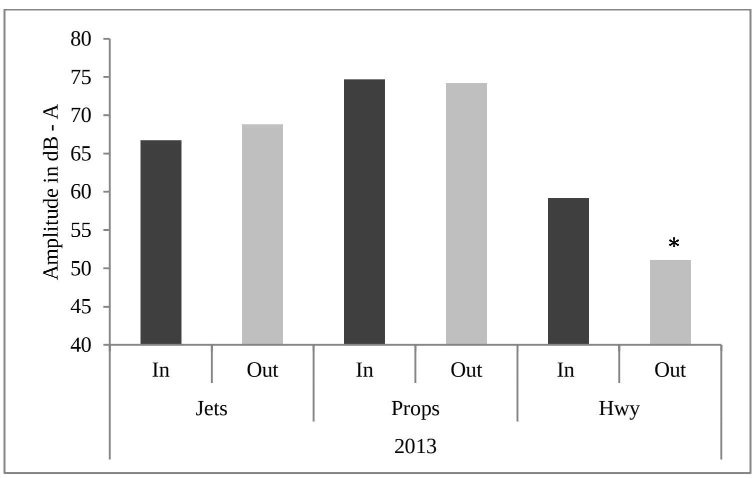

Fig. 8. Average peak amplitudes (dBA) of each type of noise in the spring of 2013, Gunnison, CO.
* indicates statistically significant means ($\alpha = 0.05$).

Gunnison Sage-grouse Vocal Masking by Anthropogenic Noise

We were unable to quantitatively demonstrate masking because the specific hearing threshold of Gunnison sage-grouse is unknown and unmeasured. However we can qualitatively address the issue of masking of sage-grouse communication by anthropogenic noise. The average amplitude of anthropogenic events on all 11 leks measured was 65.7 dBA with frequencies between 50 and 2,500 Hz. We did not measure the precise distance from the grouse to the SLM meter when recording grouse vocalizations, but we can confidently state that the birds were within 10 m (confirmed by direct visualization at the Waunita lek). At these distances, the maximum amplitudes of grouse vocalizations did not exceed 51 dBA. The frequency of the grouse vocalizations, within those same distance parameters, was between 73 and 800 Hz. Because the frequencies of the grouse vocalizations overlap with the anthropogenic noise frequencies, and because grouse vocalizations were considerably lower than the mean amplitude of anthropogenic noises, the mechanism for masking exists.

Gunnison Sage-grouse Male High Counts in Relation to Anthropogenic Road Noise Sources

Consistent with 1998 – 2012 findings, there were fewer birds on the inside leks compared to the outside leks in 2013 (Figs. 9 and 10). Although the Miller lek had a male high count (MHC) of 31, the other 5 inside leks had high counts of 11 or fewer males, whereas all the outside leks in 2013 had a MHC of greater than 11 with Hartman's Gulch having the most at 43. While there is no causality demonstrated by these data relating anthropogenic road noises to sage-grouse lek attendance, the correlation is interesting.

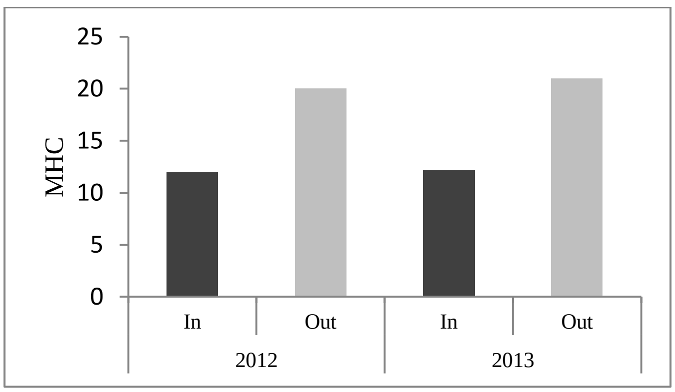

Fig. 9. Comparison of Gunnison sage-grouse male high counts (MHC) at six leks inside the road boundary (In) and five leks outside the road boundary (Out). On the left, data are for the 15-year period from 1998-2012, whereas on the right the data are just from the 2013 lek season.

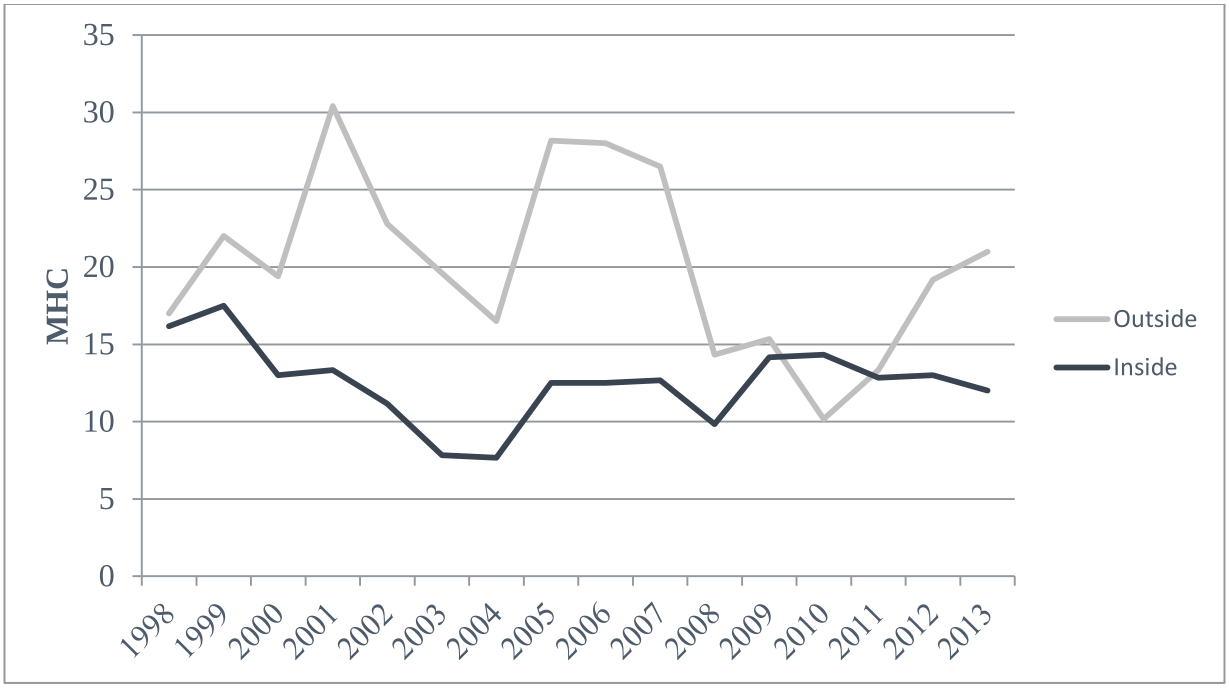

Fig 10. Average male high counts from 1998 – 2013 for the 6 outside leks and the 6 leks inside the 2 mile boundary within the Gunnison Basin, Colorado.

Relationship Between Traffic Volume and Gunnison Sage-grouse Lek Attendance

Traffic counts near Doyleville on U.S. Highway 50 were not highly correlated (Correlation co-efficient r = 0.42) with male high counts of Gunnison sage-grouse at the Waunita lek (Fig 11).

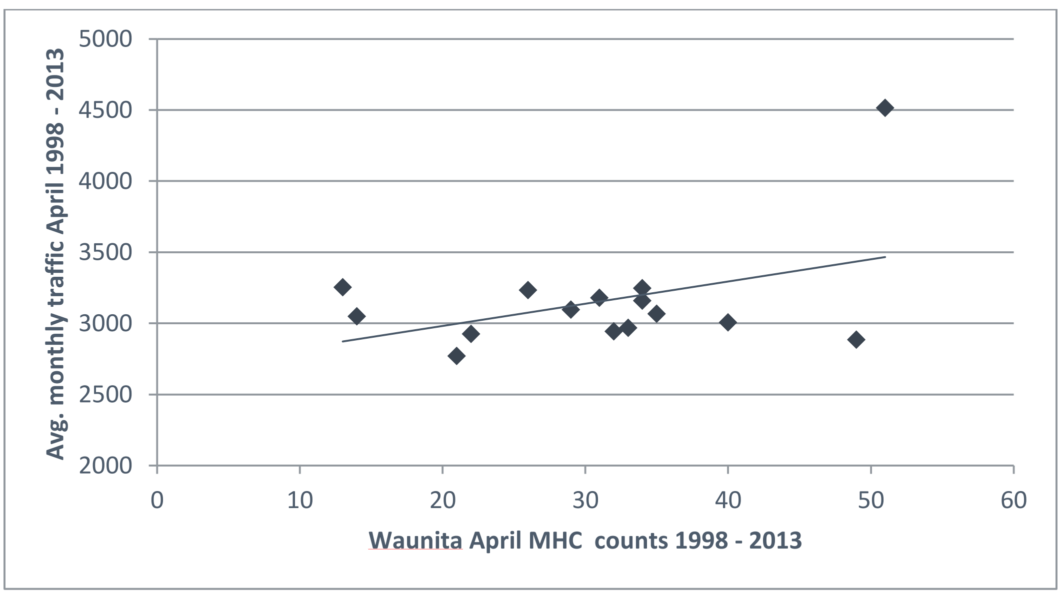

Fig 11. Traffic counts from Colorado Department of Transportation OTIS U.S. Highway 50 station number 102270 correlated with Waunita lek counts, April 1998 – 2013 (correlation coefficient = 0.42).

Effects of Anthropogenic Noise on Gunnison Sage-grouse Vocal Communication

Gunnison sage-grouse lekking intensity, measured by vocalizations per minute or pops per minute (ppm), differed significantly before, during, and after anthropogenic noise disturbances (Fig. 12). The overall mean of Gunnison sage-grouse vocalizations (pops) prior to anthropogenic noise events was 43 ppm (95% CI 20.18 - 63.81 ppm). During the noise event, the overall mean dropped to 16 ppm (95% CI 2.2 – 29.3 ppm) a significant reduction in intensity (non-paired mixed effects model, $P < 0.001$). After the noise event ceased, grouse display intensity rebounded significantly (non-paired mixed effects model, $P < 0.0001$) to 29 ppm (95% CI 17.3 – 40.7) (Fig. 13). In the paired mixed effects model, vocal intensity (ppm) dropped significantly from before noise to during noise events ($P < 0.001$), and vocal intensity dropped significantly from before to after noise events ($P < 0.001$) (Fig. 14).

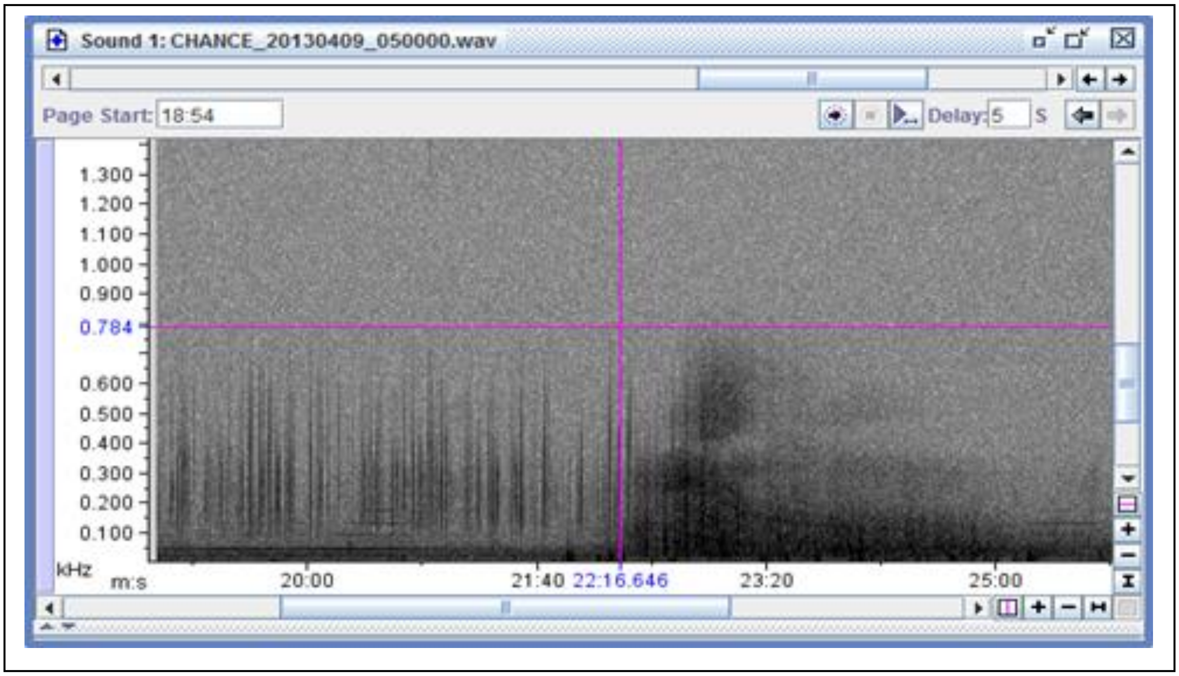

Fig. 12. Spectrogram from Raven Pro software of a 7-minute sound bite from Chance lek, 9 April 2013from 05:18:54 – 05:25:30. Vertical lines in lower left represent Gunnison sage-grouse “pops”. The dark low frequency noise in the lower right is a jet aircraft. Note the few grouse “pops” during the noise event.

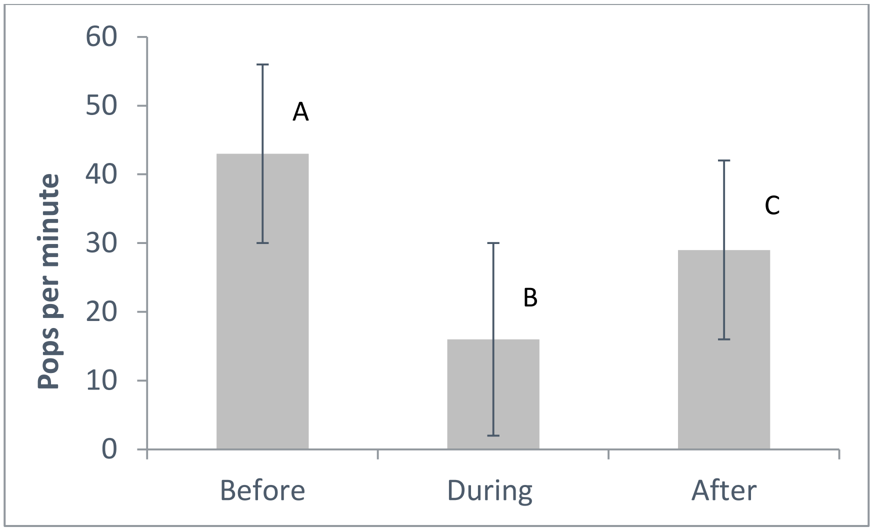

Fig. 13. Non-paired mixed effects model of Gunnison sage-grouse vocalizations (pops per minute) recorded on 11 leks before noise events, during noise events, and after noise events in the Gunnison Basin, Colorado during spring 2013 (different letters above bars represent significant differences with $p < 0.001$).

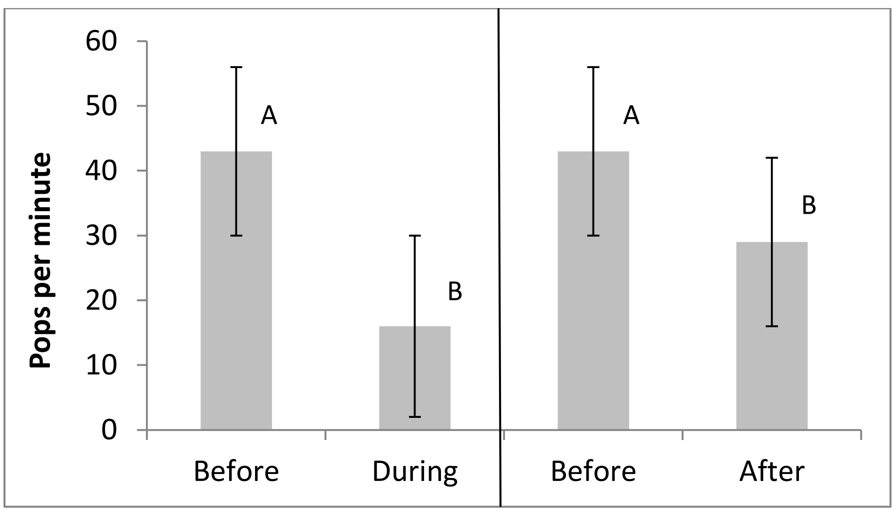

Fig. 14. Paired mixed effects model of Gunnison sage-grouse vocalizations (pops per minute) recorded on 11 leks before noise events, during noise events, and after noise events in the Gunnison Basin, Colorado during spring 2013. In this model vocal intensity is compared before and during noise events and before and after noise events (different letters above bars represent significant differences with $p< 0.001$).

DISCUSSION

Ambient Noise Levels in the Gunnison Basin

We conducted two years of data collection on twelve Gunnison Sage-grouse leks to quantify the ambient acoustic habitat in the Gunnison Basin, Colorado. Overall, acoustic habitat at leks is highly variable temporally within a lek and among leks. Further, soundscapes vary geo-spatially. Despite this noteworthy variability, our measurements suggest that ambient noise level (defined by the L_{90} or quietest 10% of measurements) experienced by humans at leks is approximately 17.2 dBA (Table 5). As dBA adjusts amplitude to human hearing threshold, it is likely that grouse experience a unique acoustic habitat compared to humans, and this ambient level is unknown, but ours is a conservative estimate of ambient conditions experienced by grouse (Francis and Barber 2013). Ambient values are similar at inside and outside (proximity to roads) leks, because roads do not produce noise in the absence of vehicles, and vehicle traffic was intermittent and thus did not affect the quietest 10% of measurements (the L_{90}). Gunnison sage-grouse mating displays and their lek reproductive system in part evolved under acoustic selective pressures, therefore if the ambient acoustic habitat is largely undisturbed by anthropogenic noises, this measurement is a meaningful baseline for grouse conservation efforts associated with managing and/or regulating noise levels. Our ambient noise data for the Gunnison Basin are similar to ambient values of 16 - 20 dBA collected in greater sage-grouse habitats in Wyoming (Patricelli et al. 2013) and to Environmental Protection Agency ambient noise measurements in wilderness (16-22 dBA) (Ambrose and Florian 2013).

Table 5. Summary of anthropogenic noise measurements on leks close to roads (Inside), farther away from roads (Outside), and for all 11 leks combined (n = 5 for Outside, n = 6 for Inside). L_{50} and L_{90} are measured in dBA.

Anthropogenic noise on Gunnison sage-grouse leks	**L_{EQ} dBA** **Mean amplitude adjusted to human hearing**	**L_{EQ} dBF** **Mean amplitude averaged across all frequencies**	**L_{50} dBA** **Median amplitude**	**L_{90} dBA** **Ambient noise amplitude (quietest 10%)**
Mean for Inside Leks	32.3	61.5	21.0	17.3
Mean for Outside Leks	31.1	66.3	19.2	17.1
Mean for all Leks Combined	31.7	63.9	20.1	17.2

Effects of Roads and Highways on Anthropogenic Noise Levels at Gunnison Sage-grouse Leks

We examined differences in acoustic habitats for grouse leks relatively close to roads and those further away from roads. Proximity to noise sources likely influences acoustic habitat at leks in complex ways as the noise characteristics and transmission across the landscape interacts with local topography. Further, the geometry of the sound wave influences transmission through the landscape. For spherical wave fronts the amplitude of sound decays by 6 dB for every doubling of distance from the source of the sound, but for cylindrical wave fronts, such as highway noise, the sound only decays at a rate of 3 dB per doubling of distance (Francis and Barber 2013). In 2012, sound amplitude at the leks closer to roads was higher than leks farther away from roads by more than 7 dB (more than twice as loud), however, in 2013 mean sound amplitude was similar on leks closer to roads (62 dBA) compared to leks farther away from sources of noise (63 dBA). In 2013, the difference in average amplitude was only 1.2 dBA. It is unlikely that such a small difference in amplitude is a concern regarding management implications. While overall noise amplitude was similar on leks near and far from roads, noise associated just with automobile traffic was significantly higher on leks close to roads (59.2 dBA) compared to leks farther from roads (51.1 dBA). The 8.2 dBA difference in road traffic noise at leks closer to and farther away from roads may be significant in isolation from other anthropogenic noises.

The lack of significant difference in overall noise amplitudes at leks closer to roads and those farther away, may be explained by the relative contribution to the noise environment made by aircraft relative to automobiles. Perhaps planes, which clearly are not dependent on roads for travel routes, and their corresponding noise contribute more than automobiles to the noise experienced by grouse at leks. If so, we predict a decoupling of noise amplitude at a lek from proximity of roads to leks. In fact, leks near and far from roads had very similar average maximum amplitudes in regards to aircraft overflights. The mean amplitude of jet noise at inside leks was 66.7 dBA, whereas the mean jet noise was 68.8 dBA at outside leks. Similarly, the mean noise amplitude for propeller planes at inside leks was 74.7 dBA compared to 74.2 dBA at outside leks. It is noteworthy that jet and propeller planes had higher amplitudes than automobile traffic, with highest amplitudes originating from relatively low flying prop planes (74.7 dBA). Airplane noise may trump automobile noise under certain conditions when both occur simultaneously. A simple relationship between road proximity and noise at the lek is unlikely as roads that are very near leks or roads with high traffic volume and the corroborating topography that funnels sound from the source to the lek, would potentially contribute more noise at the lek. Road/highway traffic noise is more variable at leks then airplane noise and more dependent on the local topography and vegetation that influences sound transmission from sound source to lek. While the highest amplitudes from anthropogenic noises were associated with prop planes, a noisy acoustic habitat was created by all three noise sources with a 33 dBA minimum excess of noise above ambient conditions (Table 6).

Table 6. Overall mean anthropogenic noise amplitude (dBA) and mean amplitude of jet airplanes, propeller airplanes, and automobiles relative to proximity to roads/highways in the Gunnison Basin, Colorado, spring 2013. Magnitude of amplitude in excess of ambient (17.2 dBA measured in this study) is reported.

Anthropogenic Noise Source	**Amplitude (dBA) Closer to Road/Highway**	**Amplitude (dBA) Farther from Road/Highway**	**Amplitude (dBA) Above Gunnison Basin Ambient**
Overall	62	63	>44
Automobiles	59.2	51.1	>33
Jet Airplanes	66.7	68.8	>49
Propeller Airplanes	74.7	74.2	>57

The frequency of occurrence of anthropogenic noise events may have a larger effect on grouse than the amplitude of the noise. Blickley et al. (2012) measured an immediate and sustained reduction in grouse lekking activity in response to the experimental introduction of natural gas compressor and drilling noises. Further, greater sage-grouse lek attendance declined over three years by 29% in response to experimental additions of natural gas drilling noise which was continuous, and declined 73% where intermittent noise was added from truck traffic on roads adjacent to drilling activities (Blickley et al. 2012). Interesting, and of concern for the Gunnison Basin leks, the anthropogenic noise sources in the

Gunnison Basin are intermittent in nature. The inside leks had more intermittent noise than the outside leks due to the higher prevalence of road/highway traffic. The outside leks averaged 7 automobile events per day (0000 – 1000 h), whereas the inside leks averaged 19.9 events per day (0000 – 1000 h). Data from Colorado Parks and Wildlife lek counts showed that outside leks have had higher male counts (21 MHC) than inside leks (12 MHC) from 1998 to 2013.

The median (L_{50}) amplitude for all 11 leks in the study was 20.1 dBA, only about 3 dBA above ambient. The mean (L_{EQ}) amplitude was 31.7 dBA, 14.5 dBA above ambient. The difference between L_{50} and L_{EQ} reveals there is skewing in the data which is explained by occasional sounds such as bird song or wind gusts that occur above the background residual sound level. The mean amplitude is influenced more by these events than the median. Intermittent anthropogenic noise events most likely contributed to the difference in the average amplitude and median amplitude in our study. The Gunnison Sage-grouse Rangewide Conservation Plan (RCP 2005) recommends that continuous anthropogenic noise not exceed 10 dBA above ambient. Because the RCP does not specify which metric (L_{50} or L_{EQ}) to use, we cannot state definitively whether the 10 dBA threshold for constant noise is being violated. Patricelli et al. (2013) recommend that the median (L_{50}) should be used to assess compliance in the measurement of continuous noise; using this recommendation, these leks are not in violation of the 10 dBA threshold. However, we believe the intermittent introduction of aircraft and highway noise may be more pervasive (Blickley et al. 2012) on Gunnison sage-grouse activity and a change in the RCP policy may be advisable. Indeed, Patricelli et al. (2013) argue that the 10 dBA rule is insufficient for protecting against intermittent noise, and recommend that policy focus on limiting vehicle activity during critical times near leks and other critical areas. Our data suggest that the RCP policy should expand to consider noise recommendation relative to intermittent noise sources as well as continuous noise disturbances.

Which metric (L_{50} or L_{EQ}) is more appropriate for determining whether or not the noise level around Gunnison sage-grouse leks exceeds ambient by 10 dBA or greater? Median amplitude indicates a relatively quiet soundscape around leks. Mean amplitude integrates intermittent noise and illustrates the shift in magnitude above ambient conditions associated with occasional noise disturbances, and therefore is a more appropriate measure. However, both measurements are time-averaged and are not recommended as the best metrics for quantifying intermittent noise (Patricelli et al. 2013, Francis and Barber 2013). Instead, L_{MAX} or L_{PK} more relevantly express the noise magnitude impacting wildlife (Francis and Barber 2013). In our study, average L_{PK} noise levels ranged from 51.1 dBA for automobiles to 74.4 dBA for propeller planes; these values exceeded ambient by 33.9 – 57.2 dBA. These unpredictable, short duration, high amplitude noise pollutants may seriously degrade acoustic habitat (Blickley et al. 2012).

Gunnison Sage-grouse Vocal Communication Masking by Anthropogenic Noises

Masking is one of several mechanisms of noise impact on wildlife (Blickley and Patricelli 2012). In the absence of masking, grouse may avoid habitats where loud noises occur, perhaps due to fear or stress. Masking as a mechanism of noise impact means that grouse are unable to carry out their normal auditory communication due to either high amplitude noises that cover up the sound reception of the listener, and/or the overlap in frequencies of aural communication or noise. Without an audiogram for the Gunnison sage-grouse, masking cannot be quantitatively determined. No audiograms currently exist for this species or for any closely related grouse. Nevertheless, the amplitude of intermittent noise measured in our study is sufficiently high, even from highways and aircraft miles away, to cover the lower amplitudes of Gunnison sage-grouse vocalizations and likely interfere with listening. The precise amplitude of grouse vocalizations must be measured to determine whether noise amplitude covers up grouse vocalizations, and to do this the distance from the grouse to the sound recorder must be measured. For instance, we are unsure at this time what amplitude of anthropogenic noise will be enough to mask the popping vocalization at close range (<10 meters) between a male (source) to a female (receptor).

When male grouse are displaying on the lek in an effort to compete with other males for dominance and to attract females, loud noise may not interfere at close quarters, however, another function of male displays is to advertise the location of leks to juvenile males and females that are spread out across the landscape. Because masking reduces the distance over which an acoustic signal is heard (Blickley and Patricelli 2012), it is more likely that loud anthropogenic noises interfere with this advertisement function or "acoustic beacons" (Francis and Barber 2013). This may have implications for Gunnison sage-grouse transplant efforts, where birds from the Gunnison Basin are trapped and moved to smaller populations. Once delivered to unknown habitat, the hope is that the transplanted individuals will recruit to existing leks – presumably auditory communication plays an important role in lek recruitment.

While sound amplitude is a function of distance from source, frequency of sounds is independent of distance and our data show that the low frequency noise produced by highway traffic, jets and propeller planes falls within the same frequency range of Gunnison sage-grouse vocalizations (70 – 800 Hz). Therefore, our evidence suggests masking is likely occurring however more work will have to be done in order to demonstrate this fully.

Effects of Traffic Volume on Gunnison Sage-grouse Lek Attendance

We used highway traffic data from the Colorado Department of Transportation (CDOT) from the Transportation OTIS U.S. Highway 50 station number 102270 to assess the relationship between traffic patterns and lek activity. We found there was low correlation between monthly traffic patterns and lek counts ($r = 0.42$). Our investigation was only a preliminary attempt using data from just one highway location to investigate relationships over time between lek attendance and traffic volume trends in the Gunnison Basin. A problem with this portion of the study was that the traffic patterns reported from the Colorado Department of Transportation are monthly averages. There were no daily data summaries available or data for specific times within a day (corresponding to early morning grouse lek activity and attendance). One solution and an interesting study would be to place traffic counters on pertinent roads and highways while measuring sound at a lek and look for patterns with that specificity.

Effects of Anthropogenic Noise on Gunnison Sage-grouse Lekking Behavior

Visual analysis of the Raven Pro spectrograms revealed an interesting relationship between noise events and Gunnison sage-grouse vocalizations (Fig. 12). We counted Gunnison sage-grouse display vocalizations or "pops" for 1 minute prior to a noise event, for 1 random minute during the noise event, and for 1 minute after the completion of the noise event. Prior to a noise event grouse vocalized ("popped") at a frequency near 43 pops per minute (ppm) (95% CI 20.18 - 63.81 ppm). During the noise event, the overall mean was 16 ppm (95% CI 2.2 – 29.3 ppm) a significant reduction in intensity ($P < 0.001$). After the noise event ceased, grouse display intensity rebounded significantly ($P < 0.0001$) to 29 ppm (95% CI 17.3 – 40.7) but still remained significantly lower than the vocal intensity prior to the noise disturbance (Fig. 13). The model detected significant declines in frequency of grouse vocalizations in response to noise disturbances on all leks studied, and for all three noise events (propeller planes, jet planes, automobiles). The presence of noise disturbance was related to decreased vocal communication independent of the amplitude of the noises experienced at the lek, perhaps suggesting that Gunnison sage-grouse are sensitive to even subtle acoustic disturbances while lekking. Interestingly, we found in the model that the noise source was not a significant predictor of the magnitude of the effect on grouse behavior. This is consistent with the intermittent noise introduction studies as described previously (Blickley at al. 2012). Further, we found that amplitude was not a significant predictor of the decline in grouse vocal intensity. This is not surprising, however, because only the mean peak amplitudes (loudest noises) were available to load into the model. We may find different results if we could model the crescendo and de-crescendo of each of the anthropogenic events.

Not only are amplitude and frequency important characteristics of noise that influence wildlife behavior and habitat use, but also the continuous versus intermittent nature of the noise is important as mentioned above. In our study, noises were intermittent in that jet planes, propeller planes, and automobiles moved across the landscape, eventually approaching a lek near enough for the noise produced by the vehicle to reach the lek for a period of time and then fade as the vehicle moved on. Evidence for greater sage-grouse suggests that intermittent truck traffic has a greater negative effect on grouse lek attendance than continuous noise from natural gas drilling and compressor operations (Blickley et al. 2012). Indeed, behaviors of greater sage-grouse during noise events are similar to the behaviors described here, with males temporarily decreasing display activity during the experimental presentation of sounds from passing vehicles (Blickley 2012). It may be counter-intuitive that a lek that is "quiet" much of the time is more vulnerable to noise disturbance than a lek that is continuously impacted by anthropogenic noise. Continuous noise is not an issue at this time on sage-grouse leks or other sage-grouse habitats in the Gunnison Basin. However, as mentioned above, the nature of noise at Gunnison sage-grouse leks is intermittent and the mean amplitude of all three noise sources exceeded ambient by at least 30 dBA (Table 6). And, in fact, peak noise amplitude measured for aircraft flying above leks was 80 dBA. To reiterate, noise management recommendations and/or regulations should consider effects of intermittent noise as well as continuous noise.

Our data suggest that intermittent noise from automobiles on roads and highways up to 2 miles from the lek, jet airplanes, and lower flying propeller planes (highest amplitudes) have a negative impact on Gunnison sage-grouse lek activities. Correlative data suggests a potential relationship between lek noise levels and lek attendance, with louder leks having significantly lower male high counts over 16 years compared to quieter leks farther from roads/highways. Further, our analyses revealed that Gunnison sage-grouse vocal communications on leks are disrupted by noise disturbances with significant declines in acoustic displays during intermittent noise events. Specific recommendations to address intermittent noise amplitude should be considered (Patricelli et al. 2013). Much grouse lekking activity ends as anthropogenic activities gear up in the morning. Timing restrictions on certain activities may be appropriate, such as travel on roads adjacent to leks or on early morning propeller plane (the loudest noise sources heard on leks) departures during the lek season. Management of intermittent noise in the forms of automobiles and airplanes is complicated. Roads and highways are in place and rerouting them is expensive and unlikely. However, topographic sound barriers (noise attenuation walls or berms) could be considered to produce noise buffers, especially in sites where narrow topographic features funnel noise from a highway to a lek (i.e., Waunita lek). While jet airplane routes are established, altering jet traffic patterns could be considered. The majority of jet traffic over the Gunnison Basin originates out of basin and would require regional planning.

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APPENDIX I

We conducted preliminary acoustic monitoring of the Knorr lek which is located approximately 20 miles south of Kremmling, CO. This area has not been monitored previously and, rather than being Gunnison Sage-grouse habitat, it is home to the Greater Sage-grouse. CPW is concerned about expansion of oil and gas development into Middle Park, CO on sage-grouse populations. We monitored the lek for two mornings, 16-17 March 2013 from 0000 – 1000 h using the same monitoring parameters as described in the methods.

Overall we found the ambient noise level to be nearly identical to the Gunnison Basin at 17.3 dBA. The main differences between the Knorr lek and the Gunnison Basin leks are the frequency and type of anthropogenic events. We used two of the Gunnison Basin leks, both having a direct line of sight to the highway, as a comparison to the Knorr lek; the Waunita lek which is closer to the highway (approximately 1 mile) and the Stevens Creek lek which is approximately the same distance (1 mile) from the highway as the Knorr lek. As previously mentioned the ambient noise level of the Knorr lek was 17.3 dBA which is 0.1 dBA higher than the Gunnison Basin. The mean (L_{EQ}) for the 2 days at the Knorr lek was 35.1 which is 3 dBA less than Waunita (38 dBA) and 6 dBA higher than the Stevens Creek lek (28.9 dBA). The median amplitude (L_{50}) of 27.1 dBA was significantly higher than the Waunita lek at 21.4 dBA and the Stevens Creek lek at 18.8 dBA ($p = 0.01$). These findings of the differences are supported in the increased traffic patterns experienced at the Knorr Lek. Although the number of aircraft detected, prop planes had an average of 7 during the 10 hour period and jets had an average of 6, there were significantly more automobile events at Knorr than the two Gunnison leks; 49 average highway events at Knorr, 28 at Stevens and 36 at Waunita (Table 1).

Table 1. Summary of acoustic variables and noise events at the Knorr lek with comparative data from 2 Gunnison Basin leks; Stevens Creek and Waunita in the spring of 2013.

Lek	Dates	L_{EQ} dBA	L_{50}	L_{90}	Avg Jet	Avg Prop	Avg Hwy
Knorr	16, 17 March	35.1	27.1	17.3	6	7	49
Stevens	2, 3, 4 May	28.9	18.8	16.4	5	9	28
Waunita	12, 13, 14 April	38.7	21.4	17.6	6	8	36

It would seem the increased traffic events effected the median amplitude as the average peak amplitude of the events at the Knorr lek were also nearly identical to the Waunita and Stevens leks, jets 66 vs. 68 dBA, props 77 vs. 74 dBA, and hwy 58 vs. 60 dBA, respectively.

It would be interesting to do more monitoring in the Middle Park area and look for similar trends in lek attendance in regards to proximity to highway noise. It would also be interesting to model Greater Sage-grouse vocalizations against anthropogenic noise sources as well. Although we have no male high count data for the Knorr lek we can see definite trends in acoustic signatures of leks in proximity to anthropogenic noise sources.