Wyoming Game and Fish Department
Protocols for Measuring and Reporting Sound Levels at Greater Sage-grouse Leks

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Wyoming Game & Fish Department's protocol for measuring and reporting sound levels relative to Greater Sage-grouse leks is presented below. For more background and supporting science, see Nevada Department of Wildlife's 2018 Review (Appendix A).

Protocol for Sound Level Measurements:

- Establish baseline ambient sound at each lek's perimeter using L_{A90} dBA measurements for the entire day.
- Measure new project sound levels at each lek's perimeter using L_{A50} dBA measurements.
- Data analysis: Hourly metrics (L_{min}, L_{max}, and median L_{Aeq}, L_{A10}, L_{A50}, and L_{A90}) should be calculated for each hour. Summary site metrics should be calculated for all hours (0000-2400) and hours important to lekking sage-grouse (6pm to 8am). 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.
- 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 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 <15 dBA 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. 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 sounds are very 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 A

Acoustic Impacts and Greater Sage-grouse:

A Review of Current Science, Sound Measurement Protocols,

and Management Recommendations

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Anthropogenic activities (e.g., mining and energy development, ranching and agricultural conversion, roads and highways, urbanization) have long been identified as causal factors in the range-wide decline of the greater sage-grouse (Braun 1987, 1998, Swenson et al. 1987, Connelly and Braun 1997, U.S. Fish and Wildlife Service 2013). Recent work has focused on examining less understood mechanisms that should be considered when making land management decisions that might impact sage-grouse. The effect of anthropogenic noise on sage-grouse has been a field of research that has received significant attention recently resulting in a greatly expanded understanding of sound and its influence on sage-grouse (e.g., Blickley and Patricelli 2012, Hess and Beck 2012, Blickley et al. 2012b, 2012a, Blickley 2013, Patricelli et al. 2013). The potential influence on sage- grouse demonstrates a need to incorporate noise considerations into land use decisions in and around sage-grouse habitats.

Because of the relatively rapid increase in knowledge on the subject of anthropogenic noise impacts on sage-grouse and a lack of consistent application of management actions relative to this issue, a summary of this knowledge and clear management guidance is needed. This document seeks to fulfill both of these needs to help guide the Nevada Department of Wildlife's personnel in reviewing and providing recommendations to federal land management agencies on land use decisions in greater sage-grouse habitats.

Introduction

Wildlife are highly attuned to their environment because they rely on environmental cues and the ability to detect these cues to choose behaviors that maximize their survival and reproductive potential (Rabin and McCowan 2003). Anthropogenic noise is a well-recognized influence that impacts animals (Rabin and McCowan 2003, Barber et al. 2010, Kight and Swaddle 2011, Blickley and Patricelli 2012, Mcclure et al. 2013, Shannon et al. 2014, Bunkley et al. 2015), and anthropogenic noise is distinct in intensity, periodicity, and frequency compared to noises that occur in natural environments (Warren et al. 2006). Noise pollution is widespread and an emerging area of study in wildlife conservation and applied ecology that needs to be incorporated into wildlife impact assessment and mitigation (Pater et al. 2009, Francis and Barber 2013).

Perhaps the most well understood impact from anthropogenic noise is the effect of acoustic masking, or decreasing the threshold of detection for sound from the aggregated presence of other sounds (Barber et al. 2010). Masking impedes the ability of animals to communicate through vocalizations and other acoustic events used for signaling by making such noises difficult or impossible to distinguish from background noise. Masking can reduce the ability to find mates (Blickley and Patricelli 2012, Ríos-Chelén and Quirós-Guerrero 2013), reduce the strength of pair bonds (Swaddle and Page 2007), shift predator response behavior (Barber et al. 2010, Chan et al. 2010), increase vigilance behavior (Rabin et al. 2006, Shannon et al. 2014), and interfere with foraging activities (Bunkley et al. 2015).

As early as 1982, wildlife managers were taking advantage of artificial noises to mask approaches when trapping sage-grouse in order to improve trap efficiency (Giesen et al. 1982). Although focused on the practical application of noise for capture of sage-grouse in monitoring and research, Geisen et al. (1982) link the value of a quiet environment for sage-grouse in detecting potential predators or other threats in their environment.

The importance of sound as a means of communication in sage-grouse has been long recognized. The first study exploring the role of sound in sage-grouse mating behavior and success analyzed sound components of lekking displays in sage-grouse (Gibson and Bradbury 1985). Gibson and Bradbury (1985) found a significant relationship between acoustic signaling and mating success in male sage-grouse, underscoring the importance of acoustic signals in sage-grouse breeding behavior. Gibson (1989) found female sage-grouse on leks to be attracted to recorded playbacks of the acoustic signal from males that were successful breeders suggesting acoustic signals serve as a phenotypic trait for sexual selection. The importance of male acoustic signals was confirmed in a subsequent, more detailed study of male mating success that examined a variety of phenotypic characteristics finding that acoustic signals were highly correlated with breeding success (Gibson et al. 1991).

In addition to the effects from masking natural sounds, numerous physiological impacts have been identified from chronic noise exposure in animals, including neuroendocrine responses (e.g., stress hormones, blood glucose levels), reduced fecundity, developmental abnormalities, weight loss, heightened cholesterol, increased heart rate, cardiovascular tissue damage, immune system function decrease, and carcinogenic responses (see Knight and Swaddle 2011 for review). Although not specific to sage-grouse, these studies of physiological impacts occur across a broad range of animal taxa and have been proposed as mechanisms leading to sage-grouse declines in studies examining sage-grouse responses to oil and gas development (Holloran 2005, Blickley et al. 2012a). At least one study has provided a mechanistic link between anthropogenic noise and heightened stress in sage- grouse. Blickley et al. (2012b) found elevated stress levels as measured from fecal corticosterone metabolites in sage-grouse at experimental sites where birds were exposed to chronic anthropogenic noise versus control sites.

Sound Basics

The New Oxford American Dictionary (Stevenson and Lindberg 2010) defines sound as "vibrations that travel through the air or another medium and can be heard when they reach a person's or animal's ear." These vibrations have both a frequency and amplitude component, with frequency measured in Hertz (Hz) and heard by humans across a range from about 20–20,000 Hz (Ambrose and Florian 2014). Although the range of perceptible frequencies varies by species, all animals hear across a wide range of frequencies. Amplitude is perceived as the loudness of sound, and is commonly measured in decibels (dB), a logarithmic unit for quantifying the intensity of sound. The dB system was originally developed to measure the amount of signal loss in telephone circuitry (deci means 10 for the logarithmic scaling factor and bel is a reference to Alexander Graham Bell, the inventor of the telephone).

As applied to sound, dB serves as a unit measuring sound pressure levels. Because it is measured on a logarithmic scale, it is difficult to interpret dB levels intuitively because of the nonlinear relationship of the scale of measure (Fig. 1). To illustrate, at any given level of sound measured, an increase in 20 dB is equivalent to a 10 times increase in the sound pressure ratio between those two levels of sound and a subjectively perceived loudness that is four times greater (Table 1). Hence, a watch tick measured at 20 dB creates ten times less sound pressure than quiet street noises measured at 40 dB and a hundred times less sound pressure than conversation in a crowded room measured at 60 dB.

Table 1. Common sounds and representative measures of sound pressure (dB), sound pressure ratio over 0 dB baseline (SPR), and perceived loudness over 0 dB baseline.

Sound Event	dB	SPR	Perceived loudness
Hearing threshold	0	1 x	1 x
Rustling leaves in the distance	10	3 x	2 x
Watch ticking	20	10 x	4 x
Soft whisper	30	32 x	8 x
Quiet street noises	40	100 x	16 x
Average home	50	316 x	32 x
Conversation, crowded room	60	1,000 x	64 x
Vacuum cleaner, 1 m	70	3,162 x	128 x
Curbside busy road, 5 m	80	10,000 x	256 x
Diesel truck, 10 m	90	31,623 x	512 x
Chainsaw, 1 m	100	100,000 x	1,024 x
Threshold of discomfort	120	316,227 x	2,048 x

Table sources: Hodgson 2008, Sengpiel 2014.

In order to relate the measure of sound in a meaningful way that incorporates frequency and amplitude, sound measures are weighted. A commonly used weighting method for environmental and industrial measurement of sound that relates perceived loudness to human hearing is with A- weighted decibels (dBA). A-weighting reduces the emphasis on both high and low frequency sounds as those frequencies are generally harder to perceive by humans, and it provides a defensible approximation of the sound spectrum for many birds, including sage-grouse (Dooling and Popper 2007, Patricelli et al. 2013). Animals that are sensitive to extremely high or low frequencies would perceive those sounds more loudly than a human, but the use of A-weighting provides a standard to account for the general tendency in many animals to be more sensitive to mid-range frequencies. In effect, A-weighting is an anthropocentric measure of sound used for convenience in interpretation, but it provides a scale of measure that relates reasonably well to sage-grouse (Dooling and Popper 2007, Pater et al. 2009, Patricelli et al. 2013).

Additionally, the sound pressure level (L) can be reported in numerous ways generally using some exceedance percentile (L_x) where L is measured as dBA that is exceeded *x* percent of the time for the measurement period (Ambrose and Florian 2014). For example, L_{50} is the sound pressure level exceeded 50 percent of the time, thus also the median sound pressure level. Likewise, L_{90} would be exceeded 90% of the time and provide a sound pressure level measured during 90% of the measurement period. One can think of L_{90} measures as a common or nearly persistent level of sound pressure for a given location, therefore measures at L_{90} are often used to determine "background noise", or baseline sound. The maximum and minimum recorded sound levels are reported as L_{max} and L_{min}, respectively. The logarithmic average is reported as L_{eq} and represents the equivalent sound level expressed as the total sound energy over a given period of time. The L_{eq} is different from L_{50} as it takes all decibel measurements for a given time period, for example one hour, converts them to sound pressure levels, averages those for the total number of samples, then converts that back to decibels for a level for that hour. L_x measures are exceedances, not averages of the given level x. Although commonly reported, L_{eq} should be used with caution for management considerations of ambient sound conditions because very loud, but infrequent sounds can overinflate this value.

Ambient Baseline for Sound

Of importance for wildlife management considerations is determining an accurate background or baseline ambient sound level for a given location. This background should be measured and reported for the entire day, and against which acceptable thresholds for mitigation or adaptive management triggers are based (Ambrose and Florian 2014). The background ambient is the sound level at a site *in the absence of anthropogenic influence* and needs to be measured carefully to exclude potential human influences. As noted above, L_{90} should be used to determine background ambient sound at a site as it will statistically exclude relatively short-duration, but loud noises such as nearby jet traffic, infrequent vehicle traffic and similar short-term noise-producing activities in an environment.

If a site has near-constant or very frequent anthropogenic sources of noise occurring during the period of the day for which baseline ambient needs to be measured (e.g., the hours of typical activity for lekking sage-grouse), those sources have to be removed to determine an accurate baseline ambient sound level. Using an L_{90} measure will do this statistically for anthropogenic noise sources that are intermittent (e.g., infrequent vehicle travel). Frequent noises in the environment need to be manually isolated from sound recordings or the sources need to be silenced for the period of measure to achieve an accurate baseline measure (Patricelli et al. 2013). The former is tedious and requires listening to the entire recording for the sample period, accounting for anthropogenic noise sources, and removal of those sounds from the samples used to calculate L_{90}. The latter may not be possible if the noise sources cannot be isolated and manually removed for the measurement period.

Recent information suggests that sound levels in sagebrush habitats are generally lower than expected. BLM has used background ambient sound levels of 39 dBA as this was the $L_{90,0\text{-}24}$ value reported for a "farm valley" in California as was assumed useful for an array of rural-type conditions (EPA 1970). However, recent information indicates background sound levels in rural Wyoming average 15 dBA $L_{90,0\text{-}24}$. A sound level of 39 dBA is almost 1000 times higher than 15 dBA (Ambrose et al., in prep).

Sound Monitoring

Follow-up measurements of sound must be made to assess the relative impact of anthropogenic sources of noise for the area of interest. For greater sage-grouse, noise impacts should be limited to ≤10 dBA above ambient levels in breeding, nesting, and foraging habitats (Patricelli et al. 2013). Although research on impacts of noise have been limited to breeding sites for sage-grouse (Blickley and Patricelli 2012, Blickley et al. 2012b, 2012a, Blickley 2013), we recommend using a 5 km (3.1 mi) buffer on active and pending leks (i.e., those with known breeding bird activities) for applying the 10 dBA limit on noise-generating activities because buffering leks provides conservation benefits across seasonal habitats, especially for nesting hens (Holloran and Anderson 2005, Coates et al. 2013).

When sound monitoring is required, it should follow protocols suitable for the target species and during periods relevant to the behavior of the species. For greater sage-grouse, Ambrose and Florian (2014) provide a thorough and robust protocol with detailed methods based off of management recommendations developed by Patricelli and Blickley (2013) and from standards applied by the National Park Service (2013). For convenience, the general protocol for measuring sound levels relative to greater sage-grouse habitats (Ambrose and Florian 2014) is reproduced below with some modification for consistency, simplification, and inclusion of most recent information.

Protocol for sound level measurements in greater sage-grouse habitats (Ambrose et al., in prep; Ambrose and Florian 2014 p. 37, with modifications)

- Sound level meters should meet ANSI Type 1 standards.
- Sound level meters should be capable of the full acoustic environment of the study area. New information from rural Wyoming found sound levels in undisturbed sagebrush habitats are occasionally near 0 dBA. At a minimum, sound level meters should be capable of measuring <15 dBA. Sound level meters and microphones that are capable of measuring 0 dBA are considered ideal. The noise floor of the instrumentation should be reported in the methodology.
- Correction for Instrument Noise Floor: When reported sound levels are within 10dB of the instrumentation's noise floor, actual environmental sound levels are lower. In this situation, the reported sound levels should be corrected for the instrument's noise floor in order to produce a more accurate environmental sound level.
- Data collected should include dBA, dBC, and dBF, and unweighted one-third octave band frequency data, 12.5-20,000 Hz.
- Decibel data should be collected continuously, at 1-second intervals, with sound level meter set to "fast" time response.
- Data analysis: At a minimum, report hourly dBA, dBC, and dBF, and unweighted one-third octave band metrics, including L_{eq}, L_{10}, L_{50}, L_{90}, L_{min}, and L_{max}. Summary metrics should be

calculated for all hours (0000-2400) and hours important to lekking sage grouse (0800-0800). Unweighted one-third octave band metrics, including L_{eq}, L_{10}, L_{50}, L_{90}, L_{min}, and L_{max} should be reported for all hours of the day as well as those hours important to lekking sage grouse.

- Microphone height should be 0.3 m, approximate ear height of greater sage-grouse.
- Measurement duration should be for the entire day for a minimum of 10–14 consecutive days between March 1 and June 30 (critical periods for sage-grouse breeding, nesting, and early brood- rearing) at each location (minimum of 7 quality days of data, i.e., no interruptions, unique disturbance events, unusual weather, etc.).
- Continuous digital recordings should be collected at all measurement locations. This will ensure all unusual sound sources and sound levels can be reviewed, and will allow the opportunity to determine the percent time that different sound sources are audible. 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 needed to assess influence of wind pressure on dB data. However, when microphones are placed at 0.3 m, appropriate quality windscreens are to be used, and when measurements are made in sagebrush habitat that is higher than 0.3 meters, it is unlikely that wind pressure over microphone will influence dB data. Therefore, wind speed data are not required if the microphone height of 0.3 meters is used in conjunction with proper windscreens. If meteorological data are needed for modeling efforts, such should be collected with anemometer at 1.5-2.0m during the measurement period. The anemometer should be sufficient distance from the lek so as not to influence grouse attendance or behavior.
- Sound level meters should be placed at the perimeter of the lek, but in a location and manner that will not influence grouse activity or behavior, for example, in areas of sagebrush so the equipment is not visible to grouse. The sound level meter, should be placed on the perimeter edge closest to the proposed project boundary. Grouse display sounds at the lek can elevate sound levels for short time periods, roughly 0500-0800, however, such relatively short periods generally do not significantly influence overall daily sound levels. Visitation by field personnel to the sound level meter should occur outside of lekking periods, preferably from 0900 to 1400 hours, and only on an as needed basis.
- Measurements should be collected at multiple active and pending leks (3-4) adjacent to the proposed project area. Priority should be given to leks within a 5 km (3.1 mi) buffer around the proposed project boundary; sites should be selected with consultation from NDOW and BLM biologists.
- For determining baseline ambient sound levels, the L_{90} metric should be used. It is important that all hours of the day be considered when determining baseline ambient sound levels. While lekking hours are important to grouse, females with nestlings rely on relatively low-level calls to maintain contact with each other and to warn of potential predators. Therefore, all hours should be measured and reported so management recommendations can be developed specific to the proposed activities and for critical periods for sage-grouse.

Management Recommendations

Based on what is currently known from research on the effects of noise on greater sage-grouse, the Nevada Department of Wildlife (NDOW) has the following general recommendations to minimize the influences of anthropogenic noise:

1) Establish baseline ambient sound (i.e., natural sound in the absence of all anthropogenic influences) at the project location from L_{90} dBA measures for the entire day using the protocols above. Alternatively set 15 dBA for all hours of the day as the baseline per prior sound studies in greater sage-grouse habitats (Ambrose et al., in prep.; Patricelli et al. 2013).
2) Set a noise disturbance threshold of 10 dBA over ambient for all hours of the day from March 1 to June 30 within 5 km (3.1 mi) of active and pending leks to account for all habitats critical to successful reproduction and recruitment of greater sage-grouse (i.e., lekking, nesting, and early brood-rearing; Patricelli and Blickley 2013); all operational activities should be required to stay at or below sound pressure levels of ambient baseline + 10 dBA (L_{50}) for these habitats (e.g., for 15 dBA baseline, threshold sound levels are 25 dBA) for all hours of the day or be restricted to 25 dBA in the absence of adequate sound measures of the local ambient environment.
3) Adopt adaptive management actions in NEPA documents to provide opportunities to reduce noise sources if threshold compliance is not being achieved; require adaptive management actions as soon as possible if compliance requirements are determined to have been unmet.
4) Collect compliance measurements during March 1 through June 30 to determine sound pressure compliance at key lek sites within sage-grouse habitats; compliance measurement sites should be selected by NDOW and land management agency biologists; compliance monitoring should occur during all hours of operational activities and reported at L_{50} (Patricelli et al. 2013).
5) Site access roads at least 1.6 km (1 mi) from leks as possible; restrict traffic between sunrise ±2 hrs during the breeding season March 1 through May 15 when roads cannot be located at least 1.6 km (1 mi) from leks (Patricelli et al. 2013); road-related noises still need to meet the requirements of recommendation #2.
6) Provide annual noise reporting by August 1 of each year of permitted activity; coordinate with a wildlife working group consisting of, at a minimum, one project representative, one NDOW biologist, and one BLM biologist by September 1 of each year to assess current management and mitigation activities and possible adaptive management responses.

Literature Cited

Ambrose, S., and C. Florian. 2014. Sound levels at greater sage-grouse leks, Pinedale Anticline Project Area, Wyoming, April 2013. Castle Valley, UT.

Barber, J. R., K. R. Crooks, and K. M. Fristrup. 2010. The costs of chronic noise exposure for terrestrial organisms. Trends in Ecology and Evolution 25:180–189.

Blickley, J. L. 2013. The effects of anthropogenic noise on Greater Sage-Grouse (*Centrocercus urophasianus*) lek attendance, communication, and behavior. University of California, Davis.

Blickley, J. L., D. Blackwood, and G. L. Patricelli. 2012a. Experimental evidence for the effects of chronic anthropogenic noise on greater sage-grouse at leks. Conservation Biology 26:461–471.

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:23–35.

Blickley, J. L., K. R. Word, A. H. Krakauer, J. L. Phillips, S. N. Sells, C. C. Taff, J. C. Wingfield, and G. L. Patricelli. 2012b. Experimental chronic noise is related to elevated fecal corticosteroid metabolites in lekking male greater sage-grouse (*Centrocercus urophasianus*). PLOS One 7:e50462.

Braun, C. 1987. Current issues in sage grouse management. Proceedings of the Western Association of Fish and Wildlife Agencies 67:134–144.

Braun, C. E. 1998. Sage-grouse declines in western North America: what are the problems? Proceedings of the Western Association of Fish and Wildlife Agencies 78:139–156.

Bunkley, J. P., C. J. W. Mcclure, N. J. Kleist, C. D. Francis, and J. R. Barber. 2015. Anthropogenic noise alters bat activity levels and echolocation calls. Global Ecology and Conservation 3:62–71.

Chan, A. A. Y.-H., P. Giraldo-Perez, S. Smith, and D. T. Blumstein. 2010. Anthropogenic noise affects risk assessment and attention: the distracted prey hypothesis. Biology letters 6:458–61.

Coates, P. S., M. L. Casazza, E. J. Blomberg, S. C. Gardner, S. P. Espinosa, J. L. Yee, L. Wiechman, and B. J. Halstead. 2013. Evaluating greater sage-grouse seasonal space use relative to leks: implications for surface use designations in sagebrush ecosystems. Journal of Wildlife Management 77:1598–1609.

Connelly, J. W., and C. E. Braun. 1997. Long-term changes in sage grouse *Centrocercus urophasianus* populations in western North America. Wildlife Biology 3:229–234.

Dooling, R., and A. Popper. 2007. The effects of highway noise on birds. California Department of Transportation Division of Environmental Analysis, Sacramento, California, USA.

Francis, C. D., and J. R. Barber. 2013. A framework for understanding noise impacts on wildlife: an urgent conservation priority. Frontiers in Ecology and the Environment 11:305–313.

Gibson, R. 1989. Field playback of male display attracts females in lek breeding sage grouse. Behavioral Ecology and Sociobiology 24:439–443.

Gibson, R., and J. Bradbury. 1985. Sexual selection in lekking sage grouse: phenotypic correlates of male mating success. Behavioral Ecology and Sociobiology 18:117–123.

Gibson, R. M., J. Bradbury, and S. Vehrencamp. 1991. Mate choice in lekking sage grouse revisited!: the roles of vocal display, female site fidelity, and copying. Behavioral Ecology 2:165–180.

Giesen, K., T. Schoenberg, and C. Braun. 1982. Methods for trapping sage grouse in Colorado. Wildlife Society Bulletin 10:224–231.

Hess, J., and J. Beck. 2012. Disturbance factors influencing greater sage-grouse lek abandonment in north central Wyoming. The Journal of Wildlife Management 76:1625–1634.

Hodgson, D. J. 2008. A decibel primer. http://dallashodgson.info/articles/Acrobat/DecibelPrimer.pdf.

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

Holloran, M. J., and S. H. Anderson. 2005. Distribution of greater sage-grouse nests in relatively contiguous sagebrush habitats. Condor 107:742–752.

Kight, C. R., and J. P. Swaddle. 2011. How and why environmental noise impacts animals: an integrative, mechanistic review. Ecology Letters 14:1052–1061.

Mcclure, C. J., H. E. Ware, J. Carlisle, G. Kaltenecker, and J. R. Barber. 2013. An experimental investigation into the effects of traffic noise on distributions of birds: avoiding the phantom road. Proceedings of the Royal Society B 280:1–9.

National Park Service. 2013. Acoustical monitoring training manual. U.S. Department of Interior, National Park Service, Fort Collins, CA.

Pater, L. L., T. G. Grubb, and D. K. Delaney. 2009. Recommendations for improved assessment of noise impacts on wildlife. The Journal of Wildlife Management 73:788–795.

Patricelli, G. L., J. L. Blickley, and S. L. Hooper. 2013. Recommended management strategies to limit anthropogenic noise impacts on greater sage-grouse in Wyoming. Human-Wildlife Interactions 7:230–249.

Rabin, L. a., R. G. Coss, and D. H. Owings. 2006. The effects of wind turbines on antipredator behavior in California ground squirrels (*Spermophilus beecheyi*). Biological Conservation 131:410–

420.

Rabin, L., and B. McCowan. 2003. Anthropogenic noise and its effect on animal communication: an interface between comparative psychology and conservation biology. International Journal of Comparative Psychology 16:172–192.

Ríos-Chelén, A., and E. Quirós-Guerrero. 2013. Dealing with urban noise: vermilion flycatchers sing longer songs in noisier territories. Behavioral Ecology and Sociobiology 67:145–152.

Sengpiel, E. 2014. Table of sound pressure levels. http://www.sengpielaudio.com/TableOfSoundPressureLevels.htm.

Shannon, G., L. M. Angeloni, G. Wittemyer, K. M. Fristrup, and K. R. Crooks. 2014. Road traffic noise modifies behaviour of a keystone species. Animal Behaviour 94:135–141.

Stevenson, A., and C. A. Lindberg (Eds.). 2010. New Oxford American Dictionary. 3rd edition. Oxford University Press.

Swaddle, J. P., and L. C. Page. 2007. High levels of environmental noise erode pair preferences in zebra finches: implications for noise pollution. Animal Behaviour 74:363–368.

Swenson, J. E., C. a. Simmons, and C. D. Eustace. 1987. Decrease of sage grouse *Centrocerus urophasianus* after ploughing of sagebrush steppe. Biological Conservation 41:125–132.

U.S. Fish and Wildlife Service. 2013. Greater sage-grouse (*Centrorcercus urophasianus*) conservation objectives: final report. Denver, CO.

Warren, P. S., M. Katti, M. Ermann, and A. Brazel. 2006. Urban bioacoustics: it's not just noise. Animal Behaviour 71:491–502.

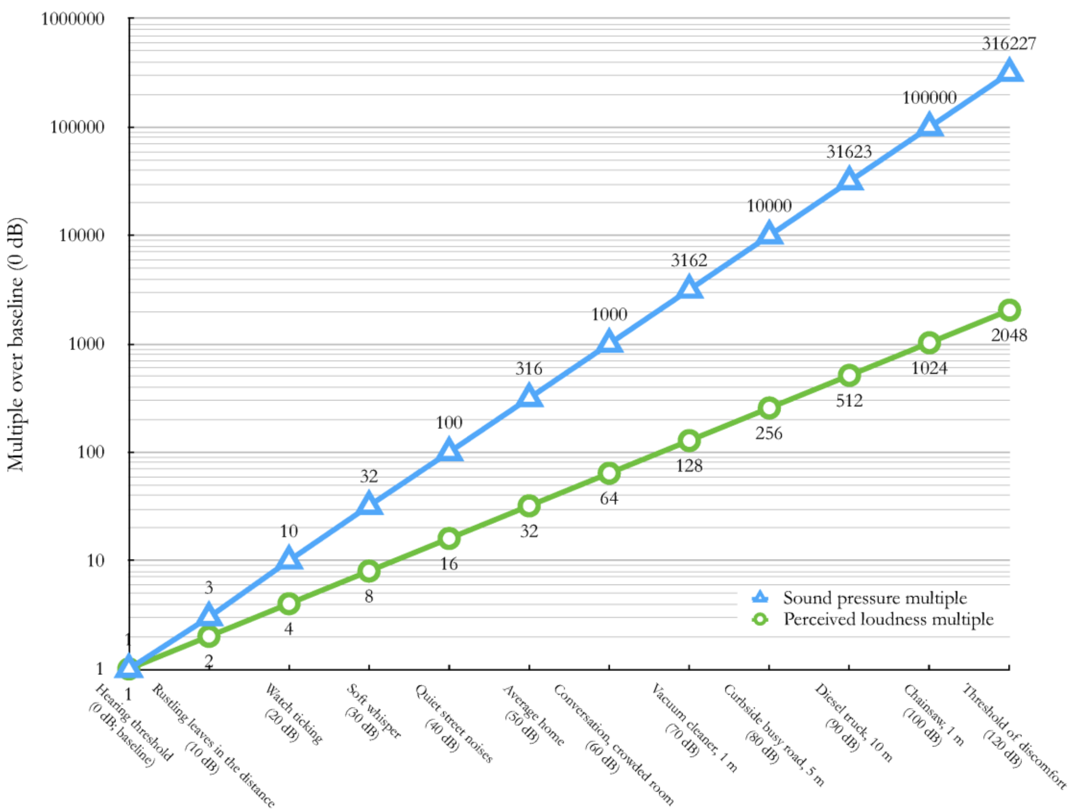

Figure 1. Sound pressure and perceived loudness relative to decibel levels on a logarithmic scale.

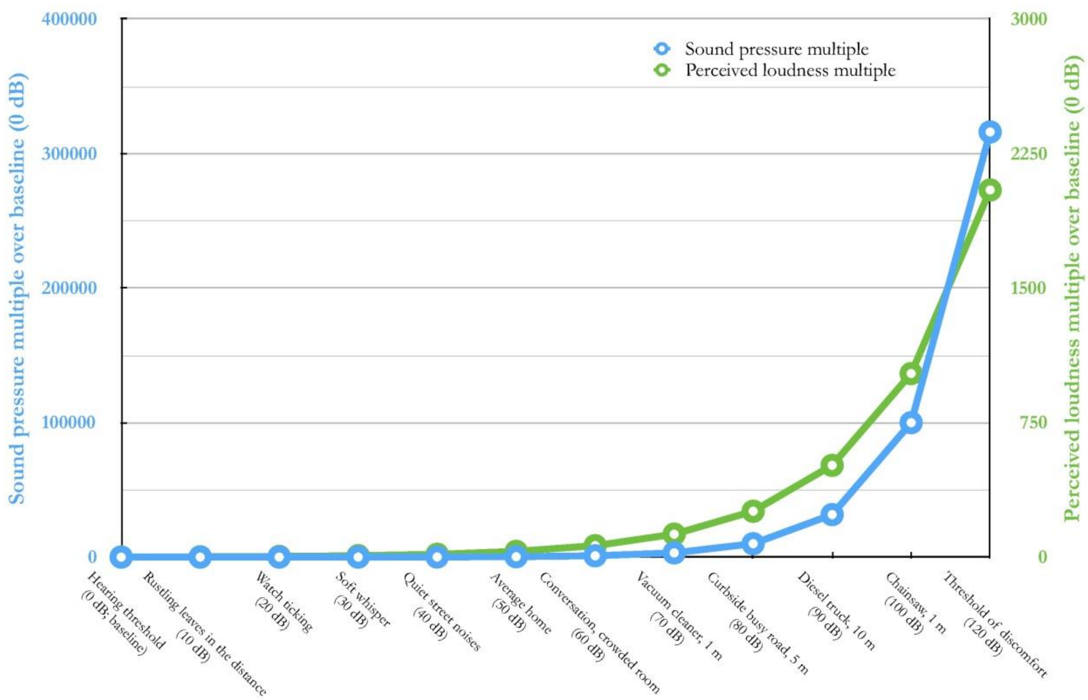

Figure 2. Sound pressure and perceived loudness relative to decibel levels on a linear scale.