LANDSCAPE-SCALE MANIPULATION OF THE ACOUSTIC ENVIRONMENT

ALTERS THE DISTRIBUTION OF BREEDING BIRDS AND ARTHROPODS

by

Elizeth Cinto-Mejia

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Elizeth Cinto-Mejia

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Jesse R. Barber, Ph.D.	Chair, Supervisory Committee
Marie-Anne de Graff, Ph.D.	Member, Supervisory Committee
Christopher J. McClure, Ph.D.	Member, Supervisory Committee

The final reading approval of the thesis was granted by Jesse R. Barber, Ph.D., Chair of the Supervisory Committee. The thesis was approved by the Graduate College.

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ABSTRACT

Oil and gas development has rapidly increased across the world over the last several decades. Anthropogenic noise, an invisible pollutant that alters animal distribution and behavior, could be responsible for documented wildlife population declines near loud compressor stations in energy extraction fields. We experimentally played back compressor noise, creating a "phantom natural gas field" in a large-scale experiment, and tested the effects of noise on songbird distributions during the breeding season and on arthropod distributions. Further, to begin to understand the influence of noise produced by different types of extraction infrastructure, we examined the effects of sound intensity and bandwidth, or the amount of frequencies emanating from a noise source, on bird and insect abundance.

Breeding songbird distributions were negatively affected by broadband, high sound level noise exposure. We observed a 25.9% decrease in abundance of the songbird community and three individual species showed declines in noise. Our results further show that higher intensity and bandwidth are positively associated with the arthropod abundance of most groups, where for instance sap-feeders, omnivores, and grazers increased over 30% with increased sound levels. In contrast, lower intensity and bandwidth playback was negatively associated with arthropod abundance, where omnivores and grazers decreased over 19% with increased sound levels. Noise could impact trophic relationships in the sage steppe ecosystem. Any increase in herbivore arthropod species, could intensify herbivory, resulting in changes in plant chemistry. We

demonstrate the importance of understanding the potential landscape-scale costs of noise

exposure and the acoustic structure of noise on wildlife.

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LEQ   Equivalent Continuous Sound Pressure Level

NOAA National Oceanic and Atmospheric Administration

LANDSCAPE-SCALE MANIPULATION OF THE ACOUSTIC ENVIRONMENT ALTERS THE DISTRIBUTION OF BREEDING BIRDS: EVIDENCE FROM A PHANTOM NATURAL GAS FIELD

Introduction

Decades of work have demonstrated that human-caused disturbance alters animal behaviors and distributions (Benitez-Lopez et al.2010) (Fahrig & Rytwinski 2009). An important component of this disturbance is human-caused noise (Francis & Barber 2013). Extensive literature documents the negative effects of noise on foraging efficiency, survival, distribution, and reproductive success of wildlife (see reviews (Francis & Barber 2013)(Shannon et al. 2016). Recent studies have experimentally broadcast noise to disentangle the role of the acoustic environment from other co-varying factors associated with human disturbance (e.g., direct deaths, edge effects, chemical pollution). Playback of intermittent traffic noise decreased male sage grouse (*Centrocercus urophasianus*) lek attendance by almost three-quarters (Blickley et al. 2012). Broadcast of noise replicating the soundscape of a highway has demonstrated that louder acoustic environments can alter bird distribution (McClure et al. 2013), change the age structure of a community (McClure et al. 2016) and thwart bird's ability to gain weight during migratory stopover (Ware et al. 2015). Importantly, noise is not limited to transportation infrastructure.

From urban areas to the deepest ocean trench (NOAA), anthropogenic noise is ubiquitous (Barber et al. 2010). An underappreciated and globally distributed source of noise is energy extraction (Bentley 2002) (Allred et al. 2015). Energy extraction fields cause habitat loss, fragmentation, and bring roads and other permanent infrastructure to the landscape (McDonald et al. 2009), consequently reducing songbird abundance, altering nesting success, and changing large mammal space use and behavior (Northrup & Wittemyer 2013). Previous studies have taken advantage of variation in sound levels created by different types of energy extraction infrastructure: loud compressor stations (engines that maintain pressure in pipelines) and quieter well pads. Comparing bird communities near these types of infrastructure, Bayne and colleagues (Bayne et al. 2008) showed that density and occupancy rates of several songbird species decreased near loud compressor stations in the Canadian boreal forest. Francis and coworkers describe similar patterns in a natural gas field in New Mexico; they report decreased songbird species richness near loud gas compressor stations (Francis et al. 2009), which altered ecosystem services such as pollination and seed dispersal (Francis et al. 2012). Further work in the same gas field has documented reduced bat activity (Bunkley et al. 2015), and altered arthropod distributions (Bunkley et al. 2017). Even so, other unmeasured factors in these natural experiments (e.g., air pollution; (Roy et al. 2014)) could have influenced the results. Regardless of caveats these studies strongly indicate that the causal factors behind these ecological effects are likely noise mediated.

Because of the importance of understanding the spatial scale of noise effects and the significant and expanding footprint of energy extraction noise globally, we sought to experimentally verify the role of noise in the documented impacts of energy extraction

landscapes on wildlife. In addition, we sought to experimentally test the influence of noise on landscape-scale space use during the breeding season, a critical time for wildlife. For these reasons we used speaker arrays to broadcast compressor station noise on a spatial scale large enough (sites distributed across 100 km^2) and a temporal scale long enough (an entire breeding season), to alter populations— creating a 'phantom natural gas field'. We conducted our experiment in the sagebrush steppe, an ecosystem that due to human expansion and disturbance has suffered rapid alterations (Knick et al. 2003), including widespread energy extraction (Northrup & Wittemyer 2013).

Based on economic incentives and resource properties there are many types of compressor stations (US Energy Information Administration), that produce different spectral bandwidths (the range of frequencies contained in a sound source) and associated sound levels (Francis et al. 2011). Given this variation, we replicated two distinctly different noise profiles, one more broadband and higher intensity than the other (Figure 1.1). We predicted that playback of compressor station noise of broader bandwidth and intensity would have a greater negative impact on bird abundance owing to increased overlap with the hearing ranges of birds and other trophically-connected groups (Greenfield 2014). Within each playback type we tested two hypotheses: 1) the dose-response hypothesis where we predicted bird abundance to decrease proportionally with sound level across a gradient of exposure, and 2) the threshold hypothesis, where we predicted that a sound level threshold existed above which bird distribution would be effected similarly (Mason et al. 2016).

Materials and methods

Phantom Energy Extraction Field

We broadcasted compressor station noise in the sagebrush steppe of Southwest Idaho from April 1st to October 15th for two years. Experimental sites were randomly selected; 7 control and 8 noise sites in 2014, where we played back our narrowband playback, and 6 control and 6 noise sites in 2015, where we played our broadband playback (details below). At the control sites, we placed dummy 'speakers' that were similar in shape, size, and color to our broadcast speakers. All sites were at least 1km apart and 500m away from a dirt road. Our sites had similar plant communities, dominated by big sagebrush (*Artemesia tridentata*). To quantify the percentage of vegetation cover at each site we used photographic methods implemented in SamplePoint (Booth et al. 2006).

We measured vegetation along five 300 m transects radiating from the center of each site. With a camera (Fujifilm FinePix XP70 16.4 Megapixel Compact Camera) attached to a two meter pole (Sokkia 724290 Economy 2 m Aluminum 2 Section GPS Rover Rod) we photographed 20 points along each transect that were 15 m apart, obtaining a hundred pictures per site. We obtained 1 m^2 photographs that were analyzed in the lab using the open source software SamplePoint (version 1.58) described by Booth et al. (2006) (Booth et al. 2006). We identified the vegetation type of 68 individual points of each photograph to obtain a percent cover for sagebrush.

Noise playback and acoustic monitoring

We broadcast two noise stimuli, one per year (figure 1.1A-C). For each stimulus type, we used two different speaker systems. Arrays were mounted on support structures

2 m above the ground (figure 1.1D). For the narrowband playback in 2014, we placed 4 horn-loaded speakers (Dayton RPH16; MCM 40W; 400–3,000 Hz ±5 dBA) in the 4 cardinal directions, and amplified them using Parts Express amps (Class D, 2W, 4-ohm). In 2015, for the broadband playback, we used omni-directional speakers (Octasound SP820A; 35–20,000 Hz ±10dB,) and subwoofers (Octasound OS2X12; 25–20,000 Hz ±10dB) driven by class T amplifiers (Lepai LP-2020A 20W, 4-ohm). Amplifiers were powered by solar array systems (Solarland SLP 15S-12 panels, Morningstar PS-30M controllers and PowerSonic 12 V batteries). We broadcast sound files (WAV) using Olympus LS-7 players that were powered with LiFePO4 (Batteryspace) batteries.

We played synthetic compressor noise, created in Audacity version 2.1.2 from an average of 3 compressor stations recorded in the San Juan basin, NM and Green River Basin, WY. Compressor stations were recorded with a Sennheiser ME66 microphone (40–20,000Hz; ±2.5dB) and Roland R-05 recorder (sampling rate 48 kHz) at 40 m. We created a 3-hour playback file that was repeated 24 hr/day over both years. It is important to note that the compressor stations we recorded very likely produced energy below 20 Hz (Francis et al. 2011), the lower limit of our microphone.

To measure sound levels at each site through the season, we placed acoustic recording units (ARUs; Roland R-05 audio recorders mounted inside a protective wind screen) at each point count location (30 in 2014 and 24 in 2015). We camouflaged ARUs in shrubs and mounted them 50 cm above the ground by lashing support rods to vegetation. Using a custom program (Damon Joyce, NPS, AUDIO2NVSPL), we converted our MP3 recordings into hourly sound pressure levels. Next, we obtained

hourly sound levels (equivalent continuous sound level LEQ in dBA) using a second custom program (Damon Joyce, NPS, Acoustic Monitoring Toolbox).

Bird Surveys

We counted all birds at each site 7-9 times from April 8th to June 17th of 2014 during the narrowband playback, and 6-8 times from April 5th to June 15th of 2015 during the broadband playback. At each site, we placed point count locations 50 m from the speaker array (direction determined randomly) and 250 m from the array directly opposite the 50 m point, with the aim of maximizing the independence of count locations. All counts were 6 min. in length, and completed by two individuals within 4 hours after sunrise. No surveys were conducted under strong wind or heavy rain following a modified protocol of the Rocky Mountain Bird Observatory (Hanni, D. J., C. M. White, N.J. Van Lanen, J. J. Birek, J.M. Berven, and M.A. McLaren 2014, unpublished report). For each bird that was detected, we recorded species, direction, and distance of all birds.

We identified species by call, song, or sight. Because probability of detection can vary between observers (McClure et al. 2015) (Alldredge et al. 2007) (Sauer et al. 1994), we randomized which point count locations were surveyed having both point counters visit all sites. All surveys were conducted randomly within site (50 m vs 250 m) and between sites. Excessive noise can decrease the number of birds detected during point counts (e.g., (McClure et al. 2015) (Simons et al. 2007) (Pacifici et al. 2008)). However, Ortega and Francis (2012) found that noise from natural gas compressors did not interfere with detection rates until background noise levels reached roughly 45 dB. Further, Koper et al (2016) showed that quiet to moderate levels of extraction noise were unlikely to interfere with detection of songbirds. We therefore turned off our speakers during point

counts so that noise would not interfere with rates of detection (McClure et al 2013). Because noise levels were roughly 42 dB under noise-off conditions at control and noise sites, comparison of bird counts between the two site-types should not be biased by imperfect detection.

Statistical Analysis

We analyzed all data using R (Team RC 2000), version 3.2.1 and packages MuMIn and nlme (Pinheiro et al. 2011), and truncated data to include detections only within 150 m from point count centroids. We were interested in the five songbird species that breed in our site and are associated with the sagebrush ecosystem - Brewer's sparrow (*Spizella breweri*), horned lark (*Eremophila alpestris*), western meadowlark (*Sturnella neglecta*), sagebrush sparrow (*Artemisiospiza nevadensis*), and sage thrasher (*Oreoscoptes montanus*) (Baker et al. 2014).

We modeled songbird abundance using generalized linear mixed models with a Poisson distribution (Bolker et al. 2009). To test the effects of different playbacks independently and because models combining data from both years failed to converge, we z-transformed our parameters and analyzed each year separately. In our models, we included combinations of monthly sound level (LEQ in dBA) at each point count location, linear and quadratic effects of date (to include seasonal fluctuations), percent sagebrush cover (because habitat variables can be predictors of songbird settlement decisions (Chalfoun & Martin 2007)), treatment (noise vs. control), and an interaction of treatment and point count location, with site and point count location as random effects. We ranked and compared models using Akaike's Information Criterion (AIC) (Akaike 1974) corrected for small sample size AICc (Hurvich & Tsai 1989). We considered

covariates as useful for inference if they were within models that did not contain

uninformative parameters that were within ΔAICc<2 and had 95% confidence intervals

excluding zero (Arnold 2010). We used the same procedure to analyze individual species

(Table S1.2).

Results

The phantom natural gas field encompassed approximately 100 km^2, broadcasting noise

for approximately 3 continuous months per year. We monitored sound levels at each

point count location throughout two years of fieldwork, allowing us to quantify over

20,000 hours of background sound levels, the largest experimental quantification of the

acoustic environment in an ecological study to our knowledge. Across our study site, the

gradient of background noise ranged from ~30 dB(A) to 65 dB(A) under which we

sampled songbird abundance (Figure 1.2).

In 2014, under the narrowband playback (Figure 1.1A), sound levels at 50 m

averaged 56.3±1.5 dB(A) (mean±s.e.) at noise sites and 41.9±1.4 dB(A) at control sites.

At 250 m, noise sites averaged 47.3±1.1 dB(A) and control sites 41.6±1.3 dB(A). In

2015, under the broader bandwidth and higher intensity playback (Figure 1.1B), sound

levels at 50 m averaged 61.6±1.4 dB(A) at noise sites and 39.2±1.3 dB(A) at control

sites. At 250 m, noise sites averaged 44.3±1.2 dB(A) and control sites averaged 41.7±1.3

dB(A). In 2014, we excluded 1 month of data from a noise site at 250 m owing to intense

anthropogenic activity.

Over two years, we recorded 2,088 detections of the five songbird species that

nested in our study site (Table S1.1). The model that best explained songbird abundance

under the narrowband playback contained linear and quadratic effects of day (Table S1.2-

S1.4). Only Brewer's sparrow showed a negative response to the interaction of treatment and point count location, providing support for the threshold hypothesis (Table S1.2-S1.3). At the 50 m noise sites, Brewer's sparrow counts decreased 5.1% (average count 1.18±0.1 at control and 1.12±0.1 at noise sites); no change was present between noise and control sites at 250 m.

For the broadband playback, the only model with informative parameters explaining the abundance of the songbird community contained linear and quadratic effects of day, and a negative association with treatment, with a decrease of 25.9% at noise sites (5.8±0.3 vs. 4.3±0.2), supporting the threshold hypothesis (table S1.2-S1.4). For individual species, Brewer's sparrow and sagebrush sparrow responded negatively to treatment, having linear and quadratic effects of day and treatment as informative parameters (with a decrease of 35% (2.2±0.2 vs. 1.4±0.2) and 36.7% (1.2±0.1 vs. 0.7±0.1), respectively) indicating that their distribution was best explained by the threshold hypothesis (Table S1.2-S1.4). Both models containing informative parameters for western meadowlark indicated a negative effect of dBA. Western meadowlark therefore responded negatively to sound levels, providing support for the dose-response hypothesis, with a decrease of 38% per ~9 dB (95%, C.I: 0.95-0.40). Under both playbacks, sage thrasher abundance was the only model where the percentage of sagebrush cover was included as an informative parameter. Linear and quadratic effects of day also explained sage thrasher abundance (Table S1.2-S1.4). Horned larks showed no response to sagebrush cover, noise, or day.

Because we randomized the assignments of treatments to sites each year, and used some of the same sites across years, we tested for carry over effects on bird abundance

from the treatment in the previous year. Admittedly, our low sample sizes provide only a weak test. No difference was observed in 2015 songbird abundance when comparing control sites that were exposed to noise in 2014 (N=2) to sites that did not receive noise exposure in either year (i.e., they were controls in both years) (N=2) to control sites studied only in 2015 (N=2), indicating carryover effects were unlikely (β=0.23, ±0.36, p=0.52; Figure S1.1). In addition, most Brewer's sparrow males in our system that were banded for a different study were aged as first year adults based on plumage, indicating that most individuals were first time breeders during both years. Our findings could have been influenced by a year effect. However, the numbers of bird encounters each year were similar (Table S1.1), and our experiment was designed to test the relative, not absolute, differences between noise and control sites between treatments.

Discussion

Our experimental broadcast of compressor station noise at the landscape scale markedly increased the sound level of the acoustic environment and revealed a powerful effect of broadband noise on breeding songbird distributions. Under the narrowband playback, only one species was negatively affected, whereas under the broadband playback, the distribution of all birds combined and three individual species decreased in our phantom natural gas field. Importantly, we demonstrate that noise alone recreates the patterns of songbird space use found in 'real' natural gas fields. Gilbert and Chalfoun (Gilbert & Chalfoun 2011) obtained remarkably similar results in a Wyoming natural gas field where a nearly identical songbird community showed similar changes in abundance as density of natural gas extraction infrastructure increased near bird count locations. In addition, our work broadly confirms other studies performed in energy extraction fields

that were targeted at teasing apart noise from other confounding variables (Bayne et al. 2008) (Francis et al. 2009), experimentally corroborating that noise is a key predictor of bird distributions near energy development.

Under the broadband playback, western meadowlark responded to increased sound levels in a dose-response fashion—individuals decreased proportionally as sound levels increased. In contrast, the sagebrush songbird community (all species combined) and two individual species (Brewer's sparrow and sagebrush sparrow) responded negatively to noise with a threshold response best explaining their distributions. In other words, these birds decreased in abundance across the entire ~0.5 km^2 area we surveyed at each noise site, even though there was a 17 dB(A) difference on average between the 50 m and the 250 m point count locations (distances measured from site centroids), and the 250 m survey sites averaged only ~2 dB(A) above ambient levels. Birds make habitat selection assessments at large scales (Hutto 1985) (Johnson 1980) and it seems the soundscape is an important parameter in these decisions.

Under the narrowband broadcast, only Brewer's sparrow distributions decreased in noise, and only at the 50 m survey locations, indicating a threshold response to this lower intensity and lower bandwidth playback. When comparing the relative changes in bird abundance between control and noise broadcast sites between years and thus bandwidth treatments, we cannot separate the independent roles of increased bandwidth from increased sound level. Regardless, our broadband treatment plainly had a stronger influence on bird space use.

Although we do not know the mechanism behind the decrease in songbird abundance we observed, our phantom natural gas field could have increased visual

vigilance behavior, owing to lost auditory awareness, and thus reduced foraging rates - forcing birds to leave (Ware et al. 2015). Alternatively, foraging behavior might have been altered owing to reduced acoustic detectability of prey (Montgomerie & Weatherhead 1997), or indirectly by altering arthropod distributions (Bunkley et al. 2015), perhaps by altering food webs (Morley et al. 2014). In fact, a recent study indicates that arthropods change space use in a natural gas field in response to noise (Bunkley et al. 2015). A recent meta-analysis found that songbirds that feed partially or entirely on arthropods are more affected by anthropogenic noise (Francis 2015). All species that declined in noise in our system are omnivores (The Cornell lab of Ornithology) with the exception of horned larks (The Cornell lab of Ornithology) that showed no response to noise.

Songbird species that produce lower-frequency songs exhibit a stronger avoidance response to anthropogenic noise (Francis 2015). In our sagebrush songbird community most species have similar song bandwidth and peak frequency (see Table S1.5), with the exception of horned larks that have a slightly broader bandwidth of frequencies in their song. Thus, song frequency and diet seem to differentiate horned larks, a species that did not avoid our noise broadcasts, from the rest of the community. However, sage thrashers, a species with the lowest peak frequency song in our community and an omnivorous diet showed no response to noise exposure. It seems that diet and song characteristics, although showing intriguing trends with bird responses, are not completely reliable predictors of the distributional shifts we quantified. Thus, it remains unclear if the underlying sensory mechanism driving bird distributional shifts was energetic or informational masking (i.e., distraction) (Francis & Barber 2013).

Altered conspecific interactions, perhaps driven by vocalization-medicated processes, such as altered interactions between males (Kleist et al. 2016) and mates (Halfwerk et al. 2011), might underpin some of the results from our study (Francis et al. 2009) (Francis et al. 2012). It is also conceivable that altered abundances of species in the community might have changed interspecific interactions (Grade & Sieving 2016). Our study is a critical first step in understanding the consequences of large-scale noise exposure for breeding songbirds. Yet future research into the causes of altered distributions is essential, to provide better predictive models of the traits that increase risk for wildlife exposed to chronic anthropogenic noise. These predictive models will be particularly important for extrapolating to communities that cannot be studied owing to low resources, inaccessibility, or looming development projects.

The data we present here are important for management decisions regarding how future energy extraction infrastructure is designed and current implementation of mitigation strategies in existing oil and gas fields. Compressor engines themselves can be designed to be quieter and to produce lower bandwidth noise (Motriuk 2000). Placing noise-attenuating walls around existing compressor stations will reduce both the sound level and the bandwidth of noise that intrudes onto adjacent wildlife habitat (Francis et al. 2011). Energy development and its associated chronic noise exposure come with a cost, and the current efforts by the US government to open up drilling in protected areas (whitehouse.gov) will degrade the habitat quality of these critical reserves. Our data clearly show that noise should be considered when placing energy extraction infrastructure in wildlife habitat and that noise mitigation should be executed in energy extraction fields on public lands with a mandate to protect wildlife.

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Figures
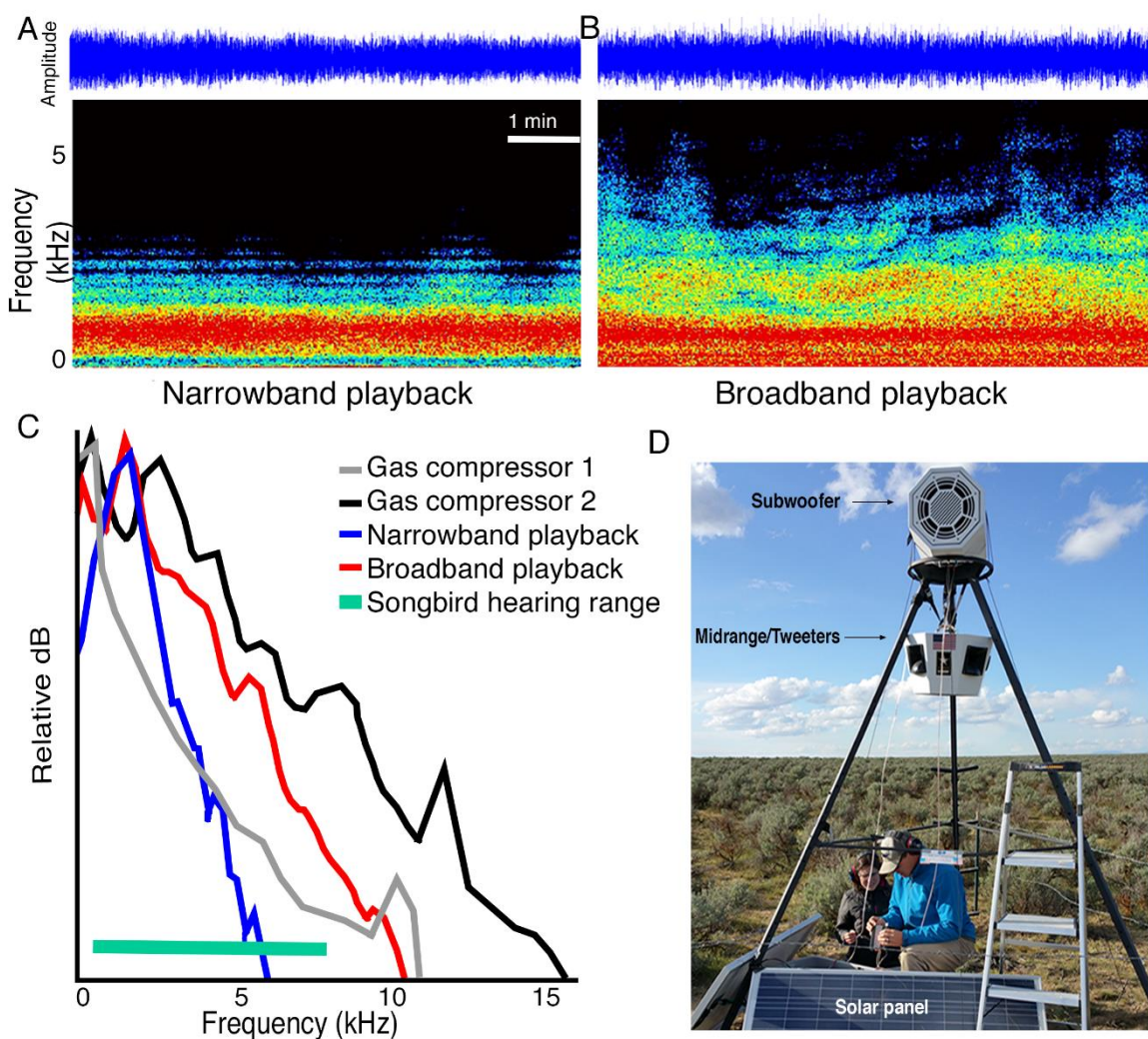
Figure 1.1   Broadcast files and equipment. (A) A 5-min recording of our playbacks displayed as a spectrogram (frequency x time) and oscillogram (voltage x time). (B) Power spectra (sound level x frequency) of two gas compressor stations in NM(1) and WY(2), and recordings of the two files broadcast in our experiment (all files recorded at 40 meters). The broadband playback was ~6kHz higher in bandwidth as measured 55dB below peak. The average songbird hearing range (as measured 55dB above the best threshold) is depicted by the horizontal green bar [57], showing strong overlap between our noise broadcasts and bird spectral sensitivity. When comparing the narrowband and broadband playbacks, note the greater spectral overlap of the broadband treatment with bird hearing at both low and high frequencies. (C)

Example of the solar-powered 3-way speaker system (25Hz-20kHz ±10dB) used for the broadband playback.
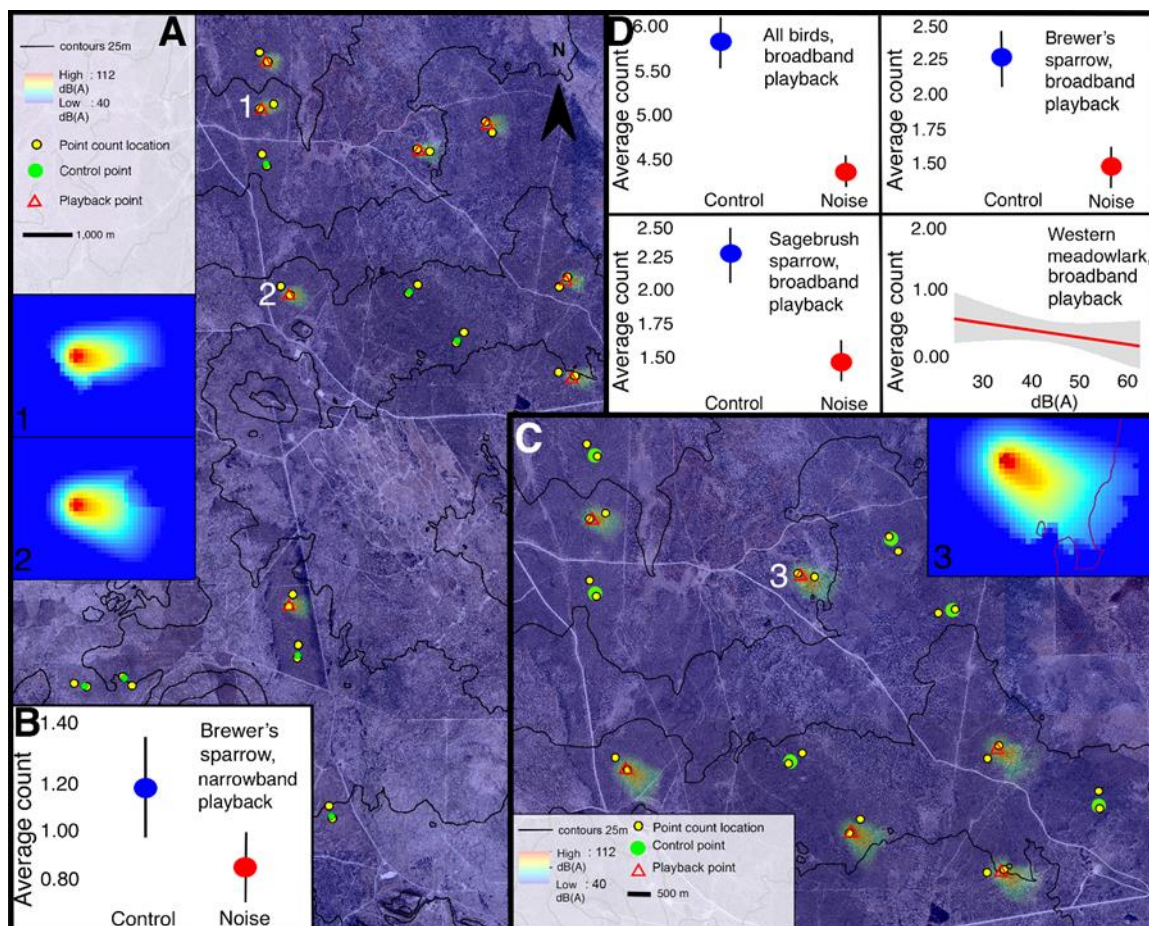
Figure 2. **The phantom natural gas field. (A) Estimated sound levels (dB(A) 1 hr LEQ) of noise sites against a background of 42 dB(A), the average for control sites from May to June during the narrowband playback (2014). Sound level was modeled using SPreAD-GIS with incorporated wind effects (see supplement for details). Circles (control) and triangles (noise) represent the center of the site, speakers or dummy speakers (objects of similar shape, size, and colour to our speakers). (B) Narrowband playback results: average of Brewer's sparrow abundance at the 50m point count. (C) Estimated sound levels (dB(A) 1 hr LEQ) of noise sites against a background of 42 dB(A), the average for control sites from May to June during the broadband playback (2015). (D) Broadband playback results: average count of all species combined, Brewer's sparrow and sagebrush sparrow, all of which responded negatively to noise at both 50m and 250m count locations; Western meadowlark which responded in a dose-response fashion to sound level.**

Supplementary materials and methods

<u>Soundscape modeling</u>

Sound level maps presented in figure 2 were modeled using SPreAD-GIS. Land cover data were obtained from the National Land Cover Database with a 30x30 m cell size. In our sound models we used temperature, humidity and wind speed data from the last two weeks of April (from 2014 and 2015) taken from NOAA measurements at a station 26km from our study sites (https://www.ncdc.noaa.gov/data-access/quick-links#loc-clim). We calculated the relative humidity using the Agust-Roche-Magnus approximation. Wind direction was based on an average of the direction of the two strongest gusts for each day. To parameterize our sound models we used recordings 5m from our speaker arrays for both narrowband and broadband playbacks. These recordings were made with a Sennheiser ME66 microphone (40–20,000Hz; ±2.5dB) and a Roland R-05 recorder. In 2014, predicted sound levels exceeded measured sound levels by 3.3 ± 2dB (14.7 to 16.6 min/max, 8.5 root mean squared error). In 2015, predicted sound levels exceeded measured sound levels by 0.8 ± 1.5dB (8.7 to 7.1 min/max, 3.6 rmse). The predicted sound levels were overlaid over recent aerial photos (USDA-FSA-APFO 2016).

Table S1.1. **Common name, scientific name and number of birds detected within 150 m of each point count location in our southwestern Idaho study site from April 8th to June 17th of 2014 during the narrowband playback and April 5th to June 15th of 2015 during the broadband playback.**

Year 2014-narrowband playback		
Common name	Scientific name	# of detections
Horned lark	*Eremophila alpestris*	520
Brewer's sparrow	*Spizella breweri*	272
Western meadowlark	*Sturnella neglecta*	227
Sagebrush sparrow	*Artemisiospiza nevadensis*	126
Sage thrasher	*Oreoscoptes montanus*	41
Year 2015-broadband playback		
Common name	Scientific name	# of detections
Brewer's sparrow	*Spizella breweri*	324
Horned lark	*Eremophila alpestris*	305
Sagebrush sparrow	*Artemisiospiza nevadensis*	174
Western meadowlark	*Sturnella neglecta*	52
Sage thrasher	*Oreoscoptes montanus*	47

Table S1.2. **Bias -corrected Akaike's Information Criterion value corrected for small sample size (AICc), the difference between a given model and the model with the lowest AICc value (ΔAICc), number of parameters (k), and the AICc weight (wi) of each model. A response to noise existed if treatment, dB or a covariate was within ΔAICc<2 of the best model and 95% confidence intervals excluding zero.**

All birds narrowband	AICc	ΔAICc	K	wi
sage+day+day^2	1062.6	0	6	0.273
treatment+day+day^2	1062.8	0.16	6	0.251
dB+day+day^2	1063.3	0.71	6	0.191
treatment+day+day^2+sage	1063.8	1.18	7	0.151
dB+sage+day+day^2	1064.5	1.85	7	0.108
treatment*point+sage+day+day^2	1067.3	4.69	9	0.026
treatment	1080.8	18.18	4	0
dB	1081.4	18.72	4	0
treatment*point	1084.6	21.94	6	0
treatment*point+sage	1086.1	23.44	7	0
Brewer's sparrow narrowband	AICc	ΔAICc	K	wi
treatment*point+sage+day+day^2	613.1	0	9	0.563
dB+day+day^2	615.3	2.22	6	0.186
dB+sage+day+day^2	616.4	3.35	7	0.105
sage+day+day^2	617.5	4.37	6	0.063
treatment+day+day^2	617.8	4.68	6	0.054
treatment+day+day^2+sage	619	5.95	7	0.029
treatment*point	727.2	114.13	6	0

dB	728	114.96	4	0
treatment*point+sage	729.2	116.07	7	0
treatment	729.9	116.82	4	0
Sagebrush sparrow narrowband	AICc	ΔAICc	K	wi
treatment	431.1	0	4	0.251
dB	431.3	0.11	4	0.238
sage+day+day^2	432.3	1.19	6	0.139
treatment+day+day^2	433.4	2.25	6	0.081
dB+day+day^2	433.5	2.38	6	0.077
treatment*point	434	2.82	6	0.061
treatment+day+day^2+sage	434.3	3.14	7	0.052
dB+sage+day+day^2	434.5	3.31	7	0.048
treatment*point+sage	434.8	3.68	7	0.04
treatment*point+sage+day+day^2	437.2	6.02	9	0.012
Western meadowlark narrowband	AICc	ΔAICc	K	wi
dB+day+day^2	572.5	0	6	0.324
treatment+day+day^2	573.4	0.89	6	0.208
sage+day+day^2	573.9	1.43	6	0.159
treatment*point+sage+day+day^2	574.6	2.05	9	0.117
dB+sage+day+day^2	574.6	2.09	7	0.114
treatment+day+day^2+sage	575.4	2.89	7	0.076
dB	585.4	12.87	4	0.001
treatment*point	586	13.5	6	0
treatment	586.9	14.38	4	0
treatment*point+sage	588	15.5	7	0
Sage thrasher narrowband	AICc	ΔAICc	K	wi
sage+day+day^2	218.1	0	6	0.396
treatment+day+day^2+sage	218.9	0.86	7	0.258
dB*sage+day+day^2	219.7	1.58	7	0.18
treatment*point+sage+day+day^2	221	2.96	9	0.09
treatment*point+sage	223.6	5.51	7	0.025
dB+day+day^2	223.9	5.85	6	0.021
treatment+day+day^2	224.1	5.98	6	0.02
dB	227.2	9.16	4	0.004
treatment	227.3	9.25	4	0.004
treatment*point	229.4	11.32	6	0.001
Horned lark narrowband	AICc	ΔAICc	K	wi
dB+day+day^2	844	0	6	0.212
dB	844.2	0.24	4	0.188
sage+day+day^2	844.6	0.57	6	0.159
treatment+day+day^2	844.8	0.76	6	0.145
treatment	845.1	1.06	4	0.125
dB+sage+day+day^2	845.9	1.9	7	0.082
treatment+day+day^2.sage	846.6	2.59	7	0.058
treatment*point	849.1	5.08	6	0.017

	AICc	ΔAICc	K	wi
treatment*point+sage+day+day^2	850.7	6.72	9	0.007
treatment*point+sage	850.8	6.79	7	0.007
All birds broadband	**AICc**	**ΔAICc**	**K**	**wi**
treatment+day+day^2	741.1	0	6	0.85
treatment*point+sage+day+day2	744.7	3.53	9	0.145
dB+day+day^	751.3	10.17	6	0.005
dB+sage+day+day^2	753.1	11.94	7	0.002
sage+day+day^2	756.2	15.05	6	0
treatment	803.3	62.16	4	0
treatment*point	805.1	64.01	6	0
treatment*point+sage	807.1	66.01	7	0
dB	812.6	71.45	4	0
Brewer's sparrow broadband	**AICc**	**ΔAICc**	**K**	**wi**
treatment+day+day^2	540.7	0	6	0.553
treatment*point+sage+day+day^2	541.5	0.76	9	0.378
dB+date	545.5	4.76	6	0.051
dB+sage+day+day^2	547.6	6.91	7	0.017
sage+day+day^2	554.7	14	6	0.001
treatment*point	651.7	110.94	6	0
treatment	653.1	112.34	4	0
treatment*point+sage	653.8	113.11	7	0
dB	657.7	116.98	4	0
Sagebrush sparrow broadband	**AICc**	**ΔAICc**	**K**	**wi**
treatment+day+day^2	432.1	0	6	0.827
treatment*point+sage+day+day^2	436.4	4.34	9	0.094
dB+day+day^2	438.6	6.54	6	0.031
sage+day+day^2	438.7	6.59	6	0.031
dB+sage+day+day^2	440.6	8.53	7	0.012
treatment	443.2	11.12	4	0.003
treatment*point	445.5	13.36	6	0.001
treatment*point+sage	447.5	15.42	7	0
dB	449.1	17.02	4	0
Western meadowlark broadband	**AICc**	**ΔAICc**	**K**	**wi**
dB+sage+day+day^2	231	0	7	0.405
dB+day+day^2	232	0.98	6	0.248
treatment*point+sage+day+day^2	233.4	2.37	9	0.124
dB	233.9	2.88	4	0.096
sage+day+day^2	234.7	3.69	6	0.064
treatment+day+day^2+sage	236.7	5.65	7	0.024
treatment*point+sage	237.3	6.27	7	0.018
treatment+day+day^2	238.2	7.11	6	0.012
treatment*point	238.9	7.87	6	0.008
treatment	242.3	11.27	4	0.001

Sage thrasher broadband	AICc	ΔAICc	K	wi
sage+day+day^2	210.5	0	6	0.419
dB.sage+day+day^2	210.9	0.48	7	0.33
treatment+day+day^2+sage	212.5	2.04	7	0.151
treatment*point+sage+day+day^2	215.1	4.6	9	0.042
treatment*point+sage	215.8	5.39	7	0.028
dB+day+day^2	217.5	7.02	6	0.013
dB	217.6	7.12	4	0.012
treatment+day+day^2	220.3	9.87	6	0.003
treatment	221.6	11.15	4	0.002
treatment*point	224.1	13.6	6	0
Horned lark broadband	AICc	ΔAICc	K	wi
dB	551.5	0	4	0.366
treatment	552.3	0.8	4	0.245
sage+day+day^2	553.8	2.37	6	0.112
dB+day+day^2	554.6	3.13	6	0.076
treatment+day+day^2	555.3	3.79	6	0.055
dB+sage+day+day^2	555.5	4.07	7	0.048
treatment+day+day^2+sage	556	4.51	7	0.038
treatment*point	556.4	4.89	6	0.032
treatment*point+sage	557	5.57	7	0.023
treatment*point+sage+day+day^2	560.2	8.76	9	0.005

Table S1.3.   A summary of the negative responses to compressor station noise exposure we quantified from the overall songbird community and from individual species during both narrowband and broadband playbacks. A response to noise was recognized if a top model included dB, treatment or an interaction of point count with treatment. Further the model was interpreted only if it included informative parameters and 95% confidence intervals excluding zero (Arnold 2010).

	Response to noise: narrowband		Response to noise: broadband	
	Treatment	**dBA**	**Treatment**	**dBA**
All birds			–	
Sagebrush sparrow				
Horned lark				
Sagebrush sparrow			–	
Western meadowlark				–
Brewer's sparrow	–		–	

Table S1.4. Beta (β) scaled values and standard errors (s.e.) of all variables within the highest AICc-ranked models with informative parameters (95% confidence intervals excluded zero) that predict bird distribution.

		intercept	dB(A)	noise	noiseXpoint	vegetation	day^2	day
All birds narrowband	β	1.57					-1.74	1.71
	s.e.	0.04					0.38	0.38
Brewer's sparrow narrowband	β	-0.17			0.55		-11.30	10.90
	s.e.	0.16			0.25		1.21	1.15
Sage thrasher narrowband	β	-2.21				0.60		
	s.e.	0.29				0.23		
All birds broadband	β	1.73		-0.30			-4.58	4.65
	s.e.	0.04		0.07			0.60	0.60
Brewer's sparrow broadband	β	0.65		-0.50			-11.5	11.51
	s.e.	0.08		0.11			1.19	1.18
Sage thrasher broadband	β	-1.64				0.74		
	s.e.	0.24				0.23		
Sagebrush sparrow broadband	β	0.17		-0.49			-5.36	5.37
	s.e.	0.11		0.17			1.41	1.41
Western meadowlark broadband	β	-1.88	-0.47					
	s.e.	0.41	0.22					
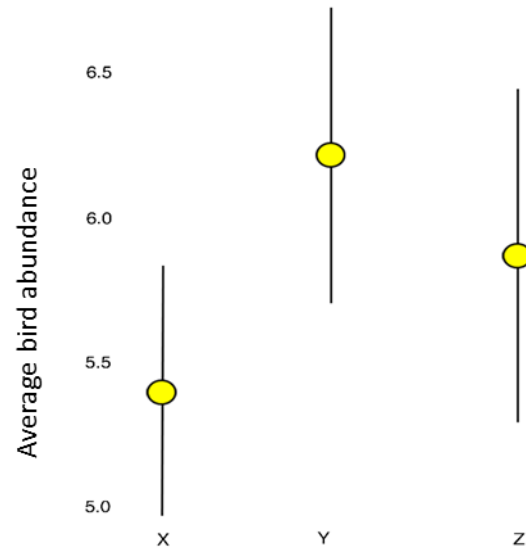
Figure S1.1. Songbird abundance at control sites during the broadband playback in 2015. X: average bird abundance from control sites studied only in 2015 (N=2) (5.4±0.4, (mean±s.e.); N=2); Y: 2015 average bird abundance from sites that did not receive noise exposure in either year (i.e., they were controls in both years) (6.2±0.5; N=2); and Z: 2015 average bird abundance from control sites that were exposed to noise in 2014 (5.8±0.6; N=2).

EXPERIMENTAL MANIPULATION OF THE ACOUSTIC ENVIRONMENT
ALTERS ARTHROPOD DISTRIBUTIONS.

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Introduction

Current biodiversity estimates place the number species on our planet at ~7.7 billion (Mora et al. 2011). Over 60% of these species are arthropods (Scheffers et al. 2012). Given their worldwide distribution and diversity, insects shape all environments on earth. They strongly influence the distributions of vertebrates (Saab et al. 2014) and govern critical ecosystem functions such as soil carbon dynamics (Overby et al. 2000), decomposition rates (Pechal et al. 2014)(Ramsfield et al. 2016), hydraulic processes (Savannas 2005)(Dangerfield, J., Mccarthy, T., & Ellery 1998), pollination (Klein et al. 2007), and seed dispersal (MacMahon et al. 2000). Still, not all insects are beneficial, some groups can become crop pests (Bebber et al. 2014) or even threaten regeneration of forests (Hódar et al. 2003).

Many anthropogenic factors influence insect distributions and community organization. For instance, air pollution, fires, habitat fragmentation, and plant invasions change arthropod richness and abundance (Zvereva & Kozlov 2010)(Moretti et al. 2006)(Siemann et al. 1997)(Bale et al. 2002)(Rossetti et al. 2017)(Simao et al. 2010). Anthropogenic noise, an invisible pollutant that changes distributions, foraging efficiency, survival, and reproductive success of vertebrates (Francis & Barber

2013)(Shannon et al. 2016), could be another factor that governs invertebrate behaviors and distributions, but has been poorly studied.

Recent research shows that male bow-winged grasshoppers (*Chorthippus buguttulus*) from noisy roadside habitats elevate the frequency of their songs (Lampe et al. 2012). A cicada species (*Cryptotympana takasagona*) shifts their calls to higher frequencies under elevated urban noise levels (Shieh et al. 2012). Male tree crickets (genus Oecanthus) are less likely to call under road noise exposure (Costello & Symes 2014), and female field crickets (*Gryllus bimaculatus*) have lower responses to male songs under anthropogenic noise (Schmidt et al. 2014). Similar to vertebrates, arthropods use acoustic cues to communicate, find prey, and detect predators (Morley et al. 2014), thus it is likely that anthropogenic noise has been shaping arthropod communities for decades (reference Swaddle et al. TREE).

From air and boat traffic, to terrestrial transportation infrastructure, urbanization, and energy development, human-caused disturbance and its associated noise changes animal distributions and behavior (Francis & Barber 2013)(Shannon et al. 2016)(Slabbekoorn et al. 2010). A pervasive and perhaps less appreciated source of anthropogenic noise comes from oil and gas development, a type of noise that is responsible for a variety of ecological impacts on vertebrates (Northrup & Wittemyer 2013). However, only one study, to our knowledge, has examined the effects of increased background levels on arthropod abundances (Bunkley et al. 2017). Bunkley and colleagues took advantage of variation in sound levels created by loud compressor stations (large engines that maintain pressure in pipelines) and quieter well pads in a natural gas field in New Mexico, and found that noise from compressors altered the

abundance of six arthropod families. Their experimental design indicates that noise is likely the main factor behind these ecological changes.

In this study, we aimed to better understand noise effects on arthropods, key players in all terrestrial systems (Morley et al. 2014). To do this, we experimentally tested the role of noise alone on arthropod distributions by using speaker arrays to broadcast compressor station noise creating a 'phantom natural gas field'. We conducted our experiment in the sagebrush steppe, an ecosystem that due to human expansion and disturbance has suffered rapid alterations (Noss et al. 1995), including widespread energy extraction.

We tested the effects of two different compressor stations that produce different spectral bandwidths (the range of frequencies contained in a sound source) and associated sound levels, having one playback more broadband and higher intensity than the other (figure 1). For a better understanding of how these noise sources affect arthropod abundance at a landscape scale, within each playback type we tested two hypotheses: 1) the dose-response hypothesis where we predicted arthropod abundance to decrease or increase proportionally with sound level across a gradient of exposure, and 2) the threshold hypothesis, where we predicted that a sound level threshold existed above which arthropod distribution would be effected similarly.

Materials and methods

Phantom Energy Extraction Field

We broadcast compressor station noise in the sagebrush steppe of Southwest Idaho from April 1st to July 15th for two years. Experimental sites were randomly selected; 3 control and 4 noise sites in 2014, where we played back our narrow bandwidth

treatment, and 6 control and 6 noise sites in 2015, where we played our broad bandwidth treatment (details below) (Figure 2.1 A,C). At the control sites, we placed dummy speakers of similar shape, size, and color to the real speakers. All sites were at least 1 km apart and 500 m away from a dirt road. Our sites had similar plant communities, dominated by big sagebrush (*Artemesia tridentata*). To quantify the percentage of vegetation cover we used photographic methods implemented in SamplePoint.

We measured vegetation along five 300 m transects radiating from the center of each site. With a camera (Fujifilm FinePix XP70 16.4 Megapixel Compact Camera, fisheye 180°) attached to a two meter pole (Sokkia 724290 Economy 2 m Aluminum 2 Section GPS Rover Rod) we photographed 20 points along each transect that were 15 m apart, obtaining a hundred pictures per site. We obtained 1 m2 photographs that were analyzed in the lab using the open source software SamplePoint (version 1.58) described by Booth et al. (2006). We identified the vegetation type of 68 individual points of each photograph to obtain a percent cover for sagebrush, bare ground, grasses, and moss.

Noise playback and acoustic monitoring

For each bandwidth type (Figure 2.1-A), we used two different speaker systems that produced two different spectra of noise. Arrays were mounted on structures 2 m above the ground (Figure 2.1-B). For the narrow bandwidth in 2014, we placed 4 horn-loaded speakers (Dayton RPH16; MCM 40 W; 400–3,000 Hz ±5 dBA) in the 4 cardinal directions, and amplified them using Parts Express amps (Class D, 2W, 4-ohm). In 2015, for the broad bandwidth, we used omni-directional speakers (Octasound SP820A; 35–20,000 Hz ±10 dB,) and subwoofers (Octasound OS2X12; 25–20,000 Hz ±10 dB,) and class T amplifiers (Lepai LP-2020A 20 W, 4-ohm). Amplifiers were powered by solar

array systems (Solarland SLP 15S-12 panels, Morningstar PS-30M controllers and PowerSonic 12V batteries). We broadcasted sound files (MP3, 128kbps) using Olympus LS-7 players that were powered with LiFePO4 (Batteryspace) batteries.

We played synthetic compressor noise, created in Audacity from an average of 3 compressor stations recorded in the San Juan basin, NM and Green River Basin, WY. The noise files were recorded with a Sennheiser ME66 microphone (40–20,000 Hz; ±2.5 dB) and Roland R-05 recorder (sampling rate 48 kHz) at 40m. We created a 3-hour playback file that was repeated 24hr/day over both years (Figure 2.1). It is important to note that the compressor stations we recorded very likely produced energy below 20 Hz (U.S. Energy Information Administration 2007), the lower limit of our microphone.

To measure sound levels (dBA) at each site through the season, we placed acoustic recording units (ARUs; Roland R-05 audio recorders mounted inside a protective wind screen) at each site 50 m from the noise source (7 in 2014 and 12 in 2015). We camouflaged ARUs in shrubs and mounted them 50 cm above the ground by lashing support rods to vegetation (figure 2.2-B). Using a custom program (Damon Joyce, NPS, AUDIO2NVSPL), we converted our MP3 recordings into hourly sound pressure levels. Next, we obtained hourly sound levels (LEQ in dBA) using a second custom program (Damon Joyce, NPS, Acoustic Monitoring Toolbox).

Insect sampling

To obtain species composition and abundance from all strata, we used pitfall traps to collect terrestrial arthropods, flying traps for flying insects, and beat netted sagebrush to collect arthropods living on shrubs (Lowe et al. 2010).

We built pitfall traps using wide-mouth 236 ml Mason jars, buried in the ground half filled with propylen glycol (Ferro & Park 2013). We used plastic mesh (1.9cm grid size) to keep larger animals from accessing the collected arthropods. During our narrowband playback in 2014, at all 7 sites, we located pitfall traps at different distances. We placed 2 traps (in opposite directions) at 25 m, 2 traps at 50 m, and 2 traps at 100 m (n=42) from the center of the site. Under the broad bandwidth treatment, at all 12 sites, we placed 2 traps (in opposite directions) at 25 m and 2 traps at 50 m from the center (n=48) (figure 1-C).

To build flying insect traps we used Japanese beetle yellow and blue (i.e. different insect groups are attracted to different colors (Lowe et al. 2010)) top assemblies (Great Lakes IPM) attached to a Nalgene cup (Fisher Scientific), and an insecticide strip (Hot Shot No-Pest Strip). Flying traps were mounted on a 50 cm tall piece of rebar placed 50 m away from the center of the site. During both narrowband and broadband playbacks, we positioned two traps at each site, 1 blue and 1 yellow in opposite directions (narrowband playback n=14 and broadband playback n=24) (figure 2.1-C). We left both trap types (pitfall and flying traps) in the field for 7 days bi-weekly, from May 4th to July 10th of 2014 (narrowband playback) and from May 10th to July 13th of 2015 (broadband playback).

To beat net, we used a modified version of the described by Sandford and Huntly 2010 (Sanford & Huntly 2010). We beat shrubs using an 18in. aerial net (Bioquip) and a 1m wooden stick. We hit each shrub 4 times in each cardinal direction keeping the net underneath, and one "sweep" above the shrub to catch any flying insect that was once rested on that shrub. We beat netted 4 shrubs at each site bi-weekly from May 4th to July

10th of 2014 (narrowband playback) and 2 shrubs bi-weekly from April 20th to July 2nd of 2015 (broadband playback).

Statistical analysis

We analyzed all data using R (Fay 1988), version 3.2.1 (packages: MuMIn and lme4). We analyzed both playbacks (years) separately, truncated the data to include families that were collected 10 times or more, and modeled arthropod abundance using generalized linear mixed models with a Poisson distribution (Bolker et al. 2009). To examine the influence of vegetation on different arthropods, for each playback, we first analyzed each family individually against vegetation parameters. In our vegetation models we included a combination of cover for sagebrush, moss, grasses, bare ground, and time of sampling (week). Secondly, to assess how noise impacts different arthropods, we again analyzed each family separately. In our models, we included combinations of monthly sound levels (LEQ in dBA), week, treatment (noise vs. control), and a vegetation parameter only for those families where vegetation predicted arthropod abundance, with site as a random effect. Because some sampling methods were designed for terrestrial or aerial arthropods, any incidentally collected specimen from a flying insect in the pitfall traps or a ground arthropod in the flying traps was excluded from the analysis.

We ranked and compared all models using Akaike's Information Criterion (AIC) (Akaike 1974) corrected for small sample size AICc (Hurvich & Tsai 1989).We considered covariates as useful for inference if they were within models ΔAICc<2 and 95% confidence intervals excluding zero. We interpreted models ΔAICc<2 and 85% confidence intervals excluding zero as weak responses to noise. Following the same

statistical approach, we evaluated the impacts of noise on arthropods by foraging-guild groups (Table S2.1). We classified all families as grazers, predators, pollinators, parasitoids, sap-feeders, omnivores, scavengers, detritivores, and borers. For this analysis we incorporated families that included more than 10 specimens. The models for the guild analysis included a combination of monthly sound levels (LEQ in dBA), treatment (noise vs control), and time of sampling (week).

Results

The phantom energy extraction field encompassed approximately 100 km^2, broadcasting noise continuously for 3 months per year. We monitored sound levels at each point count location throughout two years of fieldwork, allowing us to quantify over 10,000 hours of background sound levels. Across our study site, the gradient of background noise ranged from ~30 dB (A) to 65 dB (A) under which we sampled songbird abundance (Figure 2.2-A,C).

In 2014, under the narrowband playback, sound levels at 50m averaged 56.3±1.5 dB (A) (mean±s.e.) at noise sites and 41.9±1.4 dB (A) at control sites. In 2015, during the broadband playback, sound levels at 50m averaged 61.6±1.4 dB (A) at noise sites and 39.2±1.3 dB (A) at control sites (Figure 2.2-A,C).

We collected 78,733 individuals of 187 families between both years (Tables S2.2 and S2.3). Under the narrowband playback in 2014, sound level (dBA) was in the most informative model for 27 families (Table S2.5). Halictidae, Melyridae, Psyllidae, Sarcophagidae, Sepsidae, Chalcidoidea, Tachinidae, Tenebrionidae, Thripidae, and Vespidae showed a strong (95% confidence interval excluding zero) negative response to sound level (distributions explained by the dose-response hypothesis), and Sphecidae,

Aeolothripidae, Apidae, Cicadellidae, and Curculionidae showed a weak (85% confidence interval excluding zero) negative response to sound level. Sphingidae, Acari, Miridae, Eulophidae, and Salticidae showed a strong positive response to sound level, and Bombyliidae, Carabidae, Chloropidae, Formicidae, Ortheziidae, Phoridae, and Sciaridae showed a weak positive response to sound level. Treatment was in the top model of 3 families with Geocoridae and Mythicomyiidae having a strong negative response to treatment and Hesperiidae a strong positive response (distributions explained by the threshold hypothesis) (Table S2.4).

Under the broadband playback in 2015, sound level (dBA) was in the most informative model for 21 families (Table S2.7). Thripidae, Acari, Calliphoridae, Cicadellidae, Eulophidae, and Melyridae showed a strong (95% confidence interval excluding zero) negative response to sound level (distributions explained by the dose-response hypothesis), and Platygastridae, Agromyzidae, Sepsidae, and Tachinidae showed a weak (85% confidence interval excluding zero) negative response to sound level. Miridae, Tenebrionidae, Chalcidoidea, Chloropidae, Chrysididae, Formicidae, and Liposcelididae, showed a strong positive response to sound level, and Entomobryidae, Mutillidae, and Psyllidae showed a weak positive response. Treatment was in the most informative model of 9 families with Gnaphosidae, Salticidae, and Sciaridae having a strong positive response to treatment, Coleophoridae, Dermestidae, Gelechiidae, Isotomidae, and Lygaeidae showing a weak positive response to treatment and only Chironomidae showing a weak negative response to treatment (distributions explained by the threshold hypothesis; Table S2.6).

During the narrowband playback in 2014, borers, grazers, omnivores, predators, and scavengers decreased as decibels increased. Pollinators were the only group with a positive association with noise (Table 2.1). During the broadband playback in 2015, scavengers, detritivores and pollinators decreased with increased decibels (Table 2.2). Grazers, omnivore, parasitoids, predators and sap-feeders increased with increased decibels. All groups responded to noise with 95% confidence interval excluding zero (Table 2.3).

Discussion

Our findings demonstrate that noise from gas compressor stations alone changes arthropod distributions. By markedly increasing the sound level of the acoustic environment, we altered the abundance of 26 families. Our results clearly indicate that two different noise profiles, change arthropod communities differently.

Under the narrowband playback, most of the foraging groups (borers, grazers, omnivores, predators, and scavengers) decreased in abundance with increased sound levels. Under the broadband playback, there was a marked switch, where we observed an increase in abundance for most of the foraging groups (grazers, omnivores, predators, scavengers, detritivores, parasitoids and, sap-feeders) as sound levels increased. Noise could have changed arthropod communities directly, by altering families that are sensitive to noise, and negatively affecting arthropod abundance, or indirectly, by negatively affecting the distribution and behavior of vertebrate predators (e.g. songbirds and bats), and positively affecting arthropod abundance.

During our previous study on songbird distributions, (see Chapter 1), we showed that our broadband playback dramatically affected the distribution the songbird

community whereas during our narrowband broadcast only one species changed distributions. Throughout the breeding season, all the songbird species that avoided the broadband playback, feed entirely on arthropods (Cornell Birds of North America) (Table S2.9). Fewer songbirds, and potentially less bat activity and foraging efficiency (Siemers & Schaub 2011) (Bunkley & Barber 2015) can benefit arthropods by releasing them from predation (Chapter 1 and Table S2.9), and alter arthropod distributions through a trophic cascade. Thus, we suggest the decrease in arthropod abundances we observed under the narrowband playback (when we did not change vertebrate insectivores) was operated via a direct effect of noise on arthropod communities, and the increase in arthropod abundances we documented during the broadband playback (when songbird density decreased in our noise sites) was driven by an indirect route due to a release from predation.

Several mechanisms could be behind a decrease in arthropod abundance in the presence of noise during the narrowband playback. Noise could have interfered or masked communication of arthropods that use acoustic cues to perceive the world, (Drosopolous & Claridge 2006) (Greenfield 2002) (Shamble et al. 2016) (Polidori et al. 2013). Further, noise could increase visual vigilance behavior and stress, due to a lost in auditory awareness, and potentially alter foraging behavior (Clinchy et al. 2013) (Dror Hawlena and Oswald J. Schmitz 2010), or change acoustic detectability of invertebrate predators (e.g. spiders) (Shamble et al. 2016), forcing some arthropods to leave.

Both of our playbacks of gas compressors of different intensity and bandwidth changed our arthropod community differently. We show the significance of taking into account different noise sources when examining the impacts of noise on arthropods, and

support the importance of considering invertebrates when assessing the impacts of noise

pollution (Morley et al. 2014) as any change at the arthropod level, could cascade to plant

communities (Nabity et al. 2009)(Schmitz 2008).

As energy development is predicted to increase (Mora et al. 2011)(Bentley 2002),

we believe that our findings are valuable for understanding ecosystems. Further, it is

essential to think of the costs of noise from all forms of anthropogenic noise exposure

and particularly, energy extraction noise on invertebrates. Sound levels have already

doubled in almost two-thirds of the most protected lands in the US over the past century

(Buxton et al. 2017). Noise is a potential ecological pollutant for all animals and habitats.

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Figures
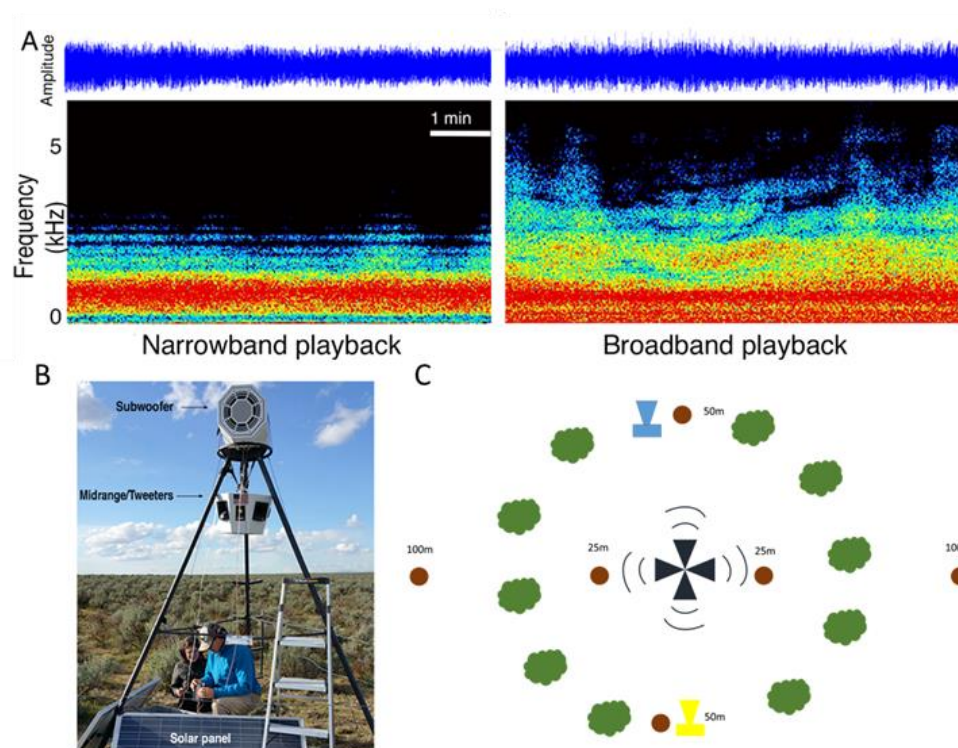
Figure 2.1.   Broadcast files and equipment methods. (A) A 5-min recording of our playbacks displayed as a spectrogram (frequency x time) and oscillogram (voltage x time). The broadband playback was ~6kHz higher in bandwidth as measured 55dB below peak. (B) Example of the solar-powered 3-way speaker system (25Hz-20kHz ±10dB) used for the broadband playback. (C) Model of the trap locations at each site during the narrowband playback in 2014. Pitfall traps are represented in brown, flying traps in blue and yellow, and in green, an example of the beat netted shrubs.
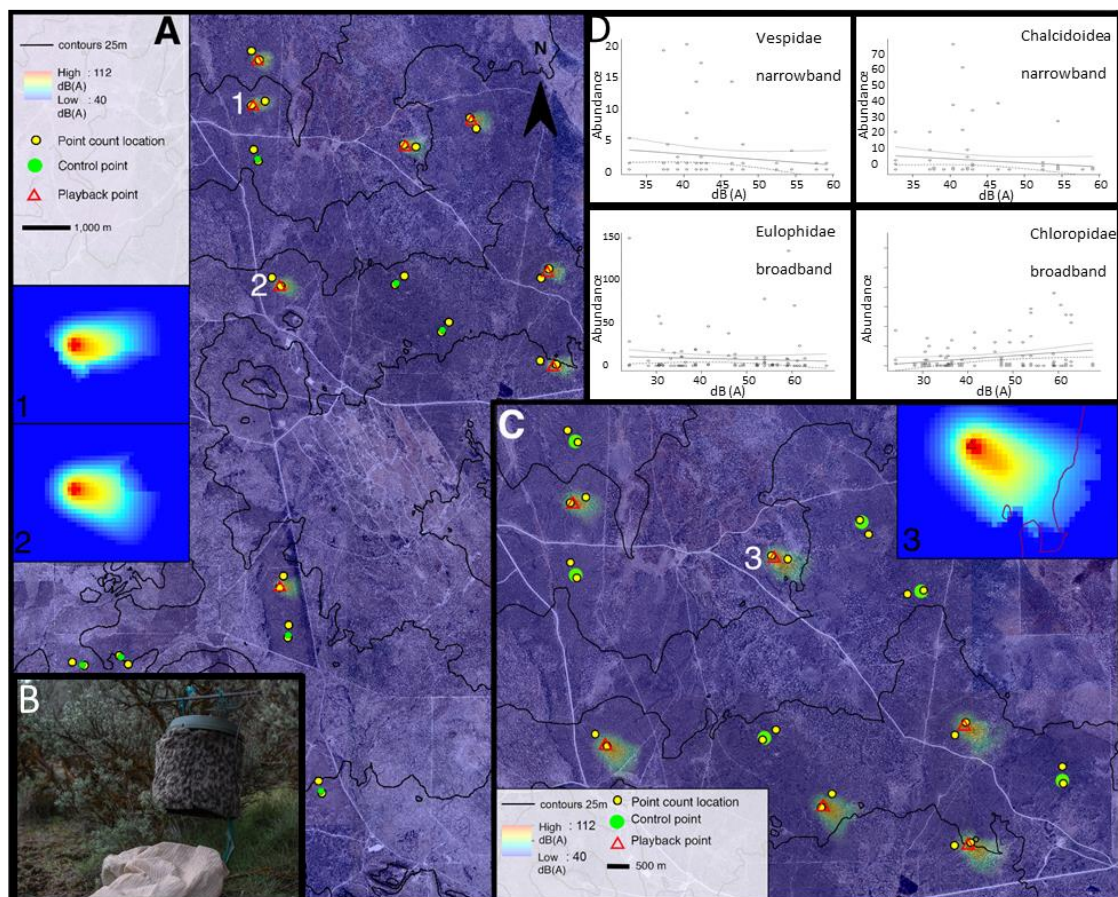
Figure 2.2. **The phantom natural gas field. (A) Estimated sound levels (dB(A) 1h LEQ) of noise sites against a background of 42dB, the average for control sites from May to June during the narrowband playback (2014). Sound level was modeled using SPreAD-GIS with incorporated wind effects (see supplement for details). Circles (control) and triangles (noise) represent the center of the site, speakers or dummy speakers (objects of similar shape, size, and colour to our speakers). (B) Example of a camouflaged acoustic recording unit (ARU). (C) Estimated sound levels (dB(A) 1h LEQ) of noise sites against a background of 42dB, the average for control sites from May to June during the broadband playback (2015). (D) Narrowband and broadband playback results of some insect families that showed a positive or negative response to noise (dBA).**

Tables

Table 2.1.   **Beta (β) scaled values, standard errors (s.e.), and percent change in response to noise of all variables within the highest AICc-ranked models (85% and 95% confidence intervals excluded zero) that predict guild groups distributions during the narrowband playback in 2014.**

Narrowband-2014		week	dB	treatment	%change/~8 dB	%change in noise	95 C.I.	mean±s.e.
Scavenger	β	-0.13	-0.62		-47%		2.73-1.26	
	s.e.	0.01	0.20					
Borer	β	-0.09	-0.18		-16%		0.87-0.8	
	s.e.	0.00	0.02					
Grazer	β	-0.13	-0.22		-19.6%		0.88-0.73	
	s.e.	0.00	0.05					
Omnivore	β	-0.22	-0.25		-22.1%		0.89-0.68	
	s.e.	0.03	0.07					
Pollinator	β	-0.06		0.56		31%increase in noise		Control; 0.41±0.08 Noise;
	s.e.	0.01		0.28				0.78±0.14
Predator	β	-0.12	-0.30		-25.8%		0.85-0.64	
	s.e.	0.01	0.07					

Table 2.2. Beta (β) scaled values, standard errors (s.e.), and percent change in response to noise of all variables within the highest AICc-ranked models (85% and 95% confidence intervals excluded zero) that predict guild groups distributions during the broadband playback in 2015.

Broadband-2015		week	dB	%change/~12 dB	95 C.I.
Detritivore	β	-0.37	-0.36	-30%	0.78-0.62
	s.e.	0.00	0.06		
Grazer	β	-0.10	0.29	+33.7%	1.43-1.25
	s.e.	0.00	0.03		
Omnivore	β	-0.09	0.27	+30%	1.65-1.03
	s.e.	0.03	0.12		
Parasite	β	0.03	0.17	+18.8%	1.27-1.10
	s.e.	0.00	0.04		
Pollinator	β	-0.01	-0.13	-12.40%	0.96-0.79
	s.e.	0.01	0.05		
Predator	β	0.07	0.15	+16.4%	1.23-1.09
	s.e.	0.00	0.03		
Sap-feeder	β	-0.23	0.25	+30%	1.47-1.12
	s.e.	0.01	0.07		
Scavenger	β	-0.10	-0.16	-14.3%	0.97-0.75
	s.e.	0.01	0.06		

Table 2.3. A summary of the negative and positive responses to compressor station noise exposure we quantified from foraging strategy groups (those with n>1) during our broadband playback in 2015. A response to noise was recognized if a top model included dB or treatment. Responses to noise are indicated as positive (+), negative (-), or no response (blank). Further the model was interpreted only if it included informative parameters (Arnold 2010). The asterisk (*) indicates that 95% confidence intervals excluded zero.

	Response to noise	
Narrowband-2014	**dB**	**Treatment**
Borer	-*	
Grazer	-*	
Omnivore	-*	
Pollinator		+*
Predator	-*	
Scavenger	-*	
	Response to noise	
Broadband-2015	**dB**	**Treatment**
Detritivore	-*	
Grazer	+*	
Omnivore	+*	
Parasitoids	+*	
Pollinator	-*	
Predator	+*	
Sap feeder	+*	
Scavenger	-*	

Supplementary materials and methods

Table S2.1.   Families collected during both playbacks southwestern Idaho classified by foraging guilds.

Family	Foraging group	Family	Foraging group
Acanthosomatidae	Sap-feeder	Hydrophilidae	Predator
Acari	Undetermined	Hydroscaphidae	Undetermined
Acrididae	Grazer	Ichneumonidae	Parasite
Adrenidae	Pollinator	Isotomidae	Detritivore
Aeolothripidae	Undetermined	Latridiidae	Scavenger
Aeolothripidae	Undetermined	Lauxaniidae	Detritivore
Agelenidae	Predator	Leiodidae	Detritivore
Agromyzidae	Grazer	Linyphiidae	Predator
Andrenidae	Pollinator	Liposcelidae	Detritivore
Anthocoridae	Predator	Lycosidae	Predator
Anthomyiidae	Grazer	Lygaeidae	Undetermined
Aphididae	Sap-feeder	Margarodidae	Sap-feeder
Apidae	Pollinator	Megachilidae	Pollinator
Apioceridae	Undetermined	Megaspilidae	Parasite
Araneidae	Predator	Meinertellidae	Scavenger
Argomyzidae	Grazer	Melittidae	Pollinator
Asilidae	Predator	Meloidae	Grazer
Bethylidae	Parasite	Melyridae	Predator
Bibionidae	Scavenger	Milichiidae	Predator
Bombyliidae	Pollinator	Miridae	Sap-feeder
Braconidae	Parasite	Muscidae	Saprophagous
Bruprestidae	Undetermined	Mutillidae	Nectar
Bucculatricidae	Grazer	Mycetophilidae	Undetermined
Buprestidae	Borer	Mymaridae	Parasite
Calliphoridae	Scavenger	Mymaridae	Parasite
Caponiidae	Predator	Mythicomyiidae	Undetermined
Carabidae	Predator	Nabidae	Predator
Cecidomyiidae	Grazer	Nitidulidae	Sap-feeder
Cerambycidae	Borer	Noctuidae	Grazer
Ceraphronidae	Parasite	Nymphalidae	Nectar
Ceratophyllidae	Parasite	Ortheziidae	Sap-feeder
Ceratopogonidae	Undetermined	Oxyopidae	Predator
Cercopidae	Sap-feeder	Pentatomidae	Grazer
Chalcididae	Parasite	Philidromidae	Predator
Chalcidoidea	Parasite	Philodromidae	Predator
Chamaemyiidae	Predator	Philodromidae	Predator

Chilopoda	Predator	Phlaeothripidae	Detritivore
Chironomidae	Sap-feeder	Phoridae	Parasite
Chloropidae	Grazer	Pieridae	Pollinator
Chrysididae	Parasite	Piophilidae	Undetermined
Chrysomelidae	Grazer	Pisauridae	Predator
Chrysopidae	Undetermined	Pityococcidae	Sap-feeder
Chyphotidae	Predator	Platygastridae	Parasite
Cicadellidae	Eliza	Platygastridae	Parasite
Cicadidae	Sap-feeder	Pompilidae	Predator
Cleridae	Undetermined	Pseudococcidae	Sap-feeder
Clubionidae	Predator	Pseudoscorpiones	Predator
Coccinellidae	Grazer	Psocidae	Detritivore
Coleophoridae	Grazer	Psyllidae	Sap-feeder
Coleoptera	Undetermined	Pteromalidae	Parasite
Collembola	Detritivore	Pterophoridae	Grazer
Colletidae	Pollinator	Ptinidae	Scavenger
Conopidae	Anthophilous	Pyralidae	Undetermined
Corinnidae	Predator	Reduviidae	Predator
Cosmopterigidae	Grazer	Rhaphidiophoridae	Omnivore
Crabronidae	Predator	Rhaphidophoridae	Grazer
Culicidae	Undetermined	Rhinotermitidae	Undetermined
Curculionidae	Grazer	Rhyparochromidae	Undetermined
Cybaeidae	Predator	Riodinidae	Nectar
Cydnidae	Detritivore	Salticidae	Predator
Dermestidae	Scavenger	Sarcophagidae	Scavenger
Diapriidae	Parasite	Scarabaeidae	Grazer
Dictynidae	Predator	Scathophagidae	Undetermined
Diplura	Detritivore	Scenopinidae	Predator
Douglasiidae	Nectar	Sciaridae	Detritivore
Drosophilidae	Undetermined	Scorpiones	Predator
Dryinidae	Parasite	Sepsidae	Scavenger
Elachistidae	Grazer	Sessidae	Undetermined
Elateridae	Borer	Silphidae	Scavenger
Embolemidae	Undetermined	Simuliidae	Undetermined
Empididae	Predator	Sminthuridae	Sap-feeder
Encyrtidae	Parasite	Solifugae	Predator
Entomobryidae	Detritivore	Sphaeroceridae	Saprophagous
Ephemerellidae	Grazer	Sphecidae	Predator
Ephydridae	Undetermined	Sphindidae	Detritivore
Eucinetidae	Detritivore	Sphingidae	Nectar
Eulophidae	Parasite	Staphylinidae	Predator/Scavenger

Eumastacidae	Grazer	Stratiomyidae	Scavenger
Eupelmidae	Parasite	Stylopidae	Parasite
Fanniidae	Detritivore	Syrphidae	Anthophilous
Filistatidae	Predator	Tachinidae	Parasite
Formicidae	Grazer	Tachinidae	Parasite
Fulgoridae	Undetermined	Tenebrionidae	Omnivore
Gelechiidae	Grazer	Tenthredinidae	Undetermined
Geocoridae	Predator	Tephritidae	Grazer
Geometridae	Grazer	Theridiidae	Predator
Glaresidae	Undetermined	Thomisidae	Predator
Gnaphosidae	Predator	Thripidae	Grazer
Gracillariidae	Grazer	Tipulidae	Grazer
Halictidae	Pollinator	Torymidae	Undetermined
Heleomyzidae	Detritivore	Trichogrammatidae	Parasite
Hemerobiidae	Predator	Vespidae	Predator
Hesperiidae	Grazer		
Histeriidae	Undetermined		

Table S2.2   Number of arthropods collected per family in our southwestern Idaho study site from May 4th to July 10th of 2014 during the narrowband playback.

Individuals collected-Narrowband playback-2014			
Family	Beat-netting	Pitfall	Flying	Total
Acanthosomatidae	1	0	0	1
Acari	123	1933	240	2296
Acrididae	11	7	2	20
Adrenidae	0	0	17	17
Aeolothripidae	5	6	132	143
Agelenidae	2	0	0	2
Andrenidae	0	0	2	2
Anobiidae	0	1	0	1
Anthocoridae	0	19	3	22
Anthomyiidae	0	956	405	1361
Aphididae	2867	193	43	3103
Apidae	15	1	299	315
Apioceridae	0	3	0	3
Araneidae	8	2	0	10
Argomyzidae	1	0	0	1
Asilidae	0	4	6	10
Bethylidae	0	14	2	16
Bibionidae	0	0	1	1
Bombyliidae	0	2	254	256
Braconidae	10	19	18	47
Bruprestidae	1	0	10	11
Bucculatricidae	45	10	18	73
Buprestidae	0	0	10	10
Calliphoridae	0	115	8	123
Caponiidae	0	1	0	1
Carabidae	0	41	2	43
Cecidomyiidae	7	101	28	136
Cerambycidae	0	0	7	7
Ceraphronidae	1	20	8	29
Ceratophyllidae	0	2	0	2
Ceratopogonidae	0	3	1	4
Cercopidae	19	2	2	23
Chalcididae	0	6	6	12
Chalcidoidea	13	21	387	421
Chamaemyiidae	0	0	1	1
Chilopoda	0	2	0	2
Chironomidae	2	6	32	40
Chloropidae	2	7	291	300

Chrysididae	0	21	11	32
Chrysomelidae	11	35	34	80
Chrysopidae	9	0	0	9
Chyphotidae	0	0	6	6
Cicadellidae	1896	1199	210	3305
Cicadidae	1	0	4	5
Cleridae	1	0	3	4
Clubionidae	2	0	0	2
Coccinellidae	11	4	15	30
Coleophoridae	8	7	9	24
Colletidae	0	0	19	19
Conopidae	0	0	2	2
Crabronidae	0	17	70	87
Culicidae	0	6	0	6
Curculionidae	13	10	3	26
Cybaeidae	0	1	0	1
Cydnidae	0	3	0	3
Dermestidae	0	6	19	25
Diapriidae	0	3	1	4
Dictynidae	4	10	0	14
Diplura	1	0	0	1
Douglasiidae	1	4	3	8
Drosophilidae	0	2	0	2
Dryinidae	8	3	0	11
Elachistidae	0	1	18	19
Elateridae	0	11	2	13
Empididae	0	0	2	2
Encyrtidae	3	5	2	10
Ephydridae	0	0	2	2
Eucinetidae	0	0	2	2
Eulophidae	9	8	352	369
Eumastacidae	2	1	0	3
Eupelmidae	0	1	0	1
Fanniidae	0	1	0	1
Filistatidae	0	1	0	1
Formicidae	340	2105	136	2581
Fulgoridae	1	0	0	1
Gelechiidae	1	28	5	34
Geocoridae	2	14	5	21
Geometridae	13	1	0	14
Glaresidae	0	0	1	1
Gnaphosidae	2	146	1	149
Gracillariidae	12	4	5	21

Halictidae	1	2	1008	1011
Heleomyzidae	0	2	0	2
Hemerobiidae	2	1	1	4
Hesperiidae	0	0	530	530
Histeriidae	0	6	7	13
Hydrophilidae	0	1	0	1
Hydroscaphidae	0	1	0	1
Ichneumonidae	1	43	22	66
Latridiidae	1	1	0	2
Lauxaniidae	0	0	2	2
Leiodidae	0	0	1	1
Linyphiidae	13	19	1	33
Liposcelididae	2	7	0	9
Lycosidae	1	114	0	115
Lygaeidae	1	0	0	1
Margarodidae	6	16	5	27
Megachilidae	0	0	8	8
Megaspilidae	1	3	1	5
Meinertellidae	0	4	0	4
Melittidae	0	0	6	6
Meloidae	0	1	47	48
Melyridae	18	70	2118	2206
Milichiidae	0	0	2	2
Miridae	733	216	219	1168
Muscidae	0	13	0	13
Mutillidae	0	8	17	25
Mycetophilidae	0	0	1	1
Mymaridae	0	1	1	2
Mythicomyiidae	0	0	130	130
Nabidae	19	3	2	24
Nitidulidae	0	3	0	3
Noctuidae	79	77	21	177
Nymphalidae	0	0	2	2
Ortheziidae	234	14	2	250
Oxyopidae	1	5	0	6
Pentatomidae	16	0	3	19
Philidromidae	8	1	0	9
Philodromidae	10	38	4	52
Phlaeothripidae	0	0	1	1
Phoridae	2	380	16	398
Pieridae	0	0	28	28
Piophilidae	0	0	1	1
Pisauridae	0	1	0	1

Pityococcidae	2	0	0	2
Pompilidae	0	87	12	99
Pseudococcidae	1	0	0	1
Pseudoscorpiones	0	7	0	7
Psocidae	56	31	4	91
Psyllidae	208	108	16	332
Pteromalidae	2	1	1	4
Pterophoridae	2	0	1	3
Ptinidae	0	2	6	8
Pyralidae	0	0	1	1
Reduviidae	1	1	0	2
Rhaphidiophoridae	0	1	0	1
Rhaphidophoridae	0	13	0	13
Rhinotermitidae	0	1	1	2
Rhyparochromidae	1	4	4	9
Riodinidae	0	0	1	1
Salticidae	47	40	9	96
Sarcophagidae	0	38	0	38
Scarabaeidae	0	16	26	42
Scathophagidae	0	11	1	12
Sciaridae	2	32	5	39
Scorpiones	0	2	0	2
Sepsidae	4	0	329	333
Sessidae	2	0	0	2
Silphidae	0	5	0	5
Simuliidae	4	1	0	5
Solifugae	0	19	0	19
Sphaeroceridae	0	2	1	3
Sphecidae	0	2	65	67
Sphindidae	0	2	0	2
Sphingidae	0	0	38	38
Staphylinidae	1	5	8	14
Stratiomyidae	0	0	1	1
Stylopidae	0	2	0	2
Syrphidae	0	0	3	3
Tachinidae	0	12	42	54
Tenebrionidae	1	181	41	223
Tenthredinidae	0	0	2	2
Tephritidae	0	1	6	7
Theridiidae	0	1	1	2
Thomisidae	43	29	5	77
Thripidae	5	12	595	612
Tingidae	0	15	0	15

Tipulidae	3	1	3	7
Tomoceridae	1	19	0	20
Tortricidae	1	0	14	15
Trichoceridae	0	0	2	2
Trichodectidae	0	1	0	1
Trichogrammatidae	0	0	3	3
Vesbidae	0	0	1	1
Vespidae	0	13	136	149
Xylomyidae	0	1	0	1
Yponomeutidae	0	0	3	3
Zopheridae	0	1	0	1

Table S2.3.   Number of arthropods collected per family in our southwestern Idaho study site from May 10th to July 13th of 2015 during the broadband playback.

Individuals collected-Broadband playback-2015			
Family	Beat-netting	Pitfall	Flying	Total
Acari	350	747	208	1305
Acrididae	13	30	11	54
Aeolothripidae	0	2	27	29
Agromyzidae	0	5	47	52
Anthocoridae	0	1	22	23
Anthomyiidae	1	1723	534	2258
Aphididae	865	40	168	1073
Apidae	0	0	411	411
Araneidae	30	7	20	57
Bethylidae	0	21	17	38
Bombyliidae	0	7	480	487
Braconidae	4	39	36	79
Bucculatricidae	7	3	7	17
Buprestidae	0	0	14	14
Calliphoridae	5	1109	1489	2603
Carabidae	0	20	1	21
Cecidomyiidae	0	217	28	245
Cerambycidae	0	13	9	22
Cercopidae	18	9	2	29
Chalcidoidea	1	120	3610	3731
Chironomidae	1	2	31	34
Chloropidae	3	16	520	539
Chrysididae	0	33	34	67
Chrysomelidae	22	62	24	108
Chrysopidae	3	4	3	10

Cicadellidae	605	707	315	1627
Cleridae	2	0	1	3
Coccinellidae	13	6	68	87
Coleophoridae	0	4	24	28
Conopidae	0	0	17	17
Cosmopterigidae	1	0	0	1
Crabronidae	0	38	131	169
Curculionidae	2	1	11	14
Cydnidae	0	0	1	1
Dermestidae	0	21	45	66
Diapriidae	0	2	0	2
Dryinidae	5	2	1	8
Elachistidae	5	0	5	10
Elateridae	1	24	7	32
Embolemidae	0	10	5	15
Empididae	1	2	12	15
Encyrtidae	2	12	4	18
Entomobryidae	0	2097	79	2176
Ephemerellidae	1	0	0	1
Eulophidae	3	59	1136	1198
Formicidae	116	4932	1044	6092
Gelechiidae	130	40	86	256
Geocoridae	0	6	13	19
Geometridae	6	0	0	6
Gnaphosidae	0	53	2	55
Gracillariidae	1	0	10	11
Halictidae	0	6	2690	2696
Hemerobiidae	1	0	0	1
Hesperiidae	0	0	82	82
Ichneumonidae	6	16	27	49
Isotomidae	0	8363	100	8463
Liposcelididae	1	96	3	100
Lygaeidae	2	10	36	48
Margarodidae	1	22	14	37
Megachilidae	0	0	21	21
Megaspilidae	1	1	3	5
Melyridae	6	68	9676	9750
Miridae	589	130	856	1575
Muscidae	0	36	12	48
Mutillidae	0	16	6	22
Mymaridae	0	12	6	18
Mythicomyiidae	0	3	130	133
Nabidae	14	2	4	20

Noctuidae	1	2	7	10
Ortheziidae	139	5	0	144
Oxyopidae	1	0	0	1
Pentatomidae	0	4	2	6
Philodromidae	14	0	0	14
Phoridae	1	249	121	371
Pieridae	0	0	16	16
Platygastridae	0	16	51	67
Pompilidae	0	44	21	65
Pseudoscorpiones	0	14	0	14
Psocidae	9	10	32	51
Psyllidae	86	3	18	107
Pterophoridae	12	0	3	15
Rhaphidophoridae	0	33	0	33
Salticidae	11	44	49	104
Sarcophagidae	0	242	64	306
Scarabaeidae	0	3	9	12
Scenopinidae	0	1	8	9
Sciaridae	9	111	58	178
Sepsidae	0	2	302	304
Sminthuridae	0	189	16	205
Solifugae	0	15	0	15
Sphecidae	0	1	108	109
Staphylinidae	0	4	10	14
Stratiomyidae	1	0	0	1
Syrphidae	2	1	1016	1019
Tachinidae	1	16	351	368
Tenebrionidae	0	179	4	183
Tephritidae	2	0	9	11
Theridiidae	0	1	0	1
Thomisidae	26	16	32	74
Thripidae	2	24	1642	1668
Tipulidae	2	1	8	11
Torymidae	0	3	5	8
Trichogrammatidae	0	1	22	23
Vespidae	0	0	178	178

Table S2.4.   A summary of the negative and positive responses to compressor station noise exposure we quantified from individual families (those with n>10) during our narrowband playback in 2014. A response to noise was recognized if a top model included dB or treatment. Responses to noise are indicated as positive (+), negative (-), or no response (blank). Further the model was interpreted only if it included informative parameters (Arnold 2010). The asterisk (*) indicates that 95% confidence intervals excluded zero.

Narrowband	Pitfall trap		Flying trap		Beat netting		All traps combined		Pitfall+Flying		B. netting+Flying		B. netting+Pitfall	
Family	dB	Treat	dB	Treat	dB	Treat	dB	Treat	dB	Treat	dB	Treat	dB	Treat
Acari							+*							
Acrididae														
Aeolothripidae			-											
Anthocoridae														
Anthomyiidae														
Aphididae														
Apidae			-											
Bombyliidae			+											
Braconidae														
Bucculatricidae														
Calliphoridae														
Carabidae							+							
Cecidomyiidae														
Ceraphronidae														
Cercopidae														
Chalcidoidea			-*											
Chironomidae														
Chloropidae			+*											
Chrysididae														
Chrysomelidae														
Cicadellidae							-*							
Coccinellidae														
Coleophoridae														
Collembola														
Crabronidae														
Curculionidae					-*									
Dermestidae														
Eulophidae			+*											
Formicidae							+							
Gelechiidae														
Geocoridae								-*						
Gnaphosidae														
Gracillariidae														
Halictidae			-*											
Hesperiidae				+*										
Ichneumonidae														
Linyphiidae														
Lycosidae														
Margarodidae														
Meloidae														
Melyridae							-*							
Miridae							+*							
Mutillidae														
Mythicomyiidae				-*										
Nabidae														
Noctuidae														
Ortheziidae					+									
Philodromidae														
Phoridae			+											
Pieridae														
Pompilidae														
Psocidae														
Psyllidae											-*			
Salticidae													+*	
Sarcophagidae							-*							
Scarabaeidae														
Sciaridae								+						
Sepsidae			-*											
Sphecidae									-					
Sphingidae				+*										
Tachinidae			-*											
Tenebrionidae							-*							
Thomisidae														
Thripidae			-*											
Tomoceridae														
Vespidae			-*											

Table S2.5.   Bias-corrected Akaike's Information Criterion value corrected for small sample size (AICc), the difference between a given model and the model with the lowest AICc value (ΔAICc), number of parameters (k), and the AICc weight (wi) of models for families with a response to noise during the narrowband playback in 2014.

Narrowband-2014					
Cicadellidae	df	logLik	AICc	delta	weight
dB+week	4	-3348.09	6704.3	0	1
week	3	-3362.73	6731.5	27.24	0
Treatment+week	4	-3362.58	6733.2	28.97	0
dB	3	-4491.15	8988.4	2284.08	0
treatment	3	-4745.54	9497.1	2792.85	0
Formicidae	df	logLik	AICc	delta	weight
dB+week	4	-2372.36	4752.8	0	0.47
week	3	-2373.58	4753.2	0.4	0.385
Treatment+week	4	-2373.53	4755.2	2.34	0.146
treatment	3	-2396.88	4799.8	47.01	0
dB	3	-2396.89	4799.8	47.02	0
Melyridae	df	logLik	AICc	delta	weight
dB+week	4	-5823.3	11654.7	0	1
Treatment+week	4	-5844.9	11697.9	43.19	0
week	3	-5847.31	11700.7	45.98	0
dB	3	-6129.72	12265.5	610.8	0
treatment	3	-6256.09	12518.2	863.54	0
Anthomyiidae	df	logLik	AICc	delta	weight
dB+week	4	-1917.12	3842.3	0	0.997
week	3	-1924.28	3854.6	12.29	0.002
Treatment+week	4	-1924.14	3856.4	14.03	0.001
dB	3	-2244.42	4494.9	652.56	0
treatment	3	-2300.91	4607.9	765.55	0
Miridae	df	logLik	AICc	delta	weight
dB+week	4	-1544.34	3096.8	0	0.604
week	3	-1546.44	3098.9	2.16	0.206
Treatment+week	4	-1545.5	3099.1	2.32	0.19
dB	3	-1725.44	3456.9	360.15	0
treatment	3	-1726.1	3458.3	361.48	0
Psyllidae	df	logLik	AICc	delta	weight
dB+week	4	-329.928	668.1	0	0.995
week	3	-337.005	680.1	12.07	0.002
Treatment+week	4	-336.034	680.3	12.21	0.002
dB	3	-339.457	685	16.97	0
treatment	3	-362.082	730.3	62.22	0

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Ortheziidae	df	logLik	AICc	delta	weight
dB+week	4	-428.346	864.9	0	0.548
week	3	-429.961	866.1	1.13	0.311
Treatment+week	4	-429.702	867.7	2.71	0.141
dB	3	-447.173	900.5	35.55	0
treatment	3	-453.503	913.2	48.21	0
Tenebrionidae	df	logLik	AICc	delta	weight
dB+week	4	-464.096	936.3	0	0.953
week	3	-468.765	943.6	7.3	0.025
Treatment+week	4	-467.874	943.8	7.56	0.022
dB	3	-504.735	1015.5	79.24	0
Treatment	3	-513.817	1033.7	97.4	0
Aeolothripidae	df	logLik	AICc	delta	weight
dB+week	4	-225.881	460.5	0	0.916
dB	3	-229.526	465.5	4.97	0.076
Treatment+week	4	-230.797	470.4	9.83	0.007
Week	3	-234.898	476.3	15.71	0
Treatment	3	-240.942	488.3	27.8	0
Sphecidae	df	logLik	AICc	delta	weight
dB	3	-225.473	457	0	0.375
Week	3	-225.961	458	0.98	0.23
dB+week	4	-225.236	458.6	1.59	0.17
treatment	3	-226.439	459	1.93	0.143
Treatment+week	4	-225.957	460.1	3.03	0.083
Carabidae	df	logLik	AICc	delta	weight
dB+week	4	-141.513	291.1	0	0.493
Week	3	-142.92	291.9	0.78	0.334
Treatment+week	4	-142.903	293.9	2.78	0.123
dB	3	-145.338	296.7	5.61	0.03
Treatment	3	-145.753	297.6	6.44	0.02
Sciaridae	df	logLik	AICc	delta	weight
Treatment+week	4	-126.667	261.4	0	0.597
Week	3	-128.637	263.3	1.9	0.23
dB+week	4	-127.908	263.9	2.48	0.173
treatment	3	-140.418	286.9	25.47	0
dB	3	-141.737	289.5	28.1	0
Sarcophagidae	df	logLik	AICc	delta	weight
dB	3	-138.545	283.1	0	0.64
dB+week	4	-138.457	285	1.86	0.253
treatment	3	-141.19	288.4	5.29	0.045
week	3	-141.191	288.4	5.29	0.045
Treatment+week	4	-141.188	290.5	7.32	0.016

Geocoridae	df	logLik	AICc	delta	weight
Treatment+week	4	-79.206	166.5	0	0.541
Week	3	-80.956	168	1.46	0.26
dB+week	4	-80.274	168.6	2.14	0.186
treatment	3	-84.4	174.9	8.35	0.008
dB	3	-85.131	176.3	9.81	0.004

Salticidae	df	logLik	AICc	delta	weight
dB+bare ground	4	-218.781	445.7	0	0.465
dB+week+ bare ground	5	-218.123	446.4	0.74	0.321
dB	3	-221.355	448.8	3.1	0.099
dB+week	4	-220.374	448.9	3.19	0.095
week	4	-222.142	452.4	6.72	0.016
Treatment+week	4	-224.685	457.5	11.81	0.001
Treatment	3	-225.928	457.9	12.25	0.001
Bare ground +week	4	-225.052	458.2	12.54	0.001
Treatment+week+ bare ground	5	-224.573	459.3	13.64	0.001
Treatment+ bare ground	4	-225.797	459.7	14.03	0

Acari	df	logLik	AICc	delta	weight
dB+week	4	-4130.93	8270	0	0.661
dB+week+moss	5	-4130.58	8271.3	1.34	0.339
Week	3	-4284.57	8575.2	305.24	0
Moss+week	4	-4284.09	8576.3	306.31	0
Treatment+week	4	-4284.33	8576.8	306.8	0
Treatment+week+moss	5	-4284.05	8578.2	308.28	0
dB	3	-4452.05	8910.2	640.21	0
dB+moss	4	-4451.58	8911.3	641.3	0
Treatment	3	-4530.5	9067	797.09	0
Treatment+moss	4	-4530.24	9068.6	798.62	0

Sphingidae	df	logLik	AICc	delta	weight
Treatment+week+sagebrush	5	-57.731	126.7	0	0.558
Treatment+week	4	-60.027	128.8	2.18	0.188
Week	3	-61.948	130.4	3.7	0.088
Sagebrush+week	4	-61.137	131.1	4.4	0.062
Treatment+sagebrush	4	-61.519	131.8	5.16	0.042
dB+week	4	-61.948	132.7	6.02	0.028
dB+week+sagebrush	5	-61.045	133.3	6.63	0.02
Treatment	3	-63.95	134.4	7.7	0.012
dB	3	-65.872	138.2	11.54	0.002
dB+sagebrush	4	-65.029	138.8	12.18	0.001

Halictidae	df	logLik	AICc	delta	weight
dB+week	4	-706.741	1422	0	0.484
Treatment+week	4	-707.099	1422.7	0.72	0.338

Week	3	-709.33	1425	2.96	0.11
Treatment	3	-710.02	1426.4	4.34	0.055
dB	3	-711.401	1429.1	7.11	0.014

Thripidae	df	logLik	AICc	delta	weight
dB+week	4	-873.993	1756.5	0	0.989
dB	3	-879.591	1765.5	8.98	0.011
week	3	-933.67	1873.7	117.14	0
Treatment+week	4	-933.471	1875.5	118.95	0
Treatment	3	-1001.48	2009.3	252.76	0

Hesperiidae	df	logLik	AICc	delta	weight
Treatment+week	4	-578.943	1166.4	0	0.923
Week	3	-583.056	1172.4	6.01	0.046
dB+week	4	-582.313	1173.2	6.74	0.032
dB	3	-797.834	1602	435.57	0
Treatment	3	-835.183	1676.7	510.27	0

Chalcidoidea	df	logLik	AICc	delta	weight
dB	3	-598.369	1203	0	0.653
dB+week	4	-597.91	1204.3	1.3	0.341
Week	3	-603.426	1213.2	10.11	0.004
Treatment+week	4	-603.414	1215.4	12.3	0.001
Treatment	3	-606.418	1219.1	16.1	0

Phoridae	df	logLik	AICc	delta	weight
dB	3	-44.631	95.6	0	0.34
Treatment	3	-44.865	96	0.47	0.269
Treatment+week	4	-44.367	97.3	1.69	0.146
dB.week	4	-44.416	97.4	1.78	0.139
Week	3	-45.791	97.9	2.32	0.106

Eulophidae	df	logLik	AICc	delta	weight
dB+week	4	-454.822	918.3	0	1
Week	3	-472.375	951.1	32.84	0
Treatment+week	4	-472.372	953.4	35.1	0
dB	3	-474.471	955.3	37.03	0
Treatment	3	-526.148	1058.7	140.39	0

Sepsidae	df	logLik	AICc	delta	weight
dB	3	-430.954	868.3	0	0.637
dB.week	4	-430.386	869.4	1.13	0.363
Week	3	-441.891	890.2	21.87	0
Treatment+week	4	-441.223	891.1	22.8	0
Treatment	3	-445.36	897.1	28.81	0

Apidae	df	logLik	AICc	delta	weight
dB+week	4	-334.175	676.9	0	0.614
week	3	-336.048	678.4	1.53	0.285

Treatment+week	4	-335.98	680.5	3.61	0.101
dB	3	-362.754	731.8	54.94	0
Treatment	3	-371.288	748.9	72.01	0
Chloropidae	df	logLik	AICc	delta	weight
dB	3	-431.047	868.5	0	0.718
dB+week	4	-430.856	870.3	1.87	0.282
week	3	-440.875	888.1	19.66	0
Treatment+week	4	-440.244	889.1	20.65	0
Treatment	3	-442.757	891.9	23.42	0
Bombyliidae	df	logLik	AICc	delta	weight
dB+week	4	-293.615	596.1	0	0.535
week	3	-295.241	597	0.91	0.34
Treatment+week	4	-295.069	599	2.91	0.125
dB	3	-347.335	701.2	105.1	0
Treatment	3	-371.34	749.2	153.11	0
Vespidae	df	logLik	AICc	delta	weight
dB+week	4	-190.715	390.1	0	1
week	3	-200.611	407.6	17.53	0
Treatment+week	4	-200.486	409.6	19.54	0
dB	3	-202.353	411.1	21.01	0
Treatment	3	-205.121	416.6	26.55	0
Mythicomyiidae	df	logLik	AICc	delta	weight
Treatment+week	4	-212.908	434.6	0	0.713
Week	3	-215.506	437.5	2.87	0.17
dB+week	4	-214.715	438.2	3.61	0.117
Treatment	3	-225.035	456.5	21.93	0
dB	3	-227.567	461.6	27	0
Tachinidae	df	logLik	AICc	delta	weight
dB	3	-96.705	199.7	0	0.443
dB+week	4	-95.655	199.8	0.12	0.418
Week	3	-98.357	203	3.3	0.085
Treatment+week	4	-97.933	204.4	4.67	0.043
Treatment	3	-100.388	207.1	7.37	0.011
Carabidae	df	logLik	AICc	delta	weight
dB+week	4	-104.634	217.5	0	0.382
Week	3	-105.837	217.8	0.32	0.325
Treatment+week	4	-105.803	219.8	2.34	0.119
dB	3	-106.935	220	2.52	0.108
Treatment	3	-107.42	221	3.49	0.067

Table S2.6.   A summary of the negative and positive responses to compressor station noise exposure we quantified from individual families (those with n>10) during our broadband playback in 2015. A response to noise was recognized if a top model included dB or treatment. Responses to noise are indicated as positive (+), negative (-), or no response (blank). Further the model was interpreted only if it included informative parameters (Arnold 2010). The asterisk (*) indicates that 95% confidence intervals excluded zero.

Broadband Family	Pitfall trap		Flying trap		Beat netting		All traps combined		Pitfall+Flying		B. netting+Flying		B. netting+Pitfall	
	dB	Treat	dB	Treat	dB	Treat	dB	Treat	dB	Treat	dB	Treat	dB	Treat
Acari							-*							
Acrididae														
Aeolothripidae														
Agromyzidae			-											
Anthocoridae														
Anthomyiidae														
Aphididae														
Apidae														
Araneidae														
Bethylidae														
Bombyliidae														
Braconidae														
Calliphoridae			-*											
Carabidae														
Cecidomyiidae														
Cerambycidae														
Cercopidae														
Chalcidoidea			+*											
Chironomidae											-			
Chloropidae			+*											
Chrysididae							+*							
Chrysomelidae														
Cicadellidae							-*							
Coccinellidae														
Coleophoridae				+										
Collembola														
Crabronidae														
Dermestidae								+						
Elateridae														
Entomobryidae	+													
Eulophidae			-*											
Formicidae							+*							
Gelechiidae				+										
Gnaphosidae														+*
Halictidae														
Hesperiidae														
Ichneumonidae														
Isotomidae												+		
Liposcelididae	+*													
Lygaeidae								+						
Margarodidae														
Megachilidae			-											
Melyridae							-*							
Miridae							+*							
Muscidae														
Mutillidae									+					
Mythicomyiidae														
Nabidae														
Ortheziidae														
Phoridae														
Platygastridae			-											
Pompilidae														
Psocidae														
Psyllidae												+		
Rhaphidophoridae														
Salticidae														+*
Sarcophagidae														
Sciaridae							+*							
Sepsidae			-											
Sminthuridae														
Sphecidae														
Syrphidae														
Tachinidae			-											
Tenebrionidae							+*							
Thomisidae														
Thripidae			-*											
Trichogrammatidae														
Vespidae														

Table S2.7. Bias-corrected Akaike's Information Criterion value corrected for small sample size (AICc), the difference between a given model and the model with the lowest AICc value (ΔAICc), number of parameters (k), and the AICc weight (wi) of models for families with a response to noise during the broadband playback in 2015.

Broadband-2015				
Chalcidoidea	df	AICc	delta	weight
dB	3	10944.6	0	0.717
dB+week	4	10946.5	1.86	0.283
Treatment	3	11060.9	116.28	0
Treatment+week	4	11063	118.35	0
Week	3	11063.1	118.46	0
Miridae	df	AICc	delta	weight
dB+week	4	4452.9	0	1
Week	3	4469.4	16.47	0
Treatment+week	4	4470.6	17.67	0
dB	3	4503.8	50.95	0
Treatment	3	4525.4	72.48	0
Tenebrionidae	df	AICc	delta	weight
dB+week	4	695.9	0	0.571
Treatment+week	4	697.5	1.64	0.251
Week	3	698.3	2.4	0.172
dB	3	705.5	9.61	0.005
Treatment	3	707.7	11.78	0.002
Sciaridae	df	AICc	delta	weight
Treatment+week	4	745.6	0	0.715
dB+week	4	748.7	3.04	0.156
Week	3	749.1	3.44	0.128
Treatment	3	766.2	20.61	0
dB	3	769	23.39	0
Salticidae	df	AICc	delta	weight
Treatment+week	4	300.7	0	0.645
dB+week	4	302.2	1.43	0.315
Week	3	306.9	6.15	0.03
Treatment	3	309.9	9.18	0.007
dB	3	311.3	10.58	0.003
Mutillidae	df	AICc	delta	weight
dB+week	4	168.5	0	0.457
week	3	169.2	0.77	0.311
Treatment+week	4	170.1	1.61	0.204
dB	3	174.8	6.31	0.019
Treatment	3	176.5	8.05	0.008

Megachilidae	df	AICc	delta	weight
dB+week	4	120.5	0	0.386
Week	3	120.7	0.25	0.34
Treatment+week	4	121.6	1.15	0.217
dB	3	125.4	4.88	0.034
Treatment	3	126	5.54	0.024
Melyridae	df	AICc	delta	weight
dB+week	4	45545.8	0	0.539
dB+week+moss	5	45546.1	0.31	0.461
Week	3	45563.9	18.1	0
Moss+week	4	45565.1	19.36	0
Treatment+week	4	45565.8	19.98	0
Treatment+week+moss	5	45567.1	21.36	0
Treatment	3	45927.1	381.28	0
dB	3	45927.1	381.34	0
dB+moss	4	45928.3	382.51	0
Treatment+moss	4	45928.4	382.62	0
Formicidae	df	AICc	delta	weight
dB+week+sagebrush	5	14472.6	0	0.987
dB+week	4	14481.3	8.71	0.013
Sagebrush+week	4	14638.4	165.79	0
Treatment+week+sagebrush	5	14639.9	167.3	0
Week	3	14652.6	179.97	0
Treatment+week	4	14653.4	180.8	0
dB+sagebrush	4	14723.2	250.55	0
dB	3	14730.6	257.98	0
Treatment+sagebrush	4	15021.1	548.5	0
Treatment	3	15034.5	561.83	0
Eulophidae	df	AICc	delta	weight
dB+week+moss	5	2960.8	0	0.576
dB+week	4	2962.5	1.73	0.243
Moss+week	4	2964	3.21	0.116
Treatment+week+moss	5	2966.1	5.3	0.041
Week	3	2967.9	7.1	0.017
Treatment+week	4	2969.4	8.66	0.008
dB+moss	4	3316.3	355.5	0
dB	3	3321.2	360.39	0
Treatment+moss	4	3323.5	362.78	0
Treatment	3	3326.9	366.12	0
Liposcelididae	df	AICc	delta	weight
dB+week+moss	5	426.7	0	0.424
Treatment+week+moss	5	427.1	0.42	0.344
Moss+week	4	428.2	1.5	0.2

	df	AICc	delta	weight
dB+moss	4	432.7	6.07	0.02
Treatment+moss	4	434.2	7.59	0.01
Week	3	438.5	11.88	0.001
dB+week	4	440.6	13.92	0
Treatment+week	4	440.6	13.94	0
dB	3	447.2	20.56	0
Treatment	3	447.5	20.87	0

Gnaphosidae	df	AICc	delta	weight
Treatment+moss	4	312.8	0	0.38
dB+moss	4	313.4	0.6	0.282
Treatment+week+moss	5	314.7	1.96	0.143
dB+week+moss	5	315.4	2.61	0.103
Treatment	3	318.1	5.34	0.026
dB	3	318.8	6	0.019
Moss+week	4	318.8	6.02	0.019
Week	3	319.8	7.02	0.011
Treatment+week	4	320	7.27	0.01
dB+week	4	320.8	7.98	0.007

Dermestidae	df	AICc	delta	weight
Treatment+week+grasses	5	396.1	0	0.33
Grasses+week	4	396.2	0.1	0.313
dB+week+greasses	5	397	0.96	0.204
Treatment+week	4	399.2	3.18	0.067
Week	3	399.9	3.82	0.049
dB+week	4	400.5	4.38	0.037
Treatment+grasses	4	420.1	24	0
dB+grasses	4	421.3	25.25	0
Treatment	3	423.4	27.29	0
dB	3	424.9	28.87	0

Acari	df	AICc	delta	weight
dB+week	4	5706.2	0	0.603
dB+week+grasses	5	5707	0.84	0.397
Treatment+week	4	5736.3	30.1	0
Treatment+week+grasses	5	5737.6	31.42	0
Week	3	5741.7	35.47	0
Grasses+week	4	5742.5	36.36	0
dB	3	5805.6	99.41	0
dB+grasses	4	5806.5	100.27	0
Treatment	3	5814.4	108.18	0
Treatment+grasses	4	5815.7	109.52	0

Cicadellidae	df	AICc	delta	weight
dB+week	4	3850.1	0	0.447
dB+week+grasses	5	3850.2	0.09	0.427

	df	AICc	delta	weight
Grasses+week	4	3854	3.98	0.061
Week	3	3855.5	5.43	0.03
Treatment+week+grasses	5	3856	5.93	0.023
Treatment+week	4	3857.2	7.14	0.013
dB+grasses	4	3968	117.93	0
dB	3	3968.6	118.5	0
Treatment+grasses	4	3969.2	119.15	0
Treatment	3	3970.1	119.99	0
Calliphoridae	df	AICc	delta	weight
dB+week+grasses	5	8086.8	0	0.654
dB+week	4	8089.1	2.31	0.206
Grasses+week	4	8091.3	4.42	0.072
Treatment+week+grasses	5	8093	6.2	0.029
Week	3	8093.3	6.44	0.026
Treatment+week	4	8094.7	7.86	0.013
dB+grasses	4	8212.3	125.46	0
dB	3	8214.7	127.91	0
Treatment+grasses	4	8217.7	130.84	0
Treatment	3	8219.4	132.6	0
Agromyzidae	df	AICc	delta	weight
dB+week+bare ground	5	233.1	0	0.305
dB+bare ground	4	233.4	0.26	0.268
Bare ground+week	4	234.2	1.05	0.18
Treatment+bare ground	4	235.6	2.42	0.091
Treatment+week+bare ground	5	236	2.91	0.071
dB	3	238	4.86	0.027
dB+week	4	238.1	4.95	0.026
Week	3	239.4	6.29	0.013
Treatment	3	239.6	6.5	0.012
Treatment+week	4	240.6	7.49	0.007
Tachinidae	df	AICc	delta	weight
dB+week+bare ground	5	895.2	0	0.302
dB+week	4	895.5	0.3	0.26
Bare ground+week	4	896.3	1.1	0.174
Week	3	896.6	1.41	0.149
Treatment+week+bare ground	5	898.5	3.27	0.059
Treatment+week	4	898.6	3.4	0.055
dB+bare ground	4	910.2	15	0
dB	3	911.3	16.09	0
Treatment+bare ground	4	913.6	18.35	0
Treatment	3	914.4	19.21	0

Thripidae	df	AICc	delta	weight
dB+week	4	2647.5	0	0.399
dB+week+bare ground	5	2647.7	0.19	0.364
Treatment+week	4	2650.6	3.08	0.086
Treatment+week+bare ground	5	2650.9	3.37	0.074
Bare ground+week	4	2651.8	4.28	0.047
Week	3	2652.6	5.13	0.031
dB+bare ground	4	2922.3	274.84	0
dB	3	2923.2	275.67	0
Treatment+bare ground	4	2927	279.49	0
Treatment	3	2927.7	280.24	0
Chrysididae	df	AICc	delta	weight
dB	3	378.8	0	0.254
dB+sagebrush	4	379.4	0.53	0.195
Treatment	3	380.1	1.28	0.134
dB+week	4	380.6	1.73	0.107
Treatment+sagebrush	4	380.6	1.78	0.104
dB+week+sagebrush	5	381.1	2.27	0.082
Treatment+week	4	381.7	2.84	0.061
Treatment+week+sagebrush	5	382.3	3.42	0.046
Week	3	385.5	6.62	0.009
Sagebrush+week	4	386.1	7.29	0.007
Gelechiidae	df	AICc	delta	weight
Treatment+week	4	306	0	0.22
Week	3	306.1	0.05	0.215
Treatment+week+sagebrush	5	306.6	0.56	0.167
Sagebrush+week	4	306.6	0.62	0.161
dB+week	4	307.2	1.19	0.121
dB+week+sagebrush	5	307.8	1.74	0.092
Treatment+sagebrush	4	312.6	6.57	0.008
Treatment	3	312.9	6.92	0.007
dB+sagebrush	4	313.8	7.76	0.005
dB	3	314	7.94	0.004
Sepsidae	df	AICc	delta	weight
dB+week	4	508	0	0.274
week	3	508.4	0.39	0.226
Sagebrush+week	4	509.1	1.07	0.16
dB+week+sagebrush	5	509.5	1.47	0.131
Treatment+week	4	509.5	1.51	0.129
Treatment+week+sagebrush	5	510.5	2.48	0.079
Treatment+sagebrush	4	826.6	318.55	0
dB+sagebrush	4	827.1	319.07	0

	df	AICc	delta	weight
Treatment	3	831	323.01	0
dB	3	831.6	323.55	0
Chloropidae	**df**	**AICc**	**delta**	**weight**
dB+week+sagebrush	5	1261.5	0	0.685
dB+week	4	1263	1.55	0.315
Treatment+week+sagebrush	5	1280.8	19.33	0
Sagebrush+week	4	1280.8	19.37	0
Week	3	1283.3	21.87	0
Treatment+week	4	1283.5	22.07	0
dB+sagebrush	4	1375.8	114.34	0
dB	3	1376.9	115.48	0
Treatment+sagebrush	4	1395.6	134.12	0
Treatment	3	1397.3	135.82	0
Psyllidae	**df**	**AICc**	**delta**	**weight**
Treatment+week	4	386.2	0	0.395
Week	3	386.3	0.03	0.389
dB+week	4	387.4	1.21	0.216
Treatment	3	502.8	116.58	0
dB	3	504.2	118.01	0
Coleophoridae	**df**	**AICc**	**delta**	**weight**
Treatment+week	4	122.4	0	0.568
Week	3	123.8	1.43	0.278
dB+week	4	125	2.61	0.154
Treatment	3	140.5	18.06	0
dB	3	143.2	20.77	0
Lygaeidae	**df**	**AICc**	**delta**	**weight**
Treatment+week	4	333.2	0	0.413
Week	3	333.5	0.21	0.372
dB+week	4	334.7	1.4	0.205
Treatment	3	341	7.78	0.008
dB	3	343.3	10.08	0.003
Entomobryidae	**df**	**AICc**	**delta**	**weight**
dB+sagebrush	4	6886.4	0	0.423
dB+week+sagebrush	5	6888	1.61	0.189
Treatment+sagebrush	4	6888.7	2.36	0.13
Sagebrush+week	4	6889.1	2.69	0.11
Treatment+week+sagebrush	5	6890.7	4.34	0.048
dB	3	6890.8	4.43	0.046
dB+week	4	6892.4	6.01	0.021
Treatment	3	6893.1	6.71	0.015
Week	3	6893.5	7.16	0.012
Treatment+week	4	6895	8.67	0.006
Platygastridae	**df**	**AICc**	**delta**	**weight**

	df	AICc	delta	weight
dB	3	280.5	0	0.409
Treatment	3	281.8	1.29	0.215
dB+week	4	281.9	1.41	0.203
Week	3	283.4	2.85	0.098
Treatment+week	4	283.9	3.39	0.075

Table S2.8. **Bias-corrected Akaike's Information Criterion value corrected for small sample size (AICc), the difference between a given model and the model with the lowest AICc value (ΔAICc), number of parameters (k), and the AICc weight (wi) of models for guild grouping strategy with a response to noise during the narrowband and broadband playback.**

Narrowband-2014				
Scavengers	df	AICc	delta	weight
dB+week	4	4094.2	0	0.994
Week	3	4105.5	11.3	0.003
Treatment+week	4	4105.9	11.65	0.003
dB	3	4168.9	74.72	0
Treatment	3	4218.1	123.93	0
Borer	df	AICc	delta	weight
dB+week	4	213452.9	0	1
Treatment+week	4	213515.6	62.72	0
Week	3	213516.5	63.58	0
dB	3	215466.4	2013.51	0
Treatment	3	215930.5	2477.62	0
Grazer	df	AICc	delta	weight
dB+week	4	39070.9	0	1
week	3	39092	21.13	0
Treatment+week	4	39092.8	21.94	0
dB	3	40019.9	949.07	0
Treatment	3	40228.6	1157.69	
Omnivore	df	AICc	delta	weight
dB+week	4	1054.1	0	0.946
week	3	1060.9	6.84	0.031
Treatment+week	4	1061.6	7.46	0.023
dB	3	1133.6	79.46	0
Treatment	3	1150.4	96.33	0
Pollinator	df	AICc	delta	weight
Treatment+week	4	11526.1	0	0.486
Week	3	11527.3	1.13	0.276
dB+week	4	11527.6	1.42	0.239
Treatment	3	11574.6	48.47	0
dB	3	11576.2	50.06	0
Predator	df	AICc	delta	weight
dB+week	4	31379.7	0	0.999
Treatment+week	4	31393.2	13.47	0.001

Week	3	31396.5	16.81	0
dB	3	31786.3	406.62	0
Treatment	3	31912.9	533.21	0
Scavenger	df	AICc	delta	weight
dB+week	4	4094.2	0	0.994
Week	3	4105.5	11.3	0.003
Treatment+week	4	4105.9	11.65	0.003
dB	3	4168.9	74.72	0
Treatment	3	4218.1	123.93	0

Broadband-2015				
Detritivore	df	AICc	delta	weight
dB+week	4	78642.1	0	1
Week	3	78683.6	41.44	0
Treatment+week	4	78685.1	42.92	0
dB	3	87615.6	8973.41	0
Treatment	3	87676.6	9034.43	0
Grazer	df	AICc	delta	weight
dB+week	4	76325.3	0	1
Week	3	76391.4	66.09	0
Treatment+week	4	76393.2	67.87	0
dB	3	77206.2	880.89	0
Treatment	3	77369.1	1043.75	0
Omnivore	df	AICc	delta	weight
dB+week	4	695.9	0	0.571
Treatment+week	4	697.5	1.64	0.251
Week	3	698.3	2.4	0.172
dB	3	705.5	9.61	0.005
Treatment	3	707.7	11.78	0.002
Parasite	df	AICc	delta	weight
dB+week	4	49838.5	0	1
week	3	49860.3	21.8	0
Treatment+week	4	49861.1	22.61	0
dB	3	49891.7	53.16	0
Treatment	3	49907.4	68.92	0
Pollinator	df	AICc	delta	weight
dB+week	4	19111.1	0	0.627
dB	3	19112.5	1.39	0.314
week	3	19116.9	5.77	0.035
Treatment+week	4	19118.9	7.78	0.013
Treatment	3	19119.2	8.13	0.011
Predator	df	AICc	delta	weight
dB+week	4	102478.2	0	1
week	3	102499.7	21.51	0
Treatment+week	4	102501.6	23.41	0

dB	3	102876.1	397.9	0
Treatment	3	102876.6	398.38	0
SapFeeder	df	AICc	delta	weight
dB+week	4	16656.8	0	0.998
Week	3	16669.8	12.98	0.002
Treatment+week	4	16671.3	14.45	0.001
dB	3	17787.7	1130.89	0
Treatment	3	17828.9	1172.06	0
Scavenger	df	AICc	delta	weight
dB+week	4	15443.1	0	0.849
week	3	15447.3	4.22	0.103
Treatment+week	4	15448.8	5.75	0.048
dB	3	15709.8	266.75	0
Treatment	3	15712.8	269.75	0

Table S2.9.   Arthropod families found in the diet of the three songbird species that were negatively affected by the broadband playback in 2015 (Rotenberry 1980) (Wiens and Rotenberry 1979)(see Chapter 1). Families that were collected in our study during the broadband playback (†), and families that were affected by noise positively (+), or negatively (-) during the broadband playback.

Families found in songbird's diet	Present in our study	Families affected by noise	Families found in songbird's diet	Present in our study	Families affected by noise
Acrididae	†		Histeridae		
Anthicidae			Ichneumonidae	†	
Apidae	†		Lygaeidae	†	+
Araneida	†		Membracidae		
Cantharidae			Miridae	†	+
Carabidae	†		Pentatomidae	†	
Cerambycidae	†		Phymatidae		
Chrysomelidae	†		Raphidiidae		
Cicadellidae	†	-	Scarabaeidae	†	
Cicadidae			Scutelleridae		
Coccidae			Solpugidae		
Coccinellidae	†		Sphecidae	†	
Coreidae			Staphylinidae	†	
Curculioliidae	†		Tenebrionidae	†	+
Diplopoda			Tettigoniidae		
Elateridae	†		Tingidae		
Formicidae	†	+	Tipulidae	†	
Gryllidae			Zygoptera		
Halictidae	†				

CONCLUSION

Since the Industrial Revolution, noise produced by humans has increased globally. Anthropogenic noise now shapes natural soundscapes in many ecosystems. In this research, I focused on the effects of oil and gas development on wildlife, specifically, noise from gas compressor stations. Using speaker arrays, I replicated noise from gas compressor stations, creating a phantom natural gas field, and tested the effects on songbird and arthropod distributions. Our experiment encompassed approximately 100 km^2, and the gradient of background noise ranged from ~30 dB(A) to 65 dB(A).

The abundance of all songbird species combined decreased by 14.37% under the broadband playback. Two species, sagebrush sparrow (*Artemisiospiza nevadensis*), and Brewer's sparrow (*Spizella breweri*), were highly impacted by noise, decreasing over 20% at our noise sites. Western meadowlark (*Sturnella neglecta*) decreased 38% per ~9 dB. Under the influence of the narrowband playback, only Brewer's sparrow distributions decreased 14.8% in noise, and only at the 50 m survey locations. These results indicate that abundance was markedly affected by exposure to the broadband treatment.

During the broadband playback in 2015, I aimed to study the consequences of gas compressor noise on Brewer's sparrows that remain at the noise sites. I nest searched and measured Brewer's sparrow territory size to get a holistic understanding of the effects of noise on breeding success and male behavior. Due to small sample size, we were not able to accomplish this goal. To ameliorate this problem in a future experiment, we would

place camera traps at each nest to obtain better information about nest predation, parental behavior (e.g. male nest visitation), and breeding success.

I was not able to discern the effects of noise on vertebrate predators that feed on songbird eggs, such as ground squirrels and snakes. Francis et al. in 2009 demonstrated that a decrease in an avian nest predator, due to its evasion of anthropogenic noise, can benefit a songbird species by release from predation. Although in our two year study I did not observe any positive association of noise on any of the five songbird species that we studied, it would be interesting to analyze species interactions under longer term noise exposure (>5 years). Results from both playbacks indicate that different noise sources affect songbird species differently, and could cascade into other trophic levels, such as arthropods.

Our phantom natural gas field also changed the abundance of many arthropod groups. Under increasing levels of the narrowband playback, most of the foraging groups decreased in abundance. There was a marked switch under increasing levels of the broadband playback, as I observed an increase in abundance of most of the foraging groups.

Changes in avian species regimes that feed entirely on arthropods during the breeding season could have released arthropods from predation. This hypothesis would explain the switch in arthropod abundance that we observed under the broadband playback. However, even though we have some information about songbird diet, our experiment does not verify the connection between songbird and arthropod abundance, and further work would be necessary to find strong support for the release from predation hypothesis.

In 2015, during the broadband playback, I trapped and collected Brewer's sparrow guano for further diet analysis. Although I was only able to collect guano samples from one species, these results could provide the information necessary to link birds and arthropods. I was not able to trap other species like sage thrashers or western meadow larks, due to our songbird trapping techniques.

I believe that the decrease in arthropod abundance that I observed during the narrowband playback in 2014 was caused by a direct effect of noise on arthropods. I present arthropod distribution data, but I do not know what mechanism is behind a change in arthropod abundance. We have little knowledge about the effects of anthropogenic noise on arthropod behavior. Future studies should include laboratory work where different arthropod families are exposed to noise. Measuring foraging behavior, predator-prey interactions or courtship behavior under these conditions would provide important information on the effects of noise on invertebrates.

My findings are key to understanding the consequences of noise from oil and gas development have on ecosystems, and add significant knowledge to previous oil and gas development literature. My experiment confirms that noise alone (excluding other confounding variables such as air pollution) recreates the patterns of songbird distributions (Gilbert & Chalfoun 2011) (Bayne et al. 2008) (Francis et al. 2009), and possibly other vertebrates (Northrup & Wittemyer 2013) found in 'real' natural gas fields.

My research is important for management decisions regarding future oil and gas development and current noise mitigation policies in existing well pads. The data I presented are from the sagebrush steppe, only one of the many ecosystems that exist on Earth. Given that each ecosystem functions differently, and have each own species and

food webs, future research should be focused on those ecosystems that are threaten by natural gas extraction. In a world where natural sounds used to shape the environment, this research shows the importance of understanding the widespread effects of anthropogenic noise on wildlife.