ECOSYSTEM SERVICES PROVIDED BY SOUNDSCAPES LINK PEOPLE AND WILDLIFE

by

Mitchell Jerome Levenhagen

A thesis
submitted in partial fulfillment
of the requirements for the degree of
Master of Science in Biology
Boise State University

May 2019

BOISE STATE UNIVERSITY GRADUATE COLLEGE

DEFENSE COMMITTEE AND FINAL READING APPROVALS

of the thesis submitted by

Mitchell Jerome Levenhagen

Thesis Title: Ecosystem Services Provided by Soundscapes Link People and Wildlife

Date of Final Oral Examination: 11 March 2019

The following individuals read and discussed the thesis submitted by student Mitchell Jerome Levenhagen, and they evaluated his presentation and response to questions during the final oral examination. They found that the student passed the final oral examination.

Jesse R. Barber, Ph.D.	Chair, Supervisory Committee
Julie Heath, Ph.D.	Member, Supervisory Committee
Neil Carter, 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.

ACKNOWLEDGEMENTS

I thank Zach Miller, Dylan Gomes, B. Derrick Taff, Yau-Huo (Jimmy) Shr, Crow White, Kurt Fristrup, Chris Monz, Chris McClure, Peter Newman, and Clint Francis for study design, implementation, and data interpretation. Thank you to Julie Heath and Neil Carter for providing comments on this manuscript. We thank the National Park Service and all park rangers at Muir Woods National Monument and Grand Teton National Park for access to each park unit and assistance in project facilitation. Thanks to Robin Barber, Lauren Furguson, Heather Costigan, Alissa Graunke, Elizeth Cinto Mejía, Colleen Asher, Carlie Levenhagen, Ashley Pipkin, Shan Burson, and Hunter Cole for their assistance in project set up, data collection, and/or project facilitation. A special thanks to all those past and present who work to protect and conserve all natural areas.

This study was funded by the Dynamics of Coupled Natural and Human Systems branch of the National Science Foundation. We also thank the University of Wyoming National Park Service Research Center for awarding a grant covering field housing costs during data collection while at Grand Teton National Park.

ABSTRACT

Protected natural areas are not free from noise exposure, both external to and within park boundaries. Natural soundscapes are important in animal life histories, provide positive visitor experiences, and may increase motivation to protect natural areas. To examine the potential coupling of natural and human systems via the soundscape and the use of signs as an effective anthropogenic noise mitigation strategy, we experimentally introduced educational and enforcement signage along a trail and road system in an alternating, weeklong block design within Muir Woods National Monument, CA and Grand Teton National Park, WY, respectively. In Grand Teton National Park, speed limits were reduced from 45 mph to 25 mph during sign present blocks. We continuously recorded background sound levels while conducting bird point counts and visitor-intercept surveys along each experimental corridor to assess possible linkages between the natural and human worlds via the soundscape. Sound levels were significantly lower during sign present weeks in both park units; however, bird count only decreased in response to background sound levels within the trail system. Visitor perception of bird biodiversity was positively influenced in part by mitigation signage (Muir Woods National Monument) and decreasing sound levels (Grand Teton National Park). Soundscape pleasantness rankings increased as sound levels decreased in the trail system alone. In both locations, the majority of sign mitigation strategies presented were preferred by visitors, and these preferences increased when signs were physically present, indicating sign mitigation increased conservation support by visitors. From this work, we demonstrate complete positive feedback loops between human and natural systems via the soundscape in Muir Woods National Monument. In Grand Teton National Park, we provide evidence of a positive feedback loop within the human system. We show that signs increased visitor experiences and conservation support through reduced anthropogenic noise, improved access to natural sounds, and allowed for a greater ‘carrying capacity’ of visitors through reduced human-created noises. Noise can be mitigated through sign use, but desired positive outcomes may depend on the context of the location and type of noise exposure.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AIC	Akaike's Information Criterion
ANOVA	Analysis of Variance
AOV	Analysis of Variance
ARU	Acoustic Recording Unit
dBA	A-weighted decibels
GAM	Generalized Additive Model
L50	Noise level exceed 50% of the time for the measurement duration
NPS	National Park Service

INTRODUCTION

There is currently very strong evidence that anthropogenic noise negatively affects wildlife (reviewed in Francis and Barber, 2013; Shannon et al., 2016), with transportation networks a prevalent source (Barber, Crooks, and Fristrup 2010). In addition to wildlife, visitor experiences in protected natural areas are also negatively affected by human-created noises (E. J. Pilcher, Newman, and Manning 2009; Weinzimmer et al. 2014; Tarrant, Haas, and Manfredo 1995). Increased anthropogenic noise may contribute to a reduction in nature experience for people, not only reducing health and well-being benefits due to a loss of these interactions, but potentially leading to apathy towards nature through reduced or missed opportunities for positive nature experiences (Soga and Gaston 2016). A call by researchers has been made to reverse this trend and improve beneficial opportunities for nature interaction so as to instill an appreciation for, and willingness to conserve, natural areas where such opportunities exist (Hartig et al. 2014; Soga and Gaston 2016; Frumkin et al. 2017; Seymour 2016). By further investigating the positive benefits of natural sounds, changes in public policy related to anthropogenic noise could be made based off a public value in diminished noise exposure and quieter natural spaces (Zevitas, Cybulski, and McNeely 2012).

Interactions between humans and natural systems are complex and have the potential to create feedback loops (J. Liu et al. 2007). These associated feedback loops can be either positive or negative, and the sounds present in the soundscape can elicit both negative and positive physiological and psychological reactions in human individuals.

Researchers found several negative auditory and non-auditory effects of noise in people, from hearing loss and annoyance to increased risk of cardiovascular disease, decreased cognitive performance, and increased sleep disturbance (reviewed in Basner *et al.*, 2014). On the other hand, natural sounds have many benefits including improving mood (Benfield, Taff, et al. 2014; Bratman, Hamilton, and Daily 2012) and cognitive performance (Abbott et al. 2016). Nature experience is also shown to have positive effects on memory, attention, concentration, and impulse inhibition (Bratman et al. 2012).

Several studies suggest that traffic, as well as conversational, noise have major impacts on animal abundance and species richness (Fahrig and Rytwinski 2009; Karp and Guevara 2010; Benítez-López, Alkemade, and Verweij 2010). Traffic noise near protected areas is also believed to be a contributing source of habitat degradation that can lead to reduced biodiversity protection (Arévalo and Blau 2018). Researchers have demonstrated over a one-quarter decline in bird abundance and almost complete avoidance in some migratory songbird species in response to traffic noise playback (Mcclure et al. 2013). Even greater declines in bird count and species richness have also been found in a study using conversational noise playback.

Protected parks, one such area where people may go for wildlife experiences and restorative benefits, cannot escape exposure to anthropogenic noise (Barber et al. 2011; Lynch, Joyce, and Fristrup 2011; Buxton et al. 2017). In response, parks such as Muir Woods National Monument have begun to implement soundscape management strategies and measure noise acceptability levels among park goers (E. Pilcher, Newman, and Stack 2007; Marin et al. 2011; Stack et al. 2011). However, what remains unclear is the effectiveness of signs as a noise mitigation strategy and to what degree acoustics mediate visitor interactions with wildlife. This study aims to better understand the interface and relationships of anthropogenic noise, wildlife, and human experience.

CHAPTER ONE CONTRIBUTORS

This manuscript is prepared for submission at *Nature Sustainability*. The title of the manuscript is *Ecosystem Services Provided by Soundscapes Link People and Wildlife*. The author list for this manuscript includes the following individuals: Mitchell J. Levenhagen[1], Zachary D. Miller[2], Dylan G.E. Gomes[1], Alissa R. Graunke[3], Lauren A. Ferguson[2,a], Yau-Huo (Jimmy) Shr[2,b], B. Derrick Taff[2], Crow White[3], Kurt Fristrup[4], Christopher Monz[5], Christopher J.W. McClure[1,6], Peter Newman[2], Clinton D. Francis[3], Jesse R. Barber[1]. M.J.L., B.D.T., C.W., K.F., C.M., P.N., C.D.F., and J.R.B. designed the research. M.J.L, A.R.G., and L.C.A. collated the data. M.J.L., Z.D.M., D.G.E.G., Y.S. and C.J.W.M. analyzed and visualized the data. M.J.L. and J.R.B. lead the writing of the manuscript and all authors contributed to text and review.

Affiliations:

[1]Department of Biological Sciences, Boise State University, Boise, ID 83725, USA

[2]Department of Recreation, Park and Tourism Management, Penn State University, University Park, PA 16802, USA

[3]Department of Biological Sciences, California Polytechnic State University, San Luis Obispo, CA 93407, USA

[4]Natural Sounds and Night Skies Division, National Park Service, Fort Collins, CO 80525, USA

[5]Department of Environment and Society, Utah State University, Logan, UT 84322, USA

[6]The Peregrine Fund, Boise, ID 83709, USA

[a]Now affiliated with the Department of Recreation Management and Policy, University of New Hampshire, Durham, NH 03824, USA

[b]Now affiliated with the Department of Economics, Iowa State University, Ames, IA 50011, USA

CHAPTER ONE

Ecosystem services provided by soundscapes link people and wildlife

Global urbanization and sprawl are increasing at unprecedented rates. By 2050, 66% of human beings are expected to live in urban areas, compared to just 30% in 1950 (United Nations 2015). Not only are more people living in cities and greater metropolitan areas, but larger numbers of individuals are inhabiting regions that abut and expand into wildlands (Theobald and Romme 2007). With this inward and outward growth comes increased home densities, road networks, and energy infrastructure that create substantial human-generated noise, affecting both people and wildlife in primarily negative ways.

Anthropogenic noise is a negative byproduct of development and a cause for many to seek out experiences with nature free from this din (Gidlöf-Gunnarsson and Öhrström 2007). Human experience with the natural world can influence an individual’s emotional affinity for, and positive emotions, attitudes, and behaviors toward, nature and the environment (Soga and Gaston 2016). An extinction of experience with nature and a loss of emotional affinity for nature can result in the loss of an individual’s personal connection to the environment and the motivation to visit and protect natural areas (Soga and Gaston 2016). Such meaningful interactions with nature and wildlife are crucial for preventing a negative feedback loop of disaffection towards nature, and conversely, to engender broad-based support for measures that protect natural areas and conserve biodiversity (Francis et al. 2017; J. R. Miller 2005).

Human-caused noise has recently emerged as a clear threat to natural systems (Barber et al. 2010; Kight and Swaddle 2011; Francis and Barber 2013; Shannon et al. 2016; Potvin 2016). Effects of anthropogenic noise on wildlife include compromised foraging behavior, shifted temporal activity patterns, decreased abundance, reduced body condition, and altered reproductive success (Francis and Barber 2013; Shannon et al. 2016). Humans also experience many harmful impacts due to elevated background sound levels including increased stress, sleep disturbance, fatigue, elevated blood pressure, and increased risk of heart attack (Goines and Hagler 2007; Hammer, Swinburn, and Neitzel 2014).

Natural sounds are shown to facilitate stress recovery (Ulrich et al. 1991; Alvarsson, Wiens, and Nilsson 2010), improve cognitive performance (Abbott et al. 2016), enhance emotional affect (Benfield, Nurse, et al. 2014), and have other restorative effects in people (Kaplan 1995). These cognitive and emotional benefits derived from interactions with nature are important psychological ecosystem services provided by biodiversity (Bratman et al. 2012). Psychologically restorative environments are achieved not through absolute silence, but rather by the presence of sounds with natural acoustic properties (De Coensel and Botteldooren 2006) and stimuli compatible with the environmental setting experienced (Laumann, Gärling, and Stormark 2001). Natural sounds fundamentally influence positive ratings of soundscape pleasantness (Hong and Jeon 2015).

Visitors to protected natural areas often seek opportunities to experience wildlife (Siikamäki et al. 2015) and pleasant soundscapes congruent to the area they are visiting (Haas and Wakefield 1998; McDonald, Baumgartner, and Iachan 1995); however, acoustic environments in protected natural areas are threatened by noise exposure from anthropogenic activities external to and within park boundaries (Barber et al. 2011). Nearly two-thirds of protected natural areas in the conterminous U.S. experience a doubling, and approximately one-fifth of areas experience a ten-fold increase or greater, in background sound levels due to human activities (Buxton et al. 2017). Visitor experiences in protected natural areas are negatively impacted by noise (E. J. Pilcher et al. 2009). Elevated sound levels have a masking effect on natural sounds such as wind rustling through a stand of trees or the ensemble of birds singing during dawn chorus (Barber et al. 2010). Opportunities to experience natural sounds are ranked as an important reason for protecting these spaces and as a motivation for visitors (Marin et al. 2011). An increase of only 3 decibels results in an approximate halving of an individual's listening area (human or non-human animal) – a shrinking of their auditory world and a loss of listening opportunity (Barber et al. 2010). Due to the shared negative responses of wildlife and humans at similar sound levels (Shannon et al. 2016) and the benefits ascribed to both through natural sounds, we predict that soundscapes connect natural and human systems via symmetrical feedback loops.

To examine the coupling of the natural and human worlds via the soundscape, we conducted a unique paired experiment in Muir Woods National Monument, USA. We manipulated educational signage (Figure 1.1) that encouraged visitors to behave quietly (e.g. speak softly, silence electronics) within a complex redwood forest trail system. Signage was displayed in a week-on, week-off block schedule while we simultaneously conducted bird counts and visitor-intercept surveys. We focused on birds as our biological indicator due to their overall positive perception by humans (Clergeau, Jokimäki, and Savard 2001; Belaire et al. 2015), association with stress recovery and attention restoration (Ratcliffe, Gatersleben, and Sowden 2013; Abbott et al. 2016), and their importance in providing ecosystem services (Sekercioglu 2006; Wenny et al. 2011). Simultaneously, we assessed visitor trade-off thresholds among a range of potential soundscape management actions by assessing the acceptability of a range of both direct (e.g., enforcement, restrictions) and indirect (e.g. education, information) strategies via questionnaires. We predicted that soundscapes dominated by anthropogenic noise would decrease wildlife abundance and visitor experiences, while conversely, systems dominated by natural sounds would lead to increased bird abundance, more positive visitor experiences, and, critically, a greater willingness to support soundscape mitigation actions to protect a beneficially coupled system.

Figure 1.1 Soundscape mitigation in Muir Woods National Monument during sign present treatment blocks. (A.) Educational mitigation signage was placed along the trail system in alternating week-long treatment blocks. (B.) A total of 19 mitigation signs, 9 trail counter and 13 audio recording unit/point count center locations were included as part of the study.

Results

Acoustic Environment

Daily-averaged L50 sound levels (sound level met or exceeded for 50% of the measurement time) across the site were significantly higher when signs were absent (Wilcoxon rank sum test, $n=792$, $W=85{,}337$, $p=0.016$). Sound levels (L50 dBA) averaged 40.8 ± 0.13 dB(A) (mean ± SE) with signs absent, whereas sound levels with signs present averaged 39.6 ± 0.12 dB(A), a 1.19 dB(A) reduction. This 1.19 dB(A) increase in background sound levels between sign present and absent blocks is equivalent to an ~24% loss of an individual's listening area.

Sound level varied across the protected natural area depending on the number of visitors on the trail system—as the number of people increased, so did background sound levels. However, the rate of sound level increase was much slower when mitigation signage was present (Figure 1.2). At 250 visitors the sound level was at ~38.7 dBA during sign absent treatment blocks compared to ~36.4 dBA when signs were present. At 500 visitors the sound level was at ~42.4 dBA compared to 37.1 dBA when mitigation signage was present. Generalized additive modeling (GAM) showed that mitigation signage resulted in an equivalent reduction in visitation of 46.5% through the lowering of background sound level ($n=11{,}965$, $\log_{10}$Visitor Count: $\beta=0.88$, $F=616.2$, $df=1$, $p<0.001$; s(Hour, df=4): $\beta=-0.06$, $F=85.4$, $df=1$, $p<0.001$; Treatment: $\beta=-0.41$, $F=69.6$, $df=1$, $p<0.001$) (Figure 1.2, Table S1.1). In other words, during control days, without signage, it was the acoustic equivalent of adding 46.5% of people to the trail system despite the fact that the actual number was the same.

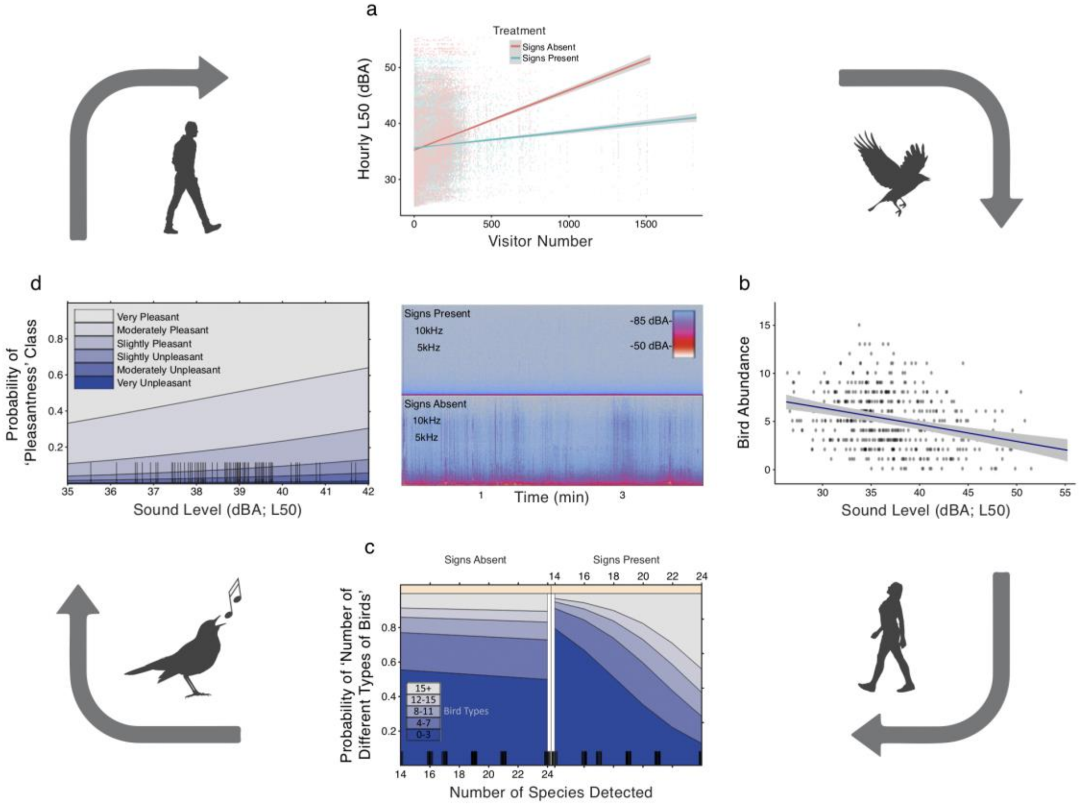

Figure 1.2 Soundscapes couple human and natural systems at Muir Woods National Monument. Signs were effective at significantly reducing background noise levels in a unique paired human and natural study during spring 2016. When surveyed, visitors preferred signage educating about soundscapes and asking visitors to limit noise among other management options. (A.) Using signs led to a soundscape with an equivalent reduction in visitation of 46.5% (p<0.001). In addition, (B.) bird detections decreased 7.16% with every 6 dBA increase in L50 (<0.001). (C.) The probability of the number of 'Different Types of Birds' class reported by visitors increased with the number of bird species detected by bird counts when interacting with sign treatment (Treatment: p=0.039; Number of Species: p=0.59; Treatment*Number of Species: p=0.034). When assessing pleasantness, (D.) the probability of a 'Very Pleasant' soundscape experience decreased with increasing hourly L50 (p=0.012).

Bird Distributions

We recorded 2,484 detections of 27 bird species within 50 m of our point count locations over 10 weeks (Table S1.2). Of these detections, 7 species were recorded 50 or more times, representing 90% of all detections. We evaluated bird count detectability of our expert observer between treatment conditions by comparing 8 detectability models, two of which included treatment as a covariate. Models containing treatment were not considered the top AIC model (Table S1.3) and bird count was not corrected for detectability in subsequent analyses. In other words, treatment condition did not affect the detection function of our distance-based bird counts. In addition to our modeling, previous research has identified 45 dBA as the approximate threshold beyond which human ability to detect birds within 60 m is impaired (Ortega and Francis 2012). Though this binary cut off may have its limitations, our L50 sound levels were below this measured threshold, further supporting subsequent count analyses without corrections for detectability.

Bird count significantly declined with increasing daily-averaged L50 dB(A) ($n=468$, $\beta=-0.06 \pm 0.008$, $p<0.001$, 95% C.I.: -0.08- -0.04), representing a ~7.2% decrease in songbird detections per each increase of 6 dB(A) (Figure 1.2). Of the six species of birds with >100 detections (*Empidonax difficilis*, Pacific-slope flycatcher; *Certhia americana*, brown creeper; *Troglodytes pacificus*, Pacific wren; *Cardellina pusilla*, Wilson’s warbler; *Regulus satrapa*, golden-crowned kinglet; *Poecile rufescens*, chestnut-backed chickadee), 4 out of 6 experienced significant declines (Pacific-slope flycatcher: ~4.4% decrease per 6 dB increase; brown creeper: ~7.6% decrease per 6 dB increase; golden-crowned kinglet: ~7.1% decrease per 6 dB increase; Wilson’s warbler: ~11.0% decrease per 6 dB increase) in response to increasing sound levels (Table S1.4).

Visitor Behavior and Soundscape Perception

Walking speed may influence visitor experience in the protected natural area. A total of 958 visitor walking speeds were measured during sign absent treatment blocks and 974 visitor walking speeds were recorded during sign present treatment blocks. Average group size for the group of the timed individual was nearly the same between treatment blocks (sign absent average=2.60 ± 0.04 individuals; sign present average group size=2.61 ± 0.04 individuals). Visitor walking speed did not vary, with average walking speed in the sign absent treatment block measured at 40.94 ± 0.70 s and 40.93 ± 0.78 s in the sign present treatment block (Table S1.5). One sample was removed from analysis as an extreme outlier. Since walking speeds between treatment conditions were similar, we did not include walking speed in our analysis of human perception and experience.

Visitor perception of the number of different types of birds present in the study area showed a significant interaction between the number of birds detected during bird surveys and treatment, with visitors perceiving a greater number of bird types with increasing diversity during sign present versus sign absent blocks (n=242, β=0.30 ± 0.14, 95% C.I.: 0.03-0.60) (Figure 1.2). Hourly sound level (L50 dB(A)) was a significant predictor of visitor soundscape pleasantness (n=453, β=-0.18 ± 0.07, p=0.01, 95% C.I.: -0.32- -0.04) (Figure 1.2).

Visitor Preferences to Soundscape Mitigation Strategies

All utility scores calculated from our stated choice model for levels of sign use, ranging from signs present to signs present with increasing ranger involvement (Information to enforcement; Table 1.1), were supported by visitors (p<0.001; Figure 1.3). Utility scores are quantitative proxies of visitor preference for management actions. The management action “no signs are posted along the trail about natural quiet” was used as the baseline condition to estimate the sum of the other levels and was therefore excluded from analysis. None of the utility scores for trail closure scenarios (Trail closures; Table 1.1) were supported by visitors ($p>0.05$; Figure 1.4). The management action “trails are open during operating hours” was used as the baseline condition to estimate the sum of the other levels and was excluded from analysis. Overall, the stated choice model for visitor soundscape management preferences, which included both sign use and trail closure levels, was significant (Log likelihood ratio= -2113.28; Pseudo R^2= 0.2873). Overwhelmingly, visitors showed increased support for at least some form of anthropogenic noise management through signs, as indicated by the low utility scores from no signs posted management action (signs absent utility score: -5.42; signs present utility score: -7.54; Figure 1.3).

Table 1.1 Muir Woods National Monument soundscape attributes and levels used in visitor-intercept surveys. Surveys were administered between May 9 and May 21, 2016 as visitors exited the park.

Information to enforcement
No signs are posted along the trail about natural quiet
Signs are posted along the trail educating visitors about natural quiet
Signs are posted along the trail educating visitors about natural quiet and asking visitors to limit noise
Signs are posted along the trail educating visitors about natural quiet and asking visitors to limit noise, and rangers are stationed along the trail to limit visitor cause noise
Signs are posted along the trail educating visitors about natural quiet and asking visitors to limit noise, and rangers are enforcing visitors to limit their noise along the trail
Trail closures
Trails are opening during operating hours
Trails are closed for one hour after dawn for the morning breeding bird chorus
Trails are closed for one hour after dawn and one hours before evening for the breeding bird chorus
Sound preference
You can rarely hear natural sounds (e.g. birdsong, small mammals) (about 5% of the time)
You can hear natural sounds (e.g. birdsong, small mammals) some of the time (about 25% of the time)
You can hear natural sounds (e.g. birdsong, small mammals) about half of the time (about 50% of the time)
You can hear natural sounds (e.g. birdsong, small mammals) most of the time (about 75% of the time

Visitors most preferred signs that educated about natural quiet and asked people to limit their noise (Figure 1.3). Viewed collectively, visitors had the highest utility for management options “Signs are posted along the trail educating visitors about natural quiet and asking visitors to limit noise” and “Signs are posted along the trail educating visitors about natural quiet and asking visitors to limit noise, and rangers are stationed along the trail to limit visitor cause noise", both of which promote an appreciation of natural quiet and move to limit visitor-caused noise (indirectly through signs and rangers) (Figure 1.3). These patterns were consistent across both sign absent and sign present periods. Critically, however, when signs were up visitors were significantly more likely to have higher utility scores for three out of four sign use options tested, implying that when quieter conditions were experienced, they were more supportive of management actions aimed at reducing visitor-caused noise (Figure 1.3).

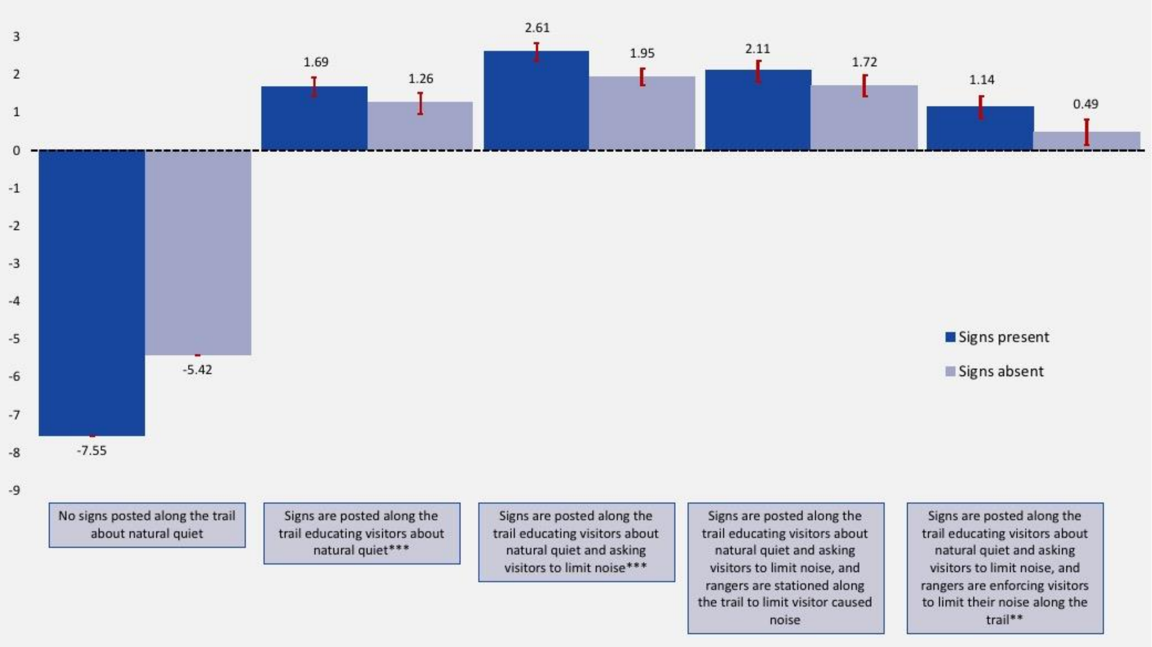

Figure 1.3 Comparison of utility scores for management options in Muir Woods National Monument. Utility scores between sign absent and sign present treatment groups were significantly different in three out of four management strategies, except "no signs are posted along the trail about natural quiet" which was estimated using the sum of the other levels. When signs were present, visitors had stronger preferences (e.g. higher utility scores) for these management options. **p<.01, ***p<.001.

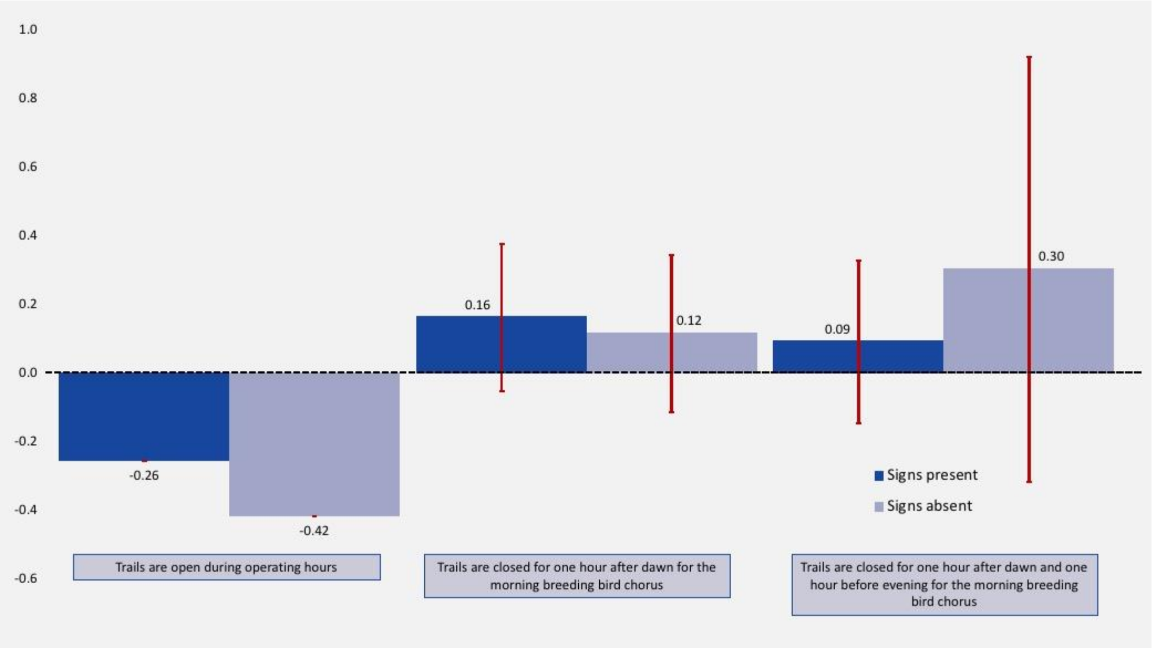

Figure 1.4 Comparison of utility scores for closures in Muir Woods National Monument. Utility scores for trail closure scenarios were not significantly different between sign present and sign absent treatment groups.

Discussion

The use of educational messaging within protected natural areas has been previously employed as a strategy to improve visitor acceptability of anthropogenic sounds and visitor experience (Taff et al. 2014; Stack et al. 2011). Our experimental addition of signage encouraging visitors to engage in quiet behaviors along the main trail system in Muir Woods National Monument significantly decreased non-motorized anthropogenic noise, thereby increasing bird availability to visitors both in reality and perception, and increasing positive human experiences. The overall bird community increased in abundance near the trail system as sound level decreased, as did four of the six most common individual species. Visitors directly perceived the increase in biodiversity – an increase in the different types of birds experienced – as anthropogenic noise was reduced. This increased availability of biodiversity and natural sounds ultimately resulted in an increased ranking of soundscape pleasantness. Perhaps most importantly, when signs were present, visitors preferred both direct and indirect management options aimed at managing soundscapes to reduce anthropogenic sound levels. The linkages between noise levels, biodiversity, human experiences, and visitor willingness to restrict access for biodiversity demonstrates a positive feedback cycle between natural and human systems mediated via the soundscape.

Interactions between humans and natural systems are complex and have the potential, as we demonstrate, to create feedback loops (J. Liu et al. 2007). As global soundscapes continue to be characterized by anthropogenic noise, the extinction of nature experience is a growing threat spread by a combination of biodiversity loss and a loss in personal orientation towards the natural world, reinforcing negative feedback loops (J. R. Miller 2005; Soga and Gaston 2016). Evidence suggests that human contact with nature can improve health and well-being (Bowler et al. 2010; Russell et al. 2013; Hartig et al. 2014; Seymour 2016), and that natural sounds can influence human experience in nature (Francis et al. 2017). Through our unique paired surveys, we assessed human rankings of soundscape pleasantness and measured how this personal experience to the natural world influenced preferences for management actions. Participants, regardless of mitigation presence, preferred soundscape management actions, suggesting that people were willing to accept trade-offs in personal freedoms to achieve a desired environmental condition (Newman et al. 2005) – an acoustic environment dominated by natural sounds. When soundscape mitigation via educational signage was in effect, people rated their soundscape experience as more pleasant and exhibited an even greater preference for soundscape mitigation strategies while also significantly reducing their noise levels along the trail system.

Mitigating noise is complicated; however, we show that non-motorized noise pollution can be reduced through the economical and relatively simple addition of educational signage. Signs improved visitor experiences and conservation support by reducing anthropogenic noise, improving access to natural sounds, and allowed for a greater ‘acoustic carrying capacity’ of visitors through reduced human-created noises. When visitors followed soundscape mitigation, sound levels around the park reduced and allowed the park to support half again as many people. As the world’s population continues to grow, finding ways to allow more people to experience natural areas without the addition of undue impacts is essential.

Anthropogenic noise has the potential to hinder ecosystem services delivered by natural soundscapes through the masking of beneficial sounds to both wildlife and humans and through the alteration of wildlife abundance and behavior. A system dominated by noise no longer confers benefits to human health and well-being; instead, opportunities for fostering positive connections with nature are lost and the health benefits conveyed to individuals immersed in natural soundscapes are absent or reversed. The relationships between ecosystem services and human well-being has proven difficult to elucidate (Raudsepp-Hearne et al. 2010), yet understanding the linkages between biodiversity, ecosystem services, and human well-being is one of the most important conservation issues of our time (Bennett et al. 2015). Our study demonstrates that the soundscape mediates some of these critical linkages. The sounds present facilitated an immediate feedback response that people both perceived and felt. Preventing excessive exposure to anthropogenic noise may assist in maintaining evolutionary and ecosystem functioning so that wildlife behaviors and human connections with the environment continue to benefit one another.

Safeguarding opportunities to experience wildlife and natural soundscapes is critical for increasing conservation efficacy and support for continued and improved landscape protection (J. R. Miller 2005). Soundscape mitigation promotes a fully-functioning feedback loop between natural and human systems that increases access to wildlife and natural sounds and improves the personal connection people feel with the natural world. Quantifying the psychological ecosystem services provided by nature is an important and required tool to inform management strategies and policy change (Frumkin et al. 2017). Continued soundscape research, education, and support for policies that preserve and restore natural quiet are crucial for maintaining and improving the connections between people and nature. Without rich aural experiences, the desire and call for conservation action may fade into the noise.

Methods

We conducted our study at Muir Woods National Monument (37°53’N, 122°34’W) approximately 20 miles north of San Francisco during spring 2016. Muir Woods is a unit of the National Park Service (NPS) and included in the Golden Gate National Recreation Area, encompassing 559 acres of old-growth coast redwood (*Sequoia sempervirens*) forest. Since the late 1990s, visitation to Muir Woods National Monument has steadily increased and has exceeded one million visitors per annum since 2014 (NPS 2017b). The mixed boardwalk, paved, and unpaved trail system bifurcates around Redwood Creek and leads to an area of the national monument known as Cathedral Grove, a primary visitor destination.

Trail Signage Manipulations and Acoustic Measurements

Trail manipulations rotated in an on/off schedule during a total of 10 week-long blocks from 14 March to 22 May 2016. We placed a series of 19 mitigation A-frame signs (e.g., “Enter Quietly”) along a ~0.6 km segment of the main trail during sign present treatment blocks and covered existing signage emphasizing the importance of quiet and quiet behaviors during sign absent blocks (Figure S1.1). Our mitigation signage provided suggestions for how visitors could reduce their noise levels. Suggestions included speaking softly, muting phones and electronics, and encouraging children to walk quietly. Hourly L50 values were continuously measured using acoustic recording units (ARUs; R-05s, Roland, California) for the duration of the study to assess background sound levels between sign absent and sign present treatment blocks. We converted 21,038 h of recordings using custom programs AUDIO2NVSPL and Acoustic Monitoring Toolbox (Damon Joyce, NPS) into hourly sound pressure levels.

From these hourly values, we calculated the daily average as the period between one hour prior to and after the earliest and latest point count start and end times (0500 – 2100), resulting in a total of 14,040 measured hours. We chose these hours because our goal was to (i) understand the impacts of background sound levels during the period surveys were conducted and bird detections recorded, and (ii) so periods with little to no visitation did not unduly hinder our ability to detect effective changes in background sound levels from alterations in visitor behavior and noise output resultant from mitigation signage. We excluded week one from sound analysis after performing a oneway analysis of variance (AOV) and post-hoc (Tukey HSD) analysis between Redwood Creek stream flow (cubic feet per second) and week of study due to significant differences in stream flow, and therefore river noise, compared to all other weeks (AOV: $F_{9,60}=5.575$, $p<0.001$). Stream flow data was obtained from the USGS National Water Information System (station USGS 11460151 Redwood CA HWY 1 Bridge A Muir Beach CA). Data from 9 April 2016 was also excluded from analysis due to elevated ambient noise resultant from heavy precipitation. After rejecting the assumption of normality and failing to reject the assumption of homoscedasticity, we compared daily averaged L50 (dBA) using the Wilcoxon rank-sum test between sign absent and sign present treatment blocks across all ARU sites.

Following the methods specified by Stack and colleagues (2011), we fit a generalized additive model (GAM) using package gam (Hastie 2017) in Program R to arrive at an equivalent reduction in visitation resultant of noise relief due to the presence of mitigation signage. We fit the GAM for hourly sound pressure level (L50) using the base ten logarithm of visitor count as tabulated by nine trail counters (Bushnell, Overland Park, Kansas), a smoothing spline for hour of the day (4 effective degrees of freedom), and the categorical factor of treatment. Previous work found that sound pressure levels were significantly correlated with visitation numbers between 1000 and 1900 hours (Stack et al. 2011). We broadened our analysis to match the hours of the day used to analyze differences in daily averaged sound pressure levels (0500-2000 hours). From the GAM, we used the ratio between the treatment and visitation coefficients to approximate the percentage of equivalent visitor reduction, or increased potential capacity, through the decrease in sound pressure levels.

Bird Abundance

We surveyed birds 40 times at each of 13 sites located ~2m-250m from the main trail system throughout the 10-week period. Two morning and two afternoon distance-based bird point count surveys were completed weekly within 5 h of sunrise (0600-1300 hours) and 5.5 h before sunset (1330-2000 hours) based on a modified protocol developed by Rocky Mountain Bird Observatory (Hanni et al. 2009). Because detection of birds varies by both time and date, we randomized point count survey order. Surveys lasted for 5 min each with observers recording both the total number of birds detected and method of detection (e.g., visual, song) for each minute of the survey. Observers used laser rangefinders (TruPulse 360R, Laser Technology, Inc., Colorado) to record the distance away from the observer for each detection.

Detectability can vary with multiple observers (McClure et al. 2015; Alldredge, Simons, and Pollock 2007; Sauer, Peterjohn, and Link 2008) and in relation to excessive background noise (McClure et al. 2015; Pacifici, Simons, and Pollock 2008; Simons et al. 2007). To combat the effects of multiple observer bias, our study utilized a single point count observer. Though our average L50 sound levels in both treatment conditions were below 45 dBA, the approximate threshold beyond which impairs human ability to detect birds (Ortega and Francis 2012), we examined potential differences in the probability of bird detection between treatment blocks using package Distance (D. L. Miller 2016) in Program R (Nichols, Thomas, and Conn 2009). We built several models using the different key functions and modeling detection either as intercept-only or as a function of treatment. We then ranked and compared detection models using Akaike's information criterion (AIC) (Arnold 2010). We considered there to be an effect of treatment on detection if the factor for treatment was in a model within the top 98% of cumulative model weight (Burnham and Anderson 2003) and was not an uninformative parameter (Arnold 2010). Although a treatment model was indeed within 98% of the cumulative model weight, it was an uninformative parameter because the parameters in the AIC-best model were a subset of those in the treatment model and the 95% (and 85%) confidence intervals on the treatment coefficient overlapped zero (Arnold 2010). We therefore concluded there were no differences in detectability between treatment blocks and did not adjust detection counts (Table S1.3). Thus, we analyzed bird count with function lme4 (Bates et al. 2015) in Program R (R Core Team 2016) using a generalized linear mixed-effects model with daily averaged L50 (dBA) as a fixed effect, site as a random effect, and detection distance truncated to 50 m from point count center.

Visitor Behavior and Perception

Using the polr function in Program R package MASS (Venables and Ripley 2002), we performed proportional odds logistic regressions to assess visitor perception of the number of different types of birds experienced in the park and visitors' pleasantness ranking of the soundscape. Participants were asked in a visitor-intercept survey (further described below) how many bird types they estimated were in the trail corridor based on their experience that day, as well as to rank soundscape pleasantness on a 6-point categorical scale from very unpleasant to very pleasant. We used the interaction between the number of birds counted during bird surveys and treatment, and the hourly L50 level for the hour in which the survey was administered, as predictors in each respective model. All ARUs within 50 m of the trail (n=9) were used to calculate the average hourly L50 level.

Visitor walking speed was measured at a total of 9 ‘walkways’ of varied lengths by starting a timer the moment an identified visitor crossed a predetermined visual marker and stopping the timer once the visitor crossed another marker at the opposite end of the walkway. These visitor movement walkways were along the trail adjacent to our bird count and ARU locations. Visitor movement speed was log-transformed and analyzed using the kruskal.wallis function in Program R for each walkway location independently.

Trained university researchers used intercept survey techniques to systematically sample Muir Woods National Monument visitors between May 9 and May 21, 2016. Visitors were intercepted near the entrance as they exited the park and were surveyed after their park visit and experience. Previous research and information from managers at Muir Woods National Monument helped inform the sampling location (E. J. Pilcher et al. 2009). We stratified data collection to represent weekends, weekdays, time of day (all times during daylight hours), and treatment and control periods. If researchers intercepted a group of people, only one person was selected to participate in the research. To avoid a self-selection bias, the person with the most recent birthday (not date of birth) was asked to participate in completing the survey. A total of 537 individuals agreed to complete the survey, resulting in a 55% response rate from the sampling effort. Participants received a laminated copy of the survey while research assistants read the instructions and each question. Response to the questions were recorded in situ on an electronic tablet device using Qualtrics to securely store data.

Similar to a variety of studies in other fields, the intercept surveys included a stated choice experiment (Louviere and Timmermans 1990) to assess visitors’ preferences for and trade-offs among a range of potential management actions related to soundscape management. Management actions included both direct (enforcement, restrictions, etc.) and indirect (education, information, etc.) components for two different attributes: information to enforcement and closures (Manning 2011). Information to enforcement contained five different levels that ranged from indirect approaches up to more direct approaches for visitor use management. The closure attribute focused on temporal aspects of restricting visitor use in MUWO. Both information to enforcement and closure concepts were developed in collaboration with MUWO managers. Sound preference was also measured as an attribute in the scenario choices with four different levels (Table 1.1). To increase the efficiency, we designed two blocks of nine choice scenarios (18 scenarios in total) with two management alternatives (Figure S1.2), and each respondent answered nine scenarios from one of the blocks. For each scenario presented, participants were asked to choose their preferred alternative.

Survey data were analyzed using a stated choice approach (Louviere and Timmermans 1990) in which visitor responses are combined together and analyzed to produce estimates, known as utility scores, for the level of preference for each of the attributes. Higher utility scores indicate more preference, and lower ones indicate less. Although this approach was originally developed in economics, it has been used in a variety of outdoor recreation and park management settings to explore visitor preferences (Lawson and Manning 2002, 2003; Newman et al. 2005; Cahill, Marion, and Lawson 2008).

We used latent class logit modeling to analyze the stated choice data and estimate the “utility scores” representing the level of preference for each of the attributes. We found a two-class latent class model has the superior model fit based on AIC and log-likelihood ratio, i.e., the model identified two types of respondents with a different set of utility scores. To analyze this type of stated choice model, the results from the survey were effect coded (Newman et al. 2005), allowing us to determine utility scores for varying attribute levels and tradeoffs visitors would be willing to make between treatment conditions to achieve a quality experience. Differences between utility scores for sign absent and sign present groups were evaluated using t-tests.

Chapter One Supplementary Materials

Figure S1.1 Experimental (top) and existing signage (bottom) at Muir Woods National Monument. Existing signs were covered during sign absent weeks so as not to reinforce quietening behaviors in park goers.

Scenario 1	Scenario 2
• You can hear natural sounds (e.g. birdsong, small mammals) about half of the time (about 50% of the time) • Signs are posted along the trail educating visitors about natural quiet and asking visitors to limit noise, and rangers are enforcing visitors to limit their noise along the trail • Trails are closed for one hour after dawn for the morning breeding bird chorus	• You can hear natural sounds (e.g. birdsong, small mammals) some of the time (about 25% of the time) • Signs are posted along the trail educating visitors about natural quiet and asking visitors to limit noise • Trails are closed for one hour after dawn for the morning breeding bird chorus

Figure S1.2 An example of a paired scenario presented to Muir Woods National Monument visitors. Visitors would be asked "Which description below would best depict your most preferred experience in Muir Woods National Monument?"

Table S1.1 Analysis of Variance (ANOVA) for parametric effects from the Muir Woods National Monument GAM and model coefficients. Equivalent reduction in visitation calculated by taking the ratio between the treatment and $\log_{10}$ visitor count coefficients.

Variable	Coefficient	df	F	p	Equivalent Reduction (%)
Intercept	35.7	--	--	--	-46.52%
log10 Visitor Count	0.88	1	616.2	<0.001	
Hour	-0.06	1	85.4	<0.001	
Treatment	-0.41	1	69.6	<0.001	

Table S1.2 Bird species detected during point counts at Muir Woods National Monument. Common name, scientific name and number of birds detected within 50 m of each point count location from 14 March to 22 May, 2016.

Common Name	Scientific Name	Detections (#)
Pacific-slope flycatcher	*Empidonax difficilis*	773
Brown creeper	*Certhia americana*	429
Pacific wren	*Troglodytes pacificus*	400
Wilson's warbler	*Cardellina pusilla*	259
Golden-crowned kinglet	*Regulus satrapa*	182
Chestnut-backed chickadee	*Poecile rufescens*	113
Dark-eyed junco	*Junco hyemalis*	79
Purple finch	*Haemorhous purpureus*	46
Pine siskin	*Spinus pinus*	29
Allen's hummingbird	*Selasphorus sasin*	28
Band-tailed pigeon	*Patagioenas fasciata*	26
Common raven	*Corvus corax*	22
Hairy woodpecker	*Picoides villosus*	18
Steller's jay	*Cyanocitta stelleri*	16
American robin	*Turdus migratorius*	16
Swainson's thrush	*Catharus ustulatus*	10
Turkey vulture	*Cathartes aura*	7
Hermit thrush	*Catharus guttatus*	7
Anna's hummingbird	*Calypte anna*	6
Mourning dove	*Zenaida macroura*	5
Pygmy nuthatch	*Sitta pygmaea*	4
Northern flicker	*Colaptes auratus*	3
Warbling vireo	*Vireo gilvus*	2
Cassin's vireo	*Vireo cassinii*	1
Orange-crowned warbler	*Oreothlypis celata*	1
Pileated woodpecker	*Dryocopus pileatus*	1
Red-shouldered hawk	*Buteo lineatus*	1
Total		2,484

Table S1.3 AIC table for Muir Woods National Monument detectability models. AIC models used to determine if treatment condition influenced probability of bird detectability. Though one of the treatment models was within 98% of the cumulative model weight, it was considered an uninformative parameter because the parameters in the AIC-best model were a subset of those in the treatment model.

Model	Key Function	Formula	AIC	***Δ***AIC	Relative Likelihood (exp(-0.5****Δ***AIC))	w*i*
A	Hazard-rate	~1	17374.59	0.0000000	1	0.37384687
B	Uniform with cosine adjustment terms of order 1,2,3	NA	17374.90	0.3133353	0.854988167	0.31963465
C	Hazard-rate	Treatment	17376.28	1.6953195	0.428416361	0.160162116
D	Half-normal with cosine adjustment terms of order 2,3	~1	17377.86	3.2689696	0.195052837	0.072919892
E	Half-normal with cosine adjustment terms of order 2,3	~1	17377.86	3.2689710	0.1950527	0.072919841
F	Half-normal with Hermite polynomial adjustment term of order 4	~1	17387.980	13.3946456	0.001234212	0.000461406
G	Uniform with cosine adjustment terms of order 1,2	NA	17392.23	17.6419149	0.000147607	5.51824E-05
H	Half-normal	Treatment	17406.61	32.0247536	1.11151E-07	4.15534E-08
Cumulative Model Weight					2.674891995	

Table S1.4 Percent decrease in detections for species with >100 detections at Muir Woods National Monument. Statistical output from generalized linear mixed models with daily-averaged L50 as the fixed effect and a random effect for site (**=p<0.01, ***=p<0.001).

Scientific Name	Intercept		Daily-averaged L50 (dB(A))	Percent Decrease	Percent dB(A) Increase	Percent decrease per 6dB(A) Increase
Cardellina pusilla	β	2.75**	-0.09***	8.93	5.10	10.98
	S.E.	0.87	0.02			
Regulus satrapa	β	1.08	-0.06**	5.81		7.14
	S.E.	0.81	0.02			
Certhia americana	β	2.07***	-0.06***	6.15		7.56
	S.E.	0.51	0.01			
Empidonax difficilis	β	1.82***	-0.04**	3.55		4.36
	S.E.	0.44	0.01			
Poecile rufescens	β	-0.28	-0.04	--	--	--
	S.E.	1.01	0.03			
Troglodytes pacificus	β	-0.33	0.002	--	--	--
	S.E.	0.55	0.01			

Table S1.5 Statistical analysis for visitor walking speeds between treatment condition along nine trail walkways at Muir Woods National Monument. Visitor walking speed was measured at a total of nine ‘walkways’ of varied lengths by starting a timer the moment an identified visitor crossed a predetermined visual marker and stopping the timer once the visitor crossed another marker at the opposite end of the walkway. There were no differences in walking speeds (p>0.05) between treatment condition at each individual walkway location.

Walkway	Kruskal-Wallis chi-squared	df	p
A	1.28	1	0.26
B	1.99	1	0.16
C	2.26	1	0.13
D	2.80	1	0.09
E	2.17	1	0.14
F	1.14	1	0.28
G	1.87	1	0.17
H	2.48	1	0.12
I	1.37	1	0.24

CHAPTER TWO CONTRIBUTORS

This manuscript is prepared for submission at *People and Nature*. The title of the manuscript is *Experimental Quieting of Traffic Noise via Speed Limit Reductions Benefit People but Not Songbirds in a Protected Area*. The author list for this manuscript includes the following individuals: Mitchell J. Levenhagen[1], Zachary D. Miller[2], Dylan G.E. Gomes[1], Alissa R. Graunke[3], Lauren A. Ferguson[2,a], Yau-Huo (Jimmy) Shr[2,b], B. Derrick Taff[2], Crow White[3], Kurt Fristrup[4], Christopher J.W. McClure[1,5], Shan Burson[6], Peter Newman[2], Clinton D. Francis[3], Jesse R. Barber[1]. M.J.L., B.D.T., C.W., K.F., P.N., C.D.F., and J.R.B. designed the research. M.J.L, A.R.P., and L.C.A. collated the data. M.J.L., Z.D.M., D.G.E.G., Y.S. and C.J.W.M. analyzed and visualized the data. M.J.L. and J.R.B. lead the writing of the manuscript and all authors contributed to text and review.

Affiliations:

[1]Department of Biological Sciences, Boise State University, Boise, ID 83725, USA

[2]Department of Recreation, Park and Tourism Management, Penn State University, University Park, PA 16802, USA

[3]Department of Biological Sciences, California Polytechnic State University, San Luis Obispo, CA 93407, USA

[4]Natural Sounds and Night Skies Division, National Park Service, Fort Collins, CO 80525, USA

[5]The Peregrine Fund, Boise, ID 83709, USA

[6]Grand Teton National Park, National Park Service, Moose, WY 83012, USA

[a]Now affiliated with the Department of Recreation Management and Policy, University of New Hampshire, Durham, NH 03824, USA

[b]Now affiliated with the Department of Economics, Iowa State University, Ames, IA 50011, USA

CHAPTER TWO

Experimental quieting of traffic noise via speed limit reductions benefit people but not songbirds in a protected area

A 60% increase in global road length is anticipated by 2050 – 25 million more kilometers of roadway than existed in 2010 (Dulac 2013). Although roads have been instrumental in facilitating economic growth and providing personal access to protected areas, their use has many negative direct and indirect effects on plants, animals, and adjacent habitat (Coffin 2007). Roads also provide access to remote areas which in turn leads to greater development and fragmentation of landscapes (Ibisch et al. 2016; Laurance et al. 2014). This fragmentation can be structural, the loss of habitat from the physical presence of the road, or functional, such as the dramatically higher habitat loss associated with a traffic noise effect zone (Madadi et al. 2017). This noise type is both a pervasive and primary source of pollution in protected natural areas (Barber et al. 2011).

Noise alters animal behavior, distributions and fitness (Barber et al. 2010; Francis and Barber 2013; Shannon et al. 2016; Kight and Swaddle 2011). For example, traffic noise increases anti-predator behavior (Shannon et al. 2014), decreases foraging success (Bunkley and Barber 2015; Siemers and Schaub 2011), disrupts mate location abilities (Gurule-Small and Tinghitella 2018; Bee and Swanson 2007), and reduces reproductive success (Kleist et al. 2018; Halfwerk et al. 2011; Kight, Saha, and Swaddle 2012). Researchers using traffic noise playback during fall migration found a nearly 25% decline in songbird abundance and near complete avoidance in two songbird species, suggesting that traffic noise alone may act as an invisible source of habitat degradation (Mcclure et al. 2013; Ware et al. 2015).

Similar evidence indicates that human experiences in protected natural areas are negatively impacted by noise (E. J. Pilcher et al. 2009). Laboratory results indicate that motorized noise negatively impacts national park landscape quality (Weinzimmer et al. 2014) and visitor ratings of anthropogenic noise in parks decreases with increasing time above natural soundscape levels (Marin et al. 2011). While the National Park Service manages soundscapes as a protected resource, national parks are not free from noise exposure (Lynch et al. 2011; Barber et al. 2011). A recent study found that noise pollution, primarily from traffic, doubled sound levels in nearly two-thirds of protected areas and resulted in a ten-fold increase in approximately one quarter of protected areas (Buxton et al. 2017). The pressures associated with traffic do not go unnoticed by park managers. In a national park unit questionnaire assessing road impacts on wildlife populations (n=106), over half of the units responded that transportation within their park unit was at or above capacity, around one-quarter of units noted that traffic volumes were high or very high and expected to increase, and approximately half of units expected impacts to worsen over the next five years (Ament et al. 2008). What remains unclear is the effectiveness of real-world traffic noise mitigation, and if successful, whether visitor-wildlife interactions are mediated through soundscape mitigation.

We evaluated speed reduction as a possible mitigation strategy for protected area noise exposure through a road corridor manipulation study using speed limit reductions and educational signage in Grand Teton National Park, USA. While alternating between sign absent and sign present treatment conditions, we simultaneously conducted bird counts and visitor-intercept surveys to test whether slower speeds improved habitat for birds and visitor experience through potential reductions in background sound levels. Previous research has called for investigations into reduced speed limits as a management strategy for improving roadside bird habitat (Parris and Schneider 2008; Ware et al. 2015; Francis et al. 2017). Visitor ranking of soundscape pleasantness and visitor trade-offs among a range of potential management actions related to soundscape management were assessed in the intercept surveys, which included both direct (e.g., enforcement, restrictions) and indirect (e.g. education, information) components. We predicted that speed limit reductions would decrease background sound levels, thus increasing bird abundance and positive visitor experiences in the park. Positive experiences as mediated through the soundscape may increase visitor willingness to trade-off personal freedoms in return for opportunities to experience increased natural soundscapes and biodiversity.

Methods

We conducted our study in Grand Teton National Park, Wyoming (43° 52’N, 110° 23’W) during summer 2016. Traffic manipulations occurred along the John D. Rockefeller Jr. Parkway/US-191/US-287/US-89 highways in the east-central region of the park known as Oxbow Bend. During the 2016 NPS centennial Grand Teton National Park received the second highest number of recreational visitors up to that year with over 3.2 million individuals visiting the park (NPS 2017a).

Road Manipulations

Traffic manipulations rotated in an on-off schedule during a total of 10 week-long blocks from 6 June to 14 August 2016. Due to project reconfiguration, weeks 3-6 did not alternate and instead consisted of two sign absent weeks (weeks 3 and 4) followed by two sign present weeks (weeks 5 and 6). During treatment blocks we reduced speed limits from 45 mph to 25 mph and placed roadside educational and enforcement signage both north- and southbound along the ~2.5 km experimental road corridor (Figure S2.1). We placed two decibel (dB) meter signs each direction within the corridor (Figure S2.1). These signs used a wireless sound level reader placed in the road shoulder leading up to the display to show the noise output of the passing vehicle on a green-yellow-red scale of noise level (green = low, yellow = intermediate, red = high).

We collected visitor driving speed data within the road corridor using a PicoCount 2500 (VehicleCounts.com) automatic traffic counter and classifier to calculate the average traffic count and average traffic speed. Two pneumatic tubes were outstretched over the highway approximately 36 inches apart and secured with rope and spikes in the road shoulder. Using program TrafficViewer Pro (VehicleCounts.com), we summarized offloaded traffic counter data into five speed ranges. We analyzed speeds using the kruskal.wallis function in Program R (R Core Team 2016) for each treatment condition. The traffic counter was operational from 8 June through 21 June, 28 June through 30 June, and 12 July through 7 August 2016.

Acoustic Measurements

In order to assess background sound levels between treatment blocks, we continuously measured hourly L50 levels along the road corridor using acoustic recording units (ARUs; R-05s, Roland, California). We converted 19,386 h of recordings using custom programs AUDIO2NVSPL and Acoustic Monitoring Toolbox (Damon Joyce, NPS) into hourly L50 (sound level met or exceeded for 50% of the measurement time) sound pressure levels. From these hourly values, we calculated the daily median using the period between one hour prior to and after (0600 – 1300) point count start and end times, resulting in a total of 6,174 measured hours. Data from 10 July 2016 was excluded from analysis due to elevated ambient noise due to heavy precipitation. We compared daily median L50 (dBA) using the Wilcoxon rank-sum test between sign absent and sign present treatment blocks across all ARU sites. Missing data for three dates was estimated for use in bird survey analysis by averaging sound pressure levels from the two closest dates with available data.

Bird Abundance

We surveyed birds 20 times at each of 11 sites located ~50-200 m from the roadway throughout the 10-week period. Our single observer completed bi-weekly point count surveys between 0700-1200 based on a modified protocol developed by Rocky Mountain Bird Observatory (Hanni et al. 2009). Because detection of birds varies by both date and time, we randomized point count location order. Surveys lasted for 5 min each with our observer recording both the total number of birds detected and method of detection (e.g., visual, song) for each minute of the survey. Our observer used a laser rangefinder (TruPulse 360R, Laser Technology, Inc., Colorado) to record the distance away from point count center for each detection. After testing for detectability (see supplementary materials), we analyzed bird count with function lme4 (Bates et al. 2015) in Program R using a generalized linear mixed-effects model with daily averaged L50 (dBA) as a fixed effect, site as a random effect, and detection distance truncated to 50 m from point count center.

Vegetation Surveys

To estimate percent cover of the vegetative layers, we used a Fujifilm FinePix XP70 16.4-megapixel compact camera attached to a two-meter survey pole (Sokkia 724290 Economy 2-meter Aluminum 2 Section GPS Rover Rod) to take downward-facing images at each point count location. We completed ten 50-meter transects (one picture every 5-meters for a total of 10 images per transect and 100 images per site) extending from the center of each site. To estimate percent cover by substrate type, we used the image analysis software Samplepoint (Booth, Cox, and Berryman 2006). Within the program interface, we selected a 7x7 crosshair grid to be randomly laid on each picture and iteratively classified the type of vegetation marked by each crosshair using customized program buttons denoting substrate types.

Visitor Behavior and Perception

Using the polr function in Program R package MASS (Venables and Ripley 2002), we performed proportional odds logistic regressions to assess visitor perception of birdsong diversity and visitors' pleasantness ranking of the soundscape. We asked participants in a visitor-intercept survey (described below) how diverse bird chorus was based on their listening experience that day, as well as to rank soundscape pleasantness on a 6-point categorical scale from very unpleasant to very pleasant. We used the number of birds counted during bird surveys and the hourly sound level for the hour in which the survey was administered as predictors in each respective model. The ARU closest to the turnout location where surveys were administered was used for the hourly sound level measurement.

Trained university researchers used intercept survey techniques to systematically sample Grand Teton National Park visitors between July 19 and August 14, 2016. We stratified data collection to represent weekends, weekdays, time of day (all times during daylight hours), and sign absent and present periods. To avoid a self-selection bias, the person with the most recent birthday was asked to participate in completing the survey. Participants received a laminated copy of the survey and responses were recorded in situ by survey administrators on an electronic tablet device using Qualtrics to securely store data.

Intercept surveys assessed visitor trade-offs among a range of potential management actions related to soundscape management in Grand Teton National Park. The survey included nine different paired scenarios, of which participants were asked to make a discreet choice between the two. We developed two different versions of the survey to increase the number of scenarios tested. Management actions included both direct (e.g. enforcement, restrictions) and indirect (e.g. education, information) components for two different attributes: information to enforcement and closures (Table 2.1) (Manning 2011). Information to enforcement contained five different levels of sign use and enforcement and the speed limit attribute focused on driving speed near important wildlife habitat. Sound preference was also measured as an attribute and solely used to standardize the statistical model across the two groups (signs present and signs absent) to allow for comparisons.

Table 2.1 Comparison of utility coefficients between treatment and control groups in Grand Teton National Park. One out of four utility scores for Speed limits showed a relationship with treatment (p<0.001). Three out of five utility scores for Information and enforcement management actions showed a relationship with treatment (p<0.01, n=2; p<.001, n=1).

Attribute		Coefficient difference	Asymptomatic t-ratio[1]	p-value
Speed limits				
1.	You can drive 45 MPH on park roads near important wildlife habitat.	--	--	---
2.	You can drive 35 MPH on park roads near important wildlife habitat.	0.512	5.253	<.001
3.	You can drive 25 MPH on park roads near important wildlife habitat.	0.140	0.733	.464
4.	You can drive 15 MPH on park roads near important wildlife habitat.	--	--	---
Information and enforcement management actions				
1.	No signs are posted along the road about natural quiet	--	--	---
2.	Signs are posted along the road educating visitors about natural quiet.	0.518	3.542	<.001
3.	Signs are posted along the road educating visitors about natural quiet and asking visitors to limit noise.	0.310	1.676	.009
4.	Signs are posted along the road educating visitors about natural quiet and asking visitors to limit noise, and rangers are stationed along the road to limit visitor caused noise.	0.407	2.277	.002
5.	Signs are posted along the road educating visitors about natural quiet and asking visitors to limit noise, and rangers are enforcing visitors to limit their noise along the road.	0.254	1.616	.107

[1] The sample sizes used to calculate the t-ratios are the number of respondents for each of the groups.

We analyzed survey data using a stated choice approach (Louviere and Timmermans 1990) in which visitor responses are combined together and analyzed to produce estimates, or utility scores, for the level of preference for each of the attributes. Higher utility scores indicate more preference, and lower ones indicate less. Although this approach was originally developed in economics, it has been used in a variety of outdoor recreation and park management settings to explore visitor preferences (Lawson and Manning 2002, 2003; Newman et al. 2005; Cahill et al. 2008).

We used latent class modeling to analyze the stated choice data. The model split respondents into one of two classes based on their preferred management scenarios. To analyze this type of stated choice model, we effect coded (Newman et al. 2005) results from the survey data to allow us to determine utility scores for varying attribute levels and tradeoffs visitors would be willing to make between treatment conditions to achieve a quality experience. Sound preference in the models was fixed across groups to allow for comparisons among the two other attributes (information to enforcement, closures). This assumes that sound preference was equal across visitors in both conditions. We evaluated differences between utility scores for sign absent and sign present groups using t-tests.

Results

Acoustic Environment and Road Manipulations

Sound levels (L50 dBA) along the road were higher during sign absent treatment blocks (Wilcoxon rank sum test, $n=687$, $W = 74{,}404$, $p<0.001$). Sign absent sound levels averaged 46.9 ± 0.10 dB(A) (mean ± SE) whereas sign present levels averaged 45.4 ± 0.10 dB(A), a 1.5 dB reduction. This decrease in background sound levels between sign absent and present blocks is equivalent to an ~29% increase of an individual's listening area.

Our traffic counter quantified 114,819 northbound and southbound vehicles during the sign absent treatment blocks and 109,090 vehicles during sign present treatment blocks. The majority of vehicles were categorized as traveling 45-49 mph (n=46,199) during sign absent blocks and 35-39 mph (n=21,564) during sign present blocks (Table S2.1). After grouping events into four speed limit bins, we found a relationship between driving speed and treatment for the 5-24 mph (Kruskal-wallis chi-squared=51.62, df=1, $p<0.001$), 25-49 mph (Kruskal-wallis chi-squared=6.90, df=1, $p=0.009$), and 50-74 mph (Kruskal-wallis chi-squared=37.73, df=1, $p<0.001$) speed limit bins (Table S2.2), with vehicles driving more slowly when mitigation signage was present. There was no relationship between driving speed and treatment for the 75+ mph speed limit bin (Kruskal-wallis chi-squared=0.17, df=1, $p=0.68$) (Table S2.2).

Bird Distributions

We recorded 1,361 detections of 43 bird species within 50 m of the center of our point count locations (Table S2.3). Of these detections, 8 species were recorded 50 or more times representing 68% of all detections. There was no relationship between bird detections and sound level ($n=212$, $\beta=0.013 \pm 0.016$, $p=0.42$, 95% C.I.: -0.02 - 0.04). For each of the four species with >100 detections (*Setophaga petechia*, yellow warbler; *Zonotrichia leucophrys*, white-crowned sparrow; *Empidonax oberholseri*, dusky flycatcher; *Vireo gilvus*, warbling vireo), there was no relationship between detection and background sound levels (Table S2.4). However, overall bird detections increased with increasing willow cover ($n=212$, $\beta=0.007 \pm 0.003$, $p=0.013$, 95% C.I.: 0.001 – 0.014) (percent willow cover by site: Table S2.5). Of the same four species, all exhibited a relationship between abundance and willow cover (yellow warbler: $n=212$, $\beta=0.05 \pm 0.018$, $p<0.01$, 95% C.I.: 0.01 - 0.09; white-crowned sparrow: $n=212$, $\beta=-0.02 \pm 0.006$, $p<0.001$, 95% C.I.: -0.03 - -0.01; dusky flycatcher: $n=212$, $\beta=-0.03 \pm 0.007$, $p<0.001$, 95% C.I.: -0.04 - -0.02; warbling vireo: $n=212$, $\beta=-0.02 \pm 0.009$, $p<0.05$, 95% C.I.: -0.04

- -0.003) (Figure S2.2). Yellow warbler abundance increased with increasing willow cover whereas white-crowned sparrows, dusky flycatchers, and warbling vireo abundance decreased with increasing willow cover.

Visitor Perception of Bird Chorus Diversity and Soundscape Pleasantness

Visitor rating of bird chorus diversity showed a negative relationship with sound level (n=469, β=-0.11 ± 0.03, p<0.001, 95% C.I.: -0.18 - -0.05) (Figure 2.1). Sound level was not a predictor of visitor ranking of soundscape pleasantness (n=469, β=0.02 ± 0.03, p=0.53, 95% C.I.: -0.04 - 0.07). However, visitor noise sensitivity and motivation to experience sounds in the park were predictors of their rankings of soundscape pleasantness, with increasing noise sensitivity decreasing pleasantness scores (n=469, β=-0.34±0.09, p<0.001, 95% C.I.: -0.51 - -0.17) and increasing motivation to experience sounds increasing pleasantness scores (n=469, β=0.24 ± 0.09, p=0.006, 95% C.I.: 0.07 - 0.42) (Figure 2.1).

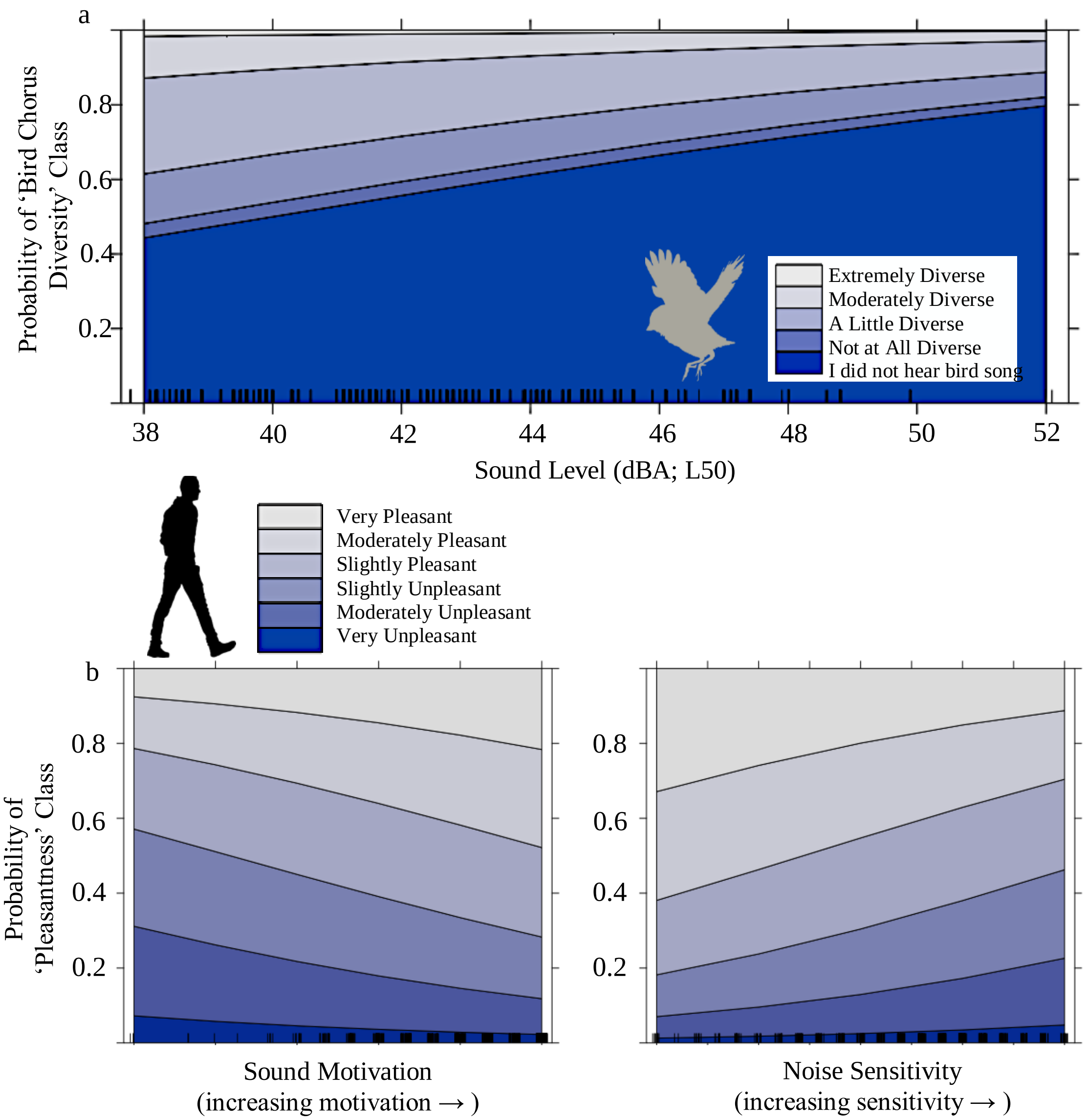

Figure 2.1 Background sound level at Grand Teton National Park and visitor traits affect human system. When surveyed, visitors preferred signage educating about soundscapes and asking visitors to limit noise among other management options. (A.) Visitors reported hearing greater birdsong diversity under lower background sound levels (n=469, β=-0.11 ± 0.03, p<0.001, 95% C.I>: -0.18- -0.05). In addition, (B.) visitor motivation to hear sounds and noise sensitivity predict soundscape pleasantness ratings (sound motivation: n=469, β=0.24 ± 0.09, p=0.006, 95% C.I.: 0.07 - 0.42; noise sensitivity: n=469, β=-0.34 ± 0.09, p<0.001, 95% C.I.: -0.51 - -0.17).

Visitor Preferences for Soundscape Management Strategies

A total of 471 individuals agreed to complete the survey, resulting in an 82% response rate from the sampling effort. Three out of four utility scores, quantitative proxies of visitor management action preferences, for levels of sign use (Information to enforcement; Table 2.1) showed a relationship with treatment condition (n=2, p<0.01; n=1, p<0.001) (Figure 2.2). In other words, when mitigation signage was present, visitors more strongly preferred three out of four signage management actions than when mitigation signage was absent. Only one out of three utility scores for speed limit levels (Table 2.1) ("You can drive 35 MPH on park roads near important wildlife habitat") showed a relationship with treatment condition (p<0.001) (Figure 2.3). Neither of the two management levels for road closures were supported by visitors (p>0.05) (Table S2.7). Management actions "No signs are posted along the road about natural quiet", "You can drive 45 MPH on park roads near important wildlife habitat", and "Park roads near important wildlife habitat are open 24 hours a day" were used as the baseline condition respectively to estimate the sum of the other levels and were therefore excluded from analysis.

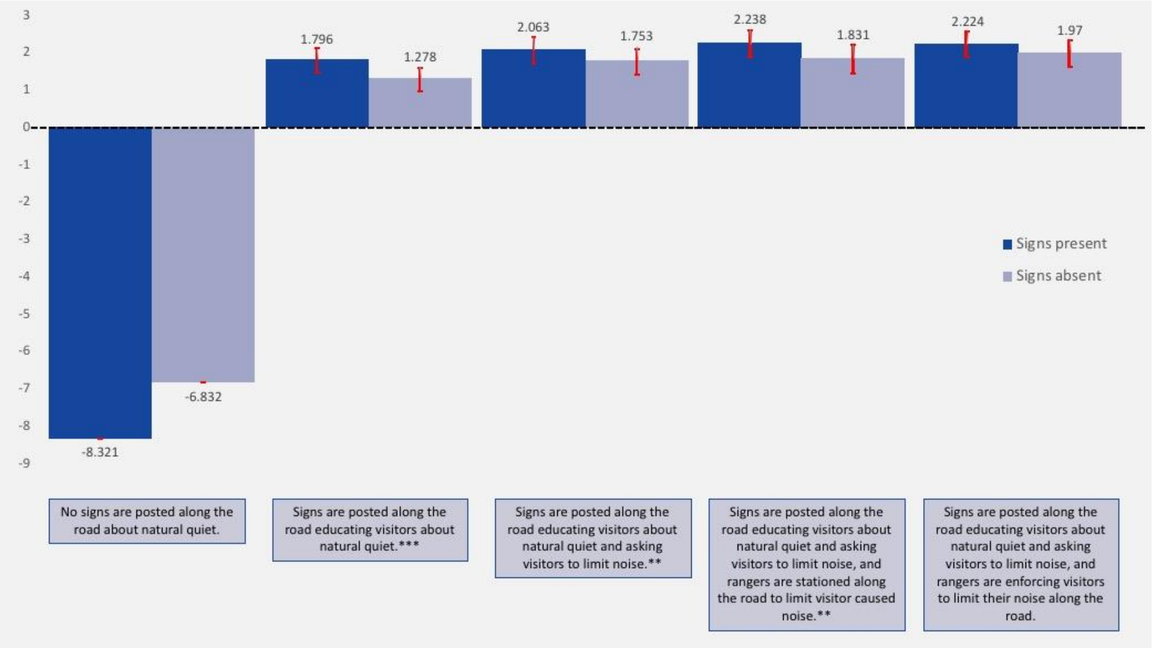

Figure 2.2 Comparison of utility coefficients for information and enforcement management actions in Grand Teton National Park. Overall, visitors had low utility coefficients for no management actions, suggesting that visitors strongly prefer at least some form of soundscape management along the road. Visitors had higher utility scores in three of the four options tested when mitigation signs were present (“No signs are posted along the road about natural quiet” was used as the baseline condition for statistical analysis and was therefore not included in this comparison). Visitors had the highest utility scores for options that provided a combination of signs and the presence of rangers to limit visitor caused noise. ***p<0.001, **p<0.01.

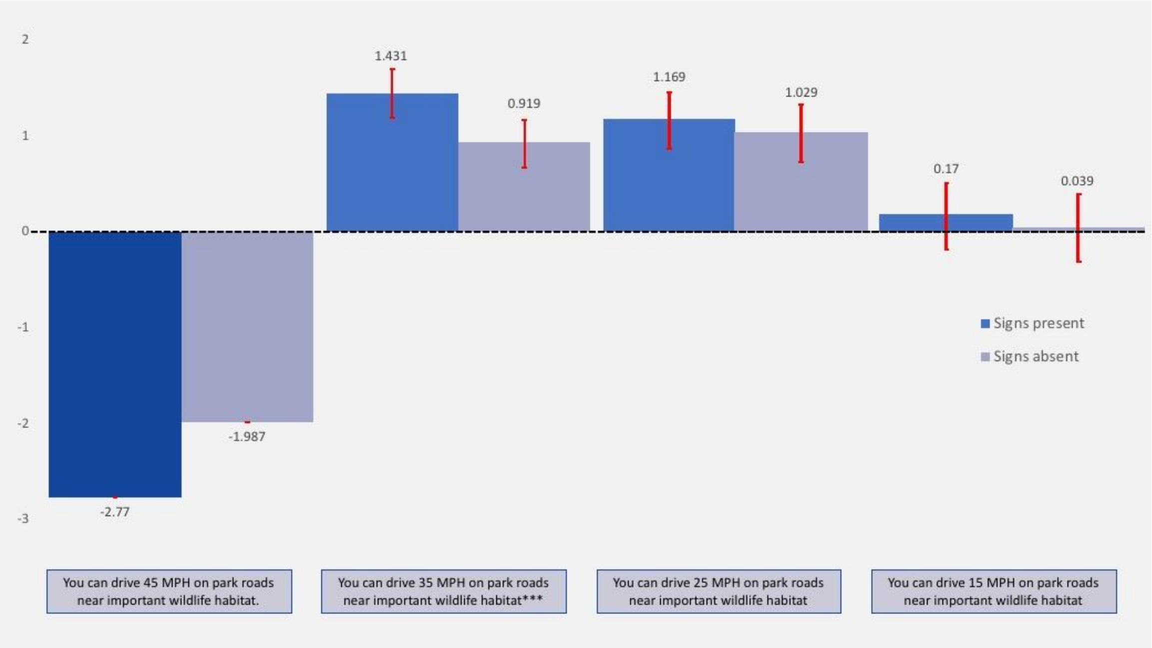

Figure 2.3 Comparison of utility coefficients for speed limit management in Grand Teton National Park. Visitors supported lower speed limits near important wildlife habitats, as indicated by the lower utility scores for 45 MPH, and by positive utility scores for all lower speed limit options. Only the 35 MPH speed limit strategy showed a significant difference between treatment (signs present) and control (signs absent) group, and visitors had stronger preferences for 35 MPH speed limits when signs were up. ***p<.001.

Overwhelmingly, visitors supported at least some form of management of visitor-caused noise through signs, as indicated by the markedly low utility scores from the no signs posted management action (signs absent = -6.832; signs present = -8.321; Figure 2.2). Of all management options involving signage, visitors’ strongest preference was for signs that educated visitors about natural quiet, asked visitors to limit their noise, and had rangers stationed along the road to limit visitor noise (Figure 2.2). Collectively, visitors had the highest utility scores for management options “Signs are posted along the road educating visitors about natural quiet and asking visitors to limit noise” and “Signs are posted along the road educating visitors about natural quiet and asking visitors to limit noise, and rangers are stationed along the trail to limit visitor cause noise”, both of which promote an appreciation of natural quiet and move to limit visitor caused noise (indirectly through signs and rangers) (Figure 2.2). These patterns were consistent across both sign absent and sign present periods. The presence of mitigation signage impacted visitor preference for mitigations action. When speed limits were slower and mitigation signage was present, visitors had higher utility scores for three of four options tested, implying that when visitors experienced quieter conditions, they were more supportive of noise mitigation actions (Figure 2.2).

Discussion

Our experimental quieting via speed limit reductions and educational signage along the road system in Grand Teton National Park decreased sound levels, thereby increasing bird availability as perceived by visitors. When signs were present, people preferred management options aimed at managing soundscapes and lowered their noise footprint through compliance with speed limit reductions. However, there was no relationship between sound level and bird abundance. In addition, soundscape pleasantness did not show a relationship with sound levels. Instead, there was a positive relationship with visitor motivation to hear sounds and a negative relationship with visitor noise sensitivity. Within the human system, we found a positive feedback loop where mitigation actions decreased noise levels, increased access to natural sounds, and resulted in stronger visitor support for soundscape mitigation strategies and quieter soundscapes.

Although soundscape pleasantness did not change with sound level, visitors perceived greater bird diversity when mitigation signage was present and under lower sound conditions—an important finding as it relates to visitor experiences in protected natural areas. Birds were present in the landscape for people to hear, and when mitigation signage was present and it was quieter, people perceived greater biodiversity. Under normal speed limits, background sound levels may have masked these natural sounds from human listeners, ultimately resulting in a lost listening opportunity. Visitor understanding behind the reasons for conservation messaging and measures, combined with visitor realization of benefits accrued from following conservation measures, is crucial for the willingness for and success of mitigation strategies (Ballantyne, Packer, and Hughes 2009). This understanding and realization is key in instilling a sense of conservation action and support in visitors of protected natural areas (Ballantyne et al. 2009).

Despite increases in biodiversity perception, bird detections remained unchanged in relation to sound level. Habitat quality may have outweighed the potential negative effects of remaining in areas exposed to traffic noise. Willow cover, not sound level, was a significant predictor of bird abundance. Previous evidence showed that a noise sensitive bird species continued to select breeding sites in habitats with elevated background sound levels despite increases in stress response and reduced fitness (Kleist et al. 2018). Willow cover (Saveraid et al. 2001) and height (Olechnowski and Debinski 2008) are important characteristics for songbird species richness, abundance, and/or density within Grand Teton National Park and the Greater Yellowstone Ecosystem. Most willow habitat was directly roadside so some findings might be related to the limited amount of this habitat in the study area at greater distances from the roadway (Table S2.5).

Another possible reason bird occupancy remained the same may be due to changes in temporal soundscape characteristics caused by speed limit reductions. At Muir Woods National Monument where visitors did not change walking speeds between treatment conditions, an even smaller overall reduction in sound level (1.19 dBA; L50) resulted in a marked shift in bird distributions (Levenhagen et al. 2019). In Grand Teton National Park where speed limits differed between treatment conditions, experimental speed limit reductions created longer noise exposure from vehicle pass by events. Instead of vehicles passing at quicker speeds and thereby creating a shorter duration of noise exposure, reductions resulted in a greater period of exposure on the landscape. Lower driving speeds may not be the best method for noise mitigation due to this extended noise exposure of individual pass by events. In addition, birds may have avoided traffic noise masking by utilizing gaps in background noise to more effectively transmit acoustic signals, a strategy found in multiple species to date (Lee et al. 2017; Gentry, Luther, and Lafayette 2017; Proppe and Finch 2017).

Lower driving speed and thus changes in sound level did not impact visitor rating of soundscape pleasantness. Instead, noise sensitivity had the strongest effect for predicting pleasantness, matching previous laboratory research (Guillén and López Barrio 2007). Ratings of soundscape pleasantness may instead be related to visitor expectations for the turnout where surveys were administered. Previous laboratory and field research has found that the majority of soundscape rating participants in these studies had pre-determined expectations of sounds present within spaces, sound controllability, and the compatibility of behaviors to the spaces (Bruce and Davies 2014; Davies et al. 2009). Visitors likely expected to hear traffic noise and understood their lack of control in avoiding noise along the roadside.

Natural soundscape management can be used as a conservation tool to enhance tourist perception and appreciation for nature and protected natural areas (A. Liu et al.

2018). Mitigation actions increased visitor conservation support through reduced anthropogenic noise and improved access to natural sounds and biodiversity. Speed limit reductions also resulted in a positive feedback loop within the human system in terms of what visitors were willing to trade-off in order to achieve soundscape and biodiversity conservation. However, the temporal consequences of slower speeds suggest that speed limit reductions may not be the best mitigation strategy. It would be best at this point to turn our attention towards investigating other possible mitigation strategies such as quiet pavement or crepuscular closures, ones promoting positive cycles in both the natural and human systems. Finding ways to mitigate noise is of utmost importance. Doing so only increases the cry for the conservation of natural soundscapes.

Chapter Two Supplementary Materials

Bird Count Detectability

Detectability can vary with multiple observers (McClure et al. 2015; Alldredge, Simons, and Pollock 2007; Sauer, Peterjohn, and Link 2008) and in relation to excessive background noise (McClure et al. 2015; Pacifici, Simons, and Pollock 2008; Simons et al. 2007). To combat the effects of multiple observer bias, our study utilized a single point count observer. Though our average L50 sound levels were just above 45 dBA, the approximate threshold beyond which impairs human ability to detect birds (Ortega and Francis 2012), we examined potential differences in the probability of bird detection between treatment blocks using package Distance (D. L. Miller 2016) in Program R. We built several models using the different key functions and modeling detection either as intercept-only or as a function of treatment. We then ranked and compared detection models using Akaike’s information criterion (Arnold 2010). We considered there to be an effect of treatment on detection if the factor for treatment was in a model within the top 98% of cumulative model weight (Burnham and Anderson 2003) and was not an uninformative parameter (Arnold 2010). Although a treatment model was indeed within 98% of the cumulative model weight, it was an uninformative parameter because the parameters in the AIC-best model were a subset of those in the treatment model and the 95% (and 85%) confidence intervals on the treatment coefficient overlapped zero (Arnold 2010). We therefore concluded there were no differences in detectability between treatment blocks and did not adjust detection counts (Table S2.6).

Figure S2.1 Enforcement and educational signage used within the experimental road corridor during treatment blocks along the John D. Rockefeller Jr. Parkway in

Grand Teton National Park. Speed reductions enforcement and educational signage alternated in week-long blocks for a total of 10 weeks from 6 June to 14 August 2016. Speed limits were reduced from 45 mph to 25 mph during sign present treatment blocks.

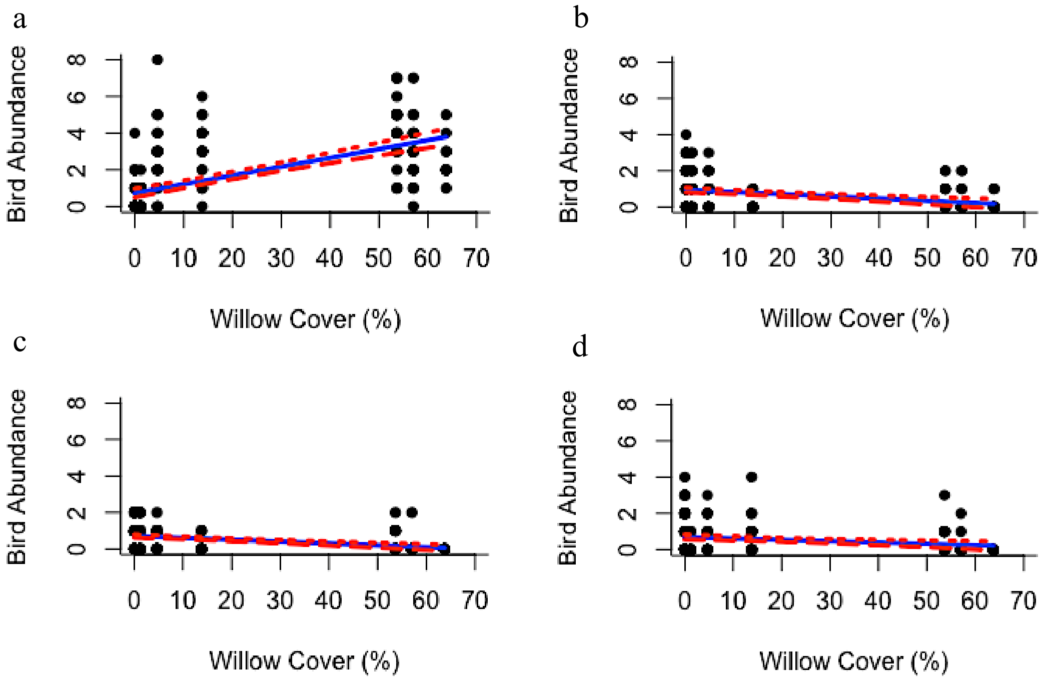

Figure S2.2 Bird abundance by willow cover for top detected (n>100) species. Bird abundance showed a relationship with percent willow cover in (a.) yellow warblers (n=212, β=0.05 ± 0.018, p<0.01, 95% C.I.: 0.01 - 0.09), (b.) white-crowned sparrows (n=212, β=-0.02 ± 0.006, p<0.001, 95% C.I.: -0.03 - -0.01), (c.) dusky flycatchers (n=212, β=-0.03 ± 0.007, p<0.001, 95% C.I.: -0.04 - -0.02), and (d.) warbling vireos (n=212, β=-0.02 ± 0.009, p<0.05, 95% C.I.: -0.04 - -0.003).

Table S2.1 Speed limit counts classified by traffic counter deployed in Grand Teton National Park road corridor. Traffic counts were classified using a traffic counter within the experimental road corridor. Visitor driving speed was classified the most in the 45-49 mph (n=46,199) range under normal conditions and in the 35-39 mph (n=21,564) during speed limit reduction treatment blocks.

Speed (mph)	Signs Absent	Signs Present
5-14 mph	90	154
15-19 mph	68	547
20-24 mph	125	5,145
25-29 mph	433	17,871
30-34 mph	1,395	20,447
35-39 mph	5,956	21,564
40-44 mph	22,944	20,899
45-49 mph	46,199	14,897
50-54 mph	27,785	5,589
55-59 mph	7,796	1,469
60-64 mph	1,558	343
65-69 mph	303	77
70-74 mph	87	37
75-79 mph	24	17
80-99 mph	56	34
Total	114,819	109,090

Table S2.2 Statistical analysis for driving speed between treatment blocks in Grand Teton National Park. There was a relationship between driving speed and treatment condition in the 5-24 mph, 25-49 mph, and 50-74 mph.

Speed (mph)	Kruskal-Wallis chi-squared	df	p
5-24 mph	51.62	1	<0.001
25-49 mph	6.90	1	0.009
50-74 mph	37.73	1	<0.001
75+ mph	0.17	1	0.68

Table S2.3 Bird species detected during point counts at Grand Teton National Park. Common name, scientific name and number of birds detected within 50 m of each point count location from 8 June to 13 August, 2016.

Common Name	Scientific Name	Detections (#)
Yellow warbler	*Setophaga petechia*	304
White-crowned sparrow	*Zonotrichia leucophrys*	159
Warbling vireo	*Vireo gilvus*	123
Dusky Flycatcher	*Empidonax oberholseri*	116
Green-tailed towhee	*Pipilo chlorurus*	62
Tree swallow	*Tachycineta bicolor*	57
Pine Siskin	*Spinus pinus*	57
Song sparrow	*Melospiza melodia*	50
Lazuli bunting	*Passerina amoena*	41
Lincoln's sparrow	*Melospiza lincolnii*	39
American Robin	*Turdus migratorius*	37
Chipping sparrow	*Spizella passerina*	34
Audubon's warbler	*Setophaga coronata auduboni*	32
Cedar waxwing	*Bombycilla cedrorum*	28
Common yellowthroat	*Geothlypis trichas*	22
Willow flycatcher	*Empidonax traillii*	22
House wren	*Troglodytes aedon*	19
Gray catbird	*Dumetella carolinensis*	17
Fox sparrow	*Passerella iliaca*	17
Red-naped sapsucker	*Sphyrapicus nuchalis*	16
Western tanager	*Piranga ludoviciana*	15
Mountain chickadee	*Poecile gambeli*	14
Brewer's blackbird	*Euphagus cyanocephalus*	12
Dark-eyed junco	*Junco hyemalis*	10
Calliope hummingbird	*Selasphorus calliope*	9
Northern flicker	*Colaptes auratus*	6
Clark's nutcracker	*Nucifraga columbiana*	6
MacGillivray's warbler	*Geothlypis tolmiei*	5
Brown-headed cowbird	*Molothrus ater*	4
American goldfinch	*Spinus tristis*	4
Black-headed grosbeak	*Pheucticus melanocephalus*	3
Rufous hummingbird	*Selasphorus rufus*	3
Broad-tailed hummingbird	*Selasphorus platycercus*	2
Hairy woodpecker	*Picoides villosus*	2
American white pelican	*Pelecanus erythrorhynchos*	2
Downy woodpecker	*Picoides pubescens*	2
Brewer's sparrow	*Spizella breweri*	2
Swainson's thrush	*Catharus ustulatus*	2
Common raven	*Corvus corax*	2
Mountain bluebird	*Sialia currucoides*	1

Bullock's oriole	*Icterus bullockii*	1
Red-tailed hawk	*Buteo jamaicensis*	1
Townsend's warbler	*Setophaga townsendi*	1
Total		1,361

Table S2.4 Percent decrease in detections for species with >100 detections at Grand Teton National Park. Statistical output from generalized linear mixed models with daily-averaged L50 as the fixed effect and a random effect for site. There was no relationship between count and sound level for each species**.**

Scientific Name	Intercept		Averaged L50 (dB(A))	p
Setophaga petechia	β	-2.45	0.04	0.33
	S.E.	1.89	0.04	
Zonotrichia leucophrys	β	0.23	-0.02	0.70
	S.E.	1.78	0.04	
Empidonax oberholseri	β	-1.48	0.02	0.74
	S.E.	2.03	0.04	
Vireo gilvus	β	-3.00	0.05	0.37
	S.E.	2.50	0.06	

Table S2.5 Percent willow cover within 50 m of each Grand Teton National Park point count center location. We estimated percent willow cover for each location using program Samplepoint. Percent willow cover was a significant predictor of bird count in our generalized linear model.

Site	Willow Cover (%)	Distance to Point Count Center from Road (m)
A	0.00	66
B	0.00	98
C	4.65	77
D	0.00	177
E	57.04	56
F	0.00	203
G	0.00	57
H	13.80	66
I	1.19	58
J	53.65	50
K	63.73	82

Table S2.6 AIC table for Grand Teton National Park detectability models. AIC models used to determine if treatment condition influenced probability of bird detectability. Models containing treatment in the formula were not AIC-best and contained uninformative parameters; therefore, bird count numbers were therefore not adjusted.

Model	Key Function	Formula	AIC	***Δ***AIC	Relative Likelihood (exp(-0.5****Δ***AIC))	w*i*
A	Uniform with cosine adjustment terms of order 1,2,3	NA	10108.01	0.0000000	1	0.304426825
B	Uniform with cosine adjustment terms of order 1,2	NA	10108.74	0.7291301	0.694498657	0.211424021
C	Hazard-rate	~1	10108.94	0.9373457	0.625832291	0.190520137
D	Half-normal with cosine adjustment term of order 2	~1	10110.23	2.2247371	0.328779308	0.100089241
E	Half-normal	~1	10110.64	2.6291069	0.268594237	0.081767291
F	Hazard-rate	Treatment	10110.68	2.6695408	0.263218604	0.080130804
G	Half-normal	Treatment	10112.53	4.527911	0.103938542	0.03164168
Cumulative Model Weight					3.284861638	

Table S2.7 Results from the stated choice model for visitor preferences for soundscape management in Grand Teton National Park for sign absent and present conditions. Overall results indicated that the statistical model was significant (Log likelihood ratio= -1999.15; Pseudo R^2= 0.2175).

Attribute		Signs present (Treatment)			Signs absent (Control)		
Speed limits		Coefficient	Std. error	*p*-value	Coefficient	Std. error	*p*-value
1.	You can drive 45 MPH on park roads near important wildlife habitat.	-2.77	--	--	-1.987	--	--
2.	You can drive 35 MPH on park roads near important wildlife habitat.	1.431	0.264	<.001	0.919	0.245	<.001
3.	You can drive 25 MPH on park roads near important wildlife habitat.	1.169	0.282	<.001	1.029	0.302	<.001
4.	You can drive 15 MPH on park roads near important wildlife habitat.	0.170	0.341	0.618	0.039	0.351	.911

Information and enforcement management actions							
1.	No signs are posted along the road about natural quiet	-8.321	--	--	-6.832	--	--
2.	Signs are posted along the road educating visitors about natural quiet.	1.796	0.332	<.001	1.278	0.323	<.001
3.	Signs are posted along the road educating visitors about natural quiet and asking visitors to limit noise.	2.063	0.353	<.001	1.753	0.341	<.001
4.	Signs are posted along the road educating visitors about natural quiet and asking visitors to limit noise, and rangers are stationed along the road to limit visitor caused noise.	2.238	0.364	<.001	1.831	0.376	<.001
5.	Signs are posted along the road educating visitors about natural quiet and asking visitors to limit noise, and rangers are enforcing visitors to limit their noise along the road.	2.224	0.335	<.001	1.970	0.345	<.001
Closures							
1.	Park roads near important wildlife habitat are open 24 hours a day.	-0.377	--	--	0.229	--	--
2.	Park roads near important wildlife habitat are closed one hour after dawn for the morning breeding bird chorus.	0.126	0.174	.470	-0.156	0.196	.425
3.	Park roads near important wildlife habitat are closed for one hour after dawn and one hour in the evening for the breeding bird chorus.	0.251	0.216	.246	-0.073	0.224	.744
Number of choice questions	3752						
Number of parameters	61						
Log-likelihood ratio	-1999.15						
Pseudo R^2	0.2175						
Note: All parameters are assumed to be normally distributed, while correlations are allowed only within levels of each attribute. The model was normalized by preference for bird song.							

CONCLUSION

Both of our studies show that anthropogenic noise can be mitigated in protected natural areas through the use of mitigation signage. The addition of signage reduced background sound levels and increased listening area in both Muir Woods National Monument and Grand Teton National Park. However, the biological impacts of noise relief varied depending on the type of mitigated noise. We found a negative relationship between background sound levels and bird count under non-motorized anthropogenic noise and found no relationship between the two in response to traffic noise. In both studies, human perception of bird biodiversity increased as a result of sign mitigation. Overall, visitors to these areas were supportive of noise management strategies utilizing signage, even more so when actively experiencing noise mitigation first hand. Importantly, we provide evidence that the soundscape mediated interactions between natural and human systems at Muir Woods National Monument. Though there was no evidence of a fully-functioning feedback cycle at Grand Teton National Park, we did find support a feedback loop within the human system in regards to soundscape mitigation preferences.

Several road ecology studies have shown a negative relationship between roads and traffic noise to wildlife abundance and distribution (Reijnen, Foppen, and Meeuwsen 1996; Fahrig and Rytwinski 2009; Benítez-López, Alkemade, and Verweij 2010). In our Grand Teton National Park study, we surprisingly found no change in bird count in response to sound levels when an even smaller noise relief at Muir Woods National

Monument showed a relationship between the two. This may be due in part to different ways in which wildlife perceive people moving through the landscape or the temporal alteration of soundscape characteristics through speed limit reductions. We postulate that birds may have circumvented masking effects by utilizing background noise gaps between traffic pass by events. A more robust analysis on the potential use of noise gaps may include using sound recordings to quantify average gap size between vehicles in each condition, or similar to Proppe and Finch (2017), measuring avian vocalization rates between sign absent and sign present traffic gap conditions. In addition, a more thorough analysis of level statistics (sound level met or exceeded for a certain percentage (e.g. 10%, 20%, etc.) of the measurement time) between treatment conditions may shed more light on the sound level threshold in which speed limit reductions and mitigation signage are no longer effective.

Our study was unique in that biological and social science assessments occurred during the same weeks at each respective park unit. While we did find evidence that human perception of bird biodiversity changed in relationship to either sound level or the interaction between the number of species present and treatment condition. One limitation of this study was that our visitor intercept surveys assessing biodiversity were not always time-matched with bird counts. A recommendation to further enhance this paired study design would be to conduct a greater amount of visitor intercept surveys during the same timeframe as bird counts to better compare visitor perception to biodiversity to actual species counts at the time of their park experience. This approach may not have been practical in order to achieve the desired sample size for stated choice modelling as the recommended time to collect bird count data is within the first five hours of sunrise (Hanni et al. 2009).

We provide evidence of a feedback loop at Grand Teton National Park where sign use reduced sound levels, thus increasing biodiversity perception and increasing support for soundscape management. Unlike Muir Woods National Monument, we found no relationship between soundscape pleasantness and background sound level. One possible explanation is that the visual aspects of the turnout location (e.g. view of Mount Moran reflecting in Oxbow Bend) positively influenced soundscape perception. Previous lab research has shown that pleasant visual images, more pleasant that the sound accompanying the image, can increase the reported pleasantness of the soundscape (Guillén and López Barrio 2007). Another possible explanation could be related to visitor expectations of the turnout where visitor-intercept surveys were administered. Research using a combination of laboratory and field experiments found that a majority of participants had a pre-determined expectation of the soundscape within spaces, that the soundscapes sounded as they should, and that these spaces were as loud as expected or quieter (Bruce and Davies 2014). Expectations for the controllability of sounds and the compatibility of behaviors to the spaces also influence soundscape perception (Bruce and Davies 2014; Davies et al. 2009). The fact that the location is a turnout from an interstate highway meant for a temporary break in park travel, it is likely that visitors expected to hear traffic noise, a fact that could not be controlled, and that the primary purpose of stopping at that location would not be to hear natural sounds.

Perhaps the most key finding of this research is that the soundscape mediates interactions within and between human and natural systems, and that mitigation increases preference and support for conservation actions. We show that sounds present in the landscape can affect wildlife count and distribution, human perception and experience with the natural world, and the willingness of individuals to trade-off personal access to promote park conditions that benefit wildlife and foster beneficial conditions for human well-being and experience. This feedback system may be coupled without visitors even knowing it exists. Finding ways to maintain natural quiet and support rich aural experiences is crucial at a time when the global population continues to rise, and with it, urbanization, sprawl, and increased anthropogenic infrastructure. Educational programs and messaging that promote natural sounds may provide an important link between human actions and desired soundscape outcomes.

Anthropogenic noise can be successfully mitigated with signs. While our studies add to a growing body of research on the impacts of noise on wildlife and humans, continued research in the area is still warranted. In particular, work on elucidating the connections between road corridor manipulation and mitigation impacts to wildlife and human experience require further study. Investigations utilizing quiet pavement or crepuscular road closures serve as potential research areas of interest. Regardless, continued exploration into conservation strategies that maintain natural soundscapes is essential and we progress into the Anthropocene. Finding ways to limit human noise is vital not only to wildlife and human interactions, but to maintaining a continued sense of natural wonder, satisfaction, and desire.

REFERENCES

Abbott, Lauren C., Derrick Taff, Peter Newman, Jacob A. Benfield, and Andrew J. Mowen. 2016. “The Influence of Natural Sounds on Attention Restoration.” *Journal of Park and Recreation Administration* 34 (3): 5–15. doi:10.18666/JPRA-2016-V34-I3-6893.

Alldredge, Mathew W., Theodore R. Simons, and Kenneth H. Pollock. 2007. “Factors Affecting Aural Detections of Songbirds.” *Ecological Applications* 17 (3): 948–55. doi:10.1890/06-0685.

Alvarsson, Jesper J., Stefan Wiens, and Mats E. Nilsson. 2010. “Stress Recovery during Exposure to Nature Sound and Environmental Noise.” *International Journal of Environmental Research and Public Health* 7 (3): 1036–46. doi:10.3390/ijerph7031036.

Ament, Rob, Anthony P Clevenger, Olivia Yu, and Amanda Hardy. 2008. “An Assessment of Road Impacts on Wildlife Populations in U . S . National Parks.” *Environmental Management* 42 (3): 480–96. doi:10.1007/s00267-008-9112-8.

Arévalo, J. Edgardo, and Emily Blau. 2018. “Road Encroachment Near Protected Areas Alters the Natural Soundscape Through Traffic Noise Pollution in Costa Rica Director y Editor : Road Encroachment Near Protected Areas Alters the Natural Soundscape Through Traffic Noise Pollution in Costa Rica.” *Revista de Ciencias Ambientales* 52 (1): 27–48.

Arnold, Todd W. 2010. “Uninformative Parameters and Model Selection Using Akaike’s

Information Criterion." *Journal of Wildlife Management* 74 (6): 1175–78. doi:10.2193/2009-367.

Ballantyne, Roy, Jan Packer, and Karen Hughes. 2009. "Tourists' Support for Conservation Messages and Sustainable Management Practices in Wildlife Tourism Experiences." *Tourism Management* 30 (5). Elsevier Ltd: 658–64. doi:10.1016/j.tourman.2008.11.003.

Barber, Jesse R., Chris L. Burdett, Sarah E. Reed, Katy a. Warner, Charlotte Formichella, Kevin R. Crooks, Dave M. Theobald, and Kurt M. Fristrup. 2011. "Anthropogenic Noise Exposure in Protected Natural Areas: Estimating the Scale of Ecological Consequences." *Landscape Ecology* 26: 1281–95. doi:10.1007/s10980-011-9646-7.

Barber, Jesse R., Kevin R. Crooks, and Kurt M. Fristrup. 2010. "The Costs of Chronic Noise Exposure for Terrestrial Organisms." *Trends in Ecology and Evolution* 25 (3). Elsevier Ltd: 180–89. doi:10.1016/j.tree.2009.08.002.

Barber, Jesse R, Kurt M Fristrup, Casey L Brown, Amanda R Hardy, Lisa M Angeloni, and Kevin R Crooks. 2010. "Conserving the Wild Life Therein: Protecting Park Fauna from Anthropogenic Noise." *Park Science* 26 (3): 26–31.

Basner, Mathias, Wolfgang Babisch, Adrian Davis, Mark Brink, Charlotte Clark, Sabine Janssen, and Stephen Stansfeld. 2014. "Auditory and Non-Auditory Effects of Noise on Health." *The Lancet* 383 (9925): 1325–32. doi:10.1016/S0140-6736(13)61613-X.Auditory.

Bates, D., M. Maechler, B. Bolker, and S. Walker. 2015. "Fitting Linear Mixed-Effects Models Using Lme4." *Journal of Statistical Software* 67 (1): 1–48. doi:10.18637/jss.v067.i01.

Bee, Mark A., and Eli M. Swanson. 2007. “Auditory Masking of Anuran Advertisement Calls by Road Traffic Noise.” *Animal Behaviour* 74 (6): 1765–76. doi:10.1016/j.anbehav.2007.03.019.

Belaire, J Amy, Lynne M Westphal, Christopher J Whelan, and Emily S Minor. 2015. “Urban Residents’ Perceptions of Birds in the Neighborhood: Biodiversity, Cultural Ecosystem Services, and Disservices.” *The Condor* 117 (2): 192–202. doi:10.1650/CONDOR-14-128.1.

Benfield, Jacob A, Gretchen A Nurse, Adam W Gibson, B Derrick Taff, Peter Newman, and Paul A Bell. 2014. “Testing Noise in the Field : A Brief Measure of Individual Noise Sensitivity.” *Environment and Behavior* 46 (3): 353–72. doi:10.1177/0013916512454430.

Benfield, Jacob A, B. Derrick Taff, Peter Newman, and Joshua Smyth. 2014. “Natural Sound Facilitates Mood Recovery.” *Ecopsychology* 6 (3): 183–88. doi:10.1089/eco.2014.0028.

Benítez-López, Ana, Rob Alkemade, and Pita a. Verweij. 2010. “The Impacts of Roads and Other Infrastructure on Mammal and Bird Populations: A Meta-Analysis.” *Biological Conservation* 143 (6). Elsevier Ltd: 1307–16. doi:10.1016/j.biocon.2010.02.009.

Bennett, Elena M., Wolfgang Cramer, Alpina Begossi, Georgina Cundill, Sandra Díaz, Benis N. Egoh, Ilse R. Geijzendorffer, et al. 2015. “Linking Biodiversity, Ecosystem Services, and Human Well-Being: Three Challenges for Designing Research for Sustainability.” *Current Opinion in Environmental Sustainability* 14: 76–85. doi:10.1016/j.cosust.2015.03.007.

Booth, D. Terrance, Samuel E. Cox, and Robert D. Berryman. 2006. “Point Sampling Digital Imagery with ‘Samplepoint.’” *Environmental Monitoring and Assessment* 123 (1–3): 97–108. doi:10.1007/s10661-005-9164-7.

Bowler, Diana E, Lisette M Buyung-ali, Teri M Knight, and Andrew S Pullin. 2010. “A Systematic Review of Evidence for the Added Benefits to Health of Exposure to Natural Environments.” *BMC Public Health* 10 (1): 456.

Bratman, Gregory N., J. Paul Hamilton, and Gretchen C. Daily. 2012. “The Impacts of Nature Experience on Human Cognitive Function and Mental Health.” *Annals of the New York Academy of Sciences* 1249 (1): 118–36. doi:10.1111/j.1749-6632.2011.06400.x.

Bruce, Neil S., and William J. Davies. 2014. “The Effects of Expectation on the Perception of Soundscapes.” *Applied Acoustics* 85. Elsevier Ltd: 1–11. doi:10.1016/j.apacoust.2014.03.016.

Bunkley, Jessie Patrice, and Jesse Rex Barber. 2015. “Noise Reduces Foraging Efficiency in Pallid Bats (Antrozous Pallidus).” *Ethology* 121: 1–6. doi:10.1111/eth.12428.

Burnham, Kenneth P., and David R. Anderson. 2003. *Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach*. Second. New York, NY: Springer Science & Business Media.

Buxton, Rachel T, Megan F Mckenna, Daniel Mennitt, Kurt Fristrup, Kevin Crooks, Lisa Angeloni, and George Wittemyer. 2017. “Noise Pollution Is Pervasive in U.S. Protected Areas.” *Science* 356 (6337): 531–33. doi:doi: 10.1126/science.aah4783.

Cahill, K. L., J. L. Marion, and S. R. Lawson. 2008. “Exploring Visitor Acceptability for

Hardening Trails to Sustain Visitation and Minimise Impacts." *Journal of Sustainable Tourism* 16 (2): 232–45. doi:http://doi.org/10.2167/jost804.0.

Clergeau, Philippe, Jukka Jokimäki, and Jean-Pierre L Savard. 2001. "Are Urban Bird Communities Influenced by the Bird Diversity of Adjacent Landscapes ?" *Journal of Applied Ecology* 38: 1122–34.

Coensel, Bert De, and Dick Botteldooren. 2006. "The Quiet Rural Soundscape and How to Characterize It." *Acta Acustica United with Acustica* 92 (August): 887–97.

Coffin, Alisa W. 2007. "From Roadkill to Road Ecology : A Review of the Ecological Effects of Roads." *Journal of Transport Geography* 15 (5): 396–406. doi:10.1016/j.jtrangeo.2006.11.006.

Davies, William J., Mags D. Adams, Neil Spencer Bruce, Melissa Marselle, Rebecca Cain, Paul A. Jennings, John Poxon, et al. 2009. "The Positive Soundscape Project: A Synthesis of Results from Many Disciplines." *38th International Congress and Exposition on Noise Control Engineering 2009, INTER-NOISE 2009* 1: 663–72. http://www.scopus.com/inward/record.url?eid=2-s2.0-84870040778&partnerID=tZOtx3y1.

Dulac, John. 2013. "Global Land Transport Infrastructure Requirements: Estimating Road and Railway Infrastructure Capacity and Costs to 2050." Paris.

Fahrig, L, and T Rytwinski. 2009. "Effects of Roads on Animal Abundance: An Empirical Review and Synthesis." *Ecology and Society* 14 (1): 21–41. doi:http://www.ecologyandsociety.org/vol14/iss1/art21/.

Francis, Clinton D., and Jesse R. Barber. 2013. "A Framework for Understanding Noise Impacts on Wildlife: An Urgent Conservation Priority." *Frontiers in Ecology and* *the Environment* 11 (6): 305–13. doi:10.1890/120183.

Francis, Clinton D., Peter Newman, B. Derrick Taff, Crow White, Christopher A. Monz, Mitchell Levenhagen, Alissa R. Petrelli, et al. 2017. “Acoustic Environments Matter : Synergistic Benefits to Humans and Ecological Communities.” *Journal of Environmental Management* 203. Elsevier Ltd: 245–54. doi:10.1016/j.jenvman.2017.07.041.

Frumkin, Howard, Gregory N Bratman, Sara Jo Breslow, Bobby Cochran, Peter H Kahn Jr, Joshua J Lawler, Phillip S Levin, et al. 2017. “Nature Contact and Human Health : A Research Agenda.” *Environmental Conservation* 125 (7).

Gentry, Katherine E, David A Luther, and West Lafayette. 2017. “Spatiotemporal Patterns of Avian Vocal Activity in Relation to Urban and Rural Background Noise.” *Journal of Ecoacoustics* 1: Z9TQHU.

Gidlöf-Gunnarsson, Anita, and Evy Öhrström. 2007. “Noise and Well-Being in Urban Residential Environments: The Potential Role of Perceived Availability to Nearby Green Areas.” *Landscape and Urban Planning* 83 (2–3): 115–26. doi:10.1016/j.landurbplan.2007.03.003.

Goines, Lisa, and Louis Hagler. 2007. “Noise Pollution : A Modern Plague.” *Southern Medical Journal* 100 (3): 287–94.

Guillén, José, and Isabel. López Barrio. 2007. “Importance of Personal, Attitudinal an Contextual Variables in the Assesment of Pleasantness of the Urban Sound Environment.” In *19th International Congress on Acoustics*.

Gurule-Small, Gabrielle A, and Robin M Tinghitella. 2018. “Developmental Experience with Anthropogenic Noise Hinders Adult Mate Location in an Acoustically

Signalling Invertebrate.” *Biology Letters* 14 (2): 20170714.

Haas, G.E., and T.J. Wakefield. 1998. “National Aprks and the American Public: A National Public Opinion Survey on the National Park System: A Summary Report.” *The Association*.

Halfwerk, Wouter, Leonard J M Holleman, C(Kate) M. Lessells, and Hans Slabbekoorn. 2011. “Negative Impact of Traffic Noise on Avian Reproductive Success.” *Journal of Applied Ecology* 48: 210–19. doi:10.1111/j.1365-2664.2010.01914.x.

Hammer, Monica S., Tracy K. Swinburn, and Richard L. Neitzel. 2014. “Environmental Noise Pollution in the United States : Developing an Effective Public Health Response.” *Environmental Health Perspectives* 122 (2): 115–19.

Hanni, David, Chris White, J.A. Blakesly, G.J. Levandoski, and J.J. Birek. 2009. “Rocky Mountain Bird Observatory Point Transect Protocol.”

Hartig, Terry, Richard Mitchell, Sjerp De Vries, and Howard Frumkin. 2014. “Nature and Health.” *Annual Review of Public Health* 35: 207–28. doi:10.1146/annurev-publhealth-032013-182443.

Hastie, Trevor. 2017. “Gam: Generalized Additive Models.” https://cran.r-project.org/package=gam.

Hong, Joo Young, and Jin Yong Jeon. 2015. “Landscape and Urban Planning Influence of Urban Contexts on Soundscape Perceptions : A Structural Equation Modeling Approach.” *Landscape and Urban Planning* 141. Elsevier B.V.: 78–87. doi:10.1016/j.landurbplan.2015.05.004.

Ibisch, Pierre L., Monika T. Hoffmann, Stefan Kreft, Guy Pe’er, Vassiliki Kat, Lisa Biber-Freudenberger, Dominick A. DellaSala, Mariana M. Vale, Peter R. Hobson, and Nuria Selva. 2016. “A Global Map of Roadless Areas and Their Conservation Status.” *Science* 354 (6318): 1423–27. doi:10.1126/science.aaf7166.

Kaplan, Stephen. 1995. “The Restorative Benefits of Nature: Toward an Integrative Framework.” *Journal of Environmental Psychology* 15: 169–82.

Karp, Daniel S, and Roger Guevara. 2010. “Conversational Noise Reduction as a Win – Win for Ecotourists and Rain Forest Birds in Peru.” *Biotropica* 43: 122–30. doi:10.1111/j.1744-7429.2010.00660.x.

Kight, Caitlin R., Margaret S. Saha, and John P. Swaddle. 2012. “Anthropogenic Noise Is Associated with Reductions in the Productivity of Breeding Eastern Bluebirds (Sialia Sialis).” *Ecological Applications* 22 (7): 1989–96. doi:10.1890/12-0133.1.

Kight, Caitlin R., and John P. Swaddle. 2011. “How and Why Environmental Noise Impacts Animals: An Integrative, Mechanistic Review.” *Ecology Letters* 14 (10): 1052–61. doi:10.1111/j.1461-0248.2011.01664.x.

Kleist, Nathan J, Robert P Guralnick, Alexander Cruz, Christopher A Lowry, and Clinton D Francis. 2018. “Chronic Anthropogenic Noise Disrupts Glucocorticoid Signaling and Has Multiple Effects on Fitness in an Avian Community.” *Proceedings of the National Academy of Sciences*, 201709200. doi:10.1073/pnas.1709200115.

Laumann, Karin, Tommy Gärling, and Kjell Morten Stormark. 2001. “Rating Scale Measures of Restorative Components of Environments.” *Journal of Environmental Psychology* 21: 31–44. doi:10.1006/jevp.2000.0179.

Laurance, William F, Gopalasamy Reuben Clements, Sean Sloan, Christine S O’Connell, Nathan D Mueller, Miriam Goosem, Oscar Venter, et al. 2014. “A Global Strategy for Road Building.” *Nature* 513 (7517). Nature Publishing Group: 229.

doi:10.1038/nature13717.

Lawson, Steven R, and Robert E Manning. 2002. “Tradeoffs Among Social, Resource, and Management Attributes of the Denali Wilderness Experience: A Contextual Approach to Normative Research.” *Leisure Sciences* 24 (3–4): 297–312. doi:http://doi.org/10.1080/01490400290050754.

———. 2003. “Research To Guide Management Of Backcountry Camping At Isle Royale National Park : Part II – Prescriptive Research.” *Journal of Park and Recreation Administration* 21 (3): 43–57.

Lee, Norman, Jessica L Ward, Alejandro Vélez, Christophe Micheyl, and Mark A Bee. 2017. “Frogs Exploit Statistical Regularities in Noisy Acoustic Scenes to Solve Cocktail-Party-like Report Frogs Exploit Statistical Regularities in Noisy Acoustic Scenes to Solve Cocktail-Party-like Problems.” *Current Biology*, 1–8. doi:10.1016/j.cub.2017.01.031.

Levenhagen, Mitchell J., Zachary D. Miller, Dylan G.E. Gomes, Alissa R. Graunke, Lauren A. Ferguson, Yau Huo Shr, B. Derrick Taff, et al. 2019. “Ecosystem Services Provided by Soundscapes Link People and Wildlife.” *Unpublished Manuscript*.

Liu, Aili, Xuan Lorna Wang, Fucheng Liu, Changhong Yao, and Zhiyong Deng. 2018. “Soundscape and Its Influence on Tourist Satisfaction.” *Service Industries Journal* 38 (3–4). Taylor & Francis: 164–81. doi:10.1080/02642069.2017.1382479.

Liu, Jianguo, Thomas Dietz, Stephen R Carpenter, Marina Alberti, Carl Folke, Emilio Moran, Alice N Pell, et al. 2007. “Complexity of Coupled Human and Natural Systems.” *Science (New York, N.Y.)* 317 (5844): 1513–16.

doi:10.1126/science.1144004.

Louviere, Jordan, and Harry Timmermans. 1990. “Stated Preference and Choice Models Applied to Recreation Research: A Review.” *Leisure Sciences* 12 (1): 9–32.

Lynch, Emma, Damon Joyce, and Kurt Fristrup. 2011. “An Assessment of Noise Audibility and Sound Levels in U.S. National Parks.” *Landscape Ecology* 26 (9): 1297–1309. doi:10.1007/s10980-011-9643-x.

Madadi, Hossein, Hossein Moradi, Alireza Soffianian, Abdolrassoul Salmanmahiny, Josef Senn, and Davide Geneletti. 2017. “Degradation of Natural Habitats by Roads: Comparing Land-Take and Noise Effect Zone.” *Environmental Impact Assessment Review* 65 (October 2016): 147–55. doi:10.1016/j.eiar.2017.05.003.

Manning, R. 2011. *Studies in Outdoor Recreation: Search and Research for Satisfaction*. Corvallis: Oregon State University Press.

Marin, Lelaina D., Peter Newman, Robert Manning, Jerry J. Vaske, and David Stack. 2011. “Motivation and Acceptability Norms of Human-Caused Sound in Muir Woods National Monument.” *Leisure Sciences* 33 (931379096): 147–61. doi:10.1080/01490400.2011.550224.

Mcclure, Christopher J W, Jesse R Barber, Heidi E Ware, Jay Carlisle, and Gregory Kaltenecker. 2013. “An Experimental Investigation into the Effects of Traffic Noise on Distributions of Birds: Avoiding the Phantom Road.” *Proceedings of the Royal Society of London B: Biological Sciences* 280 (1773): 20132290. doi:10.1098/rspb.2013.2290.

McClure, Christopher J W, Allison C. Korte, Julie A. Heath, and Jesse R. Barber. 2015. “Pavement and Riparian Forest Shape the Bird Community along an Urban River

Corridor.” *Global Ecology and Conservation* 4. Elsevier B.V.: 291–310. doi:10.1016/j.gecco.2015.07.004.

McDonald, C.D., R.M. Baumgartner, and R. Iachan. 1995. “National Park Service Aircraft Management Studies, National Park Service, USDI. Report No. 94-2.” Denver, CO.

Miller, D.L. 2016. “Distance: Distance Sampling Detection Function and Abundance Estimation.”

Miller, James R. 2005. “Biodiversity Conservation and the Extinction of Experience.” *Trends in Ecology and Evolution* 20 (8): 430–34. doi:10.1016/j.tree.2005.05.013.

Newman, Peter, Robert Manning, Donald Dennis, and Ward Mckonly. 2005. “Informing Carrying Capacity Decision Making in Yosemite National Park, USA Using Stated Choice Modeling.” *Journal of Park and Recreation Administration* 23 (1): 75–89.

Nichols, James D, Len Thomas, and Paul B Conn. 2009. “Inferences about Landbird Abundance from Count Data: Recent Advances and Future Directions.” In *Modeling Demographic Processes In Marked Populations*, 201–35. doi:10.1007/978-0-387-78151-8.

NPS. 2017a. “Annual Park Recreation Visitation (1904-2016) - Grand Teton NP.” Vol. 20. https://irma.nps.gov/Stats/SSRSReports/Park Specific Reports/Annual Park Recreation Visitation (1904 - Last Calendar Year)?Park=GRTE.

———. 2017b. “Annual Park Recreation Visitation (1904-2016) - Muir Woods NM.” Vol. 20. https://irma.nps.gov/Stats/SSRSReports/Park Specific Reports/Annual Park Recreation Visitation (1904 - Last Calendar Year.

Olechnowski, Brian F. M., and Diane M. Debinski. 2008. “Response of Songbirds to

Riparian Willow Habitat Structure in the Greater Yellowstone Ecosystem.” *The Wilson Journal of Ornithology* 120 (4): 830–39. doi:10.1676/07-132.1.

Ortega, Catherine P., and Clinton D. Francis. 2012. “Chapter 7: Effects of Gas-Well-Compressor Noise on the Ability to Detect Birds during Surveys in Northwest New Mexico.” *Ornithological Monographs* 74 (1): 78–90. doi:10.1525/om.2012.74.1.78.

Pacifici, Jamian K., Theodore R. Simons, and Kenneth H. Pollock. 2008. “Effects of Vegetation and Background Noise on the Detection Process in Auditory Avian Point-Count Surveys.” *The Auk* 125 (3): 600–607.

Parris, Kirsten M., and Angela Schneider. 2008. “Impacts of Traffic Noise and Traffic Volume on Birds of Roadside Habitats.” *Ecology and Society* 14 (1). doi:10.5751/ES-02761-140129.

Pilcher, Ericka J., Peter Newman, and Robert E. Manning. 2009. “Understanding and Managing Experiential Aspects of Soundscapes at Muir Woods National Monument.” *Environmental Management* 43: 425–35. doi:10.1007/s00267-008-9224-1.

Pilcher, Ericka, Peter Newman, and Dave Stack. 2007. “Grand Teton National Park Soundscape Report 2006-2007.”

Potvin, Dominique A. 2016. “Coping with a Changing Soundscape : Avoidance , Adjustments and Adaptations.” *Animal Cognition*. Springer Berlin Heidelberg. doi:10.1007/s10071-016-0999-9.

Proppe, Darren S, and Emily Finch. 2017. “Vocalizing during Gaps in Anthropogenic Noise Is an Uncommon Trait for Enhancing Communication in Songbirds.” *Journal of Ecoacoustics* 1: TLP16D.

R Core Team. 2016. “R: A Language and Environment for Statistical Computing.” R Foundation for Statistical Computing, Vienna, Austria. https://www.r-project.org/.

Ratcliffe, Eleanor, Birgitta Gatersleben, and Paul T. Sowden. 2013. “Bird Sounds and Their Contributions to Perceived Attention Restoration and Stress Recovery.” *Journal of Environmental Psychology* 36: 221–28.

Raudsepp-Hearne, Ciara, Garry D. Peterson, Maria Tengö, Elena M. Bennett, Tim Holland, Karina Benessaiah, Graham K. MacDonald, and Laura Pfeifer. 2010. “Untangling the Environmentalist’s Paradox: Why Is Human Well-Being Increasing as Ecosystem Services Degrade?” *BioScience* 60 (8): 576–89. doi:10.1525/bio.2010.60.8.4.

Reijnen, Rien, Ruud Foppen, and Henk Meeuwsen. 1996. “The Effects of Traffic on the Density of Breeding Birds in Dutch Agricultural Grasslands.” *Biological Conservation* 75 (3): 255–60.

Russell, Roly, Anne D Guerry, Patricia Balvanera, Rachelle K Gould, Xavier Basurto, Kai M A Chan, Sarah Klain, Jordan Levine, and Jordan Tam. 2013. “Humans and Nature : How Knowing and Experiencing Nature Affect Well-Being Further.” *Annual Review of Environment and Resources* 38: 473–502. doi:10.1146/annurev-environ-012312-110838.

Sauer, John R, Bruce G Peterjohn, and William A Link. 2008. “Observer Differences in the North American Breeding Bird Survey Published by : University of California Press on Behalf of the American Ornithologists ’ Union Stable URL : Http://Www.Jstor.Org/Stable/4088504 DIFFERENCES IN THE NORTH OBSERVER.” *Differences* 111 (1): 50–62.

Saveraid, Erika Hasler, Diane M. Debinski, Kelly Kindscher, and Mark E. Jakubauskas. 2001. “A Comparison of Satellite Data and Landscape Variables in Predicting Bird Species Occurrences in the Greater Yellowstone Ecosystem, USA.” *Landscape Ecology* 16 (1): 71–83. doi:10.1023/A:1008119219788.

Sekercioglu, Cagan H. 2006. “Increasing Awareness of Avian Ecological Function.” *Trends in Ecology and Evolution* 21 (8): 464–71. doi:10.1016/j.tree.2006.05.007.

Seymour, Valentine. 2016. “The Human – Nature Relationship and Its Impact on Health : A Critical Review.” *Frontiers in Public Health* 4 (November): 1–12. doi:10.3389/fpubh.2016.00260.

Shannon, Graeme, Lisa M. Angeloni, George Wittemyer, Kurt M. Fristrup, and Kevin R. Crooks. 2014. “Road Traffic Noise Modifies Behaviour of a Keystone Species.” *Animal Behaviour* 94: 135–41. doi:10.1016/j.anbehav.2014.06.004.

Shannon, Graeme, Megan F. McKenna, Lisa M. Angeloni, Kevin R. Crooks, Kurt M. Fristrup, Emma Brown, Katy A. Warner, et al. 2016. “A Synthesis of Two Decades of Research Documenting the Effects of Noise on Wildlife.” *Biological Reviews* 91 (4): 982–1005. doi:10.1111/brv.12207.

Siemers, Björn M, and Andrea Schaub. 2011. “Hunting at the Highway: Traffic Noise Reduces Foraging Efficiency in Acoustic Predators.” *Proceedings. Biological Sciences / The Royal Society* 278 (November): 1646–52. doi:10.1098/rspb.2010.2262.

Siikamäki, Pirkko, Katja Kangas, Antti Paasivaara, and Susanna Schroderus. 2015. “Biodiversity Attracts Visitors to National Parks.” *Biodiversity and Conservation* 24 (10): 2521–34. doi:10.1007/s10531-015-0941-5.

Simons, Theodore R., Mathew W. Alldredge, Kenneth H. Pollock, and John M. Wettroth. 2007. “Experimental Analysis of the Auditory Detection Process on Avian Point Counts.” *The Auk* 124 (3): 986. doi:10.1642/0004-8038(2007)124[986:EAOTAD]2.0.CO;2.

Soga, Masashi, and Kevin J Gaston. 2016. “Extinction of Experience : Evidence, Consequences and Challenges of Loss of Human-Nature Interactions.” *Frontiers in Ecology and the Environment* 14 (2): 94–101.

Stack, David W, Newman Peter, Robert E Manning, and Kurt M Fristrup. 2011. “Reducing Visitor Noise Levels at Muir Woods National Monument Using Experimental Management.” *The Journal of the Acoustical Society of America* 129 (3): 1375–80. doi:10.1121/1.3531803.

Taff, Derrick, Peter Newman, Steven R Lawson, Alan Bright, Lelaina Marin, Adam Gibson, and Tim Archie. 2014. “The Role of Messaging on Acceptability of Military Aircraft Sounds in Sequoia National Park.” *Applied Acoustics* 84. Elsevier Ltd: 122–28. doi:10.1016/j.apacoust.2013.09.012.

Tarrant, Michael A., Glenn E. Haas, and Michael J. Manfredo. 1995. “Factors Affecting Visitor Evaluations of Aircraft Overflights of Wilderness Areas.” *Society and Natural Resources* 8 (4): 351–60. doi:10.1080/08941929509380927.

Theobald, David M, and William H Romme. 2007. “Expansion of the US Wildland – Urban Interface.” *Landscape and Urban Planning* 83: 340–54. doi:10.1016/j.landurbplan.2007.06.002.

Ulrich, Roger S., Robert F. Simons, Barbara D. Losito, Evelyn Fiorito, Mark A. Miles, and Michael Zelson. 1991. “Stress Recovery during Exposure to Natural and Urban

Environments.” *Journal of Environmental Psychology* 11: 201–30.

United Nations. 2015. “World Urbanizaton Prospects: The 2014 Revision, (ST/ESA/SER.A/366).”

Venables, W.N., and B.D. Ripley. 2002. *Modern Applied Statistics with S*. Fourth Edi. New York: Springer.

Ware, Heidi E, Christopher J W McClure, Jay D Carlisle, and Jesse R Barber. 2015. “A Phantom Road Experiment Reveals Traffic Noise Is an Invisible Source of Habitat Degradation.” *Proceedings of the National Academy of Sciences* 112 (39): 12105–9. doi:10.1073/pnas.1504710112.

Weinzimmer, David, Peter Newman, Derrick Taff, Jacob Benfield, Emma Lynch, and Paul Bell. 2014. “Human Responses to Simulated Motorized Noise in National Parks.” *Leisure Sciences* 36: 37–41. doi:10.1080/01490400.2014.888022.

Wenny, Daniel G, Travis L Devault, Matthew D Johnson, Dave Kelly, Cagan H Sekercioglu, F Diana, and Christopher J Whelan. 2011. “The Need to Quantify Ecosystem Services Provided by Birds.” *The Auk* 128 (1): 1–14.

Zevitas, Christopher D, Jonathan D Cybulski, and Eileen McNeely. 2012. “Evaluating the Health Benefits of Natural Sounds: An Approach for Assessing the Environmental Impacts of Transportation Noise.” *41st International Congress and Exposition on Noise Control Engineering 2012 (InterNoise 2012)*, 11p. http://ntl.bts.gov/lib/45000/45800/45892/Zevitas_NaturalSounds.pdf.