

RESEARCH ARTICLE



Ecosystem services enhanced through soundscape management link people and wildlife

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Abstract

1. Burgeoning urbanization, development and human activities have led to reduced opportunities for nature experience in quiet acoustic environments. Increasing noise affects both humans and wildlife alike.
2. We experimentally altered human-caused sound levels in a paired study using informational signs that encouraged quiet behaviours in week-on, week-off blocks on the trail system of Muir Woods National Monument, California, USA to test if the soundscape influences both wildlife and human experiences.
3. Using continuous measurements from acoustic recording units ($n = 13$) spatially distributed within the park, we found signs significantly lowered sound levels by approximately 1.2 decibels (A-weighted), thereby increasing listening area by 24% and bird availability by approximately 5.8% for every 1 decibel decrease.
4. Visitor-intercept surveys ($n = 537$) revealed that our mitigation increased the number of birds perceived by visitors, rankings of soundscape pleasantness, and importantly, preferences for soundscape management.
5. By lowering human-caused sound levels, we created an acoustic environment equivalent to a ~21% reduction in visitors. The positive feedback cycle we describe may lead to increased conservation support in a time when the extinction of nature experience looms.

KEYWORDS

anthropogenic noise, coupled human and natural system, protected areas, psychological ecosystem services, soundscape mitigation

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1 | INTRODUCTION

Global urbanization is increasing at unprecedented rates. By 2050, two-thirds of humans are expected to live in urban areas, compared to approximately one-third in 1950 (United Nations, Department of Economic and Social Affairs, Population Division, 2015). Not only are more people living in metropolitan areas, but more people inhabit regions that abut and expand into wildlands (Theobald & 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 (Barber, Crooks, et al., 2010).

Human-caused noise has recently emerged as a clear threat to natural systems (Barber, Fristrup, et al., 2010; Francis & Barber, 2013; Kight & Swaddle, 2011; Potvin, 2016; Shannon et al., 2016). Effects of anthropogenic noise on wildlife include compromised foraging behaviour, shifted temporal activity patterns, decreased abundance, reduced body condition and altered reproductive success (Francis & 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 & Hagler, 2007; Hammer et al., 2014). Noise has also been shown to increase walking speeds in individuals which may influence human perception and enjoyment of locations (Franěk et al., 2018).

Anthropogenic noise is a cause for many to seek out experiences with nature free from the urban din (Gidlöf-Gunnarsson & Öhrström, 2007). Human experience with the natural world can influence an individual's emotional affinity for, and positive emotions, attitudes and behaviours towards, nature and the environment (Soga & Gaston, 2016). A degraded experience with 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 & Gaston, 2016). Such meaningful interactions with nature and wildlife are crucial for preventing a positive feedback loop of disaffection towards nature, and engendering broad support for measures that protect natural areas and conserve biodiversity (Francis et al., 2017; Miller, 2005).

Conversely to anthropogenic noise, natural sounds are shown to facilitate stress recovery (Aletta et al., 2018; Alvarsson et al., 2010), improve cognitive performance (Abbott et al., 2016), heighten emotional affect (Benfield et al., 2014) and have other restorative effects in people (Krzywicka & Byrka, 2017). 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 not achieved with absolute silence, but rather with sounds possessing natural acoustic properties (De Coensel & Botteldooren, 2006) and stimuli compatible with the environmental setting experienced (Laumann et al., 2001). These natural sounds are fundamental to our perception of soundscape pleasantness (Hong & Jeon, 2015).

People often seek protected natural areas to experience wildlife (Siikamäki et al., 2015) and pleasant soundscapes congruent to the area they are visiting (Haas & Wakefield, 1998; McDonald et al., 1995). Opportunities to experience natural sounds, such as birds singing during dawn chorus, are ranked as an important reason for protecting these spaces and as a motivation for visitors (Marin et al., 2011). 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 contiguous US experience a doubling, and approximately one-fifth of these areas experience a 10-fold increase or greater, in background sound levels due to human activities (Buxton et al., 2017), leading to a degradation of visitor experiences (Pilcher et al., 2009). An increase of 3 decibels, approximately 1.4 times the sound pressure level or a doubling of the acoustic intensity, results in an approximate halving of an individual's listening area (human or non-human animal; Barber, Crooks, 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 (Lilly et al., 2019; Marin et al., 2011), we predict that soundscapes connect natural and human systems via symmetrical feedback loops (Francis et al., 2017).

To examine the coupling of the natural and human worlds via the soundscape, we conducted a paired experiment in Muir Woods National Monument, California, USA. We manipulated educational signage (Figure 1) that encouraged visitors to behave quietly (e.g. speak and walk 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 (Belaire et al., 2015; Clergeau et al., 2001), association with stress recovery and attention restoration (Abbott et al., 2016; Ratcliffe et al., 2013), and their importance in providing ecosystem services (Sekercioglu, 2006; Wenny et al., 2011). Monitoring bird populations has also been considered a useful indicator of biological diversity and environmental health (Gregory & Strien, 2010).

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 acoustic environments more heavily influenced by anthropogenic noise would decrease wildlife availability and visitor experiences, while conversely, systems less impacted by anthropogenic noise would lead to increased bird availability, more positive visitor experiences, and, critically, a greater willingness to support soundscape mitigation actions to protect a beneficially coupled system.



FIGURE 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 counters and 13 audio recording unit/bird count locations were included as part of the study [Colour figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.com)]

2 | METHODS

We conducted our study at Muir Woods National Monument (37°53'N, 122°34'W) approximately 20 miles north of San

Francisco, California 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 1 million visitors per annum since 2014 (National Park Service, 2017). The mixed boardwalk, paved and unpaved trail system bifurcates around Redwood Creek.

2.1 | 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 behaviours during sign absent blocks (Figure 1; see Supporting Information for example mitigation and existing signage). 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. Signs were designed in collaboration with NPS staff and produced at the Boise State University Sign Shop (Boise, Idaho, USA).

Hourly L50 values (sound pressure level met or exceeded for 50% of the measurement time; equivalent to the median) were continuously measured for the duration of the study using 13 acoustic recording units (ARUs; Roland R-05s) to assess background sound levels between sign absent and sign present treatment blocks (Figure 1). L50 was selected as our acoustic metric because it is considered a representative measure of the overall acoustic environment and has been previously used for sound measurements by NPS's Natural Sounds and Night Skies Division (Buxton et al., 2017; Mennitt et al., 2013; Mennitt & Fristrup, 2012). A study of consumer-grade recording devices found that these units are able to obtain accurate sound pressure level readings when integrating across time and spectrum (Mennitt & Fristrup, 2012). Additionally, L50 is considered one of the most well-correlated physical indicators to pleasantness and perceived loudness in soundscape assessments (Aumond et al., 2017; Gontier, Aumond, et al., 2019; Gontier, Lavandier, et al., 2019).

Acoustic recording units were deployed the week preceding the start of the study and were located approximately 2–250 m from the main trail system, split between those that were within 100 m of the main trail system ($n = 9$) and those that were >100 m from the main trails ($n = 4$). A gradient of distances from the trail system were chosen to measure representative background sound levels present throughout the park. ARUs were suspended within a camouflaged fabric windscreen and mounted to vegetative structures at a height of approximately 1–1.5 m off the ground. Units were set to record MP3 files using a 44.1 kHz sampling rate and 128 kbps recording mode. Power supply cords encased within rubber hosing connected the suspended ARUs to lithium iron phosphate (LiFePO_4) rechargeable batteries (BatterySpace.com) housed within waterproof plastic containers placed on the ground (see Supporting Information for example ARU photo).

We converted a combined total of 21,038 hr of MP3 recordings measured from all ARUs into hourly sound pressure level format using custom program AUDIO2NV SPL (Damon Joyce, NPS), and from hourly sound pressure level to hourly L50 dB(A) values using the custom Acoustic Monitoring Toolbox program (Damon Joyce, NPS). From these hourly L50 dB(A) values, we calculated the daily average as the period between 1 hr prior to and after the earliest and latest point count start and end times (05:00–21:00), resulting in a total of 14,040 measured hours. We chose these hours because our goal was to understand the impacts of background sound levels during the period when the surveys were conducted and bird detections recorded, and 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 behaviour and noise output resultant from mitigation signage. Average background sound levels were calculated between sign absent and sign present treatment conditions using the 'meandb' function in Program R (R Core Team, 2016) package SEEWAVE (Sueur et al., 2008).

We excluded week 1 from sound analysis after performing a one-way 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 were obtained from the United States Geological Survey (USGS) National Water Information System (station USGS 11460151 Redwood CA HWY 1 Bridge A Muir Beach CA). Data from 9 April 2016 were 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 (dB(A)) using the Wilcoxon rank-sum test in Program R between sign absent and sign present treatment blocks across all sites.

Following the methods specified by Stack et al. (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 10 logarithm of visitor count as tabulated by five representative trail counters (Bushnell), a smoothing spline for hour of the day (4 effective degrees of freedom) and the categorical factor of treatment. The hourly sound pressure levels from the ARU closest to each of the five representative trail counters were used in the GAM analysis. Previous work found that sound pressure levels were significantly correlated with visitation numbers between 10:00 and 19:00 hr (Stack et al., 2011). We broadened our analysis to match the hours of the day used to analyse differences in daily averaged sound pressure levels (05:00–21:00 hr).

Trail counters were calibrated based on the methods developed by TRAFx Research Ltd. Each week, an observer recorded the total number of visitors passing by each counter for a period of 1 hr. The number of visitors observed was then divided by the number recorded by the counter during the calibration period to calculate an adjustment factor. The number of visitors recorded by the counter

was then multiplied by the average of all adjustment factors obtained during calibration events to calculate final visitor count estimates. From the GAM, we used the ratio between the treatment and visitation coefficients to approximate the percentage of equivalent visitor reduction, or increased visitation potential, through the decrease in sound pressure levels.

2.2 | Bird availability

We surveyed birds 40 times at each of 13 sites (a total of 520 point counts) located 2–250 m 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 hr of sunrise (06:00–13:00 hr) and 5.5 hr before sunset (13:30–20:00 hr) 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 our observer recording both the total number of birds observed and the method of detection (e.g. visual, song/call) for each minute of the survey. Our observer used a laser rangefinder (TruPulse 360R, Laser Technology, Inc.) to record the distance away from the observer at the time of first detection for each bird observation.

Detectability can vary with multiple observers (Alldredge et al., 2007; McClure et al., 2015; Sauer et al., 1994) and in relation to excessive background noise (McClure et al., 2015; Pacifici et al., 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 dB(A), the approximate threshold beyond which impairs an expert observer's ability to detect birds (Ortega & Francis, 2012), we examined potential differences in the probability of bird detection between treatment blocks using package *DISTANCE* (Miller, 2016) in Program R.

We built several models using different detection functions (e.g. half-normal, hazard rate, uniform) and modelled 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 & Anderson, 2002) 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).

Our independent study investigating expert observer detection probability (see Supporting Information) was conclusive with previous findings of unimpaired detection probability at background sound levels below 45 dB(A) (Ortega & Francis, 2012). Given that the background sound levels in our sites were below levels known

to affect expert birders and our detectability modelling efforts indicated no effect of noise on detectability, we concluded that there was no difference in detectability between treatment blocks (e.g. sign absent vs. sign present conditions). Therefore, we did not adjust detection counts for our analyses. We analysed bird count with package *LME4* (Bates et al., 2015) in Program R using a generalized linear mixed-effects model with daily averaged L50 (dB(A)) as a fixed effect, site as a random effect, a Poisson distribution for count data and detection distance truncated to 50 m from bird point count centre location. We used generalized linear mixed-effect models because they (a) use random effects (e.g. repeated sampling at our site) and (b) account for non-normally distributed data (Bolker et al., 2009).

2.3 | Visitor behaviour and perception

Trained university researchers used intercept survey techniques to systematically sample Muir Woods National Monument visitors between 9 May and 21 May 2016. Our social science work was approved by the Institutional Review Board of Pennsylvania State University (protocol#: 00004937). Visitor surveys were administered concurrently with bird counts during the final 2 weeks of the study. Visitors were intercepted near the entrance as they exited the park, after their park visit and experience. We asked each visitor for verbal consent with this script, 'Your participation in the study is voluntary. There are no penalties for not answering some or all questions, but because each participant will represent many others who will not be included in the study, your input is extremely important. The answers you provide will remain anonymous. Our results will be summarized so that the answers you provide cannot be associated with you or anyone in your group or household'.

Previous research and information from managers at Muir Woods National Monument helped inform the sampling location (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. Responses to the questions were recorded in situ on an electronic tablet device using Qualtrics software (co-headquartered in Provo, Utah, USA and Seattle, Washington, USA) to securely store data.

Our intercept surveys included a stated choice experiment (Louvière & Timmermans, 1990) to assess visitors' preferences for and trade-offs among a range of potential management actions related to soundscape management (see Supporting Information for example paired scenario survey question). 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 Muir Woods National Monument. Both *information to enforcement* and *closure* concepts were developed in collaboration with Muir Woods National Monuments managers.

Sound preference, the percentage of time visitors would prefer to hear natural sounds while in the park, was also measured as an attribute in the scenario choices with four different levels (Table 1). However, *sound preference* was solely used to standardize the statistical model across the two groups (treatment and control) to allow for comparisons. To increase the efficiency, we designed two blocks of nine choice scenarios (18 scenarios in total) with two management alternatives, 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 analysed using a stated choice approach (Louvière & Timmermans, 1990) in which visitor responses are combined together and analysed 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 (Cahill et al., 2008; Lawson & Manning, 2002, 2003; Newman et al., 2005).

We used random parameter (mixed) logit modelling to analyse the stated choice data and estimate the 'utility scores' representing the level of preference for each of the attributes. To analyse this type of stated choice model, the attributes of *information to enforcement* and *closures* are dummy coded. The management actions 'no signs are posted along the trail about natural quiet' and 'trails are open during operating hours' were used as the baseline condition. The estimates of each attribute therefore indicate the marginal changes in utility score from the corresponding baseline condition. Differences between utility scores for sign absent and sign present groups were evaluated using *t* tests.

In addition to the stated choice portion of the visitor-intercept survey focused on determining visitor utility scores for management preferences, participants were also asked 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 (very unpleasant, moderately unpleasant, slightly unpleasant, slightly pleasant, moderately pleasant and very pleasant). Using the function 'polr' in Program R package MASS (Venables & 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. Proportional odds logistic regressions are used when the response variable is an ordered category (Bender & Grouven, 1997; McCullagh, 1980). A Brant Test (Brant, 1990) was used to test the parallel regression assumption for each model using function 'brant' in Program R package BRANT (Schlegel & Steenbergen, 2018). We failed to reject the parallel regression assumption for each model ('Different types of birds' model—omnibus: $\chi^2 = 7.67$, $df = 6$, $p = 0.26$; Treatment: $\chi^2 = 4.27$, $df = 3$, $p = 0.23$; Number of Species: $\chi^2 = 3.48$, $df = 3$, $p = 0.32$; 'Pleasantness' model—omnibus: $\chi^2 = 6.09$, $df = 4$, $p = 0.19$, Hourly L50 dB(A): $\chi^2 = 6.09$, $df = 4$, $p = 0.19$). Of the 537 surveys completed, 240 surveys were conducted at the same time as our bird counts and used in the bird type analysis. Only surveys where respondents provided zip code information ($n = 434$) were included in the pleasantness analysis. We used the interaction between the number of bird species counted during bird surveys and treatment, and the hourly L50 level for the preceding 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.

Surveys also asked respondents how well they were able to hear natural sounds based on their experience that day. Respondents were able to choose from hearing natural sounds 'almost always clearly without interference', 'usually clearly without interference', 'sometimes clearly without interference', 'usually with interference' or 'almost always with interference' from human-made sound. Again, using function 'polr' in Program

TABLE 1 Stated choice model attributes used to measure visitor preference for soundscape management

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 caused 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 1 hr after dawn for the morning breeding bird chorus
Trails are closed for 1 hr 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)

R package MASS (Venables & Ripley, 2002), we performed a proportional odds logistic regression to assess visitor ability to hear natural sounds between sign absent and sign present treatment conditions ($n = 535$). The parallel regression assumption was assessed using function 'brant' in Program R package BRANT. We failed to reject the parallel regression assumption of the model (omnibus: $\chi^2 = 5.2$, $df = 3$, $p = 0.16$, Treatment: $\chi^2 = 5.2$, $df = 3$, $p = 0.16$).

Visitor walking speed was measured at a total of 9 'walkways' ranging from 23.6 to 59.1 m 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. After pooling data from each walkway, visitor movement speed was analysed using the 'kruskal.wallis' function in Program R.

3 | RESULTS

3.1 | Acoustic environment

Daily-averaged L50 sound levels across our sites were significantly higher when signs were absent (Wilcoxon rank-sum test, $n = 792$, $W = 85,337$, $p = 0.016$). Sound levels (L50) averaged 40.8 ± 0.13 dB(A) (mean \pm SE) with signs absent, whereas sound levels with signs present averaged 39.6 ± 0.12 dB(A), a 1.19 dB(A) reduction. Because decibels are logarithmic, this 1.19 dB(A) increase in background sound levels between sign present and absent blocks is equivalent to a ~24% loss of an individual's listening area (Barber, Crooks, et al., 2010). Sound level also 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. Importantly, however, the rate of sound level increase was much slower when mitigation signage was present

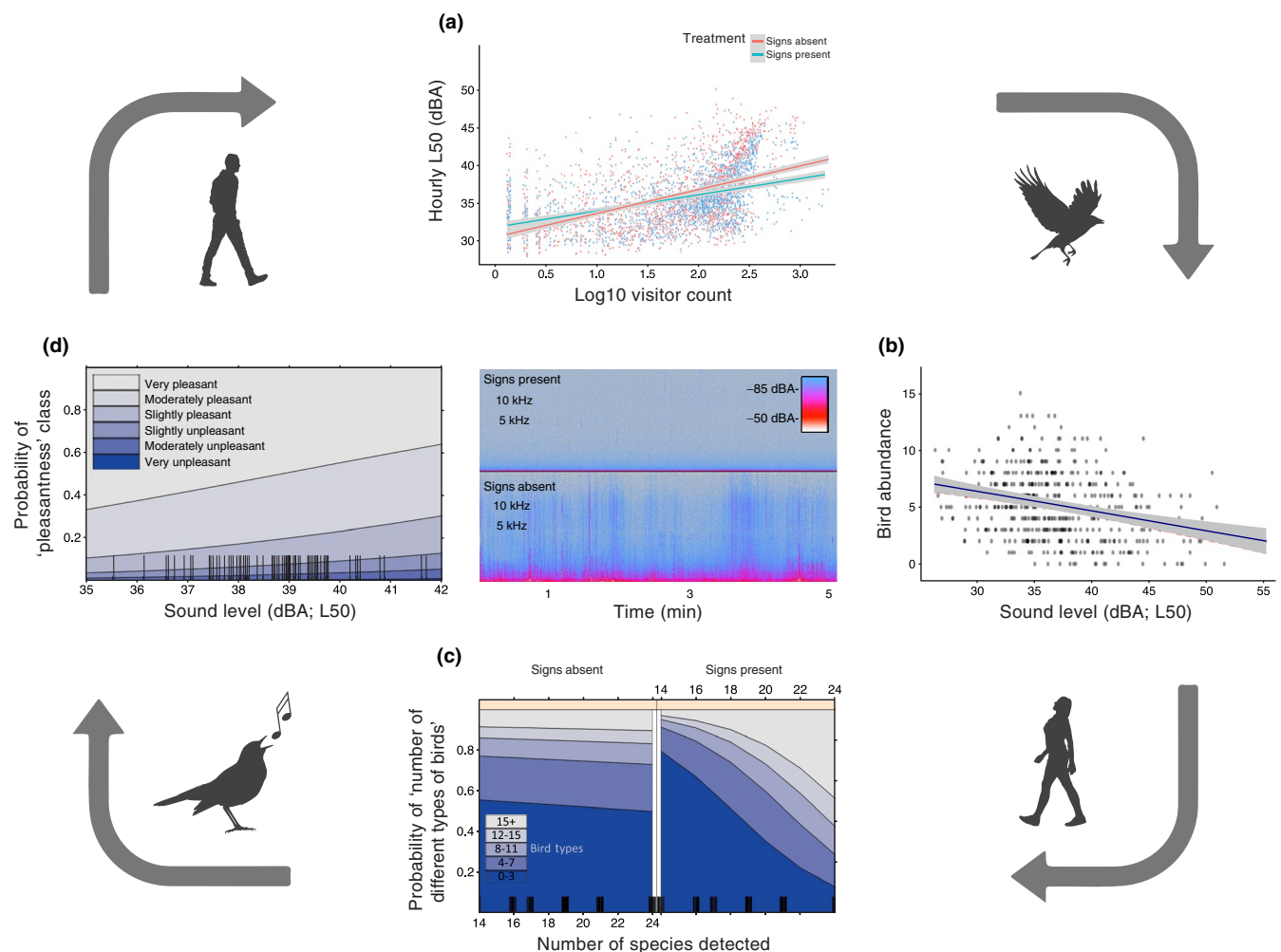


FIGURE 2 Soundscapes couple human and natural systems. Sign use significantly reduced background sound levels. The middle spectrogram displays the relative decibel (dB(A)) variation (hot colours indicate greater sound pressure level intensity) between representative periods of decreased (top panel) and increased (lower panel) background sound levels in the park. (a) Using signs resulted in an acoustic environment with an equivalent reduction in visitation of 20.6% ($p < 0.001$). In addition, (b) bird detections decreased 5.8% with every 1 dB(A) increase in L50 (< 0.001). (c) Visitors reported greater bird diversity as the number of detected species during bird counts increased and mitigation signage was concurrently present (Treatment: $p = 0.039$; Number of Species: $p = 0.59$; Treatment \times Number of Species: $p = 0.034$). When assessing pleasantness, (d) the probability of a 'Very Pleasant' soundscape experience decreased with increasing hourly L50 ($p = 0.012$) [Colour figure can be viewed at [wileyonlinelibrary.com](https://onlinelibrary.wiley.com)]

(Figure 2a). At 250 visitors, the sound level was at 38.9 dB(A) during sign absent treatment blocks compared to 36.5 dB(A) when signs were present. At 500 visitors, the sound level was at 44.0 dB(A) compared to 38.4 dB(A) when mitigation signage was present. Generalized additive modelling showed that mitigation signage resulted in an equivalent reduction in visitation of 20.6% through the lowering of background sound level ($n = 3,650$, \log_{10} Visitor Count: $\beta = 2.39$, $F = 880.7$, $df = 1$, $p < 0.001$; s(Hour, $df = 4$): $\beta = -0.14$, $F = 103.8$, $df = 1$, $p < 0.001$; Treatment: $\beta = -0.49$, $F = 19.1$, $df = 1$, $p < 0.001$; Figure 2a). In other words, during control days, without signage, we measured the acoustic equivalent of adding 20.6% more people to the trail system despite the fact that the actual number of visitors was the same.

3.2 | Bird distributions

We recorded 2,484 detections of 27 bird species within 50 m of our point count locations over 10 weeks. Of these detections, seven 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 eight detectability models, relying on noise thresholds found within the literature, and running a separate detectability experiment for point counting in noise. These methods all converge on detectability not being an issue during this experiment; thus, raw bird counts were not corrected in subsequent analyses.

Bird counts significantly declined with increasing daily-averaged L50 dB(A) ($n = 468$, $\beta = -0.06 \pm 0.01$, $p < 0.001$, 95% CI: -0.08 to -0.04), representing a $\sim 5.8\%$ decrease in songbird detections per each increase of 1 dB(A) (Figure 2b). Clearly, we can only interpret this finding across the range of background sound levels we examined. 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), four out of six experienced significant

declines per 1 dB increase in sound levels (Pacific-slope flycatcher: $\sim 3.5\%$; brown creeper: $\sim 6.1\%$ decrease; golden-crowned kinglet: $\sim 5.8\%$ decrease; Wilson's warbler: $\sim 8.9\%$). The number of species observed when visitor-intercept surveys overlapped bird counts ranged from 14 to 24 species during sign present days and 15 to 19 species during sign absent dates.

3.3 | Visitor behaviour and soundscape perception

An individual's walking speed may affect their experience in a soundscape by allowing for greater or fewer opportunities to experience natural sounds and also may potentially alter bird behaviour. 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 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 (Kruskal-Wallis $\chi^2 = 3.2$, $df = 1$, $p = 0.08$), with average walking speed in the sign absent treatment block measured at 1.03 ± 0.02 m/s and 1.01 ± 0.02 m/s in the sign present treatment block. 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-reported ability to hear natural sounds did not differ between sign absent ($n = 199$) and sign present ($n = 254$) treatment groups ($\beta = -0.08 \pm 0.16$, $p > 0.05$, 95% CI: -0.3 to 0.22 ; Table 2). However, visitor perception of bird diversity in the study area was predicted by a significant interaction between the actual diversity measured during bird surveys and treatment. In other words, visitors were better able to perceive an increase in bird diversity when soundscape mitigation was in place ($n = 240$, $\beta = 0.30 \pm 0.14$, $p = 0.03$, 95% CI: 0.03 – 0.60 ; Figure 2c). Furthermore, regardless of bird activity, hourly sound level (L50 dB(A)) itself was a significant predictor of visitor soundscape pleasantness ($n = 453$, $\beta = -0.18 \pm 0.07$, $p = 0.01$,

TABLE 2 Summary results for survey question asking respondents how well they were able to hear natural sounds during their visit

Based on your experience today, how well were you able to hear natural sounds?	Number of respondents (n)		Percent of respondents (%)	
	Signs absent	Signs present	Signs absent	Signs present
Almost always clearly without interference from human-made sound	43	56	21.6%	22.0%
Usually clearly without interference from human-made sound	68	95	34.2%	37.4%
Sometimes clearly without interference from human-made sound	56	70	28.1%	27.6%
Usually with interference from human-made sound	22	28	11.1%	11.0%
Almost always with interference from human-made sound	10	5	5.0%	2.0%
Total	199	254		

95% CI: -0.32 to -0.04 ; Figure 2d). Hourly sound levels are not necessarily connected to soundscape mitigation and reflect the background sound level at the time the survey was administered.

3.4 | Visitor preferences for soundscape management strategies

All utility scores calculated from our stated choice model for levels of sign use were supported by visitors ($p < 0.001$; Figure 3). These

levels ranged from 'Signs present' to 'Signs present with increasing ranger involvement' (from *Information* to *Enforcement*; Table 1). Utility scores are quantitative proxies of visitor preference for management actions (Newman et al., 2005). None of the utility scores for trail closure scenarios (Trail closures; Table 1) were significantly different from zero ($p > 0.05$; Figure 4). This indicates indifference for trail closures; while visitors do not support trail closures, they are also not opposed to closing trails during breeding bird chorus. Overall, the stated choice model for visitor soundscape management preferences, which included both sign use and trail closure levels, was

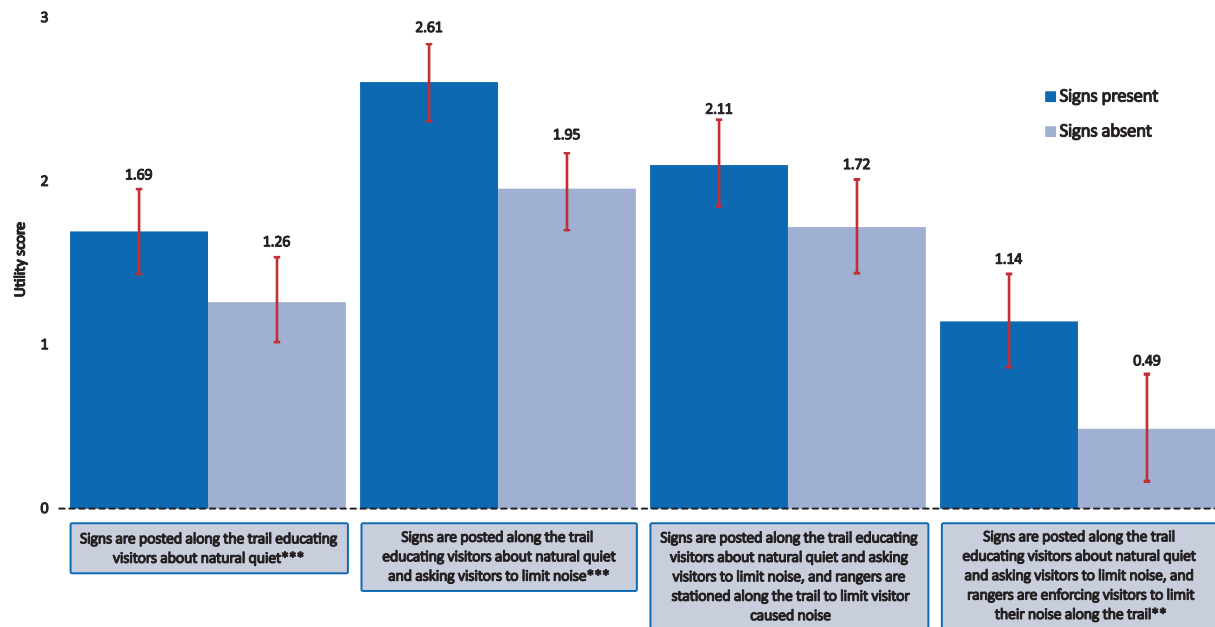


FIGURE 3 Comparison of utility scores for management options in Muir Woods National Monument. All utility scores were significantly different from zero, showing all four management actions are more preferred than 'no signs posted along the trail about natural quiet'. ** $p < 0.01$, *** $p < 0.001$ [Colour figure can be viewed at wileyonlinelibrary.com]

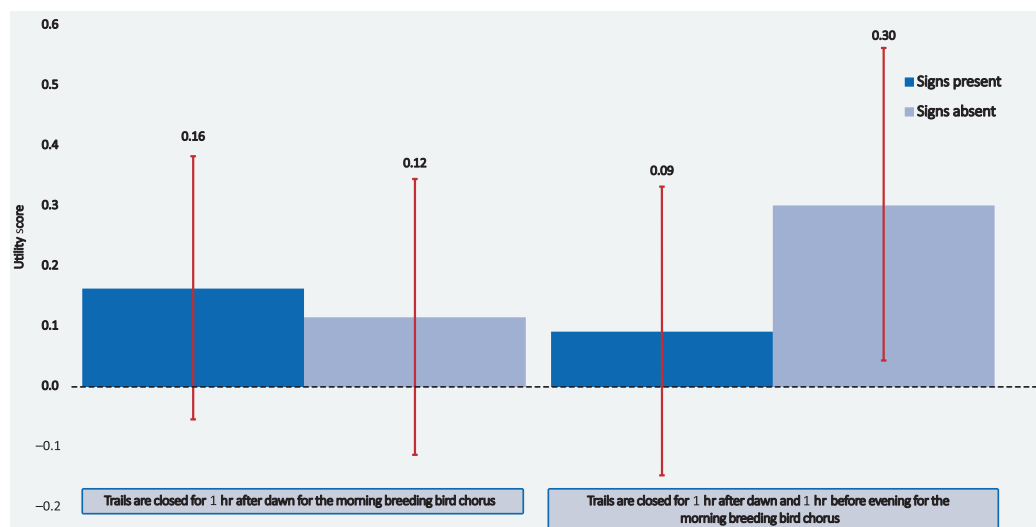


FIGURE 4 Comparison of utility scores for trail closures in Muir Woods National Monument. No utility scores were significantly different from zero, showing that no closures are more preferred nor opposed than 'trails open during operating hours'

significant (log likelihood ratio = -2,113.28; 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 positively significant utility scores from all four management action with signs posted (Figure 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 caused noise*', both of which promote an appreciation of natural quiet and move to limit visitor-caused noise (indirectly through signs and rangers; Figure 3). These patterns were consistent across both sign absent and sign present periods. Importantly, however, when signs were up, visitors were significantly more likely to have higher utility scores for three out of four sign use options tested. Though other factors such as visitor encouragement of the study may have affected utility scores, these higher scores likely imply that when quieter conditions were experienced, visitors were more supportive of management actions aimed at reducing human-caused noise (Figure 3).

4 | DISCUSSION

Mitigating anthropogenic noise can be complicated (Sakhaeifar et al., 2018; Van Renterghem et al., 2015). Here we show that sound levels from human activity can be reduced through the simple addition of educational signage along a trail system. More importantly, we demonstrate that the soundscape links people and wildlife via positive feedback loops. Signs in Muir Woods National Monument improved visitor experiences by reducing sound levels, which, in turn, increased bird availability to visitors, both in reality and perception. Interestingly, there were no differences in visitor-reported ability to hear natural sounds between the sign absent and sign present treatment groups. Mitigation signage may have primed visitors to more closely listen for and appreciate the natural sounds that were equally available, and thus resulted in visitors perceiving increased bird diversity and greater soundscape pleasantness.

Sign mitigation improved positive human experiences and allowed for a greater *acoustic carrying capacity* of visitors. In other words, the park was able to acoustically support more visitors behaving quietly compared to fewer visitors behaving normally. Critically, during the implementation of our sign-based mitigation, conservation support for management of the acoustic environment increased. As the world's population continues to grow, finding ways to allow more people to experience natural areas without the addition of undue impacts to biodiversity and human experiences is essential (Francis et al., 2017). The European Union's Environmental Noise Directive (END; Directive 2002/49/EC) is one such example with initiatives focused on preventing noise and preserving quiet areas (European Environmental Agency, 2014).

Under sign-based mitigation, sound levels throughout the park decreased to a level that supported one-fifth again as many people. This increased number of 'quiet' visitors would have the same or better per capita soundscape experience as when the park supported fewer, more noisy visitors. Defining an acoustic carrying capacity may be a useful metric in protected area management policy. For example, the NPS currently manages soundscapes as a protected resource per NPS Director's Order #47 (National Park Service, 2000). An acoustic threshold could be established in such a directive as a guide for managers and to identify areas with undue noise impacts. Maintenance of any noise mitigation tools, such as signage, would be essential to ensure that site-specific acoustic thresholds were not exceeded. Other metrics, such as a threshold based on the number of visitors at which bird abundance reaches a predetermined minimum, may also be useful tools for managers to consider. However, sound levels are much easier to measure than bird populations.

Future conservation of biodiversity is inextricably linked to human valuation of biodiversity (Dallimer et al., 2012). Improving human perception to accurately measure animal diversity has proven challenging (Dallimer et al., 2012), yet there is evidence that humans can readily recognize differences in plant richness and biodiversity (Fuller et al., 2007; Qiu et al., 2013). Here we found that people directly perceived an increase in bird biodiversity that we experimentally produced via sign mitigations. Furthermore, this increased availability of birds and natural sounds ultimately was correlated with a higher ranking of soundscape pleasantness. People were willing to accept trade-offs in personal freedoms to achieve a desired environmental condition (Newman et al., 2005)—a soundscape dominated by natural sounds.

The same soundscape conditions that increased people's experiences also increased birds' use of habitat adjacent to trails. It is possible that this effect on bird count was driven by changes in human behaviour, such as walking speeds. Yet, we found no difference in the speed of visitor travel when signs were present or absent. Thus, it seems likely that the difference in the bird behaviour we quantified was indeed the result of quieter human voices along the trail. These lower sound levels from human-generated noise do not necessarily indicate that the loss of information (e.g. via acoustic masking) underlies these ecological effects (Francis & Barber, 2013). It is equally likely that human voices added information to the soundscape and were interpreted by birds to indicate higher human activity and bird space use was thus altered out of fear (Petrelli et al., 2017). Recent work has shown that human voices alone can structure carnivore distributions and behaviour by shaping perceived levels of fear across the landscape (Smith et al., 2017). Reducing human-caused noise may be one way to reduce fear in some animals and increase human experiences with wildlife.

Although our results demonstrate that signs are an effective noise mitigation strategy coupling both natural and human systems, several limitations to the study must be noted. The study occurred along a single trail system during a single spring season, where

optimally, several trail systems across multiple years would be investigated. In addition, visitor surveys were only administered during the final 2 weeks of the study. Administering surveys throughout the duration of the study and temporally matching bird counts would have been ideal. Mitigation signage may have primed visitors to respond to our intercept surveys in a more pro-mitigation fashion. The fact that a study was taking place in the park may have encouraged such responses. It is also unclear whether increased soundscape pleasantness ratings during sign-present weeks were due specifically to decreases in background sound levels or increases in the audibility of nature sounds.

5 | CONCLUSIONS

Human contact with nature can improve health and well-being (Bowler et al., 2010; Hartig et al., 2014; Russell et al., 2013; Seymour, 2016), and natural sounds can influence individuals' experience in nature (Czerwén et al., 2016; Francis et al., 2017). A system dominated by anthropogenic noise no longer confers benefits to human health and well-being (Hammer et al., 2014); 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 (Soga & Gaston, 2016). Thus, quantifying the psychological ecosystem services provided by nature is an important tool to inform management strategies and policy change (Frumkin et al., 2017). The relationships between ecosystem services and human well-being have 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.

Sound affects bird count, human perception of the natural world and the willingness of individuals to trade-off personal access to encourage park conditions that promote wildlife and foster beneficial conditions for human well-being and experience. This feedback system may be coupled without visitors even knowing it exists. Educational programmes and messaging that promote natural sounds may provide an important link between human actions and desired soundscape outcomes.

Safeguarding opportunities to experience wildlife and natural soundscapes is critical for increasing conservation efficacy and support for continued and improved landscape protection (Miller, 2005). As acoustic environments continue to be characterized by anthropogenic noise globally, experiences with nature are regularly threatened via a loss of biodiversity and decrease in personal orientation towards the natural world (Miller, 2005; Soga & Gaston, 2016). Soundscape mitigation promotes positive feedback loops between natural and human systems that increases access to wildlife and natural sounds and improves the connection people feel with the natural world. Continued 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.

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CONFLICT OF INTERESTS

The authors declare no competing interests.








AUTHORS' CONTRIBUTIONS

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.A.F. collated the data; M.J.L., Z.D.M., D.G.E.G., Y.-H.S. and C.J.W.M. analysed and visualized the data; M.J.L. and J.R.B. wrote the first draft of the paper and all authors contributed.

DATA AVAILABILITY STATEMENT

Data are available at Dryad Digital Repository <https://doi.org/10.5061/dryad.v15dv41tp> (Levenhagen et al., 2020).

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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