Understanding park visitors' soundscape perception using subjective and objective measurement

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Environmental noise knows no boundaries, affecting even protected areas. Noise pollution, originating from both external and internal sources, imposes costs on these areas. It is associated with adverse health effects, while natural sounds contribute to cognitive and emotional improvements as ecosystem services. When it comes to parks, individual visitors hold unique perceptions of soundscapes, which can be shaped by various factors such as their motivations for visiting, personal norms, attitudes towards specific sounds, and expectations. In this study, we utilized linear models and geospatial data to evaluate how visitors' personal norms and attitudes, the park's acoustic environment, visitor counts, and the acoustic environment of visitors' neighborhoods influenced their perception of soundscapes at Muir Woods National Monument. Our findings indicate that visitors' subjective experiences had a greater impact on their perception of the park's soundscape compared to purely acoustic factors like sound level of the park itself. Specifically, we found that motivations to hear natural sounds, interference caused by noise, sensitivity to noise, and the sound levels of visitors' home neighborhoods influenced visitors' perception of the park's soundscape. Understanding how personal factors shape visitors' soundscape perception can assist urban and non-urban park planners in effectively managing visitor experiences and expectations.

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2 **measurement**
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32 **Abstract**
33 Environmental noise knows no boundaries, affecting even protected areas. Noise pollution,
34 originating from both external and internal sources, imposes costs on these areas. It is associated
35 with adverse health effects, while natural sounds contribute to cognitive and emotional
36 improvements as ecosystem services. When it comes to parks, individual visitors hold unique
37 perceptions of soundscapes, which can be shaped by various factors such as their motivations for
38 visiting, personal norms, attitudes towards specific sounds, and expectations. In this study, we
39 utilized linear models and geospatial data to evaluate how visitors' personal norms and attitudes,
40 the park's acoustic environment, visitor counts, and the acoustic environment of visitors'
41 neighborhoods influenced their perception of soundscapes at Muir Woods National Monument.
42 Our findings indicate that visitors' subjective experiences had a greater impact on their
43 perception of the park's soundscape compared to purely acoustic factors like sound level of the
44 park itself. Specifically, we found that motivations to hear natural sounds, interference caused by
45 noise, sensitivity to noise, and the sound levels of visitors' home neighborhoods influenced
46 visitors' perception of the park's soundscape. Understanding how personal factors shape visitors'
47 soundscape perception can assist urban and non-urban park planners in effectively managing
48 visitor experiences and expectations.
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Introduction

52

53   More than eighty percent of the contiguous United States has elevated sound pressure
54 levels caused by anthropogenic sources (Mennitt, Fristrup, Sherrill, & Nelson, 2013). Extensive
55 exposure to noise (defined as unwanted sound) at high levels can negatively affect human health
56 by elevating blood pressure levels, promoting stress, heart disease, hearing loss, and inadequate
57 sleep (Goines & Hagler, 2007; Hammer, Swinburn, & Neitzel, 2014). Utilizing U.S. EPA
58 (Environmental Protection Agency) estimates from 1981 and adjusting them to the U.S.
59 population (Census Bureau, 2010), 145.5 million people are potentially at risk of developing
60 hypertension as a result of noise (Hammer et al., 2014). Urban sound sources such as aircraft,
61 traffic, and people talking have been found to interfere with memory (Benfield et al., 2010), lead
62 to increased stress and lower cognitive ability (Cohen et al.,1980) and cause elevated stress
63 levels in both adults and infants (Cantuaria et al., 2018). Currently more than half (55%) of the
64 world population resides in urban areas and it has been estimated that by 2050, the urban
65 population will grow to 68% (United Nations, 2018). As our society continues to urbanize, the
66 risk for prolonged exposure to loud anthropogenic sounds will rise.
67   Parks and protected areas serve as places where visitors can find refuge from industrial
68 and community noise (Ferguson, 2018). However, a study found that 63% of protected areas in
69 the United States experience a doubling of background sound levels due to anthropogenic
70 sources and 21% experience a 10-fold increase (Buxton et al., 2017). Thus, protecting natural
71 sounds in parks is important, especially as many visitors to parks and protected areas seek natural
72 sound experiences as a sanctuary from potentially loud and noisy soundscapes they might
73 experience during the course of their daily lives.
74   Humans have an innate biological association to the natural world (Wilson, 1984) that is
75 also of value for healing the mind and body, as captured by famous nature writers such as Muir
76 (1901; 1979) and Thoreau (1854). It has also been documented by many researchers across
77 disciplines (Abbott, Taff, Newman, Benfield, & Mowen, 2016; Benfield, Taff, Newman, &
78 Smyth, 2014; Kaplan, 1995; Wilson, 2001). The positive relationship between human health and
79 spending time in nature can promote improved memory retention (Holden & Mercer, 2014) and
80 overall psychological wellbeing (Bratman, Hamilton, & Daily, 2012). Experiences in nature can
81 facilitate recovery from mental fatigue (Kaplan, 1995) and a reduction in repetitive negative
82 thoughts (Bratman, Hamilton, Hahn, Daily, & Gross, 2015). Multiple senses are stimulated by
83 natural environments, with natural sound being an important factor (Franco, Shanahan, & Fuller,
84 2017).
85   In contrast to the negative impacts related to urban noise exposure, there appear to be
86 many positive benefits or psychological ecosystem services related to exposure to natural sounds
87 (Francis et al., 2017; Kogan et al., 2021). Natural soundscapes are important resources to the
88 health and well-being of both humans and wildlife (Francis et al., 2017). For humans, natural
89 sounds improve human cognition (Abbott et al., 2016), enhance positive moods (Benfield et al.,
90 2014), and increase recovery from stress (Alvarsson, Wiens, & Nilsson, 2010). Ferraro et al.,
91 (2020) found that park visitors who were exposed to an experimental treatment of increased bird
92 chorus, had improved psychological restoration. A study in Chili's Coyhaique National Reserve
93 found positive relationships between visitor wellness motivations and soundscape ratings (Ednie
94 et al., 2022). For most visitors to U.S. parks and protected areas and abroad, hearing the sounds
95 of nature and experiencing natural quiet are important motivations for their visit (Ednie et al.,
96 2022; Haas & Wakefield, 1998; Outdoor Industry Report, 2017). As visitation to parks increase,

97 so does noise from transportation and other visitors (Levenhangen et al., 2020; NPS, 2010). As a
98 result, U.S. national parks have plans and polices in place to protect, maintain and restore natural
99 sounds and quiet for both visitor and wildlife health and wellbeing (e.g., the U.S. National Park
100 Service Director's Order #47, Soundscape Preservation and Noise Management, 2000).
101   To understand the complexity of soundscapes, geospatial data is increasingly used to
102 capture the impact of noise and natural sounds on landscapes (e.g. noise impacts throughout the
103 contiguous United States; Mennitt et al., 2016). Geospatial data depicting sound pressure level
104 have shown how sound from sources such a traffic and construction (Hong & Jeon, 2015; Lee,
105 Chang, & Park, 2008; Miller, 2003) are dispersed across landscapes, as well as the pervasiveness
106 of noise pollution in U.S. protected areas (Buxton et al., 2017). These data have also been used to
107 assess racial, ethnic, and social inequalities in relation to noise pollution (Casey et al., 2017).
108 Neighborhood sound levels can be used to answer a variety of questions pertaining to health and
109 the environment. For example, using aircraft noise contours paired with zip code blocks, Andrew
110 et al. (2013) identified a correlation between risk of cardiovascular disease in older adults and
111 proximity of their residence to an airport.
112   Several studies have explored non-acoustic factors that influence perceptions of
113 soundscapes in a park setting (Benfield, et al., 2014; Gale et al., 2020; Kogan et al., 2021; Marin,
114 et al., 2010) and in environmental noise assessments (Liu, Kang, Behm, & Luo, 2014; Miedema
115 & Vos, 1999;1; Schomer, Mestre, Schulte-Fortkamp, & Boyle, 2013). Marin et al. (2011) found
116 that motivations can influence visitors' perceptions of the park soundscapes. Another study
117 determined that landscape spatial patterns influence soundscape perceptions (e.g. density of
118 vegetation and built environment) (Liu et al., 2014). Noise sensitivity (Benfield, et al., 2014) can
119 also predict visitors' perceptions of the soundscape they experience in national parks. A recent
120 study conducted in Chilean national park found that urban visitors who sometimes or often heard
121 anthropogenic sounds perceived those sounds as more acceptable than visitors who never heard
122 those sounds (Ednie & Gale, 2021). These results raise concerns about whether or not visitors are
123 becoming complacent with noise in parks. Another study found that visitors from different urban
124 densities differed in their perception of park soundscapes (Gale, Ednie, & Befftink, 2021).
125 Specifically, visitors from more dense urban areas perceived the soundscape of the Chilean park
126 to be less pleasant. Sounds experienced in daily life influence tolerances to different sources of
127 sound, expectations for the acoustic properties of soundscapes in protected areas, plus
128 motivations for visiting locations where the sonic environment contrasts strongly from that of the
129 routine.
130   Environmental noise researchers are interested in exploring non-acoustic variables that
131 predict how individuals or communities might respond to noise from airplanes, trains, highway
132 traffic or urban environments (Haac et al., 2019; Miedema & Vos, 1999; Schomer et al., 2013).
133 While sound level meters measure objective physical components of the acoustic environment,
134 human perception of sound varies amongst individuals, communities, and circumstances. The
135 Positive Soundscapes Project, an interdisciplinary study that used qualitative feedback from
136 individuals who participated in urban sound walks, found that soundscape perception is heavily
137 influenced by cognitive and emotional effects (Davies et al., 2013). Researchers have built in this
138 work and identified soundscape descriptors, such as pleasantness, to use in predicting
139 soundscape perceptions (Aletta, Kang, & Axelsoon, 2016). Gale et al. (2021), built on methods
140 used by both protected area and urban soundscape researchers to assess soundscape perceptions
141 in a Chilean national park. This research has highlighted the value in using cognitive and
142 affective indicators to measure soundscapes.

143   Here, we sought to understand what factors influence Muir Woods National Monument
144 (MUWO) visitors' perceptions of park soundscapes. Based on the outcomes from earlier studies,
145 we predicated that individuals' motivations (Marin et al., 2011) and noise sensitivity (Benfield et
146 al. 2014) would influence visitors' perceptions of the park's soundscape. We also hypothesized
147 that the park's sound level, density of visitors on the trail, noise interference, and the sound level
148 of visitor's neighborhood would predict soundscape perceptions.

149 **Materials & Methods**

150   The analysis presented in this paper is part of a larger study. The primary purpose of the
151 larger study was to explore the coupling of the natural and human environments through the
152 soundscape, via a paired experiment at Muir Woods National Monument (MUWO). Detailed
153 methods and information about the larger study can be found in Levenhagen et al. (2020).
154 Portions of this text were previously published as part of a doctoral dissertation
155 (https://etda.libraries.psu.edu/files/final_submissions/17621). Field data collection was approved
156 by the U.S. Department of the Interior (Permit #: MUWO-2016-SCI-0001). The survey and
157 social science methodology was approved by the Institutional Review Board of Pennsylvania
158 State University (protocol#: 00004937).

159   **Study Area.** We conducted this study at MUWO (Figure 1), the first urban National
160 Monument in the United States, located 25 km north of San Francisco, California, and a popular
161 destination for tourists that includes hiking trails throughout 500 acres of coastal redwood trees
162 (*Sequoia sempervirens*). People are drawn to this park to experience the towering and awe-
163 inspiring old growth coast redwood forest. Visitation to the park has been steadily increasing and
164 in 2017, exceeded one million annual visitors (NPS, 2017). Protecting natural soundscapes is a
165 primary management objective at MUWO. Since 2005 the park has supported a variety of
166 soundscape studies (Marin et al., 2011; Pilcher et al., 2009; Stack, Peter, Manning, & Fristrup,
167 2011) that have examined the effectiveness of trail signage to reduce visitor noise (Stack et al.,
168 2011). Due to the findings from Stack et al., (2011) the park now has a sign that states "quiet
169 zone", in the Cathedral Grove area of the park.

170 (Insert Figure 1)
171 **Figure 1.** Boundary of Muir Woods National Monument
172
173   **Experimental Design and Acoustic Measures.** We expanded on methods used by Stack
174 et al. (2011) and used educational treatments to designate "quiet days" (treatment) and "control
175 days" during the study period. Stack et al. (2011) tested signage in one small area of MUWO,
176 while our project spanned the entire trail system. We used treatment and control mitigations in
177 weeklong blocks. Additionally, we had rangers enforce the quiet periods. MUWO had one main
178 entrance, which likely made the enforcement more effective than in parks with distributed
179 entrances. During the treatment or "quiet" days, 19 educational A-frame signs (e.g., 'Enter
180 Quietly', 'Maintain Natural Quiet', 'What you can do to help natural soundscapes') were placed
181 along a ~0.6 km segment of the main trail system. During control days, all educational signs
182 related to maintaining quiet were removed or covered. Additional details related to the

183   experimental design, including a map of the trail, can be found in Levenhagen et al. (2020). We
184   dummy coded this variable to include in regression modeling (0=quiet, 1=control).
185   To test the effects of the treatment on background sounds in MUWO, we deployed
186   acoustic recording devices (13 Roland R05) along the same ~0.6 km segment of the main trail
187   system. The 50th percentile A-weighted sound pressure level (the L_{50} in dBA) was calculated
188   from recordings of each device for each hour (see Levenhagen et al., 2020 for details).To test the
189   influence of the park's sound level on visitors' perception of the park soundscape, we paired
190   survey data with the average hourly L_{50} from the nine acoustic recording devices that were
191   within 50 meters of the trail. There were four acoustic recording devices placed more than 100
192   meters from the trail and those were not included in our analysis because we were only assessing
193   sound levels heard by visitors on the trail. The hourly L_{50} was matched with survey responses
194   based on the hour in which the survey was administered.
195   **Visitor Use Estimation.** For this project, we estimated the number of visitors using the
196   trail during the time that respondents were visiting the park. Automated infrared visitor monitors,
197   TrailMaster (TM1550), were deployed at the same 13 trail locations as the acoustic recording
198   devices. These are not cameras and only detect the infrared wavelength that people emit as they
199   walk by the device. Data were logged continuously from May 9th through May 21st, 2016.
200   Because automatic trail counter estimates can vary with position, angle, etc, a member of the
201   research team observed and manually counted visitors on the trail to calibrate each automated
202   counter. During the study period, each trail counter was calibrated for a total of 12 hours
203   (Pettebone, Newman, & Lawson, 2010). Manual count calibrations occurred in one-hour blocks,
204   on randomly chosen days throughout the study period.
205   For this analysis, we used the trail counter closest to the entrance (also closest to the
206   survey intercept location) to estimate the number of visitors on the trail. For most visitors, this
207   location is used as an entrance and exit for the trail system. An adjustment factor was calculated
208   by dividing the number of observed visitor pass-by events manually counted during the
209   calibration period by the number of events counted by the automatic monitor. That number was
210   then divided into two, because the monitor location is both an entrance and exit. The mean
211   number of visitors for each one-hour block of time was calculated and multiplied by the final
212   adjustment factor. Visitor estimates were matched with survey data based on the estimated
213   visitor count from the hour of the timestamp on the survey responses.
214   **Survey Data.** The research team collected a total of 537 surveys between May 9th and
215   21st, 2016, as visitors were exiting the park. All survey respondents verbally consented to
216   participating in the survey. The survey evaluated the effectiveness of realistic management
217   solutions to improve environmental conditions for wildlife and visitor experiences in MUWO. In
218   addition, we collected data on the tradeoffs visitors would be willing to make in order to achieve
219   a high-quality acoustic experience (Newman, Manning, Dennis, & McKonly, 2005). For the
220   purpose of this paper, we focused on questions specific to visitors' perceptions of the soundscape
221   in MUWO that capture pleasantness, noise sensitivity and noise interference (Table 1). In
222   addition, we asked visitors for their home zip code, to identify place of residence.
223   *Pleasantness* For this study, we wanted to test a broad scale that incorporates a positive,
224   well understood attitude towards sound, referred to as pleasantness, which has been found to be
225   an important indicator in measuring urban and rural soundscape perceptions (De Coensel &
226   Botteldooren, 2006).
227   *Noise Sensitivity Scale* A shortened field version of the Noise Sensitivity Scale (NSS)
228   can be used to measure individuals' response to noise in their everyday lives and has been

229   empirically validated (Benfield, et al., 2014). We calculated the NSS score after reverse coding
230   one of the items, "I get used to most noises without much difficulty", to create an overall noise
231   sensitivity score for each respondent. We summated items from the noise sensitivity scale.
232   Lower values indicate a decreased aversion and higher tolerance to noise and higher values
233   indicate increased aversion and lower tolerance to noise.
234   ***Noise Interference*** We developed a measure to investigate respondents' self-report of
235   how often noise interfered with hearing natural sounds or the degree to which natural sounds
236   were masked by anthropogenic sounds. The higher the value, the more interference from human-
237   made sounds the respondent reported experiencing in MUWO.
238   ***Natural Sound Motivation*** Recreation Experience Preference (REP) Scales are used to
239   measure park visitors' motivations or the desired outcomes they seek in a park or protected area
240   (Manfredo, Driver, & Tarrant, 1996). For this study, we were only interested in REP scales
241   related to natural sounds. Prior to calculating the natural sound motivation variable, the four
242   separate items were tested for reliability (Table 2). The natural sound motivation variable was
243   created by summing the four motivation questions related to natural sounds. Internal consistency
244   of the items was assessed using Cronbach's alpha. The reliability analysis indicated an
245   acceptable level of internal consistency (α=.859) (Vaske, 2008).
246
247   (Insert Table 1 here)

248   (Insert Table 2 here)
249

250   **Visitors' neighborhood sound level.** We obtained acoustic data from Mennitt et al.
251   (2016), which approximates the existing L50 sound level at 270 m resolution across the United
252   States during a typical day. We calculated the neighborhood sound level based on the boundary
253   of respondents' home zip code. For each visitor's home zip code, the mean sound level was
254   obtained by calculating an average sound level from all grid cells within the zip code. Zip code
255   boundaries were obtained from the United States Census data (Census Bureau, 2015) and
256   matched to zip codes reported by visitors. A total of 441 unique zip codes were reported by
257   survey respondents. We also eliminated visitors who resided internationally from this analysis.
258   Of these 372 zip codes matched with the boundary shapefile obtained from the Census Bureau
259   and were used for the remainder of the study. We discarded unmatched zip codes as these may
260   have been entered incorrectly. In addition to understanding neighborhood acoustic environments,
261   we used zip codes summarized by state and metropolitan area to better understand where people
262   came from to visit the park. Data on metropolitan areas were obtained from the Census Bureau to
263   identify urban-rural areas where Urbanized Areas (UAs) are defined as areas with 50,000 or
264   more people and Urban Clusters (UCs) are areas with at least 2,500 and less than 50,000 people
265   (Census Bureau, 2016). We performed all geospatial tasks in ArcMap 10.4 (ESRI, 2011).
266   **Data Analysis.** Given the potential for spatial autocorrelation in the relationship between
267   perceptions of soundscape pleasantness and neighborhood zip code sound levels, in preliminary
268   models we used the fitme function in the spaMM package (Rousset & Ferdy, 2014) in R (version
269   4.0.4 (2021-02-15)) to incorporate an exponential spatial correlation structure using the Matérn
270   correlation function (e.g., Senzaki et al. 2021; Wilson et al., 2021). We also included hour of the
271   survey nested within day as random intercepts in the model to account for hierarchical sampling
272   approach. In these and subsequent models we assumed Gaussian error and transformed

273 pleasantness with a Tukey transformation to improve model fit. There was no evidence that
274 inclusion of the spatial autocorrelation structure or hour nested within day as random effects
275 improved model fit over models that did not have these terms, thus they were removed from the
276 analysis following Bates et al. (2015). As such, we used multiple linear regression in all
277 subsequent models.
278   For formal model selection we began with a model with neighborhood sound level as the
279 single predictor for soundscape pleasantness and sequentially added additional predictor
280 variables (Table 3). Models with additional variables were retained over the previous
281 hypothesized model if the fixed effects had a p-value < 0.05 and if the Akaike Information
282 Criterion (AIC) was reduced by >2 from the previously model (Table 3). We confirmed the final
283 model met model assumptions by visually inspecting diagnostic plots and also found no issues of
284 multicollinearity among predictors using the check_collinearity function in the performance
285 package (Lüdecke,Ben-Shachar, Patil, Waggoner, & Makowski (2021). Model selection resulted
286 in a model where pleasantness was explained by neighborhood sound level, noise sensitivity,
287 noise interference, and sound motivation (Table 4 and Figure 2). We used additional linear
288 models to explore potential predictors of noise interference and noise sensitivity. They were the
289 strongest predictors of pleasantness and we wanted to know more about how they related to the
290 other independent variables in the final model. We created linear models using noise sensitivity
291 as a dependent variable and all of our hypothesized independent variables. We did the same for
292 noise interference.
293
294 (Insert Table 3 here)

295 **Results**

296   **Descriptive statistics.** The overall mean for hourly L_{50} was 41.36 dBA (Table 2).
297 Visitors who walked the trail during the quiet treatment heard a slightly lower and significantly
298 different sound level ($t = -2.43$, $p = 0.016$) sound level ($n = 212$, $M = 41.19$ dBA) than the
299 visitors who walked the trail during the control ($n = 159$, $M = 41.60$ dBA). We also estimated the
300 number of visitors using the trail during survey respondents' visit to MUWO. The mean number
301 of visitors on the trail was 214 visitors ($SD = 68.60$).
302   For the measure of soundscape pleasantness, the mean score was 5.24 (6-point scale),
303 meaning that the sample on average rated the soundscape as pleasant. Results from the noise
304 sensitivity scale indicated that there was relatively high internal consistency within items ($\alpha =$
305 .808). To create an overall noise sensitivity score for each visitor, the items were summated. The
306 minimum score was one (low noise sensitivity) and the highest score was six (high noise
307 sensitivity). The mean noise sensitivity score for visitors was 4.10, meaning that the sample of
308 visitors trend towards being sensitive to noise. For noise interference, the mean score was 2.37
309 (5-point scale). This means that on average, visitors were able to hear natural sounds usually or
310 sometimes clearly without interference from human-made sounds.
311   The top ranked motivation for visiting MUWO was "seeing the redwoods" and the
312 second was "appreciating the scenic beauty". The third most important motivation for visiting
313 the park was "to enjoy the natural quiet and sounds of nature", with a mean rating of 4.08 (on a
314 scale from one to five) (Table 2). Most visitors rated "hearing quiet and sounds of nature" as

315 very important to their visit. To better understand how visitors' motivations related to
316 soundscape pleasantness, the motivation items related to sound were combined into one
317 motivation score. Overall, these items have a relatively high internal consistency (α = .859). The
318 mean score for the combined sound motivation is 3.83 on a 5-point scale, meaning that on
319 average, visitors rated items related to hearing natural sounds as important to their visit to
320 MUWO.
321   **Sample characteristics and neighborhood sounds level.** During May 2016 we found
322 that 82% of the visitors to MWUO were from the United States, 15% were international and 3%
323 did not specify their place of residence. Within the United States, visitors came from 46 different
324 states, with the majority coming from California (30%). Twelve percent of the population were
325 from nearby large urban areas such as San Francisco or Oakland. Moreover, a significant portion
326 of the sample reported being from an urban area (77%), while the other 23% were from rural
327 locations.
328   The minimum mean L_{50} of respondents' zip codes was 31 dBA (the sound level of a soft
329 whisper or light wind) and the maximum mean was 57 dBA (the sound level of traffic). On
330 average, the mean sound level for respondents' zip codes was 47 dBA, which is comparable to
331 the sound level of a quiet residential or urban neighborhood during the day. Most visitors (63%)
332 came from a neighborhood where sound levels ranged between 40 and 49 dBA.
333   **Linear model explaining soundscape pleasantness in MUWO**. Neighborhood sound
334 level, noise sensitivity, noise interference and sound motivation explain 24% of the variance in
335 soundscape pleasantness (Multiple R^2=0.24). Based on the marginal effects from the model
336 (using the untransformed dependent variable), a 1 dB increase in neighborhood sound level
337 results in a 0.02 decrease in the rating of perceived pleasantness (6-point scale) of the
338 soundscape (Figure 2). A one-point increase in noise interference resulted in a 0.41 decrease in
339 pleasantness of the soundscape (Figure 2). A one-point increase in noise sensitivity resulted in a
340 0.14 decrease in pleasantness of the soundscape (Figure 2). Finally, a one-point increase in
341 motivation to hear natural sounds resulted in a 0.09 increase in pleasantness of the soundscape
342 (Figure 2).
343
344 (Insert Table 4 here)
345 (Insert Figure 2 here)
346 **Figure 2.** Marginal effects using the final model (Pleasantness ~ Neighborhood sound level +
347 noise sensitivity + noise interference + sound motivation). (a)Marginal effect of noise sensitivity
348 on pleasantness; (b) Marginal effect of noise interference on pleasantness; (c) Marginal effect of
349 neighborhood sound level on pleasantness; (d) Marginal effect of sound motivation on
350 pleasantness.

351   **Analysis of predictor variables.** We found that neighborhood sound level had a small,
352 but significant, negative influence on noise sensitivity (Table 5). Sound motivation had a small,
353 significant and positive effect on noise sensitivity (Table 5). Sound motivation was also a
354 significant predictor of noise interference, along with quiet v. control days (Table 6).
355

356
357 (insert table 5)
358
359 (insert table 6)

360

Discussion

362   We assessed both subjective and objective measures of visitors' park experiences. The mean
363   sound level for the park during the time visitors were in the park was 41.36 dBA, which is what
364   we would expect in a park where visitors could hear sounds like water running, birdsong, and
365   people walking and talking. We also found that the sound level was slightly lower for visitors
366   who experienced the park when quiet signs were posted. Levenhagen et al, (2020), has detailed
367   the impact of the quiet signs on park's soundscape. Based on our results from the number of
368   visitors using the trail, this is a busy trail system. Due to high visitation in MUWO, visitors are
369   now required to book a reservation. We found a combination of different factors influenced
370   visitors' perception of the pleasantness of the soundscape in a park context. Noise interference,
371   noise sensitivity, motivation to hear natural sounds, and sound level of visitor's neighborhood
372   were significant predictors of soundscape pleasantness. More objective measures, like the sound
373   level of the park and the number of visitors on the trail were not significant variables in our
374   multiple regression model.
375   **Noise interference**. A number of studies have focused on the influence of motorized
376   sounds on soundscape experience (e.g., Benfield, Taff, Weinzimmer, & Newman, 2018; Mace,
377   Bell, & Loomis, 2004; Mace, Corser, Zitting, & Denison, 2013; Weinzimmer et al., 2014). Our
378   study expands this research to highlight the impact of anthropogenic sound sources such as
379   voices, speakers playing music, and park maintenance machinery, on negative soundscape
380   experiences. Model results show a significant negative relationship between subjects' rating of
381   noise interference and pleasantness of the soundscape. This factor had the largest effect on
382   pleasantness in the model (Table 4). As the interference with natural sounds increased, the
383   perception of soundscape pleasantness decreased. Based on previous measures of the MUWO
384   soundscape, visitors talking is the most prevalent anthropogenic sound and has the potential to
385   mask or overpower natural sounds (Stack et al., 2011). Hong and Jeon (2014) also found a
386   negative relationship between human sounds and pleasantness, but in an urban context. In a lab
387   study, Benfield et al. (2010) found that hearing recordings of voices have a negative effect on
388   participants' ratings of national park scenes. Additionally, the increased volume of voice sounds
389   led to increased ratings of annoyance and negatively affected emotional ratings tranquility,
390   freedom, and naturalness (Pilcher, Newman, & Manning, 2009).
391   Our results suggest that the sound level of the park was not a significant predictor of
392   soundscape pleasantness. Noise interference, rather than the acoustic measure of the
393   environment's sound pressure level, better explained the perception of the soundscape. When a
394   person interprets a sound, it can be the sound source, rather than the sound pressure level that
395   might elicit a positive or negative interpretation or reaction (Alvarez, Angelakis, & Rindel,
396   2006). The sound level of the park includes both natural and anthropogenic sounds. For example,
397   moving water, a sound source that most people find pleasing, was a dominant sound captured by
398   many of the acoustic recording devices during the sampling period. Noise interference was more
399   accurate in predicting how visitors rate the soundscape. These findings differ from Levenhagen
400   et al., (2020) which found hourly sound level to be a significant predictor for proportional odds
401   ratios for pleasantness. Our results are not conflicting, rather in this paper we used linear

402 regression modeling to understand variables that predict pleasantness; thus, the assumptions and
403 results here are different from Levenhagen et al., (2020). Additionally, the dataset used in this
404 paper differs slightly from Levenhagen et al. (2020) because we only included visitors' responses
405 whose zip codes matched with the US Census shapefile.
406   Another notable finding in our study is that the educational signs or the experimental
407 design were not a significant predictor of soundscape pleasantness. However, in our analyses for
408 noise interference (Table 6), the educational signs (quiet v. control) were significant predictors of
409 noise interference. Although significant, the estimate is still small (0.05), suggesting its slight
410 influence on noise interference. The direction of this relationship is positive, which indicates that
411 when quiet signs were covered, ratings of noise interference increased. Levenhagen et al.,
412 (2020), using a similar dataset, found the educational signs (quiet v. control) and actual bird
413 diversity were significant in predicting visitors' perceptions of bird diversity. When the study
414 area was quieted with the treatment of educational signs, visitors were better able to observe bird
415 diversity. Our findings support the effectiveness of the signs ability to improve visitors' ability to
416 hear natural sounds with less interference from noise.
417   **Noise sensitivity.** We found noise sensitivity to be a significant predictor of soundscape
418 pleasantness. Specifically, those who were more sensitive to noise found the soundscape to be
419 less pleasant, though the influence of noise sensitivity on pleasantness was not as strong as the
420 influence of noise interference (Table 4). Nevertheless, this relationship is consistent with data
421 from Rocky Mountain National Park. Benfield et al. (2014), found that park visitors with higher
422 ratings of noise sensitivity rated aircraft noise as less acceptable and rated other human-made
423 noises as more problematic. We used a linear model to learn more about predictors of noise
424 sensitivity.
425   Neighborhood sound level had a small negative, but significant effect in predicating noise
426 sensitivity. This small, but negative relationship, suggests that noise sensitivity decreases as the
427 neighborhood sound level increases. It makes sense that these two variables would be related and
428 it would be valuable to understand more about why they are related. Ednie and Gale (2021),
429 found that visitors from urban areas who heard more anthropogenic sounds in a Chilean national
430 park more acceptable than visitors who didn't hear any anthropogenic sounds. The authors
431 question if urban visitors are complacent with noise in parks. For our study, we question if
432 people from loud neighborhoods are less sensitive to noise because they are accustomed to it? Or
433 do people that are sensitive to noise choose to live in quieter areas?
434   **Sound Motivation.** Motivation to hear natural sounds was a positive and significant
435 predictor of soundscape pleasantness. The important relationship between visitor motivations
436 and perception of the soundscape was consistent with Marin et al. (2011), who determined
437 visitors to Muir Woods with higher motivations to experience quiet had lower ratings of human
438 caused noise. This also reflects findings in our additional predictor variable analysis. We
439 determined a small positive relationship between sound motivation and noise sensitivity. The
440 more sensitive a visitor is to noise, the more likely they are to have a higher motivation score for
441 hearing natural sounds.
442   **Neighborhood sound level.** Because perception of the soundscape is influenced by
443 more than just the physical measure of sound (Benfield et al., 2014), it is important to explore
444 individual characteristics that effect soundscape judgments. Within the environmental noise
445 literature, researchers have concluded that people in different communities perceive identical
446 sounds to be either less annoying or more annoying based on their personal norms and attitudes
447 (Gale et al., 2021; Marin et al., 2011). Differing from previous research, this study is the first to

448   explore the relationship between the sound level of individuals' neighborhood and their
449   perception of park soundscapes.
450   Our findings suggest individuals' home sound environment contributes to visitors'
451   perception of the pleasantness of the park's soundscape. Specifically, as neighborhood sound
452   level increased, the rating of soundscape pleasantness decreased. These findings align with Gale
453   et al., (2021) who found visitors from more dense urban areas to rate the soundscape of a
454   national park, home, and word differently than visitors from less dense urban areas. Moreover,
455   they found a significant negative correlation between urban density and the park soundscape
456   pleasantness. Indicating that as urban density of the visitors home increased, their rating of the
457   park's soundscape pleasantness decreased.
458   Additionally, a large portion of our sampled population was from urban areas
459   (population over 50,000). While the survey did not include questions about these variables, the
460   observed trend could be the result of "learned deafness", when humans and animals become
461   accustomed to noise (Hatch & Fristrup, 2009; Fristrup, 2015). Individuals could be ignoring the
462   sounds around them to block out unwanted sounds or noise. Whether learned deafness in
463   response to irrelevant sounds transfers to learned deafness to relevant sounds is an important area
464   of future research. For instance, might "learned deafness" influence the magnitude of restorative
465   effects from natural sounds? As mentioned earlier, it's also possible that visitors are becoming
466   complacent with hearing increased noise in parks (Ednie & Gale, 2021).
467   Another justification for the negative relationship between neighborhood noise level and
468   pleasantness is that respondents living in noisier neighborhoods are accustomed to noise and
469   uncomfortable with, or less appreciative of quiet, natural soundscapes. This could also hold true
470   if those living in noisy areas are purposely masking unwanted noise with other sounds (e.g., from
471   music, television, a white noise machine, or noise canceling headphones). A habituation to noise
472   might make quieter soundscapes elicit uneasy feelings, thus rating the soundscape as less
473   pleasant. This trend could also be a result of people living in urban settings reporting higher rates
474   of noise induced hearing loss (Lewis, Gershon, & Neitzel, 2013). Many Americans are exposed
475   to harmful levels of noise (Hammer et al., 2014) and in 2012 it was estimated that 24% of adults
476   experienced hearing loss as a result of noise exposure (Carroll et al., 2017). Although it was not
477   measured in this study, it is possible that respondents living in noisy urban areas experience
478   higher rates of hearing loss or other disorders and were less likely to rate the soundscape as
479   pleasant.
480   **Planning and management implications.** Management of natural soundscapes in
481   protected areas is important for conserving wildlife, and for providing visitors with holistic
482   benefits. Our findings demonstrate how various factors influence the perception of soundscape
483   pleasantness. MUWO designates certain areas of the park as "quiet zones", and empirical
484   evidence shows that this method is successful in quieting the park (Stack et al., 2011). It is
485   important for other parks, especially those close to urban centers, to adopt similar management
486   techniques. While parks might be quieter than a busy downtown area, it's important to keep
487   these protected places quiet, so that visitors have the opportunity benefit from the ecosystem
488   services they provide (Ferraro, et al., 2020; Gidlöf-Gunnarsson & Öhrström, 2007).
489   National park units across the United States are taking steps to implement policies that
490   protect natural soundscapes. Findings from this study suggest that other protected area agencies
491   within the United States and abroad could develop plans to protect natural sounds and quiet, thus
492   leading to a quieter protected area soundscape. In a study of perceived restoration experiences in
493   urban parks, Payne (2008) found that visitors' perception of the soundscape plays a significant

494 role in their restorative experience. Urban parks that can provide experiences that improve the
495 wellbeing of urbanites should design spaces that reduce human sounds. This can be done by
496 creating messaging and associated zones that influence visitors to keep quiet, avoid cell phone
497 use, and mute music. Finally, this study highlights the importance of quiet natural places, such as
498 urban parks. As the United States continues to urbanize, cities should prioritize the development
499 and maintenance of urban parks for the wellbeing of its residents (Larson, Jennings, Cloutier,
500 2016)
501 **Limitations and future research.** Our study suggests that individual exposure to sound
502 can impact perceptions of a protected area soundscape. Additionally, we found a negative
503 relationship between noise sensitivity and the sound level associated with home zip code. It
504 would be valuable to explicitly examine how noise sensitivity varies with typical noise exposure.
505 We used acoustic data from Mennitt et al. (2016), to estimate visitor's neighborhood sound level.
506 Future researchers could consider adopting other methods for sound mapping. For example, a
507 study conducted in France used a stochastic modeling approach, which considers temporal sound
508 distribution per sound source, to estimate urban sounds (Aumond, Jacquesson, & Can, 2018).
509 Moreover, our results combined with evidence from Ednie and Gale (2021) and Gale et al.,
510 (2022) should elicit research related to complacency for noise in parks. Visitors from louder,
511 denser urban areas seem to rate park soundscapes as less pleasant. This research could be
512 extended to different national parks and urban parks across the globe to validate this trend. If so,
513 this could be problematic for parks that aim to provide restorative, natural soundscapes.

514 **Conclusion**

515 Parks are important for providing natural soundscapes, especially for people living near
516 urban centers where sound levels are the highest. We show that relationships with soundscapes
517 can be complex and that the sound level experienced on a daily basis can influence one's
518 perception of a park soundscape. We found that individuals from neighborhoods with higher
519 background sound levels rated the MUWO soundscape as less pleasant. This could be a result of
520 learned deafness and/or a comfort in urban sounds that coincide with living in areas with
521 increased sound levels. Moreover, those who experienced increased interference with natural
522 sounds found the soundscape to be less pleasant. Urban park planners can use evidence from this
523 study to inform future research and management related to natural sounds.

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Figure 1

Boundary of Muir Woods National Monument

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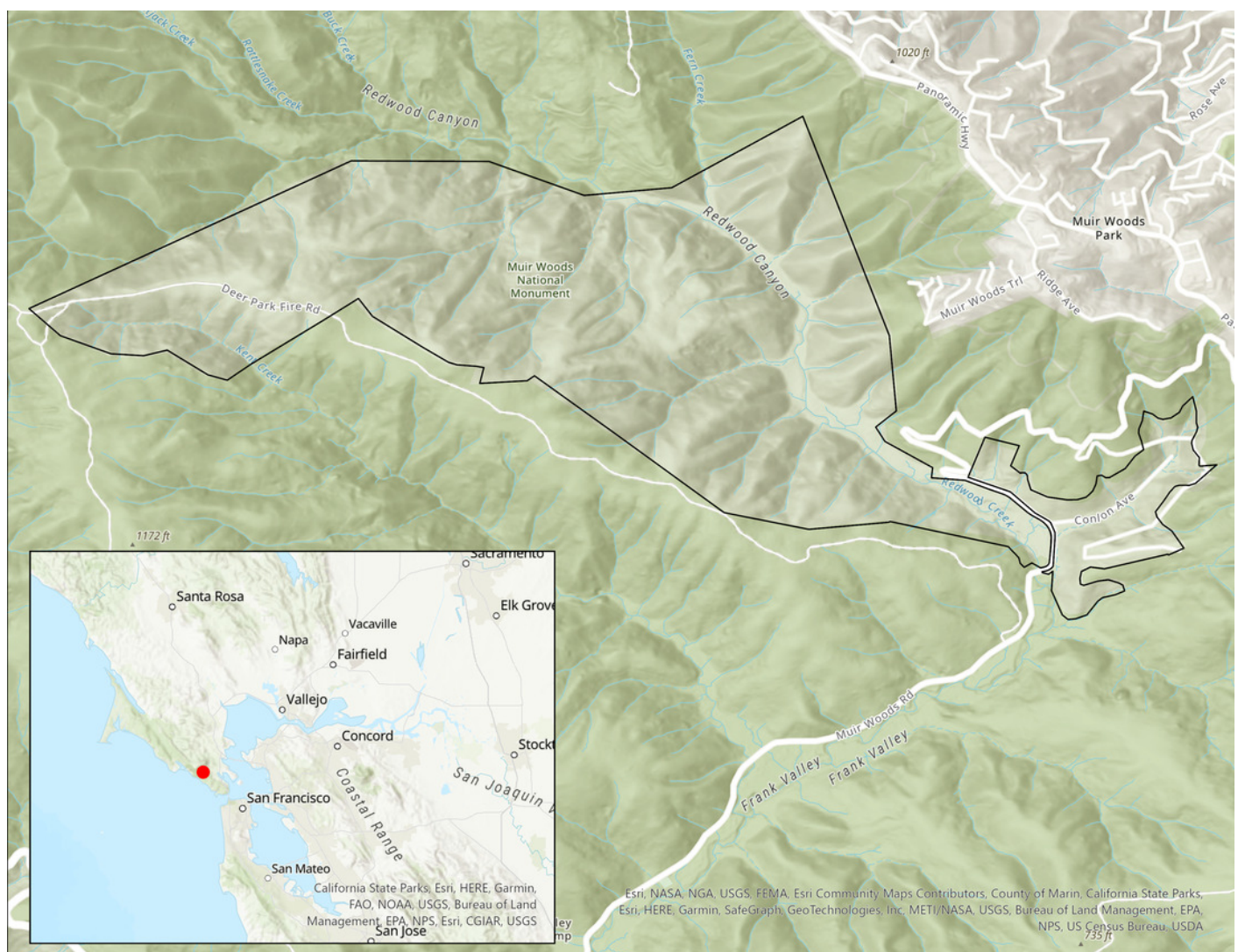
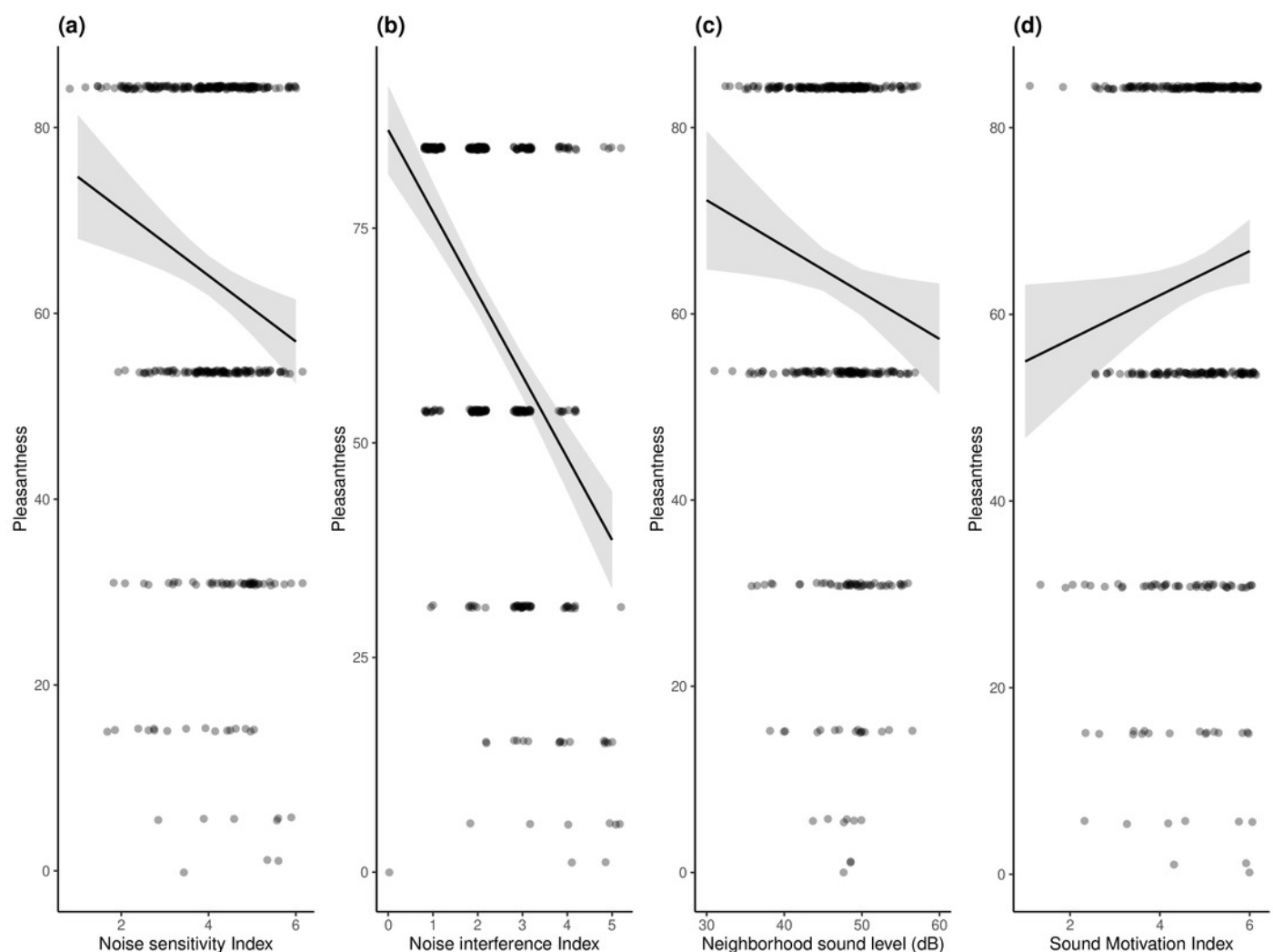


Figure 2

Marginal effects using the final model (Pleasantness ~ Neighborhood sound level + noise sensitivity + noise interference + sound motivation).

(a)Marginal effect of noise sensitivity on pleasantness; (b) Marginal effect of noise interference on pleasantness; (c) Marginal effect of neighborhood sound level on pleasantness; (d) Marginal effect of sound motivation on pleasantness.

Details on survey questions, response values and how they relate to understanding the visitor and sound perception.

	Question	**Value Range**
Motivation	Please rate the importance of each of the following reasons for your visit to Muir Woods National Monument today.	1 (not at all important) 2 (slightly important) 3 (moderately important) 4 (very important) 5 (extremely important)
Geographic location	What is your home zip code?	Enter zip code
Perceptions of the soundscape		
Pleasantness	Visitors hear a lot of sounds, including natural sounds and human-made sounds. Based on your experiences today, how would you rate your pleasantness of the soundscape?	1 (very unpleasant) 2 (moderately unpleasant) 3(slightly unpleasant) 4(slightly pleasant) 5 (moderately pleasant) 6 (very pleasant)
Noise sensitivity scale	1) I am sensitive to noise 2) I find it hard to relax in a place that's noisy. 3) I get mad at people who make noise that keeps me from falling asleep or getting work done. 4) I get annoyed when my neighbors are noisy. 5) I get used to most noises without much difficulty (reverse coded).	1 (strongly disagree) 2 (disagree) 3 (slightly disagree) 4(slightly agree) 5(agree) 6 (strongly agree)
Noise interference	Based on your experience today, how well were you able to hear natural sounds?	1 (almost always clearly without interference from human-made sound) 2 (usually clearly without interference from human-made sound) 3 (sometimes clearly without interference from human-made sound) 4 (usually with interference from human-made sound) 5 (almost always with interference from human-made sounds)

Reliability analysis and descriptive statistics from independent and dependent variables.

Variables	Mean (sd)
Single item measures	
Hourly L_{50}	41.36 (1.51)
Visitor Use Estimate	214 (68.60)
Pleasantness	5.24 (1.00)
Noise Interference	2.37 (1.07)
Motivation α = .859	
To enjoy the quiet sounds of nature	4.08 (1.01)
To get away from the noise back home	3.60 (1.30)
Enjoying the peace and quiet	3.84 (1.08)
Hearing sounds of nature	3.84 (1.08)
Noise sensitivity scale α = .808	
I am sensitive to noise	3.76 (1.59)
I find it hard to relax in a place that's noisy.	4.48 (1.35)
I get mad at people who make noise that keeps me from falling asleep or getting work done.	4.41 (1.45)
I get annoyed when my neighbors are noisy.	4.39 (1.28)
I get used to most noises without much difficulty (reverse coded).	3.27 (1.27)

Model selection for pleasantness

Model	Model equation[1]	AIC
M_1	Pleasantness ~ Neighborhood sound level	3405.89
M_2	Pleasantness ~ Neighborhood sound level + noise sensitivity	3398.69
M_3	Pleasantness ~ Neighborhood sound level + noise sensitivity + noise interference	3318.29
M_4	Pleasantness ~ Neighborhood sound level + noise sensitivity + noise interference + sound motivation	3315.47
M_5	Pleasantness ~ Neighborhood sound level + noise sensitivity + noise interference + sound motivation + quiet v. control	3316.57
M_6	Pleasantness ~ Neighborhood sound level + noise sensitivity + noise interference + sound motivation + hourly L50	3316.13
M_7	Pleasantness ~ Neighborhood sound level + noise sensitivity + noise interference + visitor count	3314.03

Final linear model for pleasantness (transformed). Pleasantness ~ Neighborhood sound level + noise sensitivity + noise interference + sound motivation

Fixed Effects	Estimate	SE	t	P
Intercept	112.89	12.72	8.88	<0.001
Neighborhood sound level	-0.50	0.22	-2.30	0.022
Noise sensitivity	-3.55	1.05	-3.36	<0.001
Noise interference	-9.54	1.02	-9.37	<0.001
Sound motivation	2.37	1.08	2.19	0.030

Linear model: Noise sensitivity ~ Neighborhood sound level + noise interference + sound motivation + hourly L_{50} + visitor count + quiet v. control

Coefficients	Estimate	SE	t	P
Intercept	6.12	2.22	2.74	<0.001
Neighborhood sound level	-0.02	0.01	-2.07	0.04
Noise interference	0.07	0.05	1.38	0.17
Sound motivation	0.13	0.05	2.52	0.01
Hourly L_{50}	-0.04	0.06	-0.70	0.48
Visitor count	-0.00	0.00	-0.95	0.34
Quiet v. control	-0.08	0.12	-0.76	0.45

2 $R^2=0.026$

Linear model: Noise Interference ~ Neighborhood sound level + noise sensitivity + sound motivation + hourly L_{50} + visitor count + quiet v. control

Coefficients	Estimate	SE	t	P
Intercept	-1.87	2.21	-0.84	0.40
Neighborhood sound level	0.01	0.01	0.84	0.40
Noise sensitivity	0.07	0.05	1.37	0.16
Sound motivation	-0.10	0.05	-1.89	0.05
Hourly L_{50}	0.08	0.05	1.42	0.15
Visitor count	0.00	0.00	3.74	0.65
Quiet v. control	0.05	0.12	0.46	<0.001

2    $R^2 = 0.096$