Landscape and Urban Planning 180 (2018) 76–84

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

Research Paper

Modeling anthropogenic noise impacts on animals in natural areas

Alexander C. Keyel[a,*], Sarah E. Reed[a,b], Kathryn Nuessly[d], Elizeth Cinto-Mejia[c], Jesse R. Barber[c], George Wittemyer[a]

[a] Dept. of Fish, Wildlife, and Conservation Biology, 1474 Campus Delivery, Colorado State University, Fort Collins, CO 80523-1474, USA
[b] Wildlife Conservation Society, Americas Program, 2300 Southern Blvd., Bronx, NY 10460, USA
[c] Dept. of Biology, 1910 University Dr., Boise State University, Boise, ID, 83725-1515, USA
[d] Natural Sounds and Night Skies Division, US National Park Service, 1201 Oakridge Drive, Fort Collins, CO 80525, USA

ARTICLE INFO

Keywords:
Conservation
Masking
NMSIMGIS
Recreation
Sound Mapping Tools
SPreAD-GIS

ABSTRACT

Noise is a globally pervasive pollutant that can be detrimental to a range of animal species, with cascading effects on ecosystem functioning. As a result, concern about the impacts and expanding footprint of anthropogenic noise is increasing along with interest in approaches for how to mitigate its negative effects. A variety of modeling tools have been developed to quantify the spatial distribution and intensity of noise across landscapes, but these tools are under-utilized in landscape planning and noise mitigation. Here, we apply the Sound Mapping Tools toolbox to evaluate mitigation approaches to reduce the anthropogenic noise footprint of gas development, summer all-terrain vehicle recreation, and winter snowmobile use. Sound Mapping Tools uses models of the physics of noise propagation to convert measured source levels to landscape predictions of relevant sound levels. We found that relatively minor changes to the location of noise-producing activities could dramatically reduce the extent and intensity of noise in focal areas, indicating that site planning can be a cost-effective approach to noise mitigation. In addition, our snowmobile results, which focus on a specific frequency band important to the focal species, are consistent with previous research demonstrating that source noise level reductions are an effective means to reduce noise footprints. We recommend the use of quantitative, spatially-explicit maps of expected noise levels that include alternative options for noise source placement. These maps can be used to guide management decisions, allow for species-specific insights, and to reduce noise impacts on animals and ecosystems.

1. Introduction

Anthropogenic noise affects species' occupancy (Francis, Paritsis, Ortega, & Cruz, 2011), behavior (Shannon et al., 2015), distribution (Ware, McClure, Carlisle, & Barber, 2015), reproduction (Francis et al., 2011), physiology (Kight & Swaddle, 2011), and ultimately fitness (Schroeder, Nakagawa, Cleasby, & Burke, 2012). Noise can be an invisible source of habitat degradation (Ware et al. 2015), influence trophic interactions (e.g., predator-prey dynamics, Francis, Ortega, & Cruz, 2009), and change the provision of ecosystem services (Francis, Kleist, Ortega, & Cruz, 2012). Although most noise studies have focused on birds, terrestrial noise has been shown to affect a wide variety of taxa, including mammals, reptiles, amphibians, and invertebrates (Bowles et al., 1999; Bunkley, McClure, Kawahara, Francis, & Barber, 2017; Morley, Jones, & Radford, 2014; Shannon et al., 2015). Consequently, there is increasing interest in describing and mitigating the impacts of noise pollution on biodiversity (e.g., Mullet, Gage, Morton, & Huettmann, 2016).

With increased awareness of the threats posed to ecological systems by noise, several approaches to model noise propagation across landscapes have been developed (e.g., Ikelheimer & Plotkin, 2005; Kragh et al., 2002; Reed, Boggs, & Mann, 2012). Sound propagation models provide a means of assessing current and predicted noise levels and evaluating noise propagation under alternative management options (Harrison, Clark, & Stankey, 1980; Reed et al., 2012) or future scenarios (Dumyahn & Pijanowski, 2011). As such, the application of propagation modeling can provide rapid and cost-effective insights for planning or management decisions to mitigate potential noise impacts (e.g., management of snowmobile noise in Yellowstone National Park, Jacobson, 2013).

Energy development and motorized recreation are noise sources of particular concern, as they are widespread and can substantially

* Corresponding author.
E-mail addresses: skeyel@gmail.com (A.C. Keyel), sreed@wcs.org (S.E. Reed), kathryn_nuessly@nps.gov (K. Nuessly), jessebarber@boisestate.edu (J.R. Barber), G.Wittemyer@colostate.edu (G. Wittemyer).

https://doi.org/10.1016/j.landurbplan.2018.08.011
Received 1 August 2017; Received in revised form 1 August 2018; Accepted 16 August 2018

increase sound levels in natural areas (e.g., Harrison et al., 1980; Ramirez and Mosley, 2015). Noise from natural gas extraction has been shown to reduce species' abundance in large areas of habitat (Bayne, Habib, & Boutin, 2008), change patterns of habitat selection (Kleist, Guralnick, Cruz, & Francis, 2017), interfere with species' hunting behavior (Mason, McClure, & Barber, 2016), alter species' physiology (Blickley et al., 2012), and influence trophic interactions (Francis et al., 2011).

Recreational noise, too, has been shown to directly, negatively affect species' behavior (Brattstrom & Bondello, 1983; Karp & Root, 2009). A recent review of recreational impacts found that ~45% of studies of summer-season motorized recreation and ~80% of snow-based, winter motorized recreation had negative effects on species (Larson, Reed, Merenlender, & Crooks, 2016). Noise is hypothesized to be an important factor driving the negative effect of motorized recreation on species (Harrison et al., 1980; but see Reimers, Eftestøl, & Colman, 2003). Among other effects, species may avoid noise sources (Bradshaw, Boutin, & Hebert, 1997), and the resulting displacements may be energetically costly (Bradshaw, Boutin, & Hebert, 1998). Noise may also mask species' communication (Lohr, Wright, & Dooling, 2003), which may cause species to compensate using a variety of potentially costly strategies (Brumm & Slabbekoorn, 2005).

Our study aims to develop approaches that allow a spatially-explicit evaluation of the benefits of different mitigation approaches to reduce the amount of area exposed to noise. We applied noise propagation models to assess noise-related impacts of gas development, off-highway vehicle use, and snowmobile use and examined the potential to reduce noise impacts through relocating noise-producing activities or, in the case of snowmobiles, by reducing noise levels at the source. A variety of acoustic metrics are available, including sound pressure levels, thresholds, audibility, and potential for masking. We demonstrate the utility of summarizing noise propagation data in these various manners, highlighting the applicability of these different metrics to different types of questions. We predicted that small changes at the planning stage could greatly reduce noise levels, especially in sensitive areas. We used threshold-, audibility-, and masking-based metrics (see Methods) as different indices of noise impacts for different ecological situations. Finally, we discuss modeling decisions to consider when developing and applying sound propagation model outputs to management questions.

2. Methods

2.1. Study area

We examined noise impacts from energy development or motorized recreation in three study locations: gas extraction in Shale Ridges Management Area, CO (39.3 N 108.3 W; BLM, 2015), all-terrain vehicle recreation in Bangs Canyon, CO (38.93 N 108.5 W), and snowmobile use in the Stanislaus National Forest, CA (38.514 N, 119.92 W). These sites were selected to represent a variety of anthropogenic noise sources relevant to land managers, and to illustrate sources with different spatial arrangements (point-, line-, and area-based noise sources). We used site-specific approaches to incorporate specific situation of each location in the noise propagation models.

The Shale Ridges Management Area has recently been the subject of a Master Leasing Plan (BLM, 2015), which included the potential for new natural gas extraction in the area. This management area also contained lands designated as Areas of Critical Environmental Concern (ACEC) for wildlife. The study landscape was comprised of ridges and valleys, with a mean elevation of 1906 m (1382–2723 m min-max, USGS, 2013), and was comprised of a variety of vegetation types, with pinyon-juniper (*Pinus edulis* and/or *Juniperus osteosperma*) woodland (30%) and big sagebrush (*Artemisia tridentata*) scrubland (21%) accounting for over half the land cover. No other land cover type accounted for more than 10% of the total land area (LANDFIRE, 2012). One of the most iconic species in the region is the mule deer (*Odocoileus hemionus*), and previous research has suggested that mule deer are sensitive to natural gas development (Johnson et al., 2016; Northrup, Anderson, & Wittemyer, 2015; Sawyer, Kauffman, & Nielson, 2009; Sawyer, Nielson, Lindzey, & McDonald, 2006). Consequently, we examined the potential for drilling and operating new wells to affect mule deer.

Bangs Canyon, adjacent to Colorado National Monument and located near Grand Junction, CO, is managed by the BLM for motorized recreation, non-motorized recreation, and wildlife. Bangs Canyon is also topographically diverse (mean: 1902 m, min-max: 1362–2955 m USGS, 2013), with a similar vegetation composition to the Shale Ridge Management Area: 30% Pinyon-Juniper Woodland, 11% Big Sagebrush Shrubland, and no other land cover > 10% of the landscape (LANDFIRE, 2012). Motorized recreation can be disruptive to non-motorized recreationists and wildlife (e.g., Rapoza, Sudderth, & Lewis, 2015; Seip, Johnson, & Watts, 2007); consequently, we tested the degree to which motorized recreation would be audible along non-motorized trails. We chose to use a single all-terrain vehicle (ATV) as our motorized source (although model results could be scaled to represent any number of ATVs), and evaluated human audibility (ISO 389-7). In addition to evaluating effects on other recreational visitors, humans are a useful proxy for many species because human hearing is similar to or better than that of many wild animals (e.g. see audiograms in Fay, 1988; Buxton et al., 2017).

Finally, we considered snowmobile use in a recreation area within Stanislaus National Forest proposed by the USDA Forest Service (hereafter 'snowmobile area'). In contrast to the other two study regions, Stanislaus National Forest was higher in elevation (mean: 2459 m, min-max: 1675–3328 USGS, 2013), but predominantly wooded (49% Red Fir Forest, no other landcove > 10% of the landscape, LANDFIRE, 2012). The potential for avian communication to be masked by anthropogenic noise has been a topic of considerable research (e.g., Brumm & Slabbekoorn, 2005; Hu & Cardoso, 2010; Lohr et al., 2003), and winter may be a time when masking of alarm and other social calls of birds place these animals in particular risk due to weather extremes and limited food (e.g., Jansson, Ekman, & von Brömssen, 1981; Robel & Kemp, 1997). Therefore, we chose to evaluate the potential for snowmobiles to mask species-specific vocalizations in a recreation area. We focused on vocalizations by White-breasted Nuthatches (*Sitta carolinensis*), as this species is present in the Stanislaus National Forest year round, vocalizes in winter, and quality recordings of the species' vocalizations are available (Nelson, 2015a, 2015b).

2.2. Modeling approach

2.2.1. Modeling approach overview

We used Sound Mapping Tools V4.4 (SMT, Keyel, Reed, McKenna, & Wittemyer, 2017 http://purl.oclc.org/soundmappingtools) with ArcGIS (10.3, 10.4, ESRI, Redlands, CA) to evaluate potential acoustic impacts using publicly-available data sets (see Table 1, code used to run the analyses given in Appendix 1). SMT provides an easy-to-use ArcGIS interface for several existing sound models: SPreAD-GIS (Harrison et al., 1980; Reed et al., 2012), NMSIMGIS (Ikelheimer & Plotkin, 2005), and a GIS implementation of ISO 9613-2 (ISO 9613-2). These sound models make spatially-explicit quantitative predictions of sound levels based on distance from a sound source, land cover, topography, and environmental conditions, and they have been used previously to address natural resource-related questions (e.g., Barber et al., 2011; Sunder, 2003).

We represented line and polygon noise sources as arrays of points to meet the point input requirement of the models. Each point source had the same starting sound level. All decibel values reported here are A-weighted sound pressure levels re: 20 μPa (dBA) unless otherwise noted. One-third octave band ranges used in the weightings are given in Table 1. We used weather data from a nearby weather station using seasonally appropriate weather conditions. Our goal was not a precise