Biological Conservation 191 (2015) 623–631

Contents lists available at ScienceDirect

Biological Conservation

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

The impact of noise from open-cast mining on Atlantic forest biophony

M.H.L. Duarte [a,b,*], R.S. Sousa-Lima [c,d], R.J. Young [e], A. Farina [f], M. Vasconcelos [g], M. Rodrigues [b], N. Pieretti [f]

[a] Conservation, Ecology and Animal Behaviour Group, Laboratório de Bioacústica, Mestrado em Zoologia de Vertebrados e Museu de Ciências Naturais, Pontifícia Universidade Católica de Minas Gerais, Rua Dom José Gaspar, 290, Bairro Coração Eucarístico, Belo Horizonte, Minas Gerais CEP 30535-901, Brazil

[b] Laboratório de Ornitologia, Departamento de Zoologia, Universidade Federal de Minas Gerais, Avenida Presidente Antônio Carlos, 6627, Bairro Pampulha, Belo Horizonte, Minas Gerais CEP 31270-901, Brazil

[c] Laboratório de Bioacústica (LaB), Departamento de Fisiologia, Universidade Federal do Rio Grande do Norte, Avenida Senador Salgado Filho, 3000, Bairro Lagoa Nova, Natal, RN 59078-970, Brazil

[d] Bioacoustics Research Program, Lab of Ornithology, Cornell University, 159 Sapsucker Woods Road, Ithaca, NY 14850, USA

[e] School of Environment and Life Sciences, University of Salford Manchester, Peel Building, Salford M5 4WT, UK

[f] Department of Basic Sciences and Foundations, University of Urbino, Campus Scientifico "Enrico Mattei" Urbino, Italy

[g] Laboratório de Ornitologia, Museu de Ciências Naturais da Pontifícia Universidade Católica de Minas Gerais, Rua Dom José Gaspar, 290, Bairro Coração Eucarístico, Belo Horizonte, Minas Gerais CEP 30535-901, Brazil

ARTICLE INFO

Article history:
Received 17 December 2014
Received in revised form 25 July 2015
Accepted 1 August 2015
Available online 24 August 2015

Keywords:
Atlantic forest
Mining activity
Biophony
Technophony
Noise disturbance

ABSTRACT

The sound produced by human-made machinery (technophony) is known to exert negative effects on animal communication and well-being. Mining is an important economic activity in Brazil, which is often conducted close to forested areas and produces a diffuse noise. In this study, the impact of such noise on biophony (biological sounds) was investigated by characterizing and comparing the soundscapes of two different sites (close versus distant from an open-cast mine) in the same Atlantic forest fragment, matched for habitat type, in Southeast Brazil. Six automated recorders were installed at each site and were programmed to record continuously during seven consecutive days every two months between October 2012 and August 2013. Technophony and biophony values were derived from power spectra and the Acoustic Complexity Index (ACI). Mann–Whitney U tests demonstrated that the biophony exhibited a switch in daily dynamics, resulting in a statistically higher biophony during the day at the site close to the mine and a higher biophony during the night at the site far from the mine. Potential species richness was found to be higher at the site that was distant from the mine. The species composition and spectral characteristics of the calls were also found to differ between the two sites. These results provide the first investigation of potential disturbances caused by mining noise on biophony, demonstrating that it can cause alterations in the temporal dynamics and daily patterns of animal sounds, which are symptoms of altered behaviors or variations in community-species composition. These findings suggest remarkable insights that should be taken into consideration in the regulating of the use of natural areas for mining.

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1. Introduction

Open-cast mining is known to produce high sound pressure levels through exploratory and production drilling, blasting, cutting, handling of materials, ventilation, crushing, conveying, ore processing and transportation (Donoghue, 2004). This massive noise pollution has the potential to negatively impact wildlife. Mining has been shown to impact breeding birds by reducing their density (Smith et al., 2005), their species diversity, and their population sizes (Saha and Padhy, 2011). Ant-species richness has also been found to decrease owing to mining activity (Queiroz, 2013). Despite the evidence that noise pollution negatively affects wildlife reproduction and longevity (Warren et al., 2006; Slabbekoorn and Ripmeester, 2008; Barber et al., 2009; Francis et al., 2011; Kight and Swaddle, 2011), sound pollution from mining activity is still poorly regulated around the world (Hessel and Sluis-Cremer, 1987; Frank et al., 2003).

Many animal species depend on acoustic signals for intraspecific communication (Catchpole and Slater, 2008). Several studies have demonstrated that high noise levels may reduce habitat quality for many species (Bayne et al., 2008) by masking sound signals and decreasing the efficiency of animal communication (Langemann et al., 1998; Lohr et al., 2003; Brumm, 2004; Bee and Swanson, 2007). Noise can also decrease reproductive success (Halfwerk et al., 2011), as well as altering mating systems (Swaddle and Page, 2007; Habib et al., 2007) and parental care in bird species (Schroeder et al., 2012). Nonetheless, some animal species are capable of adjusting their acoustic signals to communicate in noisy environments, for example, by increasing their amplitude (Brumm et al., 2004; Brumm et al., 2009), shifting frequencies

* Corresponding author at: Conservation, Ecology and Animal Behaviour Group – Laboratório de Bioacústica, Mestrado em Zoologia de Vertebrados e Museu de Ciências Naturais, Pontifícia Universidade Católica de Minas Gerais, Rua Dom José Gaspar, 290, Bairro Coração Eucarístico, Belo Horizonte, Minas Gerais CEP 30535-901, Brazil.

E-mail addresses: marinabioacustica@hotmail.com (M.H.L. Duarte), sousalima.renata@gmail.com, rsl32@cornell.edu (R.S. Sousa-Lima), r.j.young@salford.ac.uk (R.J. Young), almo.farina@uniurb.it (A. Farina), mfvasconcelos@gmail.com (M. Vasconcelos), ornito@icb.ufmg.br (M. Rodrigues), nadia.pieretti@uniurb.it (N. Pieretti).

http://dx.doi.org/10.1016/j.biocon.2015.08.006
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(Slabbekoorn and Peet, 2003; Parks et al., 2007; Nemeth and Brumm, 2009), altering their calling rates (Sun and Narins, 2005), changing call duration (Brumm et al., 2004) or by shifting their time of calling (Fuller et al., 2007; Sousa-Lima and Clark, 2008). Other species exhibit behavioral changes including avoiding noisy areas during foraging (Miksis-Olds et al., 2007; Schaub et al., 2008) and other daily activities (Sousa-Lima and Clark, 2009; Duarte et al., 2011). Area avoidance and acoustic compensatory mechanisms to reduce or offset the effects of noise may alter the acoustic complexity of a community in a given location, resulting in a decrease in species' abundance (Bayne et al., 2008) and/or diversity (Proppe et al., 2013) at noise-polluted sites.

Technophony, which is the sound produced by human-made machinery, has become omnipresent in natural soundscapes (Barber et al., 2011) and, despite evidence demonstrating negative impacts on animals, there is still a lack of official regulation of the noise produced by industrial and exploratory activities in terrestrial natural areas. The Atlantic forest in Brazil is one of the richest and most endangered biomes of the world (Myers et al., 2000) where a high level of mining activity occurs. Despite this high level of mining activity, there are no laws regulating the sound-pollution levels permitted in this biome. In many countries of the world, noise monitoring from industrial activities is required only in respect to its impacts on human health. Consequently, the effects of noise on wildlife that are already known should drive efforts to develop environmental legislation to protect wildlife (Brown et al., 2013).

Passive acoustic monitoring (PAM) methods provide opportunities to evaluate the consequences of different land-use decisions (Blumstein et al., 2011; Joo et al., 2011; Mennitt and Fristrup, 2012; Brown et al., 2012, 2013), especially in environments such as mines, that are difficult to access or monitor using conventional methods (Mellinger and Barlow, 2003; Scott Brandes, 2008). PAM devices can record data during several days continuously and, consequently, a large amount of information can be collected from the acoustic environment. As a result, special software and indices to process audio files rapidly and efficiently are required (Kasten et al., 2012; Aide et al., 2013; Sueur et al., 2014; Villanueva-Rivera and Pijanowski, 2015). In this context, Pieretti et al. (2011) introduced the Acoustic Complexity Index (ACI), which facilitates an indirect and rapid measuring of the complexity of the soundscape. The ACI has been proven to be a useful tool in tracking the dynamics of the sounds produced by animal communities (Farina et al., 2013); this is achieved by describing the spectral complexity of the biophony of soundscapes through the intrinsic variability of biotic sounds. This index has already been applied in noisy environments (Pieretti et al., 2011; Pieretti and Farina, 2013) because it possesses the particular quality of helping to filter out most technophonies, such as trains, cars or airplane transit noise; additionally, Towsey et al. (2014) indicate ACI as one of the best indicators of bird biodiversity among 14 different acoustic indices.

There are no studies investigating how anthropogenic noise affects soundscapes and biophony in mining areas. Considering that, the aim of this study was to investigate noise effects on Atlantic forest soundscape dynamics by comparing the biophony and technophony at a site close to an active open-cast mine and at a habitat-matched site that was distant from the mine or other anthropogenic activities.

2. Methodology

2.1. Study area

Data were collected at the Environmental station of Peti in the municipalities of São Gonçalo do Rio Abaixo and Santa Bárbara, Minas Gerais state, Brazil (centered at 19°53′57″S and 43°22′07″W). The climate of southeastern Brazil can be divided into two macro-climatic seasons: a hot wet season, from October to March, and a cooler dry season from April to September (Minuzzi et al., 2007).

The reserve is an Atlantic forest fragment of approximately 605 ha located in the upper Rio Doce Basin (altitude range: 630–806 m). It is estimated that the area harbors approximately 29 species of anurans (Bertoluci et al., 2009), 231 species of birds (Faria et al., 2006) and 46 species of mammals (Paglia et al., 2005). A large part of the reserve is covered by secondary arboreal vegetation of continuous canopy and large trees (Nunes and Pedralli, 1995).

Peti is surrounded by small farms and is contiguous with the Brucutu Mine, which occupies an area of 8 km^2 and produces noise through road traffic, sirens and explosions during the day and night (Roberto, 2010). Brucutu's iron ore extraction began in 1992 and it is currently one of the largest mines of the world (Roberto, 2010).

2.2. Acoustic recordings and data analysis

Sensor arrays comprising six Song Meter Digital Field Recorders (SM2) (Wildlife Acoustics, Inc., Massachusetts), distributed in two triangles, were installed at two sites and were programmed to record continuously during seven days every two months from October 2012 to August 2013 (six recording sessions). Both sites were matched by habitat and were located in the same Atlantic forest fragment. The 6-SM2 array close to the active open-cast mine was installed at a distance of 500 m from the mine and 25 m from the closest mining road. The 6-SM2 array located at the site that was far from the mine was installed at a distance of approximately 2500 m from the mine and 25 m from a rarely used road in order to control for a potential border effect due to the physical structure of the road (Fig. 1).

In order to avoid overlap of the sounds recorded, each SM2 within each sensor triangle, was placed 80 m from each other. This distance between recorders was established during a pilot study conducted in the area. The distance between the two SM2 triangles was at least 100 m in order to have two independent recording samples at each site (close and far from the mine). The distance between the arrays (far and close sites) was approximately 2300 m (Fig. 1). The triangular array geometry was chosen to have one SM2 at the forest border and two located 80 m toward the interior of the forest.

Each SM2 was fixed on a tree at 1.5 m above the ground and was placed to have the two lateral microphones clear of any surface that could be an obstacle to incoming sound waves. They were configured to record in wave format at a sampling rate of 44.1 kHz, at 16 bits. No high-pass or low-pass filters were applied. One SM2 disappeared during the fifth session (at the site close to the mine), and the second session was not considered for one SM2 installed at the site distant from the mine because the noise produced by a flooded river masked all incoming sounds.

The collected data were subsampled by analyzing the first two minutes of recordings every hour. The resulting 23,520 min (392 h) were further processed using Wavesurfer software (Sjölander and Beskow, 2000) powered by the SoundscapeMeter plug-in (Farina et al., 2012). A Fast Fourier Transform (FFT) of 512 points was applied to obtain, from every two-minute file, a matrix made by 256 frequency bins of 86.13 Hz and 10,335 time intervals of 0.012 s. The resulting database of power spectra (i.e., the sound energy values along a frequency axis in each temporal interval) was used to analyze and describe two sonic components of the soundscape in each site: technophony and biophony.

All the files were separated into two frequency bands: 1) 0–1.5 kHz (predominantly occupied by noise or technophony) and 2) 1.5–22.05 kHz (mainly occupied by biophony). The lower frequency band was used to characterize the noise by analyzing the power spectrum and the second band was further processed to extract values for the ACI (Farina et al., 2011; Pieretti et al., 2011). The threshold of 1.5 kHz was chosen because most of the energy from anthropogenic noise is primarily concentrated under 2 kHz (Warren et al., 2006); this threshold was lowered 500 Hz to prevent the exclusion of some important biophonies that were just above 1.5 kHz from the ACI calculations (Pieretti and Farina, 2013). This was possible owing to the ACI being able to filter the noise over this threshold. Nonetheless, at the site closest to the mine, the noise produced by truck transit often covered

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