Marine Pollution Bulletin 105 (2016) 65–72

Contents lists available at ScienceDirect

Marine Pollution Bulletin

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

Underwater soundscape of marine protected areas in the south Brazilian coast

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ARTICLE INFO

Article history:
Received 5 January 2016
Received in revised form 18 February 2016
Accepted 19 February 2016
Available online 26 February 2016

Keywords:
Ocean noise
Soundscape
Passive acoustic monitoring
Fish chorus

ABSTRACT

The Laje de Santos Marine State Park (LSMSP) and Xixová-Japuí State Park (XJSP) are two protected areas (PA), close to the Santos Bay in the south Brazilian coast. The region encompasses both important biodiversity and anthropogenic activities. This study aims to serve as a first reference survey of the underwater soundscape of these PAs. Additionally it evaluates the presence of the anthropogenic and biological sound in these areas. One month of continuous recorded underwater sound, at selected locations in XJSP and LSMSP, is used in this study. The data were characterized by its spectral content and by the temporal evolution of Sound Pressure Levels (SPL). Both locations showed sound events with daily periodicities, mainly related with boats and fish chorus.

1. Introduction

Underwater soundscape of a given habitat is composed by biological, abiotic and anthropogenic sound sources. The acoustic environment, that may be accessed by a Passive Acoustic Monitoring (PAM) approach, plays a fundamental role for marine ecosystems (Staaterman et al., 2013).

Additionally, long term PAM can provide relevant information on temporal and seasonal patterns of marine habitats, and can also be employed to monitor acoustic pollution and its impacts (Rountree et al., 2006; Merchant et al., 2015). Acoustic pollution can affect marine species, causing problems ranging from behavioral disturbances to loss of hearing, and even mortality (Tasker et al., 2010). Unfortunately, underwater noise has dramatically increased in recent decades. Studies estimate that ambient noise doubled in world oceans each ten years since 1950's (OSPAR, 2009). Ship traffic is recognized as the principal contributor to this acoustic noise rise, due to the increase in number, size and propulsion power of ships around world oceans (OSPAR, 2009; Thomas et al., 2009). In this context, coastal areas in which high-density anthropogenic sound sources coexist with sensitive marine fauna are a high priority.

1.1. Marine protected areas close to Santos Bay

The vicinity of Santos Bay, in the southern Brazilian coast, is recognized as an area of great biodiversity (Jorge et al., 2012; Araujo et al., 2013). At the same time, numerous sources of pollution can affect marine life in the bay region, particularly the activities related to its port. In consequence, the establishment of marine protected areas near the bay was crucial for ecosystem preservation. This area is:

Laje de Santos Marine State Park.

Established in 1993, the Laje de Santos Marine State Park (LSMSP), the only marine park of Sao Paulo state in Brazil (Jorge et al., 2012; Amado Filho et al., 2006), is located at coordinates 24°15′48″S, 46°12′00″W. The park holds valuable marine biodiversity with a big variety of fishes, algae and also marine mammals (Amado Filho et al., 2006; Luiz et al., 2008; Rocha-Campos et al., 2007). The park serves as a key habitat for fish shoals, providing food, protection and the possibility of safe reproduction (Gobbato, 2012).

1.1.1. Xixová-Japuí State Park

Xixová-Japuí State Park (XJSP), is located on the SW of Santos Estuarine System (São Paulo State, Brazil) at coordinates 24°0′22″S, 23°23′29″W. The XJSP encompasses a marine area inside the Santos bay and an adjacent inland region of tropical rain forest. Therefore, it is inside a region severely affected by environmental impacts, particularly unplanned urban settlement, industrialization and port activities (Araujo et al., 2013).

1.1.2. Previous studies and objectives

In spite of its importance, published material about environmental quality of Brazilian marine conservations units is really incipient. Particularly, there are no known studies about underwater soundscape of these sites. In addition, only three studies on underwater ambient noise in Brazilian coastal areas are known: one (Bittencourt et al., 2014) in the Guanabara Bay, in Rio de Janeiro, and two others, regarding the Santos Harbor area (Sanchez-Gendriz and Padovese, 2014;

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http://dx.doi.org/10.1016/j.marpolbul.2016.02.055

Sánchez-gendriz and Padovese, 2015). The cited studies aimed to reveal vessel noise contributions to total noise levels coming from the shipping activities.

The present paper provides the first description of the soundscape for the protected areas of LSMSP and XJSP. The work is based on approximately one month of continuous underwater acoustic records at these two different locations. Using Power Spectral Density (PSD), Spectrograms, percentiles and Sound Pressure Level (SPL) calculations, the data were analyzed and the spectral and temporal characterization of ambient noise were determined. Also, it is worth noting that this study brought valuable information for the management of the two mentioned conservation units. These results could be used to monitor the soniferous species that inhabit these areas, as well as to evaluate anthropogenic sounds and their impact on the ecosystem and also to detect and report illegal activities.

2. Methodology

2.1. Autonomous passive monitoring system and its deployment

Underwater acoustic data was recorded by means of an autonomous passive monitoring system (OceanPod 1.0), developed at LADIN (Laboratory of Dynamics and Instrumentation of the Polytechnic School of the University of Sao Paulo) (Fig. 1). Acoustic data was recorded simultaneously in both sites (LSMSP and XJSP) from February 2 to March 1, 2015. The recording, carried out at 11.025 kHz sampling rate (fs), 16 bit resolution, was continuously stored in a SD card, in wav files of 15 min durations. The sensitivity of the system was set to − 150 dB re 1 V μPa^{-1} and its frequency band set from 10 Hz to fs/2. Detailed explanation of this equipment can be found in Caldas-Morgan et al. (2015).

The selected measurement sites can be seen in Fig. 2. The OceanPod located in XJSP was installed at 9 m depth and the other, in LSMSP, at 28 m depth, both at the bottom of the sea.

2.2. Data processing

The Power Spectral Density (PSD) (Proakis and Manolakis, 2007) was estimated by the Welch method (Welch, 1967) with 0.25-s Hamming window, 50% of overlap, with 60-s temporal signal segments. Therefore, with these parameters, time resolution is 60 s and frequency resolution is 5.6 Hz. The processing resulted PSD matrices are named here as Pxx(n,m), been *n* and *m* time and frequency indexes respectively. The Pxx matrices were used as basic blocks for all subsequent calculations, which are explained below.

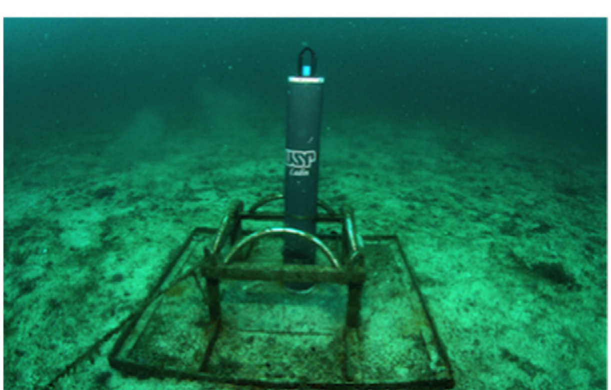

Fig. 1. OceanPod 1.0 used to record the underwater sound.

2.2.1. Sound pressure level

Sound Pressure Level (SPL) is the Mean Square Pressure (MSP) expressed in decibel (dB) relative to a reference pressure (p_{ref}) for sound in water (TNO, 2011):

$$SPL = 10 \ \log_{10} \frac{MSP}{p_{ref}^2} \left[dB \ \ re \ \ 1\mu Pa^2\right] \tag{1}$$

where MSP can be determined by Eq. (2):

$$MSP = \frac{1}{N} \sum p(j)^2 \tag{2}$$

being:

- N, the number of samples used to average the discrete vector $p(j)^2$ (Rountree et al., 2006);
- $p(j)$, the sound pressure at time index j
- $p_{ref} = 1$ μPa, the reference pressure for underwater acoustics.

Expression (2) works in time domain but, based on Parseval relation (Proakis and Manolakis, 2007), it is possible to make this computation in frequency domain. By using Pxx matrix representation, the MSP parameter, for each time window, can be calculated in frequency domain as in Eq. (3):

$$MSP(i) = \frac{1}{k} \sum_{n=ki+1}^{k(i+1)} \sum_{m=f_1}^{f_2} P_{xx}(n, m) \tag{3}$$

where $k = T/T_1$, in which T = N*fs is the integration time (Merchant et al., 2012a) and $T_1 = 60$ s is the time length of windows used in PSD calculations. This means that, *k* allows selecting the time resolution of MSP (*T*) based on time resolution of Pxx matrices (T_1). Here we select $T = 60$ s, as in (Robinson et al., 2014), but we can set $k = 5$ instead, to obtain an integration time of 300 s, like in Merchant et al. (2012a,b).

Additionally, expression (3) offers the possibility of calculating MSP and SPL in selected frequency bands. If f_1 and f_2 are set to 10 Hz and fs/2 respectively, the full frequency band (FFB) SPL will be computed. In the same way, by using adequate values of f_1 and f_2, the SPL 1/3 octave bands, or others, can be computed.

2.2.2. Percentiles

The nth percentile indicates the level below which n percentage of observations, in a group of observations, falls. In particular, the 50th percentile is also known as median. The percentile is used in this study, to summarize statistically the noise levels in frequency domain, by means of PSD percentiles (Merchant et al., 2015; Erbe, 2011) and, in time domain, through Box plot graphic.

2.2.3. Box plot representations of SPL

The statistical representation of box plot (Velleman and Hoaglin, 1981) was used to point up the variability of SPL in the recorded full frequency band for both measurement locations. For this representation the boxes show the median, and percentiles 25th (q_1) and 75th (q_3). The values not considered outliers are within the upper and lower limits L_1 and L_2, where $L_1 = q_3 + w(q_3 - q_1)$, $L_2 = q_1 - w(q_3 - q_1)$. The parameter w was set to 1.5. In this case, the values between L_1 and L_2 cover 99.3% of the data if it is normally distributed.

2.2.4. Spectrogram representation

A spectrogram can be obtained by a 2D plotting of Pxx matrices. This image-representation affords a first insight of the major frequency band contributions for each analyzed location.

By choosing convenient time and frequency intervals from Pxx(n,m), it is possible to plot a specific window of the time-frequency surface, i.e., a specific time period, or frequency band or both.