Ecological Informatics 38 (2017) 31–38

Contents lists available at ScienceDirect

Ecological Informatics

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

Temporal and spectral patterns of fish choruses in two protected areas in southern Atlantic

I. Sánchez-Gendriz *, L.R. Padovese

Mechanical Engineering Department, Polytechnic School-University of Sao Paulo, Sao Paulo 05508030, Brazil

A R T I C L E   I N F O

Article history:
Received 16 June 2016
Received in revised form 12 January 2017
Accepted 26 January 2017
Available online 27 January 2017

Keywords:
Underwater soundscape
Passive acoustic monitoring
Fish chorus
Marine protected areas

A B S T R A C T

The Laje de Santos Marine State Park (LSMSP) and Xixová-Japuí State Park (XJSP) are two protected areas (PAs) located in the southern Atlantic Brazilian coast. One month of continuous underwater sound recordings allowed determining that durable fish choruses was a major contributor of LSMSP and XJSP soundscapes. The choruses showed well defined daily periodicities and exceeded background ambient noise for some hours every day, principally at dawn and dusk. This work describes the daily temporal patterns and spectral characteristics of the studied PAs choruses. Annotations of some chorus temporal descriptors (start, peak and end time instants) allow obtaining a precise statistical representation of diel chorus occurrence. Average Power Spectral Density and cepstral analysis were used to determine quantitative values for choruses spectral characterization. Results show that the passive acoustic technique could be a cost-effective method for management and fish monitoring in PAs.

1. Introduction

The region in the vicinity of Santos Bay, in southern Atlantic, is recognized as an area where a rich biodiversity coexists with numerous sources of pollution that can affect marine life (Jorge et al., 2012; Araujo et al., 2013). In view of that, the establishment and management of marine protected areas (PAs) in the region is a true concern for ecosystem preservation.

The Laje de Santos Marine State Park (LSMSP), a marine PA in southern Brazilian coast (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 high variety of marine life (fishes, turtles, mantas rays among others). Additionally, marine mammal sightings (Luiz et al., 2008; Rocha-Campos et al., 2007) in the site are reported. The park serves as an area for reposition of fish shoals, providing food, protection and the possibility of safe reproduction (Amado Filho et al., 2006; Rountree, 2005).

Close to the LSMSP, there exists another ecologically important area, the Xixová-Japuí State Park (XJSP), located in the southwest of Santos Estuarine System (São Paulo State, Brazil) at coordinates 24°0′22″S, 46°23′29″W. The XJSP encompasses a marine area inside the Santos bay and an adjacent inland region of tropical rain forest. Being located in the vicinity of Santos Harbour, the biggest port in Brazil, all the conservation unit is inside a region severely affected by environmental impacts, particularly unplanned urban settlement, industrialization and port activities (Araujo et al., 2013).

For the dynamics and evolution of oceanic ecosystems, the acoustic environment can play an important role (Merchant et al., 2015). Patterns of the sounds that emanates from a particular place can be strongly linked to its specific characteristics and local fauna (Pijanowski et al., 2011). Especially, marine organisms have an important relation with its acoustical surroundings, since they depend on sound for communications, mating, hunting, avoiding predators and hazards and for navigation (McWilliam and Hawkins, 2013).

The collection of sounds that emanates from an environment is known as soundscape (Pijanowski et al., 2011), in scientific literature. Marine soundscape is based on the sounds related to geophony (physical events, such as wind, precipitation, breaking waves, earthquakes), biophony (mammals, fish, crustaceans), and anthrophony (man-made events) (Erbe et al., 2015).

A previous study (Sánchez-Gendriz and Padovese, 2016) described LSMSP and XJSP soundscapes for the first time. It was based on one month of continuous underwater sound recordings. The soundscape at both sites were dominated by durable acoustic events, likely related to unidentified fish shoal choruses. The choruses presented well defined daily periodicities, mainly at dusk and dawn. Five chorus types, named LS_1, XJ_1, XJ_2, XJ_3 and XJ_4, were highlighted by 24-h mean spectrogram (calculated by the arithmetic mean of daily 24-h spectrograms), as Fig. 1 illustrates. The averaged values of start and end time instants of the choruses were estimated based on visual inspection of 24-h mean spectrogram and 24-h mean Sound Pressure Level (SPL).

* Correspondence author.
E-mail address: ignaciogendriz@usp.br (I. Sánchez-Gendriz).

http://dx.doi.org/10.1016/j.ecoinf.2017.01.003

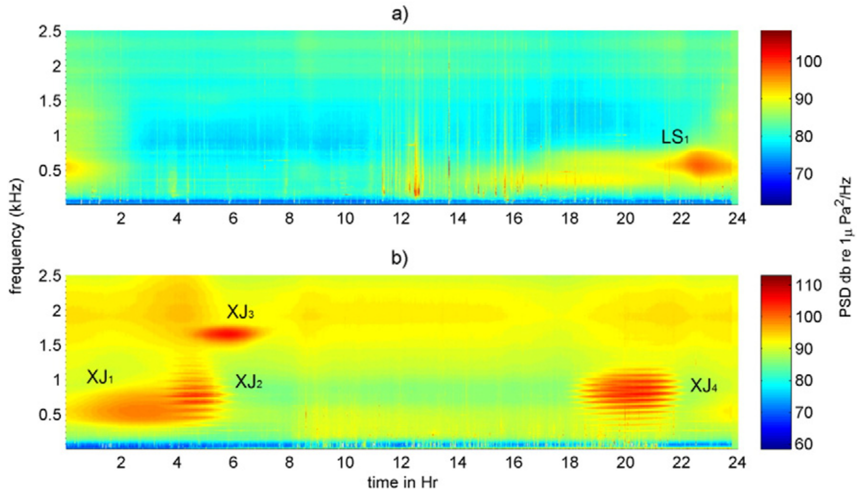

Fig. 1. 24-h mean spectrogram highlighting predominant acoustic events at studied PAs a) LSMSP and b) XJSP.

The survey (Sánchez-Gendriz and Padovese, 2016) provides an interesting, but general point of view of LSMSP and XJSP soundscapes. The present paper adds a deeper insight to the biotic component, by particularly focusing in the characterizations daily chorus types. Specifically, the current work aims to analyse daily values of temporal and spectral descriptors for each chorus type presented in data:

- Temporal descriptors: start, end and peak time instants, where peak time instant refer to moment at which a specific chorus reach its maximum SPL value.
- Spectral descriptors: dominant frequency, bandwidth and, for chorus types XJ_2 and XJ_4 the interval of constant frequency between spectral peaks was also computed.

The daily values of computed descriptors allow to obtain a statistical overview of temporal and spectral features of each chorus type.

2. Methodology

2.1. Autonomous passive monitoring system and its deployment

An autonomous passive monitoring system (OceanPod 1.0) (Fig. 2), developed at LADIN (Laboratory of Dynamics and Instrumentation of the Polytechnic School of the University of Sao Paulo) continuously recorded underwater sound at the measuring sites. Acoustic data, recorded in LSMSP from January 30 to March 1, 2015 and in XJSP from February 4 to March 4, 2015, were used in the study. 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. More details about this equipment can be found in (Caldas-Morgan et al., 2015). Ninety six (96) wav files of 15 min duration were recorded each day in accordance with the described acquisition settings, totalizing 24 h of recordings by day. Selected segments, within 1 h of chorus occurrence for each day, were used to obtain the spectral characterization for each fish chorus type presented in data, as it will be explained in Section 2.2.4.

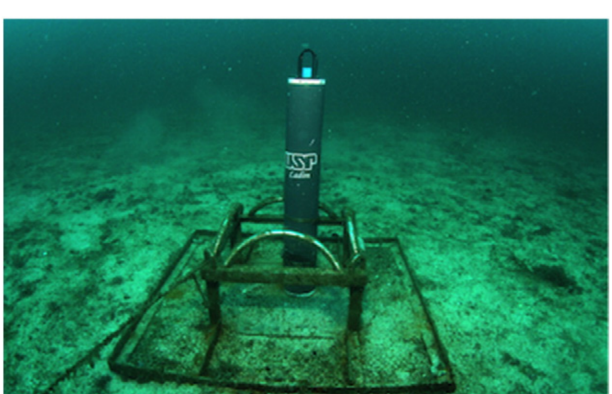

Fig. 2. OceanPod 1.0 used to record the underwater sound.

The selected measurement sites are pointed out in Fig. 3. 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) (Parsons et al., 2016b) was estimated by the Welch method (Sanchez-Gendriz and Padovese, 2014) 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. Parameters for calculating PSD were selected aiming to facilitate comparisons with others underwater monitoring studies (Merchant et al., 2014; Jordão et al., 2012; Coquereau et al., 2016; Parsons et al., 2016a; Parsons et al., 2016b) and to obtain an appropriated time-frequency spectrogram resolution for the present analysis.

The processing resulted PSD matrixes are named here as Pxx(n,m), been *n* and *m* time and frequency indexes respectively. The Pxx processing matrixes were used as basic blocks for the Sound Pressure Levels (SPL), spectrograms and statistical calculations presented in the Results section. Details for the implementations of these computational calculations are described in (Sanchez-Gendriz and Padovese, 2014).

2.2.1. SPL smoothing

For the 24-h SPL curves, a symmetrical moving average filter (Smith, 1999) was applied for minimizing transients events, which could be related to boat traffic, while preserving the overall trends associated with fish choruses (Locascio and Mann, 2008). A 61 points rectangular window was selected for the filter kernel. Since time resolution of SPL series is 60 s, the number of samples used to implement the filter represents a signal duration of 60 min, close to values used in other studies about fish choruses (Locascio and Mann, 2008; Locascio and Mann, 2005; Locascio and Mann, 2011).

Fig. 4 exemplifies the application of that kind of filter for the SPL curve of February 7, 2015 in XJSP. This figure confirms that the response of the filter removes the transients in the signal and, at the same time,