

How biological (fish) noise affects the performance of shallow water passive array system

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Abstract— Passive acoustic data off Grand Island, Goa were acquired using a single wideband hydrophone system deployed at the water depth of ~20.5 m during the month of April, 2014. The 4-element hydrophone array with an aperture of 1.5 m having design frequency equivalent to 1.5 kHz was also moored at 10 m below the water surface. The analyses carried out reveals fish chorus belonging to the family *Terapontidae*. Significant beam-pattern degradation was observed particularly in the presence of fish chorus using delay and sum beamforming. Spatially interpolated virtual hydrophone element enhancement provides improved beamforming even in the presence of fish choruses.

Keywords—fish noise; passive sonar; hydrophone array; beamforming;

I. INTRODUCTION

In shallow water, the ambient noise field is a function of noise source distribution as well as the environmental parameters (i.e., water depth, sound speed profile, and seafloor properties). In a waveguide bounded by sea surface and seabed, multipath propagation prevails and the spatial structure of the noise field is largely dependent on the seabed [1]. Also, it is possible to deduce the water column environmental properties from the noise field. Studies have been carried out in the past using passive acoustics techniques to understand the ambient noise patterns in the ocean. In this work, we present passive acoustic data acquired off Goa, Grande Island. The island is located few kilometers west from Mormugao peninsula in South Goa. The Grande Island conceals a lot of vestiges of wrecked ships of different epochs, and the faunal diversity with the presence of corals that is regarded as an important marine environment off Goa (www.thegoavilla.com). Therefore, the passive acoustic data acquisition using single wideband hydrophone as well as a vertical linear hydrophone array system from the Grande Island area off Goa is realized to be interesting research subject. This may help us to understand the shallow underwater environment. Employments of such instrumentation for short time reveals presence of fish chorus [2], and highlight their effect on the array beam patterns [3].

II. MATERIALS

A. Song Meter

The standard Song Meter (SM2M+) marine recorder has a sample rate of 44.1 kHz. A daughter card enabling the higher

sample rates provides recording and monitoring of anthropogenic and biological process generated acoustic signals (www.wildlifeacoustics.com). We have carried out passive acoustic data recording using a single wideband hydrophone (03 April-04 April 2014), and related analyses from Grande Island. The equipment was powered with 32 D cells each of 1.5V alkaline batteries. This marine recorder is a self buoyant submersible with 16-bit digital recorder designed for short or long term deployments for depths up to 150m. The SM2M+ also have the features such as flexible scheduling, extremely low power consumption, and pristine digital recording quality in audio format.

B. Passive Hydrophone Array

Array of hydrophones (www.cetaceanresearch.com) are wired together and connected to a data logger to record wide band sound signals. A self-contained battery operated autonomous multichannel data logger built around cortex-M3 arm micro-controller STM32F407 was used for simultaneous acquisition of acoustic (analog) signals from multiple hydrophones in a vertical array. The recorded signals are sampled, digitized and stored on solid state media. A pre-amplifier gain of 20 dB was used to enhance the electrical signal and reduce the possibility of noise contamination from additional environmental factors. We have designed 4-element hydrophone array having inter-element spacing of 0.5m with a design frequency equivalent to 1.5 kHz. The array having an aperture of 1.5 m was moored below 10m from the water surface where the maximum water depth was ~20.5m. The passive beamformed data (azimuth angle versus operating frequency) is being computed off line at frequencies between 0.5-5.0 kHz employing delay and sum method. The array pattern degradations are not unknown especially when limited array lengths are used. Therefore, spatial taper [3] or adaptive beamforming techniques are preferred [4]. However, due to extreme sensitivity of adaptive arrays towards the random errors, the concept of super-gain array has been employed in this study incorporating delay and sum beamforming methods [5]. In the present study, for improved beamforming, a spatially interpolated virtual element are introduced within the existing 4-element array to enhance element numbers (i.e., total seven elements) by reducing the inter-element spacing to 0.25m.

C. Ancillary Data (Current meter, Wind)

The recording current meter (RCM) deployed is based on the Sea Guard data logger (www.aanderaa.com) platform and the broadband Z-Pulse multi-frequency Doppler Current Sensor, combined with advanced digital signal processing that provides accurate and detailed measurements. In addition to the Doppler current sensor the RCM has smart sensors that include temperature, pressure, and conductivity. The data storage takes place on a secure digital card. The meteorological parameters were measured using an autonomous weather station (AWS), designed and developed at the National Institute of Oceanography (NIO) [6]. Based on operational requirements, the AWS was installed on the top of the watch keeping boat. The AWS provides digital data as 10-minutes average of 60 samples collected at 10 seconds interval. The recorded wind data is vector-averaged. The Gust (i.e., the largest wind speed amongst an ensemble of 60 samples that are measured during the 10-minute sampling span) is also recorded. A delay interval of 300 sec has been maintained between the acoustic signal transmission and reception by RCM and passive data acquisition window timing of SM2M+ and array system.

III. METHODS

The analyses of data acquired from Grande Island during the beginning April 2014 reveals fish chorus belonging to the family *Terapontidae* [7]-[8]. Analyses of the time series data acquired using SM2M+ and the corresponding spectrogram analyses further substantiate the presence of *Terapontidae* fish noise mostly during the dusk period. The spectrogram analyses display dominance of chorus sound during 14:00-02:00 hrs (Fig. 1a).

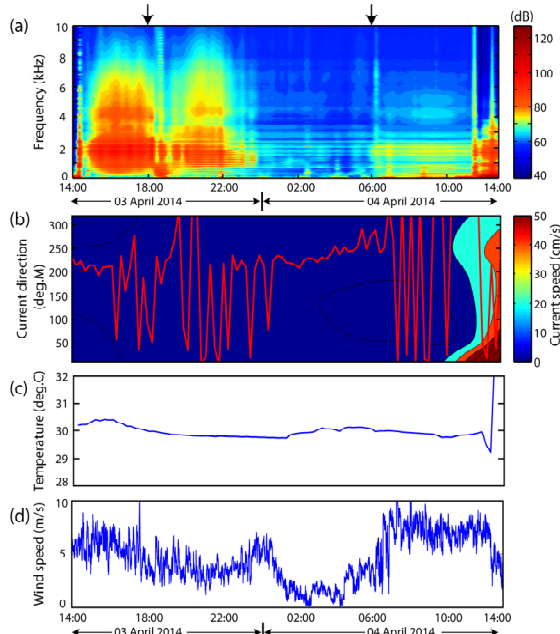


Fig. 1 (a) Spectrogram of the song meter time series, (b) RCM data [(current magnitude and direction) and (c) temperature], and (d) measured wind data.

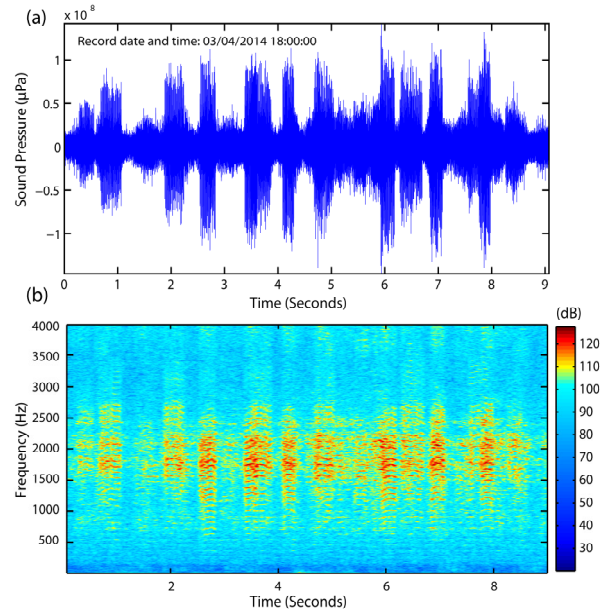


Fig. 2 (a) Waveform and (b) corresponding spectrogram of the *Terapontidae* fish chorus.

Interestingly, such noises were absent during 02:00-13:00 hr including dawn time. We have also recorded concurrent current velocity and temperature data using moored RCM (Fig. 1b and c). The acquired wind data is also presented in Fig. 1d.

The vertical linear 4-element hydrophone array was simultaneously deployed with the SM2M+ for a sampling time of 120 sec to acquire passive acoustic data at every 15 minutes of recording interval. The spectrogram corresponding to the individual records of the hydrophone elements during the presence and absence of fish noise is being analyzed to validate the results obtained using SM2M+ system. The passive beam-formed data (azimuth angle versus operating frequency) is being computed off line within the frequency range of 0.5-5 kHz.

IV. RESULTS AND DISCUSSION

A. Song Meter Data

The spectrogram i.e., short time Fourier transform (STFT) of the recorded time series passive acoustic data acquired using the song meter is presented in Fig. 1 (a) in terms of frequency (Hz) versus time (hr). Higher signal strengths are observed during 14:00-00:00 hr including dusk period as compared to dawn period (00:00- 13:00 hr). The currents, temperature, and wind speed does not exhibit any apparent variations with respect to the recorded passive signal strengths (Fig. 1 b-d) indicating fairly limited possibility of signal variation due to the physical conditions. We have analyzed the song meter data for high and low signal strengths during 18:00 hr (dusk) and 06:00 hr (dawn) respectively (indicated in the figure), in order to determine whether the variations in the data can be attributed to biological activities. The data were

analyzed by the time/ frequency spectrograms and converted into audio files (.wav) to confirm the presence of fish chorus.

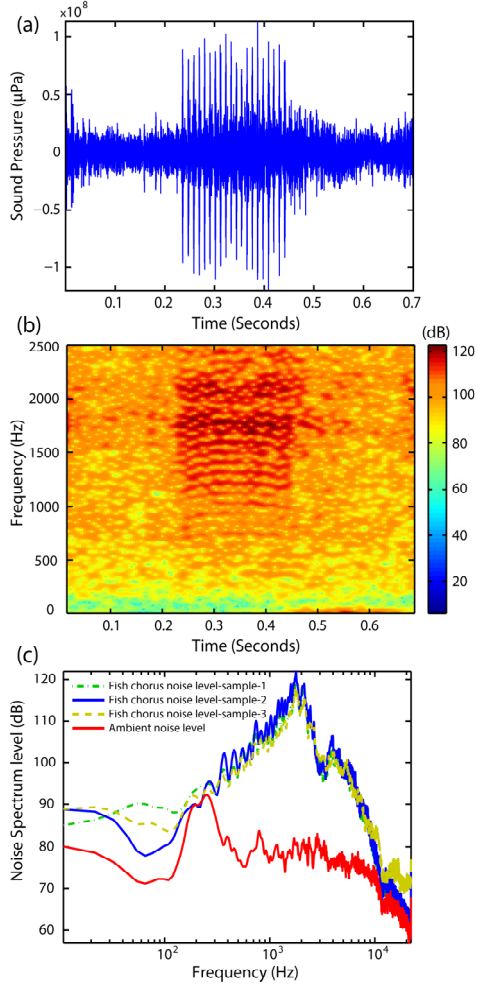


Fig. 3 (a) Waveform, (b) Spectrogram and (c) Power Spectral Density

The analysis of chorus and the associated call types indicate similar characteristics as compared to the corresponding waveforms available in the published literature. The fish chorus consists overlap of two or more individual callers, with a significant increase in the amplitudes over the background levels ($>3\text{dB}$ re $1 \mu\text{Pa}$) for long periods. The chorus observed in present context can possibly ascribe to *Terapontidae* species due to the similarity in their ‘trumpet’ like sounding [8].

The spectrogram of the data samples for duration of 09 sec during 18:00 hr is presented in Fig 2 (b). The energies within the frequency range 700-2700 Hz are observed to be dominant in the spectrogram. The time interval between 14 peaks is found to be varying within 0.40 sec (average) (Fig. 2b). The oscillogram and the corresponding spectrogram of the fish chorus indicate that the duration of a single call (average) is nearly 362 ms, comprising a series of pulses. Figure 3 shows the waveform, spectrogram, and power spectral density of a single call. The pulse repetition rate appeared in the frequency spectra at ~ 2.77 Hz and can be related to swim bladder

mechanism. The swim bladder resonant spectral peak is extended over 1.8 kHz. The spectral levels of chorus are high as shown in Fig 3. The energy levels of *Terapontidae* fish chorus observed in the shallow waters off Cochin was reported to be ~ 40 dB above ambient noise levels [7]. The energy levels of chorus generally dominate the ocean ambient noise spectra. Accordingly, in the present study the comparison of energy spectra corresponding to the chorus are also observed to be ~ 40 dB higher as compared to the spectra of ambient noise (Fig. 3c). Moreover *Terapontidae* chorus with many spectral peaks due to muscle pulse repetition rate and a broad frequency peak as a result of swim bladder resonance are observed [8]. The higher energy levels of chorus observed during the study period can be preliminarily attributed to the trumpet sound producing mechanism. The chorus was generally recorded as peaks in the oscillogram during the dusk period (14- 22 hr) and no significant biological signals were evident in the remaining data stream including the dawn period.

B. Hydrophone Array Data

Beam-forming technique has been implemented to determine directionality of the recorded signal using passive hydrophone elements array. Using beam-forming technique it is possible to direct the array elements to receive maximum signal energy from a specific angular direction. In the present study, we have used the conventional time delay beam-former to receive the signals at the array elements from different angular direction (-90 to $+90$). The algorithm was developed utilizing Matlab computation platform. The signals are first converted from ADC bits to corresponding voltage values with the time vector. The signals are then passed through a filter having bandwidth of 50Hz, within the frequencies ranging from 0.5 kHz to 5.0 kHz at an interval of 10Hz. Subsequently, the signals from the array elements are beam-formed using conventional delay and sum beam-former with an angular interval of 1° (Fig. 4).

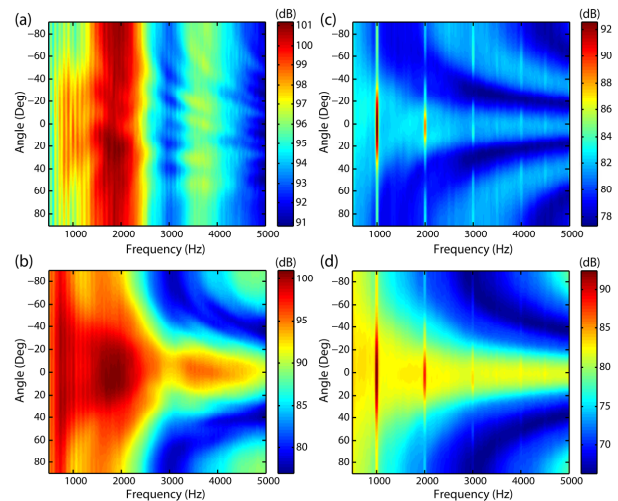


Fig. 4 Passive beam-pattern of (a) 4 –element and (b) extrapolated array-element in the presence of biological noise signal. (c) 4 –element and (d) extrapolated array- elements in the absence of biological noise signal.

We have computed four element array beam patterns in the presence of biological noise during 18:00 hr (dusk period) (arrow mark in Fig. 1 a), and analogous pattern in the absence of biological noise during 06:00 hr (dawn period). Omnidirectional beams are formed at all receiving frequencies (Fig. 4a) having strong signal gain up to 2500 Hz, followed by the reduction of signal levels. In the absence of biological noise during the dawn period, the 4-element array patterns are found to be applicable only within the limited beam direction $> \pm 40^\circ$ and frequency ranges > 3000 Hz (Fig. 4c). Comparatively, the signal levels are low in absence of biological noise. Presence of grating lobes are evident at higher frequency region indicating the lack of signal power towards the broadside directions, with equal distribution towards the other angular regions also. However, the tonal signals are present at 1000 Hz frequencies and the energies at its integer multiples are observed (Fig. 4c).

The spatially interpolated virtual elements transform the existing 4-element array to 7 elements and reduce the inter-element spacing to 0.25m. In the presence of fish noise, the array performance and the resulting beam patterns are improved particularly beyond the frequencies of 2000 Hz (Fig. 4b). In the absence of fish noise, the spatially interpolated array performance is observed to be significantly improved (Fig. 4d) within the frequency ranges. However, the occurrence of tone signals is still present.

V. CONCLUSIONS

In this work, we have recorded *Terapontidae* fish choruses during the dusk period in the month of April from Grande Island, Goa. A strong trumpet sound production pattern was revealed by the analyses carried out using the passive acoustic data acquired during the study period. The comparison of energy spectra corresponding to the chorus is observed to be ~ 40 dB higher as compared to the spectra of ambient noise. *Terapontidae* chorus with many spectral peaks due to muscle pulse repetition rate and a broad frequency peak as a result of swim bladder resonance are observed [8]. The peak of the spectrum is found to be highest at 1.8 kHz frequency. We have

also demonstrated how the presence of fish chorus degrades the performance of a short hydrophone array analyzed employing conventional (delay and sum) methods. Therefore, we have incorporated spatially interpolated virtual hydrophone elements to enhance the array beam-patterns, even in the presence of fish chorus.

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