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Passive acoustic metrics to understand shallow water biodiversity off Malvan area in the west coast of India

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Underwater soundscape monitoring is an effective method to understand the biodiversity of an ecosystem. In this context, quantitative characterization of shallow water soundscape of the Burnt Island located off Malvan area in the west coast of India (WCI) is carried out. The soundscape characterization involves analysis of the “waveform”, “spectrogram”, and the “power spectral density” (PSD) of the recorded passive acoustic data. Biophonies such as the fish chorus of *Terapon theraps*, sparse calls of Carangidae along with another unnamed fish species community is reported. Evaluation of the PSDs and corresponding peak frequencies to distinguish the wave-breaking sound and fish species are also covered. Three acoustic metrics namely acoustic entropy (H), acoustic richness (AR), and acoustic complexity index (ACI) of passive acoustic recordings are computed and analyzed to understand their role in relation to fish chorus, wave-breaking, and sparsely available fish sound.

[Keywords: Passive acoustics, Acoustic metrics, Shallow water, Biodiversity, West coast of India]

Introduction

The use of the passive acoustic techniques to understand ambient sound patterns in the ocean is well known[1]. The sound field parameters of the shallow water environment can be derived from the measurements of ambient sound[2]. It is important to investigate the variations in the ambient sound characteristics, that may comprise biophonies (fish chorus), geophonies (wave-breaking sound, tidal current), and anthroponies (boat sound etc.). In the underwater environment, the animal species use sound signal communication[3]. Nowadays, for passive acoustic data recordings, autonomous systems possessing broadband hydrophones are used for underwater sound recordings[4]. These aquatic animals use sound as their primary modality, whereas terrestrial animals use vision. The term "soundscape" is commonly used to characterize the acoustic environment[5]. Many fish species rely on vocal signaling during their activities, and produce sounds using sonic muscles that vibrate the swim bladder or rubbing of bony elements (stridulation)[6]. These complex sound patterns can be investigated by spectral analysis[7]. Using power spectral density (PSD) analysis, the spectral frequency peak is employed to identify fish species. The waveform, spectrogram, and related spectral frequency peak are investigated for identification of species in a complex habitat environment.

The biodiversity assessment is a key step for habitat monitoring in a shallow reef areas[8]. In the soundscape ecology, the automatic processing technique and resulting metrics[9] provide promising results particularly for understanding complex acoustic signatures. Acoustic complexity index (ACI)[10] is generally used to identify the temporal and spatial complexity of a soundscape. Similarly, acoustic entropy (H) based on the Shannon evenness index, is also applied for investigating temporal and spectral heterogeneity of the signal[11]. The acoustic richness index (AR) is modeled after H, but weights the signal by its median amplitude to account for background noise[12]. The ACI, H, and AR metrics are considered as a suitable proxy for biodiversity estimation and provides a fair estimation of an acoustical characteristic with minimal post-processing of the recorded field[13] data if it can be appropriately ground-truthed. Identified species using waveform, spectrogram, and spectral peak of the animal vocalizations are applied here to ground-truth the acoustic diversity indices calculated in this work.

The study location is situated in the shallow and littoral environments of Malvan area in Sindhudurg district of Maharastra state on the west coast of India (WCI)[14]. In addition to the use of conventional spectral analyses for identification of biotic and abiotic signals, an employment of the soundscape complexity analysis is initiated to look for the acoustic signatures of entire recordings using the derived metrics ACI, H, and AR.

Materials and methods

Study area

Malvan is considered as one of the bio-rich coastal zones in Maharashtra, India[14]. The present study location is situated at 15º55.33" N latitude 73º26.50" E longitudes off the western side of the Burnt island (lighthouse) and 2.5 km away from the Malvan coast (Fig. 1). It is considered as an open ecosystem and has many submerged, exposed rocks that provide a perfect place for bio-organisms to reside in. Many crevices and cracks in the rocks serve as an ideal for sheltering, feeding and breeding grounds for many invertebrates and also as an ideal substratum for harboring marine algae. It holds demersal fishery and gives a healthy proportion of the demersal fish production.

Instrument used

The Song Meter (SM2M+) system (www.wildlifeacoustics.com) is a self-buoyant submersible with 16-bit digital recorder designed for short or long term deployments depth up to 150 m. The instrument possesses standard acoustic type hydrophone (flat frequency response of 2- 48000 Hz) having a sensitivity of (-164.3 dB re 1V/µPa)[4]. The instrument was calibrated using ESSO- National Institute of Ocean Technology (NIOT) acoustic test facility (https://www.niot.res.in/index.php/node/index/185/). The data was acquired at 44100 Hz sampling frequency. The water depth at the deployment site was 22.5 m and a mooring system was used to position the instrument at 10 m water depth. The recorded signals were digitized and stored in an internal storage media. Upon retrieval, the raw data was converted from voltage to relative sound pressure level (µPa) using hydrophone sensitivity. The instrument was used to acquire passive acoustic data from 14:00 hr of 18 May 2016 to 14:00 hr on 20 May 2016.

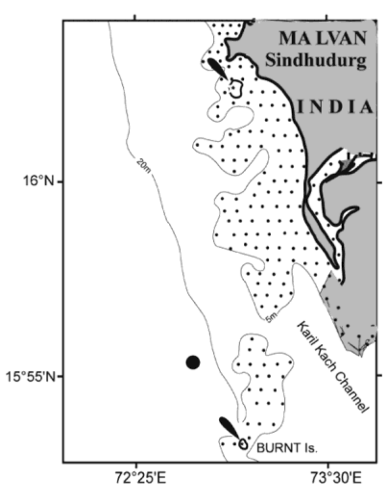

Fig. 1 — Study location off the Malvan coast (west of Burnt island) in the west coast of India

Spectral analysis

We present soundscape plot of the PSDs in time and frequency axes (Fig. 2a) of broadband data for the study location. The figure depicts the concatenated power spectral density (PSD) plots for 60 sec passive acoustic data records acquired at 15-minute intervals. The PSD of signals were computed with 50 % overlapping Hanning window of length 2048 samples (using the "pwelch" function available in Matlab).

The spectrograms of individual call signal were computed using "pwelch" function having Hanning window of length 256 samples with 50 % overlap. And, for PSDs (frequency peak estimation) of individual call signal, "pwelch" function having Hanning window of length 1024 samples with 50 % overlap is used.

SPL_{rms} data

The root-mean-square sound pressure level (SPL_{rms}) was calculated for 1 minute-long file recorded every 15 minutes. The expression for SPL_{rms} in (dB re 1 µ Pa) is given below[15]:

$$SPL_{rms} = 20\log_{10}\left(\sqrt{\frac{1}{T}\int_t P(t)^2 dt}\right) \qquad ...(1)$$

Where P(t) is a root-mean-square (RMS) pressure level. Based on the published frequency ranges[16], the majority of fish calls and snapping shrimp sounds belong within the 100 to 20,000 Hz frequency ranges. Therefore, partitioning of the acoustic spectrum into two frequency bands and focus on the dominant sound sources within each band is made. The low-frequency band (100 Hz to 2000 Hz) corresponds to the range in which most fish species vocalize. This band may also include noise generated by the wind (can be higher) and waves. The high-frequency band (2000 to 20,000 Hz) encompassed the range (typically dominated) by snapping shrimp. Boat noise covers a large frequency band and may interfere with both the bands. The root-mean-square (RMS) of the sound pressure level (SPL_{rms}) at low-frequency (100 Hz to 2000 Hz) fish band, the high-frequency (2000 to 20,000 Hz) shrimp band, and broadband (without filtering) are calculated. Below 100Hz, most contaminating flow noise has been reported[17]. Therefore, the application of the band pass filter within the range of 100 and 2000 Hz was used to isolate flow noise. The band-pass filtering involves the use of four-pole Butterworth filters in two frequency bands. However, the effect of flow noise may depict in RMS broadband sound pressure level. The computed SPL_{rms} for low-frequency, high-frequency and broadband is presented (Fig. 2b).

Acoustic metrics

Acoustic metrics were computed for both low and high-frequency bands, including broadband sounds to understand the effect of fish, shrimp and broadband sounds (i.e., fish, shrimp, wind, and flow) respectively.

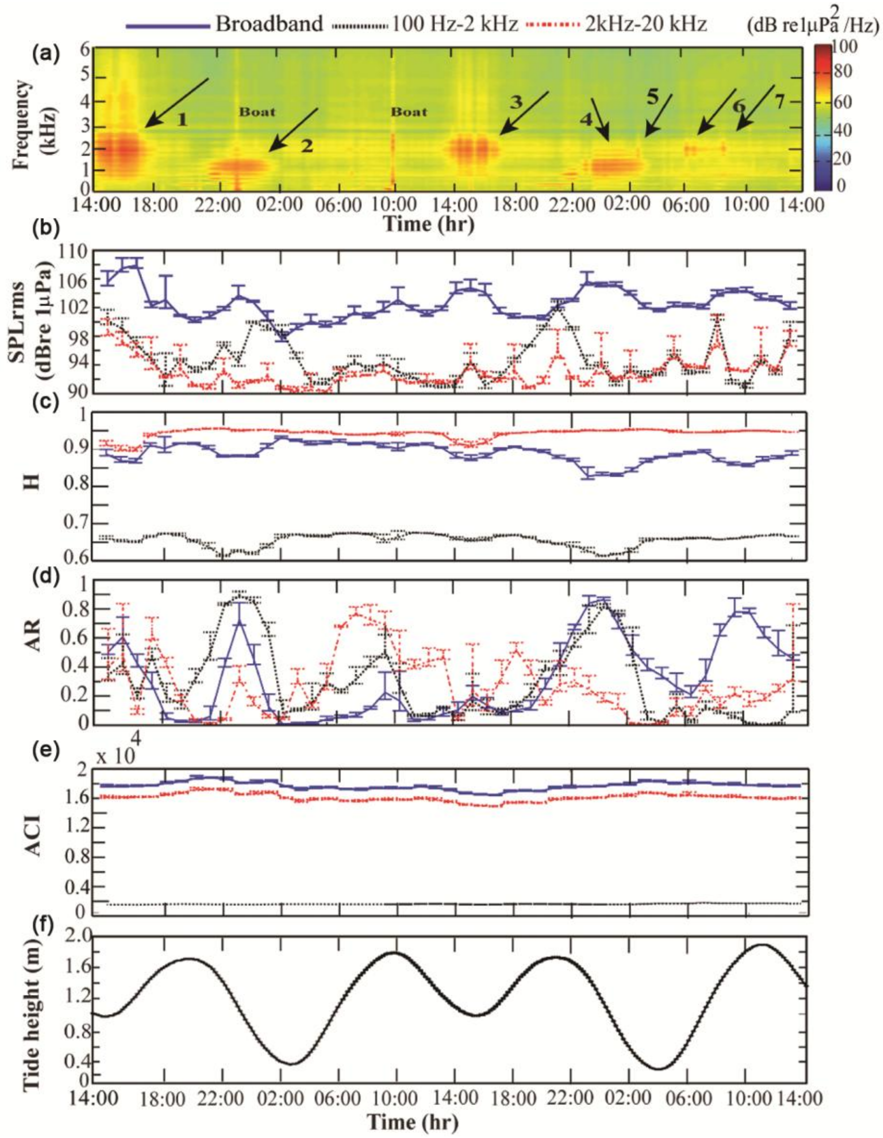

Fig. 2 — (a) Concatenated PSD (dB re 1µPa^2/ Hz), of the recorded passive acoustic data with derived metrics, (b) SPL_{rms} (dB re 1µPa), (c) Acoustic entropy (H), (d) Acoustic richness (AR), (e) Acoustic complexity index (ACI), for broadband, fish and shrimp bands, & (f) presents tide level (m) in the study location

Acoustic Entropy Index (H)

In biodiversity, the Shannon evenness index[9] is generally used for the assessment of animal sounds in an environment. The acoustic entropy index (H) is composed of two sub-metrics H_t (temporal entropy index) and H_f (spectral entropy index) entropies, which are calculated by using the Shannon theory. Temporal entropy (H_t) is computed by the application of the Hilbert transform of the signal and it is integrally scaled.

$$H_t = -\sum_{t=1}^{n} A(t) \times \frac{\log_2(A(t))}{\log_2(n)} \quad \text{...(2)}$$

Where $A(t)$ - probability mass function of amplitude envelope and n - the length of the signal. Likewise, spectral entropy (H_f) is obtained from the integral of the mean spectrum of the signal.

$$H_f = -\sum_{f=1}^{N} s(f) \times \frac{\log_2(S(f))}{\log_2(N)} \quad \text{...(3)}$$

Where, $s(f)$ - probability mass function of the mean spectrogram and N - non-overlapping Hanning window of 1024. Total entropy is calculated by the product of both temporal and spectral entropy $(H = H_t \times H_f)$ with H lies in between 0 and 1.

Acoustic Richness Index (AR)

This index is the combination of the indices described for H index and median of the amplitude envelope M (= median A (t) x $2^{(1\text{- depth})}$) with $0 \leq M \leq 1$ and depth is the digitization depth i.e., 16 bits. The index is calculated using the following formula[9]

$$AR = \frac{(rank(H_t) \times rank(M))}{n^2} \quad \text{...(4)}$$

Acoustic Complexity Index (ACI)

ACI metric was calculated utilizing a Fast Fourier Transform (FFT) size of 1024 with 44100 Hz sampling frequency having frequency bins (43 Hz each) using the formula[10]:

$$ACI = \frac{\sum_{k=1}^{n} |I_k - I_{k+1}|}{\sum_{k=1}^{n} I_k} \quad \text{...(5)}$$

Where $|I_k - I_{k+1}|$ is the absolute difference between two adjacent values of amplitude along a frequency bin, n represents the total number of temporal steps (k), and the calculation is made at an interval of 1 second. Here, employment of soundscape ecology package Seawave developed for the computing environment R version 3.2.2 for eco-acoustics indices computations are made (details are given in ref. 9).

Results and discussion

Soundscape data

The plot of the PSD in time and frequency axes of broadband data is presented for study area (Fig. 2a). The data were analyzed for the entire recordings. In this location, similar fish chorus are found within (18 May 2016; 14:00 to 17:30 hr) and (19 May 2017; 14:00 to 17:30 hr) (Fig. 2a) of the broadband sound (indicated as 1 and 3 in figure) having SPL_{rms} values (105.79±2.72 dB re 1µPa) and (103.65± 1.93 dB re 1µPa) (Fig. 2b) respectively. Thereafter, abiotic sound of similar type were found which is indicated as 2 and 4 (Fig. 2a) for 18 and 19 May 2016 (21:30 to 01:45 hr) and 20 May 2016 (00:00 to 02:30 hr) having SPL_{rms} values (100.56±0.66 dB re 1µPa) and (105.15 ± 1.17 dB re 1µPa) respectively (Fig. 2b). On 20 May 2016, sparsely available unnamed fish species sounds (indicated as 6 and 7) (Fig. 2a) are recorded from 02:45 to 08:00 hr having SPL_{rms} values (102.35± 1.03 dB re 1µPa) (Fig. 2b). Besides SPL_{rms} values of the broadband recorded data, SPL_{rms} values were also computed for the fish and shrimp bands. Like broadband data, the variations in SPL_{rms} data of the biotic (fish chorus, sparsely available fishes) i.e., areas are shown as 1, 3, 6, 7 and abiotic sounds (areas 2 and 4) are found to have insignificant variations even for the fish and shrimp band data. This indicates that the Malvan area possesses higher background sound that it does not make a significant difference in SPL_{rms} values even in the presence of fish chorus and wave-breaking sound for three selected bands.

Identification of fish sounds

Prominent biotic sounds due to the acoustic activity are indicated as 1, 3, 5, 6 and 7 (Fig. 2a), for detailed identification of fish sounds.

Terapon theraps fish sound

The chorus observed in the present study can possibly ascribe to Terapontidae family due to the similarity in their ‘trumpet’ like sounding[18-19]. Spectrogram for *Terapon theraps* species representative call data acquired on 18 May 2016 (14:00 to 17:30 hr) and on 19 May 2016 (14:00 to 17:30 hr) is indicated as 1 and 3 (Fig. 2a). The spectral frequency peak for representative single call at 1758 ± 29 Hz had a PSD level variation from 78 -

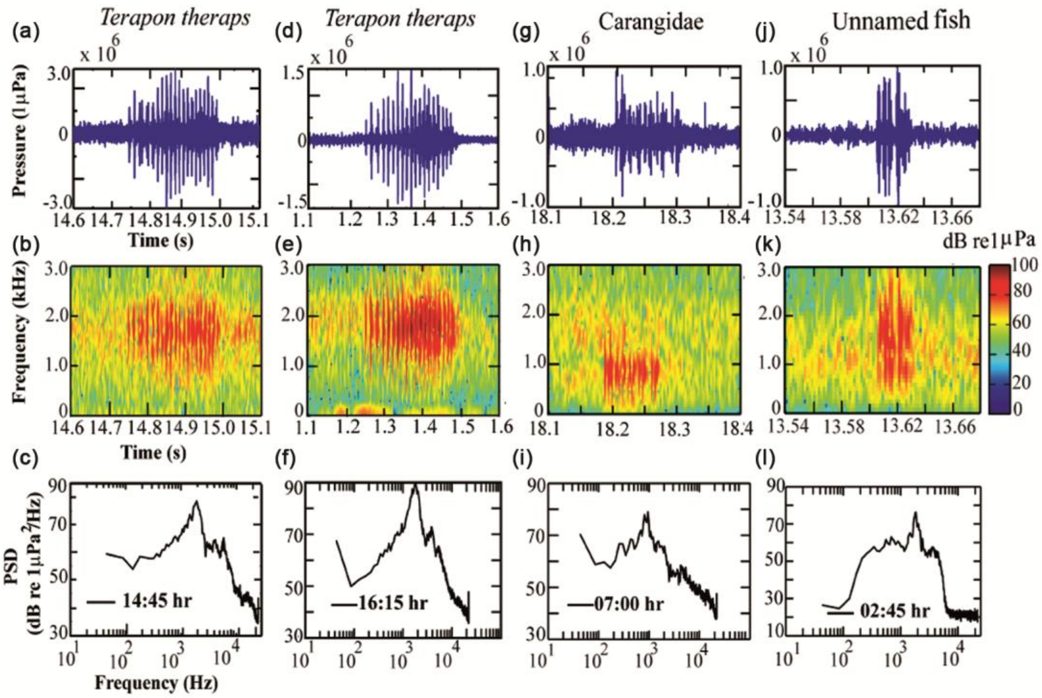

Fig. 3 — Waveform, spectrogram and PSD of representative fish species calls: (a-c) *Terapon theraps* on 18 May 2016 @ 14:45 hr, (d-f) *Terapon theraps* on 19 May 2016@ 16:15 hr, (g-i) Carangidae on 20 May 2016@ 07:00 hr, & (j-l) Unnamed fish on 20 May 2016@ 02:45 hr

90 dB re 1µPa^2/Hz (Figs. 3a-c) for 18 May 2016 data. Similarly, the waveform, spectrogram and peak PSD of representative call recorded on 19 May 2016 datasets (at 16: 15 hr) are also shown (Figs. 3d-f). A comparison between the peak PSD levels excluding the chorus i.e., in the absence of *Terapon theraps* fish sound was carried out. The peak PSD level was observed to be ~40 dB re 1µPa2/Hz lower as compared to the chorus. The spectrogram of the data samples for the duration of 08 sec during 16:30 hr and 14:45 hr (Figs. 4a & b) are presented for 19 and 20 May 2016 respectively. The energies within the frequency range 700-2500 Hz were observed to be dominant in the spectrogram. The time interval between (15-21) pulses per call was found to be varying within (0.25 ± 0.04) sec (Table 1). The peak level of the PSDs of the single call from the chorus was high as shown (Figs. 3c & f). Table 1, further provides temporal characteristics of the *Terapon theraps* fish calls[20].

Carangidae fish sound

Analyses of a limited number of waveforms, spectrogram, and PSDs from the time series data of 20 May 2016 during 07:00 hr, which produce biophonies like barks and scratchy burst [marked as '7' (Fig. 2a)] were performed. The spectral analyses results for a single call are shown (Figs. 3g-i). The peak frequency of PSDs (940 Hz) indicates the sound produced by fish belonging to the family of Carangidae[7]. Further details of the call signal are tabulated in Table 1. The limited recordings of Carangidae data show the sound duration of (0.09 ± 0.01) sec having (6-9) pulses per call. The family Carangidae is a pelagic fish[21] community with diverse

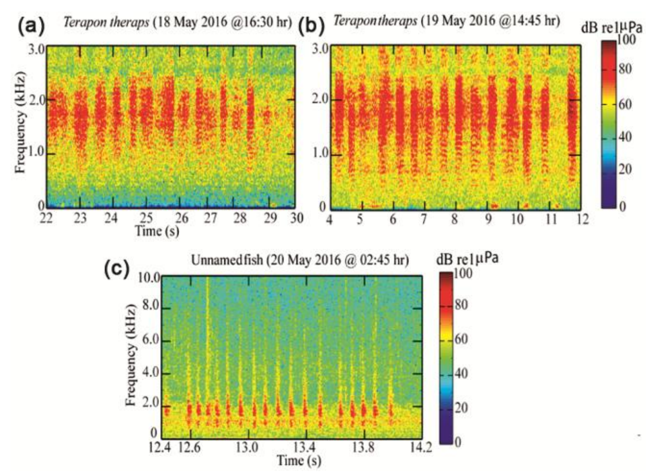

Fig. 4 — Spectrogram of the representative fish calls: (a) *Terapon theraps* on 18 May 2016, (b) *Terapon theraps* on 19 May 2016 & (c) Unnamed fish on 20 May 2016.

Table 1 — Temporal and frequency peak details of recorded fish sound data off Malvan, Maharashtra

No	*Type of Fish*	*Timings (hr)*	*No. of total calls*	*Sound duration (s)*	*No. of pulses/call Min- max*	*Peak frequency (Hz)*
1	*Terapon theraps*	18 May 2016 (14:00-17:30 hr) to 19 May 2016 (1400-1730 hr)	644	0.25±0.04	15-21	1758±29
2	Wave breaking	19 May 2016 (21:30-01:45 hr) to 20 May 2016 (00:00 - 02:30 hr)	----	-----	------	1142±23
3	Unnamed	20 May 2016 (02:45-08:00 hr)	74	0.05±0.007	04-08	1723±20
4	Carangidae	20 May 2016 (07:00 hr)	3	0.09±0.01	06-09	904±43

names like jacks, amberjacks, pompanos, scads, pilotfish, etc. The presence of Carangidae in the WCI is being reported (www.fishbase.org).

Unnamed fish sound

The PSDs of the time series data during 20 May 2016 within 02:45 hr to 08:00 hr) is shown in Figure 2(a) (indicated as 5 and 6). The fish sounds observed in the present context does not reveal any particular species. The spectrogram of the multiple calls is shown in (Fig. 4c). The single calls duration (0.05±0.01) sec and number of pulses per call (4-8) for unidentified fishes are tabulated in Table 1. The peak frequency of the PSD of a single call (Figs. 3j-l) shows a peak at 1766 Hz.

Wave-breaking sound

The wave-breaking sound is indicated as 2 and 4 in the spectrogram from 21:30 to 01:45 hr during 18/19 May 2016 and from 00:00 to 02:30 hr during the 20 May 2016 (Fig. 2a). The signal amplitude is also seen to be moderate during this period (Fig. 5). Interestingly, these variations are noticed during the predicted ebb tide[22] period (Fig. 2f). An increased wind speed increases the ambient noise due to the generated bubbles[23], and same can be measured (SPL_{rms} using the hydrophone). But the lack of wind data during the ambient noise data recordings restricted us to predict the actual contribution of the wind speed on wave-breaking phenomena. Our present analyses show the daytime recorded low signal intensity during the ebb tide period (10:15-14:15 hr on 19 May 2016 and 10:15-13:45 hr on 20 May 2016) (Fig. 2f).

The spectrogram, and PSDs of the time series data recorded during 19 May 2016 (01:30 hr) (Fig. 5a) and 20 May 2016 (01:00 hr) (Fig. 5b) are presented to verify the wave-breaking phenomena. The peak frequency is observed at 1163 Hz with a PSD level of 70 dB for 19 May 2016 data set (Fig. 5c). Similarly,

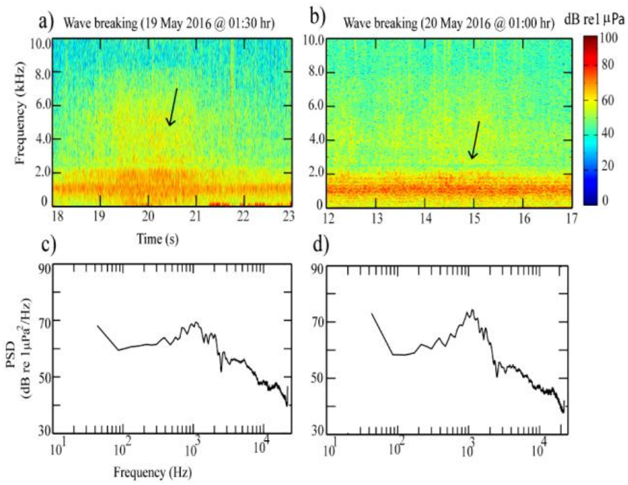

Fig. 5 — Spectrogram and PSDs of the recorded wave-breaking sound: (a) on 19 May 2016, (b) on 20 May 2016

the PSD of 20 May 2016 (01:00 hr) data shows the frequency peaks at 1163 Hz with a PSD level of 75 dB (Fig. 5d) indicating wave-breaking sound[24]. The frequency peak of wave-breaking sound observed in this study is well matched with the results shown in Deane *et al.*[25]. The time window of selected time series for the analysis is 3.0 to 3.5 sec. However, the levels of the PSDs of the wave-breaking sounds are low because of the higher distance between the source and the hydrophone.

General discussion on derived acoustic metrics *SPLrms*

In addition to the identification of fish sounds, the SPL_{rms} values were examined to assess general trends in the acoustic characteristics of the study site. Time series plots of the broadband, fish and shrimp bands are shown in Figure 2(b). The variations in SPL_{rms} values are higher during the fish chorus and abiotic sound period, notably for the broadband sound. Intermittent SPL_{rms} peaks due to boat generated sounds are observed. Sharp peaks of the SPL_{rms} are observed for the sparse fish calls that are indicated as 5, 6, 7 in Figure 2(a). Boxplots of the derived SPL_{rms} values for broadband, fish band, and shrimp band signals are presented in Figure 6(a). The mean SPL_{rms} value of the broadband signals is observed to be higher (102.42 dB re 1µPa) compared with the fish (94.62 dB re 1µPa) and shrimp (92.98 dB re 1µPa) bands. The distribution of fish band data shows more positive skewness followed by shrimp band data. Interestingly, the broadband data does not show such a skewed distribution indicating normal mode distribution of the data. The H-spread values of derived SPLrms are found to be 2.78, 5.00 and 2.21 for the broadband, fish and shrimp bands respectively.

Acoustic Entropy Index (H)

The H metrics derived from the soundscape are considered as a suitable proxy for estimating the biodiversity a reef system[8]. The H index is calculated based on the envelope and spectrum complexity of the recorded sound that varies between 0 and 1. The low values indicate pure tones and higher values signify numerous and even frequency bands present in the

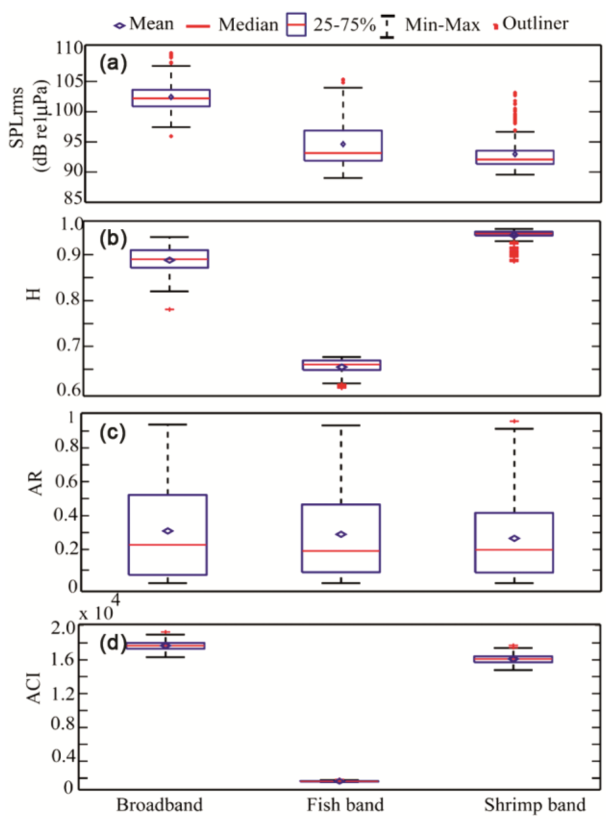

Fig. 6 — Boxplots of the derived metrics for broadband, fish bands and shrimp bands: (a) SPL_{rms}, (b) Acoustic entropy (H), (c) Acoustic richness (AR) & (d) Acoustic complexity index (ACI).

data. This metric is suitable for characterizing tropical region wherein the animal sound (biophony) dominates the background sound (geophony and anthrophony). Time series of H metrics calculated for broadband, fish and shrimp band sounds are presented in Figure 2(c). High H values were observed for shrimp band sounds followed by the broadband sound. The magnitude of H values calculated for fish band sounds was significantly low in comparison with the other two bands. Higher SPL_{rms} values due to the wave-breaking sound for the broadband and fish band was observed whereas there was a fall of H values during the dusk chorus. [when 1-4 is indicated (Fig. 2c)] and (Fig. 2b).

In the study higher H values (Fig. 6b) was observed for the shrimp band sounds (0.9423) in comparison with the broadband (0.885) and fish band (0.665) signals. The distributions of the fish band data showed a negative skewness. Interestingly, the broadband and shrimp band data did not show such a skewed distribution indicating normal mode distribution data. The H-spread of values of this distribution was found to be negligible (0.039, 0.021 and 0.010 for the broadband, fish and shrimp bands respectively).

Acoustic Richness Index (AR)

The H metric has limitations for characterizing passive acoustic recordings in the temperate habitats wherein the background sound typically dominates the animal sound[8]. The AR metric, on the other hand, combines temporal entropy and amplitude instead of the spectral entropy as used by the H metric. The AR metric derived based on the envelope complexity and intensity of the recorded data. Significant variation in the AR values (within the 0 and 1) was observed during the presence of fish chorus and wave breaking sound (Fig. 2d). It was observed that the AR values were higher during the fish chorus and wave-breaking sound (indicated as 1, 2 and 4) except during the fish chorus (indicated as 3). This highlights the need for collecting concurrent geophony data (i.e. wind, wave, and current) to explain the low AR values observed during the fish chorus sound indicated as 3. The AR values for the broadband data were also high during the presence of sound dominant during the presence of sounds produced by fishes that were available sparsely (indicated as 5 and 7 in Fig. 2a).

The box plots of AR metric showed similar variations for the broadband, fish band, and shrimp band signals (Fig. 6c). The mean AR values of the broadband, fish, and shrimp bands were found to be

0.309, 0.289 and 0.266 respectively, indicating insignificant variations in the mean values. The distributions of AR metrics for the three bands showed positive skewness, indicating no-normal data distribution. The H-spread values for the distributions were found to be 0.471, 0.400 and 0.360 for the broadband, fish and shrimp bands respectively.

Acoustic Complexity Index (ACI)

The ACI was used for analyzing avian communities and measures the intensity variation of a given recording over changing frequencies[10-13]. The metric is particularly useful in areas affected by constant anthropogenic noise pollution and helps to identify diverse natural sounds despite the presence of human-generated background noise[8]. The use of ACI metric was demonstrated in different Mediterranean soundscapes mainly composed of birds and cicada sounds[10]. The time series plot of derived ACI metric for the broadband, fish and shrimp band sounds are presented in Figure 2(e). The magnitude of ACI values were highest for the broadband sound closely followed by shrimp band sounds. The magnitude of ACI values for the fish band sound was significantly low in comparison with the other two bands. During the dusk chorus and abiotic sound due to wave-breaking, there was insignificant variation in the ACI values for broadband and shrimp band sounds, (Fig. 2e).

The mean ACI values (Fig. 6d) were significantly higher for the broadband sounds (1.77×10^4) and shrimp band sound (1.61×10^4) in comparison with the fish band (1.62×10^4). The data distributions of all the three band data showed normal distributions because no difference was observed between the mean and median values. The corresponding H-spread values were found to be 681.79, 73.13 and 684.61 for the broadband, fish and shrimp bands respectively. Intermittent boat sounds were observed in concatenated PDSs (Fig. 2a). However, the variations in such signals were not reflected in the derived ACI metrics.

General comparison of the acoustic metrics

A correlation analysis was performed using (Pearson's formula) between the acoustic metrics (H, AR and ACI) and with respect to the acoustic parameter (SPL_{rms}) in the absence of any physical forcing (wind, underwater current). A general description of the SPL_{rms} variation is covered in the previous section. The correlation coefficients were computed for four scenarios (i) entire time series data, (ii) *Terapon theraps* fish chorus timing [18 May 2016 (14:00-17:30 hr) and 19 May 2016 (14:00-17:30 hr)], (iii) wave-breaking time [(18/19 May 2016 (21:30 - 01:45 hr) and 20 May 2016 (00:00-02:30 hr)] and (iv) when sparse fish sounds are recorded [20 May 2016 (02:45-08:00 hr)]. The correlations coefficients were calculated independently for the broadband, fish and shrimp bands (Table 2).

We have found negative correlation coefficients or poor correlation coefficients for entire time series, wave-breaking and fish chorus of *Terapon theraps* sound timings for broadband, fish and shrimp bands. When sparse fishes (Carangidae or Unnamed fishes) were available for timings during 20 May 2016, positive correlation coefficients (0.151; $p < 0.502$) were observed for fish band sound. H performed poorly when background sound was dominant[11] and entire Malvan study areas possess dominant background sound as observed in soundscape data (Fig. 2a).

For entire datasets, the index AR was a good candidate for revealing acoustic diversity[26] because it provides maximum number of positive correlation coefficients with respect to the SPL_{rms} having moderate to lower values for broadband (0.606; $p < 1.693e^{-20}$) and fish band (0.224; $p < 0.0018$) for entire time series data (Table 2). A correlation coefficient between the SPL_{rms} and three acoustic metrics time series (Fig. 2b) were presented (Table 2) only for positive values. The correlation coefficients between the SPL_{rms} and ACI within the fish chorus time showed low (0.246; $p < 0.160$) and moderate (0.487; $p < 0.003$) for broadband and shrimp band respectively. Whereas moderate correlation coefficient (0.526; $p < 0.002$) was found between the SPL_{rms} and AR for broadband data. Within the abiotic sound i.e., wave-breaking sound duration, higher correlation coefficient (0.854; $p < 7.701e^{-09}$) was observed for the broadband data between the SPL_{rms} and AR. AR was seen to be well correlated with SPL_{rms} for broadband (0.731; $p < 0.001$) and fish band (0.152; $p < 0.058$) sound for other fish sound data (Table 2).

Conclusions

The passive acoustic data recorded using an autonomous system provides potential results for

Table 2 — Correlation coefficients between the SPL_{rms} and three acoustic metrics (H, AR and ACI) for broadband, fish and shrimp bands

Entire Time Series Data	*Broadband*	*Fish band*	*Shrimp band*
SPL_{rms}/H	r = -0.80	r =-0.210	r =-0.326
	p< 9.351e-44	p< 0.0035	p< 3.961e-06
SPL_{rms}/AR	r = 0.606	r = 0.224	r= -0.032
	p< $1.693e^{-20}$	p< 0.002	p<0.657
SPL_{rms}/ACI	r= -0.057	r= -0.198	r= -0.021
	p<0.435	p<0.006	p< 0.775
Fish Chorus Time (*Terapontheraps*)	*Broadband*	*Fish band*	*Shrimp band*
SPL_{rms}/H	r= -0.90	r = -0.385	r = -0.517
	p<1.087e-12	p< 0.027	p< 0.002
SPL_{rms}/AR	r = 0.526	r= -0.594	r = 0.077
	p< 0.002	p<2.134e-04	p< 0.073
SPL_{rms}/ACI	r =0.246	r = -0.594	r = 0.487
	p< 0.160	p< 2.134e-04	p< 0.003
Wave- Breaking Time	*Broadband*	*Fish band*	*Shrimp band*
SPL_{rms}/H	r =-0.896	r = -0.077	r =0.012
	p<1.209e-10	p<0.697	p< 0.954
SPL_{rms}/AR	r= 0.854	r = -0.077	r= 0.012
	p< 7.701e-09	p<0.321	p< 0.587
SPL_{rms}/ACI	r=-0.637	r = -0.146	r=-0.041
	p<2.690e-04	p< 0.460	p< 0.836
Other Fish Sound Time	*Broadband*	*Fish band*	*Shrimp band*
SPLrms/H	r = -0.971	r = 0.151	r = - 0.003
	p< 7.144e-14	p< 0.502	p< 0.988
SPLrms/AR	r= 0.731	r= 0.152	r = - 0.184
	p< 0.001	p< 0.575	p< 0.413
SPLrms/ACI	r= 0.495	r = - 0.208	r = 0.249
	p< 0.019	p< 0.352	p< 0.263

characterizing the underwater acoustic environments. Here, quantitative characterization of the ambient sounds, including the abiotic, and biological sounds off the Malvan coast (Burnt Island) was carried out. Spectral analysis techniques to identify fish species (biological) and wave-breaking (abiotic) signals were covered. The "waveform", "spectrogram", and the "power spectral density" (PSD) were examined to identify two types of fishes: a) *Terapon theraps* and b) Carangidae. During the dusk chorus, and abiotic sound due to the wave-breaking, higher broadband SPL_{rms} and corresponding fall of 'H' values were observed. This surmises that the entropy parameter (H) does not work well when applied to recordings where background sound dominates over the animal sound. The AR values significantly varied especially during the fish chorus as well as wave-breaking sound, and the values were dominant during the presence of sparsely fish sounds**.** The ACI values are the highest for broadband sounds closely followed by the shrimp band sounds in Malvan. The level of the ACI values for fish band sounds was significantly low.

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References

1 Au W W L & Hastings M C, *Principles of marine bioacoustics*, (Springer, New York) 2008, pp. 121–174.

2 Lammers M O, Brainard R E, Au W W L, Mooney T A & Wong K B, An ecological acoustic recorder (EAR) for long-term monitoring of biological and anthropogenic sounds on coral reef sand other habitats, *J. Acoust Soc Am*, 123 (2008) 1720–1728. DOI: 10.1121/1.2836780

3 Ladich F, *Sound communication in fishes*, (Springer, New York) 2015, pp. 1–243.

4 Au W W L & Lammers M O, *Listening in the Ocean*, (Springer-Verlag, NewYork) 2016, pp, 1–19.

5 Pijanowski B C, Villanueva-Rivera L J, Dumyahn S L, Farina A, Krause B L, *et al*., Soundscape ecology: the science of sound in the landscape, *Bio Science*, 61 (2011) 203–216.

6 Parmentier E & Fine M L, Fish Sound Production: Insights, In: *Vertebrate Sound Production and Acoustic Communication*, edited by R A Suthers, W T Fitch, R R Fay, & A N Popper, (Springer, Cham) 2016, pp. 19–50.

7 Fish M P & Mowbray W H, *Sounds of the western North Atlantic Fishes, A reference file of biological underwater sound*, (Johns Hopkins Press. Baltimore MD) 1970

8 Harris S A, Shears N T & Radford C A, Ecoacoustic indices as proxies for biodiversity on temperate reefs, *Methods Ecol Evol*, 7 (2016) 713–724. DOI: 10.1111/2041-210X.12527

9 Sueur J, Pavoine S, Hamerlynck O & Duvail S, Rapid Acoustic Survey for Biodiversity Appraisal, *PLoS ONE* 3 (2008)**:** pp. e4065. DOI:10.1371/journal.pone.0004065

10 Pieretti N, Farina A & Morri D A, New methodology to infer the singing activity of an avian community: The acoustic complexity index (ACI), *Ecol Indicat* 11 (2011) 868–873. DOI: 10.1016/j.ecolind.2010.11.005

11 Sueur J, Farina A, Gasc A, Pieretti N & Pavoine S, Acoustic Indices for Biodiversity Assessment and Landscape Investigation, *Acta Acustia united with Acustica*, 100 (2014) 772 – 781. DOI 10.3813/AAA.918757

12 Depraetere M, Pavoine S, Jiguet F, Gasc A, Duvail S, *et al.*, Monitoring animal diversity using acoustic indices: implementation in a temperate woodland, *Ecol Indicat*, 13 (1) (2012) 46 –54. DOI:10.1016/j.ecolind.2011.05.006

13 Farina A, *Soundscape ecology: principles, patterns, methods and applications*, (Springer-Verlag, New York) 2014.

14 Anonymous, Critical Habitat Information system of Malvan (Maharashtra India). Integrated Coastal and Marine Area Management, Project Directorate, Chennai. (Available at www.icmam.gov.in/MAL.PDF) 2001.

15 Erbe C, *Underwater Acoustics: Noise and the Effects on Marine Mammals: A Pocket Handbook*, 3rd Edn, (JASCO Applied Sciences) 2011.

16 Kaplan M B, Mooney T A, Partan J & Andrew R S, Coral reef species assemblages areassociated with ambient soundscapes, *Mar Ecol Prog Ser*, 533 **(**2015) 93–107.

17 Bassett C, Thomson J, Dahl P H & Polagye B, Flow-noise and turbulence in two tidal channels, *J Acoust Soc Am*, 135 (2014) 1764–1774.

18 McCauley R D, Fish choruses from the Kimberley, seasonal and lunar links as determined by long term sea noise monitoring, *Proceedings of Acoustics*, *21-23 November, Fremantle, Australia*, (2012) pp. 1-6.

19 Mahanty M M, Kannan R, Harikrishnan C & Latha G, *Terapon Theraps* chorus observed in shallow water environment in the southeastern Arabian sea, *Indian J Geo-Mar Sci*, 44 (2015) 150–155.

20 McCauley R D & Cato D H, Patterns of fish calling in a nearshore environment in the Great Barrier Reef, *Phil Trans R Soc Lond B*, 355 (2000) 1289–1293.

21 Clarke T A & Privitera L A, Reproductive biology of two Hawaiian pelagic carangid fishes, the bigeye scad, *Selar crumenophthalmus*, and the round scad, *Decapturus macarellus*, *Bullet Mar Sci*, 56 (1995) 33–47.

22 Unnikrishnan A S, Tidal propagation off the central west coast of India, *Indian J Geo-Mar Sci*, 39 (2010) 485–488.

23 David M F & David D L, The influence of Bubbles on Ambient Noise in the Ocean at High Wind Speeds, *J Phys Oceanogr*, 14 (1984) 1762–1778.

24 Deane G B & Stokes M D, Scale dependence of bubble creation mechanisms in breaking waves, *Nature* 418 (2002) 839-843. DOI: 10.1038/nature00967

25 Deane G B, Sound generation and air entrainment by breaking waves in the surf zone, *J Acoust Soc Am*, 102 (1997) 2671-2689. DOI: 10.1121/1.420321

26 Desjonquères C, Rybak F, Depraetere M & Gasc A, First description of underwater acoustic diversity in three temperate ponds, *Peer J*, 3 (3) (2015) pp. e1393. DOI: 10.7717/peerj.1393