Research Note

Mapping Snapping Shrimp Noise In the Indian Ocean Region

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1. INTRODUCTION

The snapping shrimp colonize warm littoral waters throughout the tropical and sub-tropical zones of the earth. The peak-to-peak source levels of a single shrimp snap have been recorded to be as high as 180 dB re 1µPa at 1m (louder than a jet at 140dB). Moreover, the combined snaps produced are essentially broadband signals and are observed to be the dominant noise source within the frequencies 2 kHz - 250 kHz. The crackling noise from these colonies often overwhelms the high frequency range ambient noise and interferes with underwater acoustic communication for humans and marine species alike. Its effect has also been seen in the IOR. [3]

In the Indian Ocean Region, which provides ideal conditions for snapping shrimp colonies, we can create a soundscape of its noise and model this noise to optimize our acoustic systems and improve signal detection in this noise. The noise can act as a unique asset for our littoral waters, owing to its use in underwater imaging, passive sensing, predicting sediment sound speed and more.

The initial efforts have to go in identifying actual shrimp hotspots in the warm shallow waters of the IOR based on their habitat features. Then we must create ambient noise maps of said noise for better underwater acoustic functioning. Then we can move to improving Signal Detection, and testing other benefits from this noise.

2. SNAPPING SHRIMP CHARACTERISTICS

The snapping shrimp (family Alpheidae) is a family of crustaceans. They are immediately recognizable due to its asymmetric front pincers, the larger of which is able to produce snaps (large surges in acoustic pressure) which are strong enough to stun or even kill small prey. It was initially hypothesized that the sound was an outcome of the two halves of the pincer physically colliding into each other. However, this has long been proven false and the phenomenon is attributed to imploding bubbles that are formed from the rapid closure of the pincer, or in other words, cavitation. [1][2]

These shrimp live in abundance (~300/colony) in favourable conditions. Seawater temperature has to be >11°C wherever depth is less than 55 meters. The density significantly decreases away from these conditions. They actively colonies corals, hard rocks and sponges, primarily because these habitats give them space to hide from prey and perform a surprise attack. Although Snapping Shrimps rarely survive in muddy or soft seabed, a few species are known to live in seagrass. Favourable habitat imply good food sources and hence is linked to the amount and quality of sound produced. [4]
Using these conditions we can effectively map probable Shrimp colony hotspots in the IOR, where said conditions are offered in the littoral waters.

The peak-to-peak source level of a snap (180 dB re 1µPa at 1m) is much louder than a jet engine 50m away! (140 dB) Thankfully these snaps only last for a few microseconds (3-6 µsec).The snaps produced are essentially broadband signals and are the dominant noise source within the frequencies 2kHz - 250 kHz. Further still, it has been suggested that the spectra goes way beyond 250 kHz. This noise proposes a unique problem to available acoustic systems that operate into the tens of kHz. [5][6]

3. SOUNDSCAPE OF WARM SHALLOW WATERS

Creating proper ambient noise maps of the Snapping Shrimp Noise requires us to study the entire soundscape of the frequency range in which this noise is significant and identify other sources of noise that are operational in this range.

The ambient Snapping noise has a broad peak between 2 kHz and 15 kHz. But the pulses are known to contain significant energy upto frequencies well beyond 100 kHz [10]. Knudsen et al [8], identified the three main ambient noise sources, while Wenz [9] gave an analysis of predominant noise in different spectra and Urick [7] precisely described sounds in different sonic ranges. Analyzing these with respect to the shrimp noise spectrum we get the following observations.

(i) **Water motion and wind noise**: Wind noise (wind dependent bubble and spray noise) is the only noise whose spectra at different sea states always lie in our frequency range. The difference between the sound pressures of shrimp noise and higher sea states (6 and 8) increases gradually from ~1 kHz, until the shrimp noise completely dominates after about 10 kHz, with a pressure difference of ~10 dB [5]. Heavy Precipitation also significantly raises ambient noise levels in 1 kHz to 100 kHz and often overlaps with shrimp noise for 1- 10 kHz with sound pressures higher or equal to the shrimp crackle. [9]

(ii) **Anthropogenic Noise**: Most shipping and manmade noise have appreciable sound levels only in low frequencies, but in some cases it might overlap with the lower band of shrimp noise, depending on the location of a shrimp bed. In shipping anchorage and heavy shipping channels, shipping noise shows less pressure difference at ~1 kHz than at coral reefs. [29]

(iii) **Marine bioacoustics:** A few species of cetaceans (whales, dolphins and porpoises) vocalize with tonal whistles in the range 2-25 kHz, or wideband echolocation clicks with maximum energy in the 40-140 kHz region. But their contribution is clearly dependent on their habitats and movement around shrimp beds. [7]

These observations were obtained from coastal waters around the world and have been generalized to help characterize the high-sonic band. In the Ultrasonic band >50 kHz, shrimp noise has significant energy, but there are only a few other contributors to the ambient noise: Rain noise, thermal noise and Ultrasonic pulses from dolphins. [10]

The levels are significantly affected by the snapping shrimp sound, when the bottom seawater temperature increases and the wind speed decreases. However, they are not excessively affected by the snapping shrimp sound when the wind speed decreases at low seawater temperatures. [27]

In the IOR, robust efforts have been made to characterize the shallow water ambient noise, like the one by Asolkar et al based on sea-surface variations [26], but snapping shrimp crackle is rarely considered in such researches. Narrowing down the locations of shrimp colonies would streamline the generation of a soundscape for the warm shallow waters.

4. SPATIAL AND TEMPORAL BEHAVIOUR

Analyzing the spatial and temporal features of the snapping shrimp will enable us to create more robust and accurate ambient noise maps. Diurnal and seasonal variations are considered for most common snapping shrimp species.

Clustering and distance of a hydrophone are also essential in such an analysis. Important facts to consider while talking about temporal and spatial variations are that most activity is dependent on availability and abundance of food sources and also the temperature of the sea waters. [4]

Snapping shrimp are known to have a very standard diurnal variability. They are louder by at least 3-6 dB at night as compared to daytimes, this is attributed to the fact that they search for food during the night time and hence produce significantly higher number of snaps. Loudest energy in the spectrum is observed just before sunrise and just after sunset. Lowest levels are observed during the afternoon. [4][7] There are however exceptions mainly due to favorable sea conditions and food availability. These are specific to particular habitats and can't be generalized.

The noise level remains essentially constant over a shrimp bed and decreases with distance from the edge of the bed. Over sea state 2 and higher shrimp noise is significant for about a mile away and in calmer waters for about 2 miles. [5]

Generally there is little to no seasonal variation in the noise in the warm tropical waters, this is due to the overlap between different generations. They don't have a breeding season as such and hence there is always an adult populace occupying the colony location. Habitat change is rarely observed. [4] At time same time there are shrimp colonies showing seasonal variation in the subtropical regions, being lowest in winters. Snapping Shrimp have also shown to be loudest during a new moon, at dusk during the summers. [28]

Potter and Koay created a stochastic tomographic inversion experiment and a signal processing algorithm to study the spatial and temporal behavior of the snapping noise. Over the gently varying mud and sand, ±3 dB horizontal isotropy was observed. This proves the shrimp noise to be a good source for ambient noise imaging. [25]

Another Experiment was designed to investigate temporal and spatial distribution and variability. The experiment was effectively able to image shrimp noise intensity on the seabed over an area of some 350 m2 with a resolution of 3.5 m2 and with an rms error below 20%, or approximately 0.8 dB. [16]

5. AMBIENT NOISE MAPPING

In marine animals, noise is largely dependent on habitat, seasonal and daily variations, whether the animals display significant movement, noise from a group is significant or from single source and also the fact that they can transmit noise anytime i. e., their noise is impulsive.

Taking into account the soundscape of these waters, the spatial and temporal statistics and the log normal pdf found in most data, we can generate ambient noise maps for the shrimp crackle.
For creating a map, a multiple receiver model should be considered to generate sound levels for the entire soundscape in a shrimp bed. The receivers are localized around the shrimp hotspots in a grid. These can be effectively deployed with SONAR systems for better navigation.

Chitre and Potter developed two physical models which can explain the log-Normal pdf that they found in the snapping shrimp data to date. The first is based on geometric considerations, and assumes that the individual shrimp snap independently. The second is based on behavioral considerations, and assumes that the probabilities of individual shrimp snapping are inter-dependent. The two models lead to a spatial and temporal explanation of the distributions, respectively. [12]

Bardyshev has conducted experiments in the shallow IOR waters, specifically, near an Atoll and has made very similar observations to what one would expect from a snapping shrimp colony. Even though he has specified the noise to be from a biological origin, he has tried to link these to other known marine species than the snapping shrimp. [30]

6. CHALLENGES

As our neighboring waters progress more and more into this field, it is imperative that we look into our marine ecosystems in order to benefit all the stakeholders of the underwater domain from that knowledge. A few challenges we face in this regard:

1. We still have a long way to go for conducting experiments to verify all possible hotspots. After we locate possible hotspots, we'll need indigenous effort to study our marine bioacoustics environment. Better understanding of the sound quality will be obtained through such efforts.

2. In all the studies, variation (based on location, country) is observed in noise, habitat, spatial temporal distribution and the soundscape. We can use them as motivation, but not as a fixed standard in studying shrimp noise. This again calls for further research into the high frequency soundscape of shallow waters that contain shrimp colonies.

3. Identifying the accurate origin of a single snap is a difficult process, there are procedures to aid this but developing better techniques would ease our understanding of clustering of colonies and will also help in studying seabed features better.[15]

4. Lot of research is being done in nearby waters in the Indian Ocean itself; we need our own indigenous capacity to stand in par with them.

7. OPPORTUNITIES

Snapping Shrimp's ambient noise has a lot of potential to be strategically studied to benefit our underwater stakeholders. Following are a few significant steps that have been taken worldwide, in this regard:

1. **Signal Detection: Chitre** et al [13, 14, 17, and 18] have worked extensively to characterize the noise in order to optimize signal detection and improve ambient noise oceanography. They uncovered the fact that the noise is non-Gaussian and the best fit for the amplitude probability distribution would be a symmetric alpha stable (SaS) model. In 2015, they proposed the αSGN(m) model to characterize snapping shrimp noise. The model does not only characterize the impulsive statistics of the noise process, but its memory or "burstiness" as well. Mahmood has created the αSGN(m) toolbox for Matlab available in the public domain. [14] Matthew Legg's thesis offers much in terms of processing and analysing snapping shrimp noise. [18] Guimaraes et al have used convex optimisation techniques for better signal processing in the shrimp noise. [22]

2. **Ambient Noise Imaging**: For ambient noise imaging, the high frequency content of these sources (up to at least 250 kHz) provides good angular resolution, at the cost of short range due to absorption. With a technique called acoustic-daylight imaging, sounds in the sea can "illuminate" submerged objects, thereby creating moving color pictures without sonar. Buckingham et al have done extensive research in using the ambient noise soundscape (including wind and rain) in Snapping Shrimp dominated areas to acoustically illuminate the sea. [20]

3. **Determining the health of Coral**: Studies have shown that by estimating the spatial and temporal distribution of snaps we can obtain ecological information about the health of coral reefs. This provides an efficient alternative over conventional monitoring which deploys human divers to conduct inspection. Localizing snaps generated by the shrimp inhabiting underwater structures, can reveal the physical forms of these submerged structures. [24]

4. **Passive Sensing:** Too Yuen Min in his thesis "Passive Sensing using Snapping Shrimp Noise", has explores methods to determine the range of a snap source, to localize the snapping shrimp noise in order to passively determine the underwater sea forms. [15]

5. **AUV Detection:** Sometimes, for proper operation of AUVs, it is important to know where the AUVs are, particularly the depth. Instead of the usual way of using active transmission, a technique is described makes use of the Ocean Ambient Noise, particularly the shrimp bed noise, rather than transmitting anything. [19]

6. **Similar species noise studies:** By studying the marine biology of the IOR, we can apply similar models and techniques for impulsive animal noise.

8. RESEARCH DIRECTIONS

We can take our research forward for the IOR in the following directions:

1. Locating/Verifying hotspots in the IOR, and establishing noise and spatial-temporal characteristics for the IOR: Identifying features and species which are unique to our waters. Establishing their soundscapes and determining the role they can play for better underwater operations

2. Creation of an effective soundscape of our littoral waters, where the snapping shrimp noise will play a key role: studying different regional characteristics and their effect and how they modify the high frequency shallow water soundscape which will most definitely contain the snapping shrimp noise.

3. Signal Detection: Motivated by the elaborate and extensive studies done in other warm coastal areas we can create our own tools and use them for better signal detection and optimized performance of underwater telemetry systems. We must research on the proper tools that work for our own underwater acoustics.

4. Discovering more uses of the ambient underwater noise and turning it into an asset for all the maritime stakeholders. This can be done by taking inspiration from the way snapping shrimp noise has been used and studied for different purposes.

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