Habitat Impact on Echo-location Characteristics of Irrawaddy Dolphins from Chilika Lake and Sunderbans

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Abstract: ***Acoustic echo-locationr characteristics of non-marine toothed whales are very critical for any conservation efforts. These species have been declared as data deficient by the IUCN and acoustic surveys are relatively cost-effective approach. Irrawaddy dolphins Orcaella brevirostris also known as facultative freshwater dolphins because they occupy both fresh- and nearshore marine waters are among the cetaceans at greatest risk to population extirpation and perhaps extinction. Their vulnerability stems from habitat requirements that are coupled to marine and freshwater habitats subjected to intense human intervention. The bio-sonar characteristics of these species are highly sensitive to their habitat and the Irrawaddy dolphins are spread across varied environments over distant geographic locations. A good understanding of their acoustic bio-sonar characteristics across habitats can potentially provide significant conservation inputs. Long recordings obtained by passive acoustic monitoring system are denoised first using wavelet transform and locations of click are detected using Teager-kaiser energy operator. The two habitats considered in this work are contrasting in their origin and evolution. The first is the rivers systems of the Sundarbans mangrove forest with a deltaic habitat and second is the Chilika Lagoon with rain water and high tide fed habitat. Detailed analysis of the Sundarbans Irrawaddy dolphins were reported in 2013 with well-defined acoustic signal parameters. Here the same parameter are applied for a comprehensive comparison of the species in the two habitats with a critical review on the correlation of the habitat features and the acoustic bio-sonar characteristics. Long term recording of the dolphin clicks in the Chilika lagoon have been analyzed and compared with the Sunderbans results available in the open literature. The acoustic parameters and their physical correlation with the animal behaviour and the habitat status have been presented. Multiple parameters such as peak frequency, signal source level, bandwidth, duration of clicks, inter-click interval, etc have been considered for study.***

Keywords: Echolocation clicks, Chilika Lagoon, Irrawaddy Dolphins, Orcaella brevirostri, Teager-kaiser energy operator

1. Introduction

Toothed whales i.e. dolphins are the top predators inhabiting in many oceans as well as in freshwater river systems. They have independently evolved with the bio-sonar system to navigate in the water. As compared to light, sound is the best communicating signal in water and hence dolphins use echolocation sounds to navigate, to catch food and to sense the environment properly. This echolocation sound is known as clicks and produced through nasal passage by passing the air back and forth. These clicks are reflected from the object in water and sensed by lower jaws of dolphins. By interpreting this reflected sound or clicks, dolphins gets the information about surroundings.

There are only seven species of non-marine freshwater dolphins in the world and exists in world's mightiest rivers like Ganges, Indus, Mekong, Yangtze and Amazon and are less active than their marine cousins [1]. The species referred in this work is Irrawaddy dolphins i.e. Orcaella brevirostris and it is one of the two facultative species in the world which can be inhabit in both fresh as well as near shore waters. The Irrawaddy dolphins have a patchy distribution in the shallow and coastal waters of the Indo-Pacific from northern Australia and the Philippines to north eastern India. Orcaella brevirostris, Irrawaddy dolphins were declared as Data deficient species in 1996 by IUCN. As population trend of Irrawaddy dolphins are decreasing, IUCN declared this species as vulnerable species in IUCN red list of threatened species (2014.3) [2].

The two habitats referred in this work are Chilika Lagoon from India and Sunderban mangrove forests from Bangladesh. The origin, evolution and the atmosphere of these habitats can be affecting the echolocation characteristics of the species. This impact of habitat on acoustic bio-sonar characteristics of the species across distinct habitat can potentially provide significant conservation inputs.

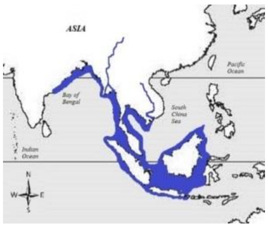

Figure 1: Irrawaddy dolphins across the world

Chilika Lagoon was the ancient port on the banks of Bay of Bengal and also was the main centre of boat building on east coast of India [3]. But as time passes, the effect of longshore drift of sediments during monsoon caused siltation in Chilika. Hence the Laggon is formed due to the spit as it closed the mouth and water becomes brackish. And this brackish water habitat is now a very suitable habitat for various flora and fauna [4]. This brackish water habitat has maximum depth of 4.2 m and temperature of habitat varies from 14°C to 40 °C.

Irrawaddy dolphins from Chilika are found in four ecological regions of the lagoon i.e. Outer

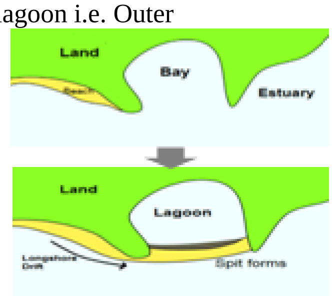

Figure 2: Chilika lagoon evolution due to spit formation

channel, Northern sector, Central sector and Southern Sector [5].These four zones of Chilika Lagoon are based mostly on salinity variations that occur within the Lagoon. Salinity in the Lagoon is driven by freshwater river drift from the north and west, and tidal ocean water from the east and south. This results in a variation of salinity in the Lagoon, from freshwater in the north, brackish waters in the center and south, and full saline waters to the east around the islands and outer channel. The boundaries between these regions shift throughout the year, driven by monsoon rains and seasonal winds.

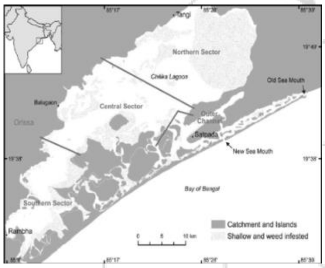

Figure 3: Chilika lagoon, India showing how lagoon is divided in different sectors [6]

Sunderbans is the deltaic region of Ganges and Brahmaputra River formed by sediment deposition. When the river flows, it carries the sediment and rock debris like as clay, sand, slit and gravel along with the flow and as the river enters in ocean or other larger water system, a deltaic region is created by settling down all the sediment it has carried for years and years. This deltaic region becomes the fertile land and deltaic region of Sunderbans is the one among the most fertile lands in the world. Sunderban is a coastal water habitat for Irrawaddy dolphins with depth varying from 20 to 500 m and temperature is 20°C to 48 °C. In monsoon, as salinity decreases and turbidity increases, dolphins move in southern area of region [7].

The freshwater habitats are more complex than the stable marine environment in terms of extremely varying depth, turbidity and salinity, hence it is more challenging to analyse the underwater behaviour of non-marine species in restricted shallow environment.

Before analysing the clicks from the long recordings, it is necessary to denoise the data as it may have ambient noise or the man-made noise. Dolphin clicks; recorded using hydrophone contains too much noise such as ambient noise and self noise which includes all variety of noise sources due hydrophones and receiving platform [8]. While examining dolphin clicks snapping shrimp (above 2 KHz), whistles of dolphin (5 to 35 KHz) are also source of interference. Thus, for characterizing dolphin clicks, it is necessary that it will be denoised first. As, this noise sources occupies wide range of frequencies, dolphin clicks are totally suppressed in it. Thus, for denoising we need some innovative approach.

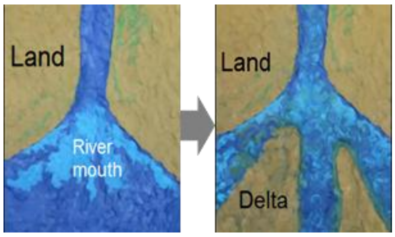

Figure4.:Sunderban evolution due sedimentation in Ganges-Bramhputra river

In passive acoustic monitoring system, many hours of vocalizing dolphins have been recorded using various configurations: two or more towed hydrophones, a few meters apart deployed behind a monitoring vessel, towed-array systems. In order to extract and evaluate the information contained in these recordings one major step should be done: find the clicks amid the hours of data. One can visually inspect the waveforms or spectrograms of the signals but a more practical solution consists of using an automatic detection algorithm. Several softwares for automatic detection of sperm whale sounds have been developed (i.e., Rainbow Click [9], Moby Click [10]). Advances have been made in classifying delphinid whistles to species [11], but little work has focused on classifying delphinid burst pulses and clicks to species, particularly at frequencies greater than 24 kHz. While the clicks of porpoises, sperm whales, and beaked whales are easily distinguishable from delphinid clicks based on time duration, inter-click interval and peak frequency characteristics [12], delphinid clicks thus far have remained unclassifiable at the species level. Most echolocation click research to date has focused on the performance of sonar systems and only a few studies look for species-specific characteristics. Detection and classification algorithm for marine mammals has been developed in [13] using Teager-Kaiser energy operator.

A lot of study had carried out on marine delphinides but freshwater delphinides are on the verge of extinction so there is need to study freshwater dolphin's vocalization to give inputs in their conservation and protection. As clutter and reverberation in socio-ecological freshwater system cannot be quatify hence it is challenging to study freshwater delphinides vocalization. As the Irrawaddy dolphins are facultative dolphins, difference in vocalization of freshwater Irrawaddy dolphins and coastal water Irrawaddy dolphins are studied in [14]. Detailed analysis of Irrawaddy dolphins from Chilika Lagoon has been carried out in [6] for species conservation. Sunderbans region from Bangladesh is habitat for the two freshwater dolphin species i.e. Irrawaddy dolphins and Ganges river dolphins. Vocalisation of both species from Sunderbans is analysed in [15] with acoustic signal parameters like centroid frequency, signal source level, peak frequency, bandwidth, duration of clicks, inter-click interval, etc. The same acoustic parameters are used in this work and analyzed the echolocation clicks of Irrawaddy dolphins from Chilika Lagoon.

2. Data Collection

Passive acoustic monitoring is increasingly being used for towed hydrophone line transect surveys and for remote, long-term monitoring of populations using autonomous instruments [16]. Recent technological advances allow long-term recordings to reach higher bandwidths, which prompts research into use of higher frequency calls for species classification. A vertical array of four hydrophones has been used to record the dolphins sounds in Sunderbans mangrove forest in Bangladesh [15]. In Chilika Lagoon, array of six hydrophones is used to obtain the recordings during daylight hours. The data is sampled with sampling frequency 500 kHz per channel and resolution of 16 bits.

3. Data Analysis

Data analysis is done with custom-written routines in MATLAB R2013a. The long recordings are denoised using Discrete Wavelet Transform. Different mother wavelets like Meyer, Coiflet, and Symlet2 are used and calculated the SNR values. Wavelet with higher SNR values gives proper denoising of signals. To analyze the clicks from the long recordings, it is necessary to properly detect the clicks. Teager-Kaiser Energy operator, followed by proper thresholding, is used to detect the clicks [13,17]. Characteristics like peak frequency, bandwidth, signal pressure level, click duration and interclick-interval of these detected clicks are extracted. Source levels (SL) is defined as the back scattered sound pressure level at 1 m from the source on the acoustic axis [18] and calculated from received pressure levels by compensating for the transmission loss (dB), estimated as the combination of spherical spreading loss and frequency dependent absorption loss over the range from the source coordinates to the receiver. Power spectrum is calculated as welch power with 32 point window size. Frequency corresponding to maximum power is referred as peak frequency of the click. -3 dB and -10dB bandwidths are calculated from the same power spectrum. Energy is calculated as squared value of signal pressure and -10 dB time window of energy is click duration [15]. Interclick interval is defined as time difference between each click and previous.

4. Results

Before analyse the echolocation clicks of Irrawaddy dolphins it is necessary to pre-process the long recordings obtained by PAM system. Denoising the long recordings with Discrete Meyer Wavelet gives higher SNR value near about 28 dB than Coiflet and Symlet2 as mother wavelet. The clicks are detected using Teager-Kaiser energy operator with properly defined threshold [13]. Accuracy of detection of clicks is more than 80% with this method. Peak frequency of clicks has value in range of 44-120kHz for N=161 and -3 dB and -10 dB bandwidths are up to 95.70 kHz and 201.17 kHz respectively. The no. of clicks in click train and the time interval between clicks depend on the variety of factors such as distance of interest, presence or

Table 1: SNR values for different mother wavelets for different samples

Sample No.	*Meyer SNR (dB)*	*Coiflet SNR (dB)*	*Symlet2 SNR (dB)*
1.	28.9012	21.8403	22.1627
2.	28.6682	25.2681	25.0534
3.	28.8218	25.0901	25.2046
4.	29.0123	27.4253	27.2212
5.	28.7010	27.2586	27.2091
6.	28.7468	24.9937	25.1767
7.	28.8423	27.2470	27.0538
8.	28.8292	23.1588	22.4244
9.	28.1691	20.6215	20.5415

Table 2: Percentage of correctly detected clicks per file

Sample no	Actual clicks	Correctly detected	Percentage accuracy
1.	42	37	88.09%
2.	55	50	90.90%
3.	54	49	90.74%
4.	33	27	81.81%
5.	44	39	88.63%
6.	66	59	89.39%

Absence of target, difficulties in target detection and animal's expectation in finding a specific target. Inter-click interval is time difference between sending out click and receiving the echo click after specific lag-time [18]. Hence there can be variation in inter-click interval in large amount. Inter-click interval of echolocation clicks from Chilika Lagoon has value in range of 30-80 msec and click duration has value near about 2-10 µsec.

Peak to peak signal pressure level has mean value 118.709 dB with standard deviation of 11.448 dB and rms signal pressure has mean value 103.209 dB with standard deviation of 11.448 dB. Whereas peak to peak signal pressure level has mean value 194.5 dB with standard deviation of 3.6 dB and rms signal pressure has mean value 185.1 dB with standard deviation of 3.6 dB for Irrawaddy dolphins from Sunderbans [15]. Lower source levels helps in detection of target in restricted environment with highly clutter and reverberation condition. It is very difficult to quantify this clutter and reverberation hence it is more challenging to work with restricted environment than oceanic conditions [15]. Reverberation from the bottom will necessarily depend on signal frequency, grazing angle, bottom sediment type, and especially depth. As depth of Chilika lagoon (maximum 4.2 m) is much less than Sunderbans (20-500 m), Irrawaddy dolphins from Chilika Lagoon has lower values of signal pressure levels [15].

Parameter	*Chilika Lagoon, India*	*Sunderbans, Bangladesh*
N	301	15
SL pp (dB)	118.709±11.448	194.5±3.6
SL rms (dB)	103.209±11.448	185.1±3.6
Fp (kHz)	44-120	65.2-125
BW_3 dB (kHz)	43.96-95.70	40.2-91.4
BW_10 dB (kHz)	72.26-201.17	83.9-143.9
Click duration (µsec)	2-10	10-18
Inter-click interval (msec)	30-80	40-200
References	This paper	[15]

5. Conclusion

In the complex acoustic environment and high amount of clutter and reverberation, toothed whale dolphins employ echolocation signals characterized by low amplitude, high frequency sonar signals emitted at high repetition rates [6]. As depth and salinity varies, the acoustic behaviour of Irrawaddy dolphins in the Sunderban Rivers and Chilika Lagoon differed in a number of aspects: amount of time spent vocalizing, shape, duration and frequencies of clicks. As the depth of Chilika Lagoon is much more less than Sunderbans mangrove forests, Signal pressure level for Chilika Lagoon Irrawaddy Dolphins is 118.709±11.448 dB while for Sunderbans dolphins, it is 194.5±3.6 dB. The cause of these low signal pressure levels may be a relaxed selection for long-range echolocation inhabiting restricted, shallow, geomorphically complex river systems, with limits on echolocation range imposed by reverberation and clutter. Acoustic discrimination between freshwater dolphins may facilitate acoustic monitoring efforts and may help to prevent a continued decline of this threatened freshwater species.

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