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Acoustic Repertoires Related to Surface Behaviours of the Irrawaddy Dolphins (*Orcaella brevirostris*) in Brunei Bay, Malaysia

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Behavioural observation and acoustic recordings of Irrawaddy dolphins (*Orcaella brevirostris*) were performed simultaneously in Brunei Bay, Malaysia. Surface behavioural observations were classified into four categories: travelling, foraging, socialising, and milling. A total of 8.43 hours of acoustic recordings were used to retrieve four different types of sounds: whistles, burst-pulsed sounds, click trains, and biphonal sounds. The recorded whistles were frequency-modulated sounds with durations ranging from 0.06 to 3.86 s and a mean minimum frequency of 6.5±2.5 kHz. The burst-pulsed frequency ranged from >48 kHz in at least four variations. Click trains were made up of broadband clicks with variable inter-click intervals and frequencies >48 kHz. The first biphonic sounds for Irrawaddy dolphins have been revealed in this study. Whistle rates were extremely high in milling. Compared to travelling and foraging, socialising had a significantly higher rate of click trains. Across all surface behaviours, there was no significant difference in burst-pulsed rates. This study laid the groundwork for ongoing monitoring of Irrawaddy dolphins and expanding conservation efforts for this species in Malaysia.

Keywords: Irrawaddy dolphins; *Orcaella brevirostris*; sounds; surface behaviours

I. INTRODUCTION

The study of animal sounds has received widespread attention and is perceived among the most promising research areas. Identifying the acoustic repertoire of Irrawaddy dolphins is an essential first step in comprehending the animal's vocalisations. Owing to this, there is currently a pressing need for extensive research into the acoustic signals of the species. Several publications have discussed the acoustic repertoires of terrestrial mammals such as primates, elephants, rhinoceroses, and bats (Bohn *et. al.,* 2008; Gros-Louis *et. al.,* 2008; Gustison *et. al.,* 2012; Lattenkamp *et. al.,* 2019; Linn *et. al.,* 2018; Nair *et al.,* 2009). Besides, previous studies have also reported on vocal descriptions of pinnipeds (Yang *et al.,* 2017), otters (Mumm *et al.,* 2014), birds (Favaro *et. al.,* 2014; Searcy *et al.,* 1999), and fish (Rice & Bass, 2009). Nevertheless, the Irrawaddy dolphin's (*Orcaella brevirostris*) acoustic repertoire is still scarce. The delphinid's acoustic repertoire knowledge will help elucidate the behavioural functions, geographic variation, and communication evolution. It can disclose details concerning identifying individuals and social groups (Bazúa-Durán & Au, 2004; Charrier *et. al.,* 2009; Neves,

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2013). Comparing acoustic repertoire across different populations can be complex due to the various types of sampling rates and parameters assessed in varied study areas (Janik, 2009; Mellinger *et al.,* 2011).

Delphinids are capable of producing at least four distinct types of sounds. These involve frequency-modulated whistles, burst-pulsed, broadband clicks, and low-frequency narrowband (LFN) sounds (Herzing, 2000; Schultz *et. al.,* 1995; Van Parijs *et al.,* 2000). Delphinids generate and employ these sounds for navigation and communication purposes (Herzing, 2000; Van Parijs *et al.,* 2000). These sounds are formed by pushing high-pressure air through phonic lips (Ridgway & Carder, 1988). Irrawaddy dolphins (*Orcaella brevirostris*) use echolocation to distinguish their targets and detect objects from a distance in murky waters and turbid environments. Echolocation is how an animal detects the surroundings by making sounds and listening to the echoes reflected from various objects (Au, 2002). It is the most effective method for the animal to perform various functions such as navigation, communication, sensing and obstacle detection (Au & Hastings, 2008). Echolocation clicks are high-frequency, directional transients (Branstetter *et. al.,* 2012; Wahlberg *et al.,* 2011) applied to acquire signals from the environment and potential prey. Burst-pulsed sounds comprise clicks with very short inter-click intervals (ICI) and are primarily associated with social communication (Blomqvist & Amundin, 2004; Herzing, 2000). The burst pulsed has been explained in the social context. It involves buzzes (Corkeron & Van Parijs, 2001), pops (Nowacek, 2005), quacks (Jacobs *et al.,* 1993), brays (Janik, 2000), barks, squawks, and screams (Herzing, 1996). It is still debatable whether they function as prey-catching, including echolocation buzzes or creaks (Miller *et al.,* 2004). Low-frequency pulses, such as bray, have been disclosed to suggest feeding activities (Janik, 2000; King & Janik, 2015). Whistles are tonal sounds with a continuous waveform and are presented as a narrowband sound with or without harmonics. It was achieved using spectrogram analysis and generalised into a contour shape (Bazúa-Durán *et al.,* 2002). The whistles are essential for the delphinid's underwater communication (Herzing, 2000; Tyack, 1998). Delphinids generally exhibit whistles that are audible to humans (below 20 kHz). Recent research has revealed that delphinids can deliver whistles with fundamental frequencies as high as 30 kHz (Bopardikar *et. al.,* 2018; Lammers *et al.,* 2003).

The Irrawaddy dolphin is a facultative known species in Southeast Asia's marine and freshwater environments (Baird & Beasley, 2005; Baird & Mounsouphom, 1994; Kreb, 2004; Minton *et. al.,* 2013; Smith *et. al.,* 2004; Teoh *et. al.,* 2013; Tongnunui *et al.,* 2011). The acoustic repertoires of delphinids such as bottlenose dolphins, killer whales, humpback dolphins, and Guiana dolphins have previously been thoroughly studied (Andrade *et. al.,* 2017; Boisseau, 2005; Riesch *et. al.,* 2008; Samarra *et. al.,* 2010; Saulitis *et. al., 2005*; Sims *et. al.,* 2012; Van Parijs & Corkeron, 2001). The first evidence of the acoustics of Irrawaddy dolphins came from captive dolphins in Indonesia (Kamminga *et al.,* 1983). The Irrawaddy dolphin whistles were absent throughout the recordings in Rocco (2009). The research considered Irrawaddy dolphins to be non-whistling dolphins, similar to the Phochaenidae family. A study in Sundarban recorded only broadband clicks from Bangladeshi Irrawaddy dolphins ranging from 65 kHz to 125 kHz (Jensen *et al.,* 2013). However, whistles were discovered in Irrawaddy dolphin recordings in Matang, Malaysia (Hoffman *et al.,* 2017), exhibiting that the animals whistle. The acoustic repertoire of the Australian snubfin dolphin (*Orcaella heinsohni*) was similar to that of *Orcaella brevirostris* (Beasley *et. al.,* 2005; Van Parijs *et al.,* 2000). This paper is the first to describe and place the acoustic repertoire of a free-ranging population of Irrawaddy dolphins of Brunei Bay in the behavioural contexts.

II. MATERIALS AND METHODS

A total of 37 boat surveys were conducted in the Brunei Bay (4º45' – 5º02' N, 114º58' – 115º10' E) during January, April, July and October 2016 (Figure 1). The surveys were performed on a 10 m wooden fishing boat powered by outboard engines rated at 30 and 60 horsepower. The boat's average speed was 15 km/h. It is carried out during daylight hours, with calm seas (Beaufort less than 3 and Swell less than 1 m) and clear visibility (more than 1 km). The survey boat was occupied with five observers on board (along with the skipper). During the surveys, three of them were stationed at the boat's bow, port, and starboard. Visual observations were made using the naked eye and binoculars to search for sighting cues in a consistent scanning technique. These cues include dolphins splashing and/or porpoising, fin sightings, and water disturbance caused by the surface activity (Stockin *et al.,* 2008).

A. Behavioural Observation

The survey boat's speed dropped to an average of 5 km/h after encountering a group of Irrawaddy dolphins. Distances of 20 to 50 metres were maintained between the survey boat and the dolphin group. Groups were defined as having two or more dolphins within 15 m away (Hartman *et. al.,* 2008; Smolker *et al.,* 1992). During the surveys, data on dolphin surface behaviours (such as travelling, foraging, socialising, and milling) were gathered, and their dorsal fins were photographed (for photo-id). The group of Irrawaddy dolphins was observed and acoustic recordings were made simultaneously for as long as the weather permitted or until the species disappeared entirely.

A visual inspection was conducted every five minutes, starting with the start of the acoustic recordings to assess the group's size, composition, location, and surface behaviour. The composition of the groups was determined by visual observation of body size, which was used to estimate and categorise them into three groups: adults, juveniles, and calves. Parra (2005) stated that an adult Irrawaddy is between 2 and 3 metres long. Meanwhile, juveniles are roughly one-third the size of adults. A calf is about half the length of an adult and is frequently spotted swimming alongside an adult female, generally assumed to be the mother.

The behavioural observation was accomplished by scanning all of the individuals in the group to distinguish the most prevalent surface behaviour patterns. Distinct behavioural patterns on the water surface were identified based on a previous study by Parra (2005). Surface behaviours that were observed during the surveys include milling, travelling, foraging, socialising and mixing. The observations were made during a period of calm weather (Beaufort less than 3; Swell less than 1 m).

B. Acoustics Recordings

Acoustic recordings were made after the focal group exhibited no apparent signs of interruption (i.e., swimming away from the survey boat repeatedly upon approaching, vigorous tail slapping, and instantaneous diving). The survey boat engine was turned off to minimise interference to the animals and recordings, with the boat distance was kept between 20 and 50 metres except the animals drew closer. Underwater recordings were made with a single-channel hydrophone connected to a Zoom H1 sampled at 96 kHz, yielding a frequency response of 10 Hz – 48 kHz, 2±dB. The hydrophone was placed between 2 and 4 metres (depending on the water depth) below the water's surface on the bow of the survey boat.

C. Analysis

All recordings were retrieved to a desktop computer running Windows 7 Professional and analysed with Adobe Audition 3.0 and Raven Pro 1.5 (Cornell Lab of Ornithology). The clips were saved in wave sound files and linked to a dataset with the recording time and date, location, and type of surface behaviour. Adobe Audition 3.0 was used to scan the acoustic recordings first. Longer recordings were splitted into shorter files to lessen the use of software memory during analysis. The acoustic data was then further visualised with Raven Pro 1.5 using spectrogram displays (window type: Hanning; hop size: 5.8 ms; overlap: 75%; grid spacing: 43.1 Hz; Fast Fourier Transform (FFT): 1024 points). The signals generated by Irrawaddy dolphins were manually chosen, classified, exported, and counted.

Delphinid's sounds produced and analysed included whistles, burst pulsed sounds, and click trains. Whistles are tonal sounds that are modulated in frequency, sometimes with harmonics. Six whistle contours were visually identified, and the frequency characteristics of each were analysed in Raven Pro 1.5. Burst-pulsed click trains have a short inter-click interval and a greater repetition rate. Meanwhile, a click train is a series of ultrasonic broadband clicks that are emitted at varying repetition rates. The number of occurrences of each category of sound was counted. The frequency with which a particular type of sound (whistles, clicks, burst-pulsed) occurs in relation to the estimated number of animals per minute is addressed as the sound rate. The sound rates of each sound type were then contrasted across various behavioural contexts and group sizes. The group size was separated into groups of less than ten people and groups of ten or more people. The classes were identified based on the median size of all sighting group sizes.

All data were saved in Microsoft *Excel* spreadsheets and statistical analyses were conducted using SPSS 16.0 (SPSS Institute Inc., Chicago, IL). Statistical tests were conducted at a significance level (p) of 0.05. The data was not normally distributed and the variance was not homogenous (Lilliefors test p<0.05; Levene's test p<0.05)., Therefore, non-parametric tests such as Kruskal-Wallis and Mann Whitney were used to evaluate whether the production rate of the Irrawaddy dolphin's sounds were differed according to behaviours and group sizes.

III. RESULTS AND DISCUSSION

The surveys lasted 177 hours and covered 2235 kilometres, with 32 spottings of Irrawaddy dolphins. Nevertheless, acoustic recordings were accomplished in 20 sightings. Figure 1 represents the study's sighting and recording areas. The recording regions ranged from 2 to 27 metres (Mean=9.6±7.8 metres).

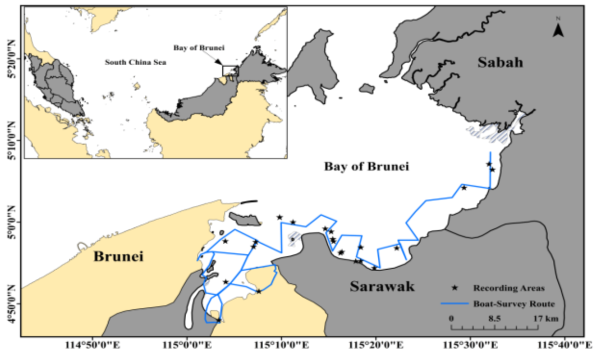

Figure 1. A map with sightings and acoustic recordings of the Irrawaddy dolphins in the Brunei Bay

When using the photo-identification method, 70 individuals of Irrawaddy dolphins were positively identified and catalogued. The recording areas have a water depth that ranged between 1 m and 26.7 m (Mean=9.17, SD=7.22). The average sea surface temperature was 30.89 °C (Min=29 °C, Max=37 °C). The water salinity was between 0.22 ppt and 32.00 ppt (Mean=23.36±8.24 ppt). The water turbidity was 39.71 NTU (Mean=5.43±9.18 NTU), especially when closer to shore.

In Raven Pro 1.5, visual inspection revealed four types of sounds: whistles, burst-pulsed sounds, click trains, and biphonal sounds. Over 7 hours of recordings were analysed, and 421 whistles, 569 burst-pulsed, 635 click trains, and 11 biphonal sounds were identified, extracted, and analysed. Table 1 summarises descriptive statistics for the identified sound's acoustic properties, and Figure 2 highlights examples of retrieved sounds.

Table 1. Acoustic characteristics of sound types produced by the Irrawaddy dolphins in Brunei Bay

	Sample (n)	**Duration (s)**	**Minimum Frequency (kHz)**	**Maximum Frequency (kHz)**	**Start Frequency (kHz)**	**End Frequency (kHz)**	**Inter-click-interval (ms)**
Whistle	421	0.5328 (±0.301)	6.469 (±2.485)	7.476 (±2.742)	6.538 (±2.486)	7.379 (±2.755)	-
Burst-Pulsed	278	0.215 (±0.316)	-	>48 kHz	-	-	-
Click Train	635	0.863 (±1.363)	-	>48 kHz	-	-	58.45 (±32.57)
Biphonal	11	-	-	-	-	-	-

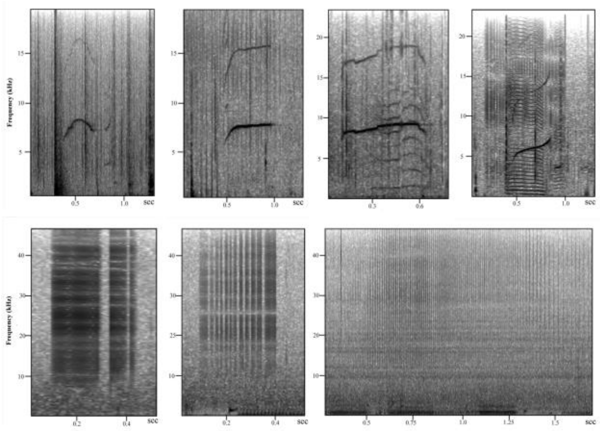

Figure 2. Spectrogram examples of the Irrawaddy dolphins sound in the Brunei Bay. From left: whistles (i-ii); biphonal sounds (iii-iv); burst pulse (v-vi); click trains (vii) (window type: Hanning; hop size: 5.8 ms; overlap: 75%; grid spacing 43.1 Hz; FFT: 1024 points).

A. Sounds of Irrawaddy Dolphins

1. Whistles

Whistles are tonal sounds that are modulated in frequency, frequently with harmonics. Irrawaddy dolphins in Brunei Bay generated a broad spectrum of frequency-modulated whistles. The whistles that were documented in this study had a diverse variety of contours, frequencies, and lengths. More than a quarter of the extracted whistles had more than one harmonic. The duration of the measurable whistles ranged from 0.06 s to 3.86 s (Mean=0.53±0.30 s, n=436). The whistles had a mean minimum frequency of 6.5±2.5 kHz and a mean maximum frequency of 7.5±2.7 kHz. This study identified six whistle contours (constant, upsweep, downsweep, convex, concave, and sine). Table 2 contains descriptive statistics regarding the contours of the whistle.

Table 2. Descriptive statistics of the acoustic properties of extracted whistles contours

	Sample (n)	**Duration (s)**	**Minimum Frequency (kHz)**	**Maximum Frequency (kHz)**	**Start Frequency (kHz)**	**End Frequency (kHz)**
Constant	227	0.49 (±0.21)	6.574 (±2.717)	7.4821 (±2.975)	6.625 (±2.706)	7.414 (±2.717)
Upsweep	142	0.59 (±0.42)	6.199 (±2.360)	7.365 (±2.697)	6.308 (±2.396)	7.218 (±2.711)
Downsweep	6	0.44 (±0.17)	6.812 (±1.464)	7.517 (±0.944)	5.721 (±1.464)	7.517 (±0.944)
Convex	16	0.63 (±0.17)	6.812 (±1.201)	7.586 (±1.188)	6.822 (±1.219)	7.521 (±1.158)
Concave	17	0.58 (±0.30)	6.964 (±2.025)	8.075 (±2.311)	7.022 (±1.944)	7.881 (±2.403)
Sine	13	0.46 (±0.18)	6.884 (±1.209)	7.648 (±1.007)	6.919 (±1.231)	7.639 (±1.011)

2. Burst-pulsed

Burst-pulsed is secluded click trains with short inter-click-interval and greater resonance frequency. This study derived 569 burst-pulsed from the recordings. These burst-pulsed were comprised of densely packed clicks with an inter-click-interval (ICI) of less than 4.0 milliseconds (ms). All burst-pulsed sounds were categorised, including squeaks, low-frequency narrowband (LFN), creaks, and buzz. This study, however, did not measure the acoustic properties of the burst-pulsed. Despite this, the mean duration of the burst-pulsed signal was 0.215±0.316 s and it was primarily broadband, with a maximum frequency above 48 kHz.

3. Echolocation click

A click train in echolocation is a sequence of ultrasonic broadband clicks emitted at differing repetition rates. The study recorded a total of 3380 click trains from the acoustic recordings. The click trains can differ in duration and repetition rates. The duration of the non-overlapping click trains ranged from 0.02 s to 19.81 s (Mean=0.863±1.363 s, n=635), with click repetition ranging from 2 to 333 clicks per click train. Moreover, the inter-click-interval (ICI) ranges between 3 and 440 milliseconds (Mean=58.45±32.57 ms, n=635).

4. Biphonal sounds

In this study, two distinct types of biphonic sounds were identified. Biphonal sounds are comprised of two sounds that coincide and have different frequencies (Volodina *et al.,* 2006). The sounds were harvested from recordings of Irrawaddy dolphins interacting. Furthermore, it was classified into bitonal whistles (n=6) and burst-pulsed+whistles (n=5). The bitonal whistles consisted of two tonal components, one at a higher frequency and one at a lower frequency. Burst-pulsed+whistles are sounds with both burst-pulsed and whistle components. The minimum frequency of the fundamental whistles in these biphonal sounds was 5 kHz (n=11).

B. Surface Behaviour Context

The Irrawaddy dolphins were spotted travelling, foraging, socialising, and milling at various sightings throughout this study. Adults, juveniles, and mother-calf pairs were grouped, ranging from 2 to 20 individuals. The Irrawaddy dolphins made the most extended acoustic recordings while foraging (6.34 hours), preceded by travelling (0.91 hours), socialising (0.71 hours), and milling (0.48 hours) (Table 3).

Table 3. A summary of recording time and type of sounds in different surface behaviour

Surface Behaviour	**Length of Recordings (hours)**	**Types of vocalisation**		
		Whistles	**Burst-Pulsed**	**Click Trains**
Travelling	0.91	113	15	48
Foraging	6.34	356	308	3101
Socialising	0.71	289	227	231
Milling	0.48	48	19	0
Total	8.43	806	569	3380

This study also notices a 0.56-hour mixing period between Irrawaddy and Indo-Pacific humpback dolphins (*Sousa chinensis*). However, the acoustic recordings of mixing behaviour were exempted since the survey could not ascertain which species generated which sounds. Whistles and burst-pulsed sounds were detected in all of observed surface behaviours. Nonetheless, during the milling of Irrawady dolphins, the click train was not present (Figure 3).

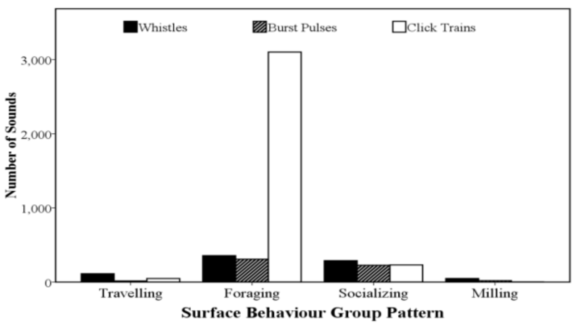

Figure 3. Distribution of three sounds in different surface behaviours

Although the numbers of recorded whistles were high during socialising, the Irrawaddy dolphins also produced whistles while foraging, travelling, and milling. There was a statistically significant difference between the whistle rates across different behaviours (Kruskal-Wallis (H)=11.66, df=3, p<0.05), with a mean rank of 26.5 for milling, 23.8 for travelling, 22.4 for socialising and 10.2 for foraging. The number of clicks trains counted during foraging was the highest of the clicks trains recorded during travelling and socialising. However, statistical tests showed significant differences in the click train rates between the behaviours (H=12.79, df=2, p<0.05), with a mean rank of 88.7 for socialising, 73.1 for foraging and 52.36 for travelling. As for the burst-pulsed, the difference in burst-pulsed rates was not statistically significant across all behaviours (H=5.12, df=3, p>0.05). Figure 4 shows a box plot for each of the sound rates of the Irrawaddy dolphins across behaviours.

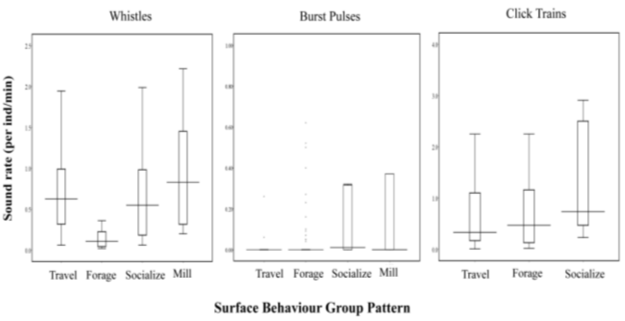

Figure 4. Boxplots of the rates (number of sound/individual/minute) of the three types of sounds in each surface behaviour

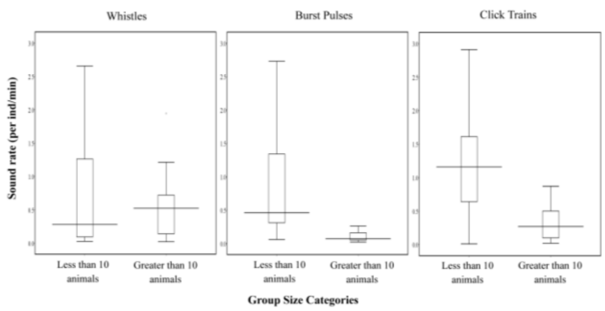

Figure 5. Boxplot of the rates (number of sound/individual/minute) of the three types of sounds in different group size

During this study, the mean group size of the Irrawaddy dolphins was 8±6 individuals. Almost 60% of the sightings occurred with less than ten individual groups. The majority of the foraging events were groups of less than ten individuals. The proportion of group sizes was approximately the same across the behaviours. There was no significant difference in whistle rates across group size classes (Mann-Whitney, U=181, p>0.05). Still, the click trains rates (U=159.5, p<0.05) and burst-pulsed rates (U=15, p<0.05) showed significant differences across group size categories. From Figure 5, both sounds were highly emitted when animals were in groups of less than ten animals.

C. Discussions

1. Sightings of Irrawaddy dolphins

Irrawaddy dolphins can be seen throughout the year, particularly near to the shore (<10 km). This study relied on visual observation, acoustic recordings, and monitoring to spot all sightings. The observations made from this research are deemed reliable because Mahmud *et al.* (2018) validated several Irrawaddy dolphin populations in Brunei Bay, which enabled a more practical search effort. The survey route was modified to fit the areas where Irrawaddy dolphins were oftenly sighted during the day.

Photo-identification is a critical instrument for approximating and assessing population size (Hammond *et. al.,* 1990; Parra & Corkeron, 2001). The procedure entails capturing and cataloguing dorsal fins, marked with distinct and permanent marks that enable identification. Due to their elusive nature, not all of the dorsal fins photographed were in the finest identification condition. Images must be captured perpendicular to the dolphin's body axis and concentrated on the dorsal section of the body. Vessel strikes could have caused the deformation, cuts, and scars on the dorsal fins, illnesses, or even confrontations between individuals (Gowans & Whitehead, 2000; Scott *et. al.,* 2005; Tongnunui *et al.,* 2011). Dorsal photographs from juveniles and calves were not used for identification due to the lack of distinguishing and lasting characteristics that enable recognition (Parra & Corkeron, 2001). Moreover, the presence of calves throughout the survey indicates that the population of Irrawaddy dolphins in Brunei Bay is still growing and is probably higher than previously expected by Mahmud *et al.* (2018). Repetitive sightings of identified individuals were confirmed by photo-identification, inferring that the animals belonged to the same group but were split into subgroups.

2. Sounds and surface behaviour context

This study examined 8.43 hours of Irrawaddy dolphin acoustic recordings from Brunei Bay. The findings show that Irrawaddy dolphins make whistles, burst-pulsed click trains, and biphonal sounds. Conversely, the Irrawaddy dolphins in Bangladesh did not generate a whistle (Rocco, 2009). It was under the impression that Irrawaddy dolphins did not produce whistles. In addition, it was also presumed that the whistles heard in Mahakam River and Balik Papan were most probable from other dolphin species that reside in the same territory (Kreb, 2004). Nonetheless, subsequent research in Matang (Hoffman *et al.,* 2017) and this current study demonstrated Irrawaddy dolphins whistle. It is conceivable that the lack of whistle production by Irrawaddy dolphins in the Bangladesh population is associated with the behavioural context. The Irrawaddy dolphins were most likely foraging when the recordings were made in Bangladesh, so the animals would have preferred to echolocate rather than a whistle.

Moreover, this study also acknowledged that the whistle rates of Irrawaddy dolphins are highly reliant on their behaviour. When foraging, Irrawaddy dolphins produced a lower whistle rate (0.02 whistles/individual/minute) compared to socialising (0.54 whistles/individual/minute) or milling (0.65 whistles/individual/minute). Whistles are considered the main communication signal in delphinids (Bazúa-Durán & Au, 2004; Herman & Tavolga, 1980). Hence, it is relatable that the whistle rate of the Irrawaddy dolphins is low during foraging sessions. The Irrawaddy dolphins made more whistles when travelling in Balik Papan and the Mahakam River (Kreb, 2004), commonly due to the animals needed to sustain group cohesion while moving. However, when the dolphins are milling, it allegedly has fewer activities, minimal physical interaction, and a lower whistle rate. The Irrawaddy dolphins may intensify the whistle rate to ease the transition from milling to other behavioural patterns (Quick & Janik, 2008, 2012). Additionally, when communicating in larger groups, it may use distinct sounds or generate signature whistles (Kriesell *et. al.,* 2014; Quick & Janik, 2012). Irrawaddy dolphin populations may have used individual signature whistles in Mahakam and Balik Papan (Kreb, 2004). Acoustic recordings made during socialisation revealed that Irrawaddy dolphins could use signature whistles. However, further investigation is required to establish the "signature whistles" theories for the Irrawaddy dolphins.

Burst-pulsed sounds are composed of a rapid click train and are classified as bray calls, moans, grunts, rasps, and barks/quacks that produce a "buzz" or "creak" sound (Janik, 2009; Kreb, 2004; Rankin *et al.,* 2007). Burst-pulsed were substantially more prevalent in smaller groups than in larger groups. As opposed to whistles, Burst-pulsed signals were hypothesised to function as a more personal form of communication (Blomqvist & Amundin, 2004; Lammers *et al.,* 2006). For both Atlantic spotted dolphins (*Stenella frontalis*) and bottlenose dolphins (*Tursiops truncatus*), burst-pulsed production has been interconnected to courtship behaviours and distress responses (Blomqvist & Amundin, 2004; Herzing, 1996). Even though burst-pulsed neurons have been related to aggressive social interactions, they may also contribute to echolocation (Yoshida *et al.,* 2014). There was no difference recorded in the burst-pulsed rates throughout the behaviours in this study.

Intriguingly, there was no correlation between the findings from this study and those from the population of Irrawaddy dolphins in Balik Papan (Kreb, 2004). Burst-pulsed recordings in Balik Papan have been reported to be most frequent during milling. Feeding has been connected to burst-pulsed like bray calls (Janik, 2000; King & Janik, 2015). Risso's dolphins (Grampus griseus) have been noticed producing burst-pulsed sounds while socialising and foraging (Neves, 2013). Meanwhile, barks were associated with socialising in humpback dolphins (Van Parijs & Corkeron, 2001). Acoustic recordings with higher frequency response, as described by Buscaino *et al.* (2015), will benefit future investigation of the various types of burst-pulsed and their acoustic characteristics.

Milling was the only behaviour in which click trains were absent. Nonetheless, when the Irrawaddy dolphins were socialising, the click train rates were significantly higher. Clicks were observed across all behaviours in Commerson's dolphins (*Cephalorhynchus commersonii*), with buzz clicks being relatively high throughout foraging (Reyes Reyes *et al.,* 2016). Clicks have been evidenced more often in foraging by Indo-Pacific humpback dolphins, Australian snubfin dolphins, Pacific white-sided dolphins (*Lagenorhynchus obliquidens*), and killer whales *(Orcinus orca*) (Henderson *et. al.,* 2011; Simon *et. al.,* 2007; Van Parijs & Corkeron, 2001). The variation in click train rates across behavioural patterns could be related to the undervaluation of click trains. It can be challenging to distinguish overlapping click trains from multiple individuals. Therefore, click trains that overlapped were excluded from consideration, which may have contributed to the study's low click train rates for some behaviours. However, it is possible that the overlapping click trains were grouped as a single train, lowering the click train rates. Besides, since the recording systems used in this study had a frequency response of less than 48 kHz, high-level click trains that may have occurred during foraging may have gone undetected (Soldevilla *et al.,* 2008).

Biphonal sounds are ubiquitous in fish, primates, and even cetaceans (Rice *et. al.,* 2011; Corkeron & Van Parijs, 2001; Filatova *et. al.,* 2009; Kaplan *et. al.,* 2017; Papale *et al.,* 2015). Nevertheless, no such sound has been encountered from Irrawaddy dolphins. It has been proposed that biphonal sound is essential in group coordination and presumably in individual identification (Miller, 2002; Papale *et al.,* 2015). During socialising, biphonal sounds were witnessed in this study. In multipod aggregations, killer whales used biphonal calls (Filatova *et al.,* 2009). Younger Atlantic spotted dolphins have been evidenced to produce biphonal sounds consisting of burst-pulsed whistles (Kaplan *et al.,* 2017). Additionally, bottlenose dolphins have exhibited biphonal sounds comprised of two whistles (Kriesell *et. al.,* 2014; Papale *et al.,* 2015). Due to the small number of sizes (n=11), this study was unable to provide in-depth descriptions of the biphonal sounds. Hence, more variation of biphonal sounds should also be recognised in future studies with larger samples. It will facilitate a better comprehension of these sounds in the Irrawaddy dolphins.

IV. CONCLUSION

The findings on acoustic repertoires of Irrawaddy dolphins in Brunei Bay are consistent with previous research on the production of delphinid sounds. It was recorded that the dolphins generate whistles, burst-pulsed trains, and click trains. Indeed, there are distinct differences in the types of sounds and the rates at which they are produced across different behaviours. This research also discovered biphonal sounds and potentially signature whistles in the acoustic repertoire of Irrawaddy dolphins. Nevertheless, the sample size and recording system limitations did not permit supplementary sound descriptions.

Henceforth, this study has presented critical information regarding the acoustic repertoire of Irrawaddy dolphins in Brunei Bay. The outcomes will significantly accelerate research on Irrawaddy dolphins by accumulating larger acoustic samples from the animals. Further research into the variation of sounds among different populations of Irrawaddy dolphins offers the opportunity for larger-scale passive acoustic monitoring of this species.

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