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Preliminary analysis of echolocation signals produced by fleeing Irrawaddy dolphins (*Orcaella brevirostris*)

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Abstract

In this study, echolocation signals were recorded from a wild Irrawaddy dolphin (*Orcaella brevirostris*) in shallow water in the Bay of Brunei. During sound recording, a small fishing boat engine startled a nearby Irrawaddy dolphin and began chasing it on two occasions. Variations in the acoustic parameters were detected. When the Irrawaddy dolphin was startled and chased, the sound pressure level, number of click trains per minute, pulse number, and average inter-pulse interval (PI) per click train were all affected. The PI increased and exhibited a slight downward trend during the chase. The increase in PI indicated an increase in the inspection distance as the dolphin escaped. Thus, Irrawaddy dolphins may adapt their echolocation signals to stand out from ambient noise in the wild and to improve their search efforts in potentially risky situations. Appropriate management of the burst noise around the dolphins is important.

Key words: click train, echolocation signal, Irrawaddy dolphin, signal change

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1 Introduction

The Irrawaddy dolphin (*Orcaella brevirostris*) is a small cetacean found in Southeast Asia and the Bay of Bengal (Beasley et al., 2013). The Irrawaddy dolphin is on the IUCN Red List of Threatened Species (Reeves et al., 2008). This dolphin is sometimes called the Irrawaddy river dolphin but it is not a true river dolphin; instead, it is an euryhaline dolphin that lives in brackish water near coasts, river mouth and estuaries. The Irrawaddy dolphin has established subpopulations in freshwater rivers, including the Ganges and Mekong, as well as the Irrawaddy River, after which it was named. The total population appears to comprise over 7 000 and over 90% occur in Bangladesh. Irrawaddy dolphins are often seen in estuaries and bays in Borneo, and sightings range from Sandakan in Sabah to Sarawak, Malaysia, and most parts of Brunei.

Few studies have investigated the biosonar signals and behavioral responses of this endangered species. Jensen et al. (2013) reported details of the signals produced by Irrawaddy dolphins in the Bangladesh part of the Sundarban mangrove, which were recorded in 2010. They demonstrated that these animals use consistently lower source levels and higher repetition rates than oceanic delphinids as an adaptation to the shallow, acoustically complex habitat with high amounts of reverberation and acoustic clutter.

In this study, we performed a joint visual–acoustics survey in the shallow water of the Bay of Brunei. During sound recordings, a small fishing boat engine startled a nearby Irrawaddy dolphin and another boat began chasing it on two occasions. In the following, we present and discuss our preliminary analysis of the echolocation signals (click trains).

2 Materials and methods

Echolocation signal recordings were obtained of the Irrawaddy dolphin (*Orcaella brevirostris*) in the shallow waters of the Bay of Brunei, Sarawak, Malaysia. This bay is near a main habitat of the Irrawaddy dolphin (Fig. 1). The data set was collec-

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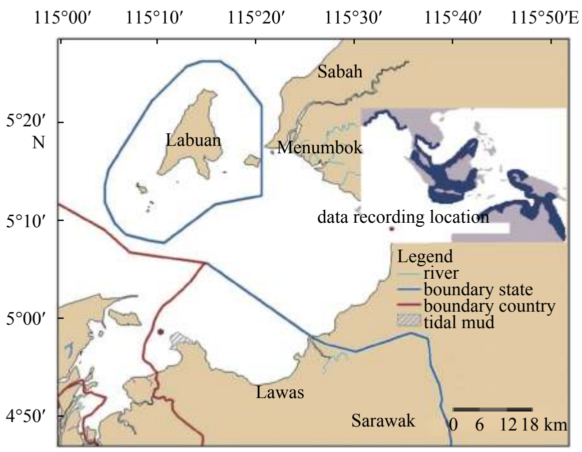

Fig. 1. Map of the study area. The red hexagram shows the study site. The inserted schematic map shows the geographic range (blue color) of Irrawaddy dolphin sightings (Stacey and Arnold, 1999; Arnold, 2002) and the location of the current study.

ted from a fishing boat on October 8, 2015. The boat was anchored away from other boat traffic and a joint visual–acoustics survey was performed to confirm that the recorded signals originated from Irrawaddy dolphins. Furthermore, no other dolphin species or marine mammals were observed in the study area during the time the recordings were made.

A voice recorder with a single hydrophone and two miniature stereo acoustic data-loggers (A-tag, Marine Micro Technology, Saitama, Japan) were employed at a depth of around 1 m below the surface. The voice recorder with a hydrophone was placed in the middle of the boat, and the two A-tags were 1 m and 10 m behind the boat.

The voice recorder data was coded as 16 bits and sampled at 24 kHz. The recording period started at 10:40 am and ended at 11:07 am. During the sound recording period, a small fishing boat engine startled a nearby Irrawaddy dolphin. Another boat then began chasing the dolphin on two occasions. These events corresponded to the sound recording time between 17 min and 20 min (approximately 10:57 to 11:00).

Each A-tag contained two external hydrophones, which were approximately 190 mm apart. The hydrophone sensitivity was –200 dB re 1 V/μPa at 100 kHz (70–130 kHz, bandwidth=5 dB). A band pass filter of 55–235 kHz was employed to match the frequency band of Irrawaddy dolphin biosonar signals, which range from 65.2 to 125 kHz with an average of (100.7±19.9) kHz (Jensen et al., 2013). The A-tags were used to detect the high-frequency echolocation click events of dolphins, which recorded and stored the sound pressure level (SPL) and the time difference (TD) (Akamatsu et al., 2005a). They did not record the waveforms of the received sound signals.

The A-tags detected the received sound pressure and calculated the peak-to-peak SPL. For reference, we considered the peak-to-peak source levels (SL) reported by Jensen et al. (2013), which are the only SLs recorded in the wild habitat for this species, where they ranged from 68.6 to 79.5 dB referred to 1 Pa with an average of 74.5 dB (N=15). A decrease of 20 dB was considered between the on-axis and off-axis SL. We set the detection threshold level of this data logger at 4.2 dB and a maximum propagation loss for detecting signals of 50.3 dB was allowed. Assuming a simple spherical propagation model based on the freshwater values specified by Fisher and Simmons (1977) (absorption coefficient of 0.004 dB/m at 100 kHz), the maximum detection distance of the stereo acoustic data logger was approximately 290 m.

TD was calculated in counts based on the difference in the time of arrival between the two external hydrophones. To determine the differences in the time of arrival, the signal recorded by one hydrophone was cross-correlated with the signal recorded by the other hydrophone, excluding surface reflections. One count denoted the monitored triggering time from both hydrophones, which was 271 ns (i.e., using a sampling operation at 3.7 MHz). Thus, the maximum TD was 475 counters.

The inter-pulse interval (PI) was defined as the time between each pulse and the previous pulse. The distribution of the PIs for on-axis clicks in the free-ranging Irrawaddy dolphin had a local minimum around 20 ms and a local maximum near 230 ms, with a mean ± standard deviation of (44.8±24.6) ms (Jensen et al., 2013). The PI values for on-axis clicks were higher than the PI values measured across the entire click series, and thus most of the PI values were shorter than 230 ms.

An automated off-line filter was used to extract click trains with Igor Pro 6.03 (WaveMetrics, Lake Oswego, OR, USA). The characteristics of the smooth changes in the patterns of the PIs and received sound pressure (Akamatsu et al., 2005a) were used to identify dolphin signals. No other cetacean species was observed during the chasing events, so species identification was not required.

3 Results

A fishing boat was near our observation vessel and the engine was shut down. An Irrawaddy dolphin was observed at about 10:45. Several minutes later, the men on the fishing boat spotted the dolphin and turned on the engine, before the dolphin was chased by another boat. The dolphin was startled and began to swim away. The chase was recorded by the voice recorder and the two A-tags.

The signal shown in Fig. 2 was acquired between 17 and 20 min from the voice recorder data (approximately 10:57 to 11:00) when the boat startled the dolphin and another boat chased it. The first box with a solid line indicates the engine starting and the next two boxes with solid lines are related to the chasing sound from the boat's engine, thereby indicating that the time of this occur-

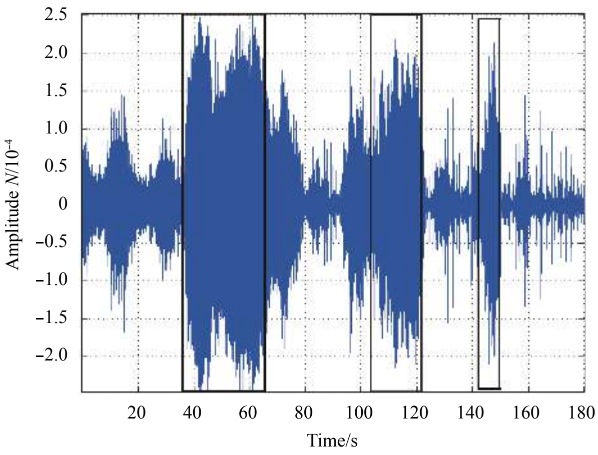

Fig. 2. Time signals containing wild Irrawaddy dolphin clicks. The boxes with solid lines represent the acoustic signals from the boat's engine. It should be noted that the echography of the dolphin's audible click sound was masked by the boat noise.

rence was about 10:58:20. The data acquired around this time from the A-tag at 10 m behind the boat are shown in Fig. 3 and Table 1.

In Fig. 3, the slope of the TD curve indicates the speed of the dolphin. The middle panel shows that the dolphin first moved away when startled and then escaped at a higher speed when it was chased. As the distance between the A-tag and the dolphin increased, the SPL also became larger than it was before and after the chasing event (Fig. 3, top panel). PI increased slightly when the dolphin was chased (Fig. 3, bottom panel).

Table 1 shows the statistics for the click events before, during and after the boat noise affected the dolphin (Fig. 3), where an event was a click train. When the dolphin was chased, 14 events were recorded per second. Before and after the chase, no more than three click events were recorded per second and the number of click events increased sharply during the period of the chase. The pulse number per click event basically remained unchanged in the period when the dolphin was chased by the boat (the time is shown in Fig. 2).

Dolphins use click trains as echolocation signals (Au, 1993). Thus, when a dolphin is swimming quickly, the environment is changing rapidly, so click events should also occur frequently. In a biosonar system, an additional lag time is required within each PI for animals to process the returning echoes (Au, 1993) and this lag time is conservatively assumed to be no more than 5 ms. Given that the acoustic speed is a simple fixed value, i.e., 1 500 m/s

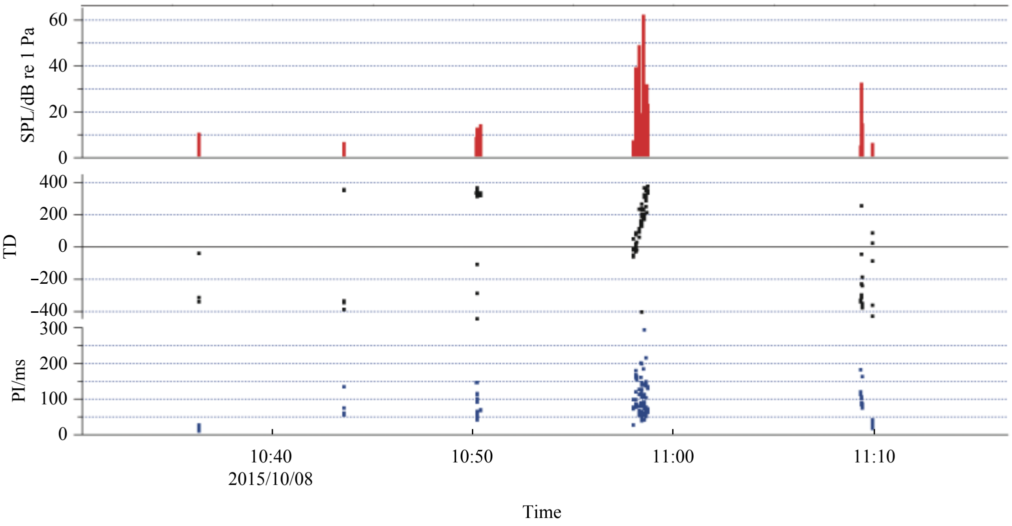

Fig. 3. Echolocation click trains acquired from the Irrawaddy dolphin passing by the acoustic data-logger (A-tag located 10 m behind the boat).

Table 1. Statistics for the echolocation click events acquired from the Irrawaddy dolphin passing by the acoustic data-logger (A-tag located 10 m behind the boat).

	Time (year/month/day hour:minute)	Pulse number of an event	Duration of an event/ms	Average inter-pulse interval of an event/ms
Events before the boat chasing	2015/10/8 10:43	5	321. 9	80.5
	2015/10/8 10:50	8	674.4	96.3
	2015/10/8 10:50	9	526.4	65.8
	2015/10/8 10:50	5	270.5	67.6
Events during the boat chasing	2015/10/8 10:58	5	269.0	67.3
	2015/10/8 10:58	5	474.0	118.5
	2015/10/8 10:58	6	565.0	113.0
	2015/10/8 10:58	5	477.4	119.3
	2015/10/8 10:58	10	658.0	73.1
	2015/10/8 10:58	5	275.5	68.9
	2015/10/8 10:58	5	561.0	140.3
	2015/10/8 10:58	19	1 680.3	93.3
	2015/10/8 10:58	9	903.9	113.0
	2015/10/8 10:58	5	308.0	77.0
	2015/10/8 10:58	6	374.0	74.8
	2015/10/8 10:58	5	273.5	68.4
	2015/10/8 10:58	7	615.4	102.6
	2015/10/8 10:58	6	459.4	91.9
Events after the boat chasing	2015/10/8 11:09	10	988.4	109.8
	2015/10/8 11:09	5	400.5	100.1
	2015/10/8 11:09	6	131.0	26.2

in water, the acoustically inspected distance was calculated based on the two-way distance travelled by sound during the average PI shown in Table 1 minus the lag time (Akamatsu et al., 2005b) (Fig. 4). The average distance inspected for the dolphin was 67 m with a maximum of up to 101.5 m. The acoustically inspected distance was far greater than the distance travelled subsequently in silence, thereby indicating that the dolphin inspected an area in advance before swimming into it silently (Akamatsu et al., 2005b).

Figure 5 shows the details acquired during the chasing event (from 10:57:45 to 10:59:00). TD changed from a negative value to a positive value, thereby indicating that the animal swam from one side of the A-tag to the other, and this was consistent with the visual observations. The trend in the SPL increased before declining, and the PI had a slight decreasing trend. Based on Figs 5 and 2, the echolocation signal level of the dolphin could be separated from the background noise. The noise from the engine was great, so the SPL was high.

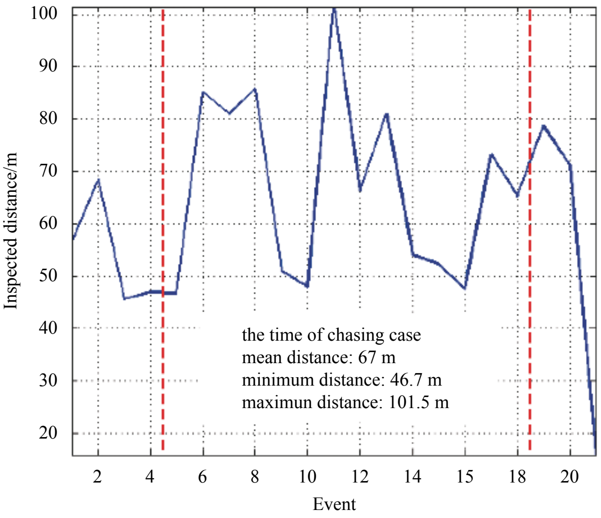

Fig. 4. Acoustically inspected distance calculated based on the two-way distance travelled by sound during a PI (Table 1). The events between the red dashed lines occurred during the chasing period. The lag time (echo signal processing duration) was assumed to be 5 ms. The median acoustically inspected distance during the chasing event was 65.7 m.

4 Discussion and conclusions

Our results showed that the click train number increased when the Irrawaddy dolphin was startled and chased. The SPL and pulse number per click train were affected by the engine noise. The average PI increased compared with that before the event and it exhibited a slight decreasing trend during the chase. Thus, the sonar signals produced by the Irrawaddy dolphin comprised high-intensity ultrasonic click trains that could be readily distinguished from ambient noise in the wild. The number of click trains emitted could have indicated the search effort of the animal. The increase in PI demonstrated that the inspection distance increased and this was related to the escape behavior of the dolphin.

Several previous studies have reported the positive response of cetaceans toward moving vessels and dolphins tend to avoid them (Aguilar and Nadal, 1984; Leatherwood et al., 1988; Goodall et al., 1988; Ng and Leung, 2003; Ribeiro et al., 2005) due to the travelling speed and noise emitted from the vessels (Richardson et al., 1995). The Irrawaddy dolphins in Cowie Bay were shown to exhibit a negative response toward moving vessels (Hashim and Jaaman, 2011), where they avoided a boat even though they were 1 km from the boat. It is possible that Irrawaddy dolphins use their biosonar systems to measure the distance to an approaching vessel and plan their escape. According to Ketten (1992), high frequency noise dissipates rapidly in water but it still causes an acoustic disturbance, especially if there is only a small distance between the dolphin and the vessel. We found that the response of the Irrawaddy dolphin to the sudden starting of an engine alerted it to engage in appropriate noise management during sudden engine operation.

The Irrawaddy dolphin that we observed being chased produced frequent sonar signal trains, thereby suggesting that the dolphin was highly reliant on its acoustic sensory systems for navigation and travelling. Prior acoustic inspection of the area ahead is essential for these animals when moving in their environment. This strategy has substantial advantages in terms of risk avoidance because the animals can detect the risk of danger as early as possible. The risks for Irrawaddy dolphins include injuries from being hit by a boat, entrapment in shallow water, and

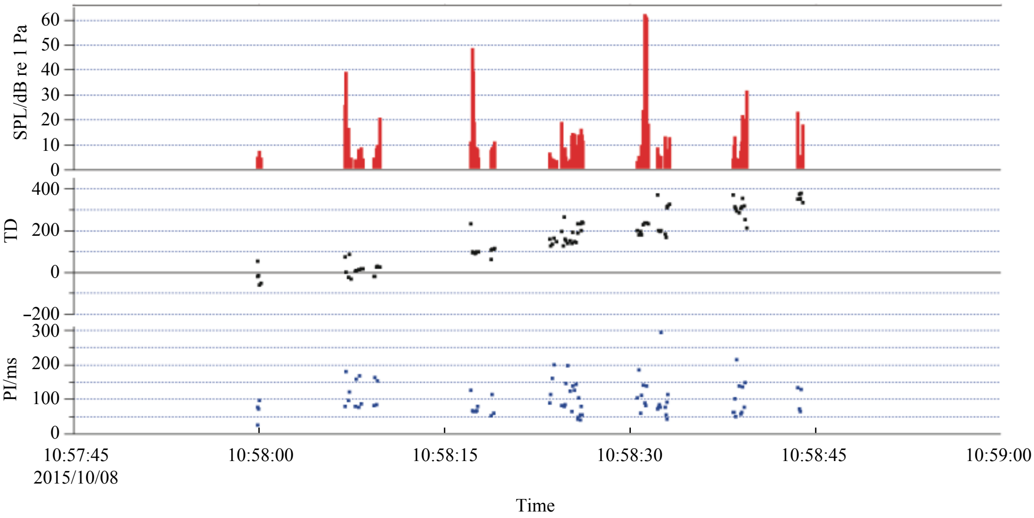

Fig. 5. Echolocation click trains while the Irrawaddy dolphin was being chased.

collisions with underwater debris and floating materials.

The limitations in terms of the detection ability of dolphins and their time-constrained search effort force them to use their systems in an appropriate manner. The Irrawaddy dolphin is a slow swimmer, although a swimming speed of 20–25 km/h was reported previously when being chased by a boat (Brian, 2008). The inspection distance for the chased Irrawaddy dolphin was as high as 101 m (Fig. 4), which could be reached within 20 s at its escape speed. Inspecting the immediate area where the dolphin is heading allows time to make decisions before encountering an actual danger. Based on the recordings obtained in this study, Figure 4 shows that the distance inspected increased three times (at Events 6, 11 and 17), thereby indicating that the escape speed increasing three times (when the dolphin was startled and chased on two occasions).

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