Acoustic occurrence detection of a newly recorded Indo-Pacific humpback dolphin population in waters southwest of Hainan Island, China

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In 2014, Indo-Pacific humpback dolphins were recorded for the first time in waters southwest of Hainan Island, China. In this paper, the temporal occurrence of Indo-Pacific humpback dolphins in this region was detected by stationary passive acoustic monitoring. During the 130-day observation period (from January to July 2016), 1969 click trains produced by Indo-Pacific humpback dolphins were identified, and 262 ten-minute recording bins contained echolocation click trains of dolphins, of which 70.9% were at night and 29.1% were during the day. A diurnal rhythm with a nighttime peak in acoustic detections was found. Passive acoustic detections indicated that the Indo-Pacific humpback dolphins frequently occurred in this area and were detected mainly at night. This information may be relevant to conservation efforts for these dolphins in the near future.

I. INTRODUCTION

Increasing exploitation of ocean resources is a significant driver of marine animals extinction (Davidson et al., 2012). Humpback dolphins (Sousa spp.) in the coastal waters of the Indo-Pacific Ocean were classified as “Near Threatened” by the International Union for the Conservation of Nature in 2008 (Jefferson et al., 2008). Range-wide incidental mortality in fishing gear and habitat degradation and loss are considered as the greatest threats to this species throughout its range (Ross et al., 1994; Jefferson and Karczmarski, 2001). However, at least three species of humpback dolphins have since been identified in the Indo-Pacific region, including Indian humpback dolphin (S. plumbea), Indo-Pacific humpback dolphin (S. chinensis), and Australian humpback dolphin (S. sahulensis) (Jefferson and Rosenbaum, 2014). The identification of multiple species led to a re-evaluation of these smaller taxonomic units under the IUCN criteria. In 2016, a revised assessment proposed a status of “Vulnerable” (VU) for the Indo-Pacific humpback dolphin (Jefferson and Smith, 2016), which ranges from the eastern India throughout Southeast Asia to central China (Jefferson and Rosenbaum, 2014). In China, the Indo-Pacific humpback dolphin has been listed as one of the Grade 1 National Key Protected Animals by China’s Wild Animal Protection Law issued in 1988. This designation requires the same priority of protection as the Yangtze River dolphin (baiji, Lipotes vexillifer), which may already be extinct (Turvey et al., 2007). With the increasing resources exploitation in southeast China coastal waters, Indo-Pacific humpback dolphins are facing many anthropogenic threats such as habitat degradation or destruction, harassment (by-catch or injuries), overfishing, water pollution, and noise pollution (Jefferson and Hung, 2004; Li et al., 2015; Wang et al., 2015a; Karczmarski et al., 2016; Liu et al., 2017). However, the population size and distribution range of this species in Chinese waters have not yet been adequately investigated and scientifically reported. According to previous studies, Indo-Pacific humpback dolphins were sporadically distributed from the Beibu Gulf to the mouth of the Yangtze River (Corkeron et al., 1997; Jefferson and Karczmarski, 2001), with the southernmost records in the Chinese waters of the Beibu Gulf (Wang and Sun, 1982). However, according to local ecological knowledge and line transect boat-based surveys conducted since 2013, a new Indo-Pacific humpback dolphin population in waters southwest of Hainan Island was recorded in 2014 for the first time (Li et al., 2016), which extends the currently known distribution range of the Indo-Pacific humpback dolphin more than 300 km southward in Chinese waters (Li et al., 2016). The temporal occurrence pattern of this new population, as well as its size, local distribution pattern, and connections to other known populations need to be investigated. In this paper, we describe the temporal occurrence pattern of Indo-Pacific humpback dolphins in waters southwest of Hainan Island using stationary passive acoustic monitoring (PAM) data. The result aims to provide baseline information for conservation of the local Indo-Pacific humpback dolphins.

Like other small odontocetes (Au and Hastings, 2008), Indo-Pacific humpback dolphins have highly developed sound production ability, and frequently produce echolocation clicks, which they use mainly for navigation and foraging (Li et al., 2013; Kimura et al., 2016; Fang et al., 2015).
Previous studies of a population of Indo-Pacific humpback dolphins in Sanniang Bay, China, produced echolocation clicks with peak-to-peak source levels ranging from 177 to 207 dB re 1 μPa at 1 m, with an average of 187.7 dB (Fang et al., 2015). The mean peak frequency was 109.0 kHz with a 3-dB bandwidth of 50.3 kHz (Fang et al., 2015). PAM methods, capable of detecting high frequency echolocation clicks of the Indo-Pacific humpback dolphins, were found to be effective for documenting their underwater temporal occurrence patterns (Lin et al., 2015; Wang et al., 2015b). Compared with visual surveys and boat-based moving PAM, stationary PAM is a relatively inexpensive solution for long-term monitoring of phonating cetaceans underwater (Mellinger et al., 2007; Li et al., 2010), and could be conducted continuously during the daytime and night even in rough weather conditions (Mellinger et al., 2007; Li et al., 2010). In addition, data obtained from stationary PAM can also avoid potential biases in visual surveys by different human observers (Mellinger et al., 2007).

II. METHODS

A. Research site and device deployment

PAM was carried out at a monitoring site, approximately 5 km off the Meilian village, Sanya, and 3 km away from the Xigu Island, Sanya, China (E 108°57′06.8″, N 18°20′56.7″, Fig. 1) between January 21 and July 22, 2016. Boat-based monthly visual surveys were conducted in advance in this area for nearly two years since 2014. During the visual surveys, only Indo-Pacific humpback dolphins were observed. The monitoring site was selected according to the result of the visual surveys, as most Indo-Pacific humpback dolphins in the investigated area were encountered in waters around it (Li et al., 2016). An acoustic device was fixed on a stainless-steel bar of a customized platform sitting on the ocean floor (Fig. 1). The platform mainly consists of a concrete part and a frame structure which is made of stainless-steel, and functioning to protect the acoustic device inside the frame structure (Fig. 1). The platform is 1.2 tons in weight and 3 m in height. The fixed acoustic device was positioned at approximately 1.5 m above the ocean floor and 8.5 m below the water surface at the deploying site with the water depth of about 10 m. It was retrieved and replaced once every month. The area around the monitoring site is characterized by a sandy–muddy bottom between 10 and 15 m water depth.

B. Acoustic device for PAM

To monitor dolphin echolocation clicks, a T-shaped self-contained and submersible acoustic data logger (A-tag, ML200-AS2, Marine Micro Technology, Saitama, Japan) was used. The device logged the occurrence of high frequency sonar pulse events, but did not record acoustic waveforms (Li et al., 2010). The A-tag consisted of two ultrasonic hydrophones (the sensitivity of −201 dB re 1 V/μPa, a frequency response ranging from 100 to 160 kHz, ±5 dB), a band-pass filter (−3 dB with a range of 55 to 235 kHz), an analog-to-digital converter, a CPU (PIC18F6620; Microchip Technology Inc., Chandler, AZ) for system control and data processing, a 128 MB flash memory module for data storage, and two UM-1 batteries in a waterproof cylindrical aluminum case (Akamatsu et al., 2005). The two hydrophones formed a stereo hydrophone array with a fixed distance of 590 mm (long baseline). The sampling interval of the T-shaped A-tag was 2 ms (corresponding to sample rate of 500 Hz). When one of the hydrophones was triggered by a signal exceeding a predetermined received level threshold, the time difference of arrival (TD) of the detected signal between the two hydrophones with a resolution of 1084 ns; sound pressure and the time were recorded as a sound pulse event. If no sound exceeded the threshold level, the A-tag would not record anything to save memory and battery.

FIG. 1. (Color online) Map of the acoustic monitoring site. The A-tag was deployed on a customized monitoring platform, which was illustrated at the lower-right corner.
The dynamic range of peak-to-peak sound levels for the A-tag was from 129 to 160 dB re 1 μPa with an internal thermal noise of approximately 134 dB (peak-to-peak). In this study, the detection threshold level of 135.8 dB re 1 μPa was manually set for the A-tag to minimize impact from its internal thermal noise.

C. Acoustic data analysis

Acoustic data recorded by the A-tag were downloaded to a standard laptop each time the A-tag was retrieved. Sonar pulse events of dolphins were extracted from the acoustic data using custom software written in Igor Pro 5.01 (WaveMetrics Inc., Lake Oswego, OR). The software was originally developed by Tomonari Akamatsu, and is freely available online (Akamatsu et al., 2011). Several discriminating parameters set in the software were used to recognize sonar pulse events of dolphins, including the minimum number of pulses and the maximum duration of inter-click interval (ICI) in a click train, and changing patterns of the ICI between two adjacent pulses. According to previous publications (Akamatsu et al., 2007; Kimura et al., 2010; Wang et al., 2014), the minimum number of pulses and the maximum duration of ICI in a click train were set at 5 and 200 ms, respectively; ICIs of the click trains have smoothly changing patterns with each ICI greater than half and less than twice of the previous one. In addition, pulses recorded within 2 ms after the detection of direct path pulse were eliminated as surface or bottom reflections (Kimura et al., 2010). The sound pressure level (SPL), TD, and ICI of click trains produced by dolphins are shown in Fig. 2 as an example. After the click trains were extracted, a manual examination was performed to eliminate false detections such as ship noise and sounds made by snapping shrimp, which were characterized by randomly changing SPLs or/and ICIs (Akamatsu et al., 1998).

D. Statistical analysis

All the acoustic data were grouped into non-overlapping 10-min bins, which began on the hour to analyze the click train events for different hours and diel phases. An acoustic detection was defined as a 10-min bin containing dolphin click trains. This metric conservatively indicates temporal occurrence of animals. The whole day was divided into two consecutive diel phases (day and night) by time of sunrise and sunset. The time boundaries for different diel phases were also rounded to the nearest 10-min bin. Each acoustic detection was assigned to an appropriate diel phase. During the study period, the time of sunrise and sunset at the acoustic monitoring site were obtained from the website of the US Naval Observatory (2016).

Hourly occurrence of dolphins at the acoustic monitoring site was calculated as the probability of acoustic detection [mean, standard error of the mean (SEM)] as a function of time of the day (o’clock, GMT+8) over the entire recording period. To examine the potential diurnal rhythm of temporal occurrence of dolphins, a cosinor analysis was used to analyze the rhythm during a period (Lentz, 1990). A function of \( y = m + A \cos(t - \phi) \) was fitted, where \( m \) is the mean value; \( t \) is the time; \( A \) is the amplitude; and the acrophase \( \phi \) is the peak time of the rhythm (Batschelet, 1981). A zero-amplitude test was used to examine the significance of diurnal rhythm.

To examine the difference in detection rates of dolphins between day and night, acoustic detection probabilities during the day and night were calculated for each day as the total number of acoustic detections during the day and night per day, divided by the total number of 10-min bins of the day time and night time, respectively. The acoustic detection probability means the average acoustic detection rate in each 10-min bin (the maximum value is 1). The acoustic detection datasets were tested for normality with a Kolmogorov–Smirnov test. When datasets were not normally distributed (\( p < 0.05 \)), a Mann–Whitney nonparametric test was used to examine the difference in the acoustic detection probabilities of dolphins between day and night. PASW Statistics 18.0 for Windows (SPSS Inc., Chicago, IL) was used to perform the statistical analysis. The critical statistical level of significance was set to 0.05.

III. RESULTS

During the monitoring period from January 21, 2016 to July 22, 2016, acoustic data from 130 days of recording were obtained. A total of 17 876 ten-minute bins were recorded, in which 262 bins (accounting for 1.5% of all 10-min bins) were confirmed to contain dolphin echolocation click trains with 1969 click trains identified. Sixty-nine recording days (accounting for 53.1% of all recording days) had at least one acoustic detection (Fig. 3 and Table I). Figure 4 shows the
number of acoustic detections per day, which varied from 0 to 16. The maximum number of 16 detections in a single day was recorded on June 12, 2016.

The mean probability of acoustic detection as a function of time of the day (o’clock, GMT+8) is shown in Fig. 5. The highest value of 0.214 was recorded at 23:00, and the lowest value of 0.008 was recorded at 7:00. Acoustic detections were concentrated during the night (between 21:00 and 4:00 local time). A 24-h time scale was used for the cosinor analysis. The cosinor function was fitted as $y = 0.087 + 0.065 \times \cos(t + 5.93)$ [sum of squared error (SSE) = 0.022, root-mean-square error (RMSE) = 0.033, $R^2 = 0.69$]. The cosinor analysis revealed a significant diurnal rhythm with the peak in acoustic detections at night for the entire monitoring period (Zero-amplitude test, $p < 0.001$, Fig. 5).

Acoustic detections at the night and day account for 70.9 and 29.1%, respectively. The difference in the acoustic detections of dolphins between the day and night for each day is shown in Fig. 6. Day and night values are indicated by asterisks and dots, respectively. The ranges of acoustic detection probabilities during the day and night are from 0 to 0.076 and from 0 to 0.246, respectively. The datasets were not normally distributed (one-sample Kolmogorov–Smirnov test, $p < 0.01$). Therefore, a Mann–Whitney test was performed, and a significant difference in the acoustic detections of dolphins between the day and night was confirmed ($p < 0.01$). The probability of acoustic detections during the night was significantly higher than that during the day.

**IV. DISCUSSION**

Odontocetes (including toothed whales, dolphins, and porpoises) are known to produce clicks used for echolocation to gather information from the surrounding environment during travelling, foraging, and social activities (Au, 1993; Au and Hastings, 2008). Although frequency ranges of odontocete clicks vary among species (Richardson et al., 1995; Erbe, 2004; Mellinger et al., 2007; Perrin and Wursig, 2009), it is still a challenge to correctly identify species by PAM. In this study, it was impossible to definitely identify species based on click events recorded by the A-tag. By local ecological knowledge interview techniques, there are Indo-Pacific finless porpoises (*Neophocaena phocaenoides*) and other unidentified small dolphins including Indo-Pacific humpback dolphins appearing in waters southwest of Hainan Island (Liu et al., 2017). However, the preferred habitat of the finless porpoise and other unidentified small dolphins usually is more than 20 km away from the shore, while Indo-Pacific humpback dolphins frequently appear in waters within 10 km off the

<table>
<thead>
<tr>
<th>Deployment Date (Y/M/D)</th>
<th>Time</th>
<th>Retrieval Date (Y/M/D)</th>
<th>Time</th>
<th>Recording duration (days)</th>
<th>Number of click trains detected</th>
<th>Total number of 10 min bins</th>
<th>Number of acoustic detections</th>
</tr>
</thead>
<tbody>
<tr>
<td>2016-1-21</td>
<td>11:48</td>
<td>2016-3-10</td>
<td>12:00</td>
<td>12</td>
<td>235</td>
<td>1562</td>
<td>42</td>
</tr>
<tr>
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<td>2016-4-22</td>
<td>11:49</td>
<td>27</td>
<td>171</td>
<td>3739</td>
<td>13</td>
</tr>
<tr>
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<td>2016-5-27</td>
<td>16:40</td>
<td>33</td>
<td>132</td>
<td>4680</td>
<td>21</td>
</tr>
<tr>
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<td>2016-6-20</td>
<td>12:45</td>
<td>25</td>
<td>785</td>
<td>3433</td>
<td>89</td>
</tr>
<tr>
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<td>2016-7-31</td>
<td>11:06</td>
<td>33</td>
<td>646</td>
<td>4462</td>
<td>97</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>130</strong></td>
<td><strong>1969</strong></td>
<td><strong>17 876</strong></td>
<td><strong>262</strong></td>
</tr>
</tbody>
</table>
coast (Liu et al., 2017). Furthermore, during our monthly visual line transect surveys of marine mammals in the inshore region of waters southwest of Hainan Island since 2014, only Indo-Pacific humpback dolphins were observed. Therefore, although we cannot completely exclude the interference from delphinids or porpoises other than Indo-Pacific humpback dolphins in this study, it is reasonable to consider that the recorded click trains were mainly produced by Indo-Pacific humpback dolphins, and the probability of detecting click trains produced by finless porpoises and other delphinids is very low.

The present study is based on a 130-day acoustic monitoring study at one site in waters southwest of Hainan Island. The number of acoustic detections is a conservative measure of the dolphin presence. This is because it only accounts for times when the animals are actively vocal. Indo-Pacific humpback dolphins were detected during almost half of the entire monitoring period and mainly in January and June (Fig. 4). This may be caused by local migration of the animals. Indo-Pacific humpback dolphins in Richards Bay, South Africa were observed to display long-distance (up to 150 km) movement patterns (Keith et al., 2002). In Algoa Bay, the migration distance of South Africa humpback dolphins were recorded up to 110 km (Karczmarski, 1996; Karczmarski et al., 1997).

Acoustic detection range of the A-tag is determined by many factors, including the intensity and directionality of echolocation click from the Indo-Pacific humpback dolphin, acoustic transmission loss, acoustic masking by the ambient noise, and the self-noise of the A-tag. The average peak-to-peak source levels of echolocation clicks was 187.7 dB re: 1 μPa on axis of the free-ranging Indo-Pacific humpback dolphins in Sanniang Bay, China (Fang et al., 2015). Acoustic transmission loss was estimated using an environment-dependent transmission loss coefficient “k” and a frequency-dependent absorption coefficient “a” (Fisher and Simmons, 1977). In this study, “k” was estimated to be 20 for spherical spreading loss in echolocation clicks (DeRuiter et al., 2010), “a” was estimated to be 0.036 dB/m by assuming an average peak frequency 109 kHz (based on echolocation clicks of the Indo-Pacific humpback dolphins in Sanniang Bay, China; Fang et al., 2015), seawater salinity of 35‰, and pH value of 8.0. In our study, the ambient noise and self-noise levels were lower than the detection threshold of the A-tag. The masking effect of the ambient noise and self-noise of the A-tag system could be ignored. Therefore, the average detection range of the on-axis Indo-Pacific humpback dolphin click could be on the order of 200 m. Dolphins outside of this range from the A-tag or oriented away from the tag would likely not be detected.

The acoustic detections of Indo-Pacific humpback dolphins in our study were mainly at night (Fig. 6). One explanation is that Indo-Pacific humpback dolphins showed a diel presence pattern around the monitoring site, and they visited the monitoring site more frequently at night than during the daytime. Alternatively, there was no diel bias for Indo-Pacific humpback dolphins, but there was a difference in echolocation activities of them between at night and during the daytime (animals may produce echolocation clicks more frequently for navigation and/or foraging at night). The diel patterns of marine mammals in previous studies varied in both beaked whales (Baird et al., 2008; Johnston et al., 2008; Arranz et al., 2011; Klinck et al., 2012; Au et al., 2013) and humpback dolphins (Lin et al., 2013; Wang et al., 2015b). Wang et al. (2015b) documented the number of echolocation detections and the biosonar activity of Indo-Pacific humpback dolphins in the Pearl River Estuary, which showed the number at night was greater than that during the daytime, while Lin et al. (2013) found that the difference in acoustic encounter rates of Indo-Pacific humpback dolphins was not significant at night and during the daytime in the Xin Huwei River Estuary, Western Taiwan. The variation in results may be caused by differences among stationary PAMs, tags, and acoustic gliders (Au et al., 2013). Acoustics tags and time–depth recorders provide a very fine temporal and spatial resolution on a few individuals during the limited time (usually less than 24 h), while stationary PAM devices can record data during a few months. Another possible reason is the difference in anthropogenic activities between regions. Dolphins may occur more frequently in regions characterized by less anthropogenic activity. The diel pattern of humpback dolphin acoustic detections in this study could also be an adaptive strategy to avoid possible intensive anthropogenic activities in the local region during the day. In addition, echolocation by marine mammals is mainly a tool for hunting, and prey availability and foraging behavior...
greatly affect predator’s distribution and echolocation activity. Previous studies showed that the concentration of finless porpoises was related to a higher density of fish (Kimura et al., 2012; Wang et al., 2014). The humpback dolphin acoustic detection is also influenced by prey (Pine et al., 2017), therefore, the diel patterns in this study could be caused by the prey availability and foraging behavior in local water areas.

Indo-Pacific humpback dolphins face great threats due to the increase in anthropogenic activities. The Indo-Pacific humpback dolphin in the Pearl River Estuary, China, which has the largest humpback dolphin population, had a continuous rate of population decline of 2.46% per annum (Huang et al., 2012). According to the recently obtained unpublished information, waters to southwest of Hainan Island could be considered as an important habitat of the Indo-Pacific humpback dolphin. Unfortunately, due to the rapid increase in human activities (i.e., harbor and artificial island constructions) in recent years, the humpback dolphin population in this water area is facing more and more survival threats, including but not limited to pollution, habitat loss and degradation, and intensive underwater noise. Although it has not been confirmed that the diel pattern in our study was an adaptive strategy of the dolphins to reduce the impact of local anthropogenic activities or not, it should be highlighted to reduce intensity of further human interference. Particularly, local underwater engineering and marine construction should avoid the peak hours of dolphin acoustic detections to mitigate any potential noise effects on dolphin activities. While this study does provide some useful information for conservation of Indo-Pacific humpback dolphins in waters southwest of Hainan Island, detailed ecology and behavior information data on humpback dolphins in waters southwest of Hainan Island is still needed to enable further effective conservation programs.

In conclusion, Indo-Pacific humpback dolphins frequently appeared in the monitoring area, and the acoustic detections occurred more frequently at night than during the daytime according to acoustic detections. In future work, to make the conclusion more solid, more monitoring sites will be required in this area to extend the range of detection. In addition, to understand the reason causing the diurnal rhythm for the echolocation, the study of click production rate of animals as well as the prey investigation should be considered because the same predator species could feed on different prey in different areas. Perhaps a tagging experiment with an acoustic logger could be used to identify day versus night click rates.

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