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Vocalization Behavior of Chinese Bahaba (*Bahaba taipingensis*) during the Reproduction Season

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Abstract: Chinese bahaba (*Bahaba taipingensis*) is a critically endangered fish species, which can produce sounds like other Sciaenidae species. In this study, sounds produced by sexually mature Chinese bahaba were recorded during the reproduction season for the first time. Two distinct types of sounds were observed during the reproduction season, termed as single drum and fast drum trains calls. Single drum callings occurred as a series of trains with rapid pulses, while fast drum trains callings were mainly made of a single signal. The single drum and fast drum trains had a peak frequency of 77.8 ± 16.2 Hz and 79.1 ± 8.7 Hz, respectively. Statistical analysis suggested significant differences in −3 dB bandwidth, signal duration, and root-mean-square sound pressure levels, except for peak frequency ($p < 0.05$) between single drum and fast drum trains sounds. Single drum occurred mainly before dawn (period range from 0:00 to 6:00 am) and less frequently after dusk (18:00–24:00 pm), and the fast drum trains occurred after dawn (6:00 am to 12:00 pm) and dusk (18:00 pm to 24:00 pm). Considering the abundance of Chinese bahaba has significantly declined, passive acoustic monitoring provides a non-invasive and low-cost effective tool to monitor sound production during reproduction season, which may help to facilitate aquaculture management and fishery population conservation in the future.

Keywords: Chinese bahaba (*Bahaba taipingensis*); sound production; acoustic features; reproduction season; passive acoustic monitoring

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1. Introduction

The teleost family Sciaenidae, including 70 genera, approximately 298 species, primarily live in turbid coastal and estuarine areas [1]. These species have high commercial and conservational values as they commonly were a major component of fishery catches and bycatches. Some Sciaenid populations, such as black drum (*Pogonias cromis*) and totoaba (*Totoaba macdonaldi*), have declined significantly in many areas due to the increasing anthropogenic activities in the oceans (e.g., overfishing, ocean pollution, etc.) and are now facing a high risk of extinction [2,3].

The development of aquaculture techniques facilitates the production of fishery resources. And in the past decades, the enhancement in aquaculture production have been witnessed in many Sciaenid species, including meagre (*Argyrosomus regius*), shi drum (*Umbrina cirrosa*), and red drum (*Sciaenops ocellatus*) [4–7]. The aquaculture production of meagre increased to 23,440 t in 2016, owing to the technology of effective spawning induction methods [5,7,8], and the red drum, a native species that inhabited the U.S. Atlantic coast down to the Gulf of Mexico, has been introduced as a commercial aquaculture species in France, Italy, and Israel. The aquaculture production of this species increased from 46,632 t in 2005 to 71,292 t in 2016 [7].

The Sciaenid family is commonly known as croakers and drummers because of its vocalization behavior [9]. Although the fishermen have used this ability to locate and capture the animals for centuries, the sound production of these species has been documented in only 24 of the 298 species [7,10,11]. The Sciaenid species use sonic muscle to contract and vibrate the inflated swim bladder to produce the species-specific drumming sound [4,12]. For example, the red drum is capable of producing low-frequency calling with main energy below 0.5 kHz and the number of pulses varying from 2 to 30 in a single sound production event [11,13]. Sciaenid species are multiple-batch spawners that could spawn several times within the reproductive period [4,14]. During these periods, the sonic muscle becomes hypertrophy-driven by androgen, which induce the variation of calling activity and temporal features of calls in Sciaenids [7,15]. For example, the red drum released a higher number of eggs, producing calls of a greater frequency and a longer duration synchronously [13]. Similarly, the large yellow croaker (*Larimichthys crocear*) generates calls with a shorter pulse period and higher peak frequency during spawning periods [15]. The evidence suggested that acoustic features could be used to predict spawning behavior in the Sciaenid family during reproduction season [7,13,15,16].

Owing to the high correlation between spawning behavior and calling activity, researchers have collected numerous acoustic features through the passive acoustic monitoring technique in the Sciaenid family during reproduction season. Additionally, this method was recognized as a non-invasive and effective method to monitor vocalization behavior [13,16]. The previous studies have reported the detailed acoustic features for a series of Sciaenid species [6,17–22]. This knowledge of sound production is vital for protecting their habitat biology in the field, which has the potential to be applied to commercial aquaculture management.

Chinese bahaba (*Bahaba taipingensis*), a member of the Sciaenid family, is one of the largest croakers. This species has a geographical distribution in the estuary areas from the Yangtze River southwards to Hong Kong in China [23]. As an endemic commercial species, the Chinese bahaba was overfished due to its economic value. This species was defined as commercially extinct in 1997. To protect the Chinese bahaba, it was listed as a Grade II state-protected species in 1988 and upgraded to Grade I in 2021. Furthermore, this species was also assessed at the level of Critically Endangered (CR) by the International Union for Conservation of Nature (IUCN red list) in 2006. Similar to most Sciaenid species, Chinese bahaba can produce species-specific acoustic signals [24,25]. However, there were no descriptions of acoustic signals in the Chinese bahaba during reproduction season. Therefore, monitoring sound production by Chinese bahaba is important for the protection and aquaculture of this endangered Sciaenid species. In the present study, the vocalization behavior of Chinese bahaba was recorded during the reproduction season for the first time. The objectives of the present study were (1) to record and describe the calling structures and characterization of Chinese bahaba during the reproductive periods; (2) to analyze acoustic features of different types of calls; (3) to investigate the temporal distribution of sound production during the acoustic monitoring period.

2. Materials and Methods

2.1. Animals Maintenance and Experimental Site

Chinese bahaba samples were maintained at Huangjing Marine Biotechnology Co., Ltd., Guangdong Province, China. These animals were rescued from the by-catch in commercial fishing and were cultured for almost three years. The acoustic recording was conducted continuously from 3 April 2022 to 13 April 2022, during the reproduction season of Chinese bahaba. A total of 8 sexually mature Chinese bahaba (5 males, 3 females), with an average weight of 23.0 ± 2.0 kg and an average length of 125.0 ± 7.1 cm, were maintained in a rectangular concrete tank (4.2 m length, 3.5 m width, 2.2 m height, 1.8 m depth). Additionally, the exogenous hormonal treatments were not used in these fishes. All animals were kept at 20–23 °C water temperature under natural light conditions.

2.2. Acoustic Recording and Analysis

The underwater acoustic data were collected using a SoundTrap ST300 HF recorder (Ocean Instruments Ltd., Auckland, New Zealand). The recorder included an omnidirectional hydrophone with a sensitivity of −188.7 dB re 1 V/µPa and a linear recording bandwidth of 20 Hz–150 kHz. The recorder was set at a 48 kHz sampling rate with a storage capacity of 256 GB. This recorder was calibrated before shipment from the manufacturer. During recording sessions, the recorder was attached to a nylon rope and deployed in the center of the rectangular concrete tank at the depth of 1.0 m below the water surface (Figure 1).

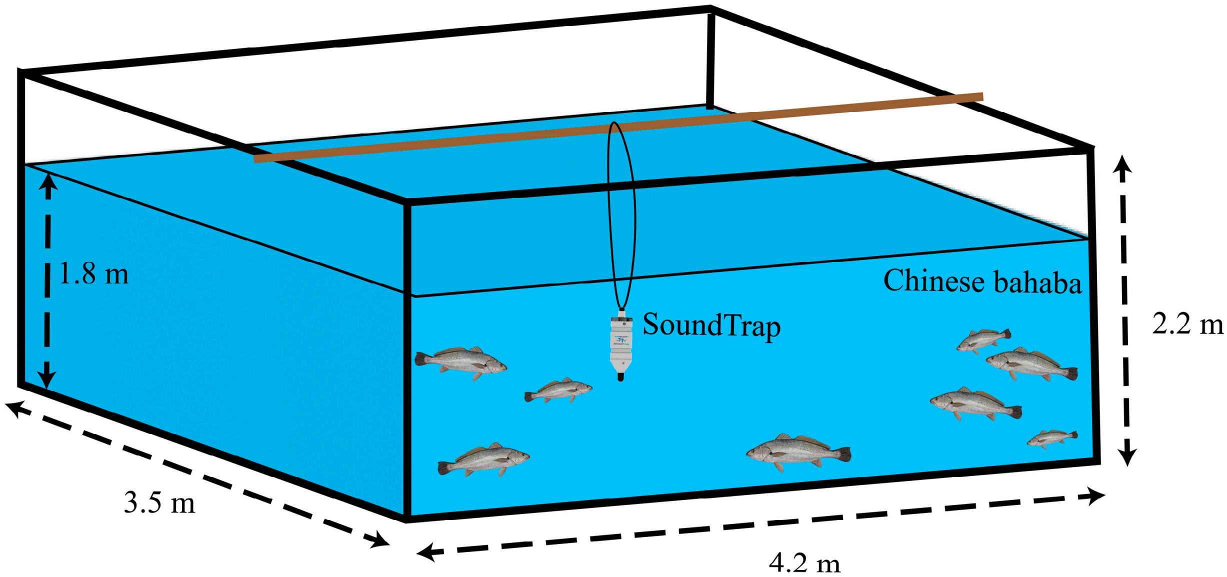

Figure 1. Acoustic recording of Chinese bahaba vocalization.

After retrieval of the recorder, the audio data (wav files) were downloaded for subsequent processing. These data were visually and auditorily examined in MATLAB (Mathworks, Natick, MA, USA). A total of 240 individual calls with a high signal-to-noise ratio (SNR) above 26.3 dB were extracted from the original acoustic files. The waveform of every individual call was checked visually. Additionally, the calls with strong reverberations were also rejected for subsequent acoustic analysis. The remaining signals were used in the the acoustic analysis by a customized routine based on MATLAB. The calls were classified into two different sound types according to their oscillograms and spectrograms, which were described as single drum and fast drum trains in the present study. Power spectra were visualized using a 2048-point fast Fourier transform (FFT). The acoustic parameters peak frequency (PF, Hz), −3 dB bandwidth ($BW_{-3\ dB}$, Hz), signal duration (DUR, ms), and root-mean-square sound pressure levels (SPL_{rms}, dB) were analyzed and used to characterize acoustic signals, which are briefly described in Table 1 [7,15,26,27]. All results were expressed as mean ± standard deviation (S.D.).

Statistical analysis was performed using nonparametric tests including the Kruskal–Wallis test and Mann–Whitney *U* test to compare the acoustic parameters (PF, $BW_{-3\ dB}$, DUR, SPL_{rms}). The significance level for these analyses were set as 0.05.

Table 1. Description of four acoustic parameters of Chinese bahaba calls.

Acoustic Parameters	Description
Peak frequency (PF, Hz)	The frequency value of peak amplitude
−3 dB bandwidth ($BW_{-3\,dB}$, Hz)	Width of the frequency band between two points that was 3 dB lower than the maximum amplitude of a power spectrum
Signal duration (DUR, ms)	Time between two points at which the time-integral energies of acoustic signals are 2.5% and 97.5%, respectively
Root-mean-square sound pressure levels (SPL_{rms}, dB).	The effective pressure level of a received sound

3. Results

3.1. Sound Characteristics

A total of 240 individual call pulses were extracted from original data.

The single drum by Chinese bahaba was usually produced as a train with a series of pulses (Figure 2a,b). A total of 90 single drum trains were recorded from the group of eight sexually mature Chinese bahaba over 11 days of the study period.

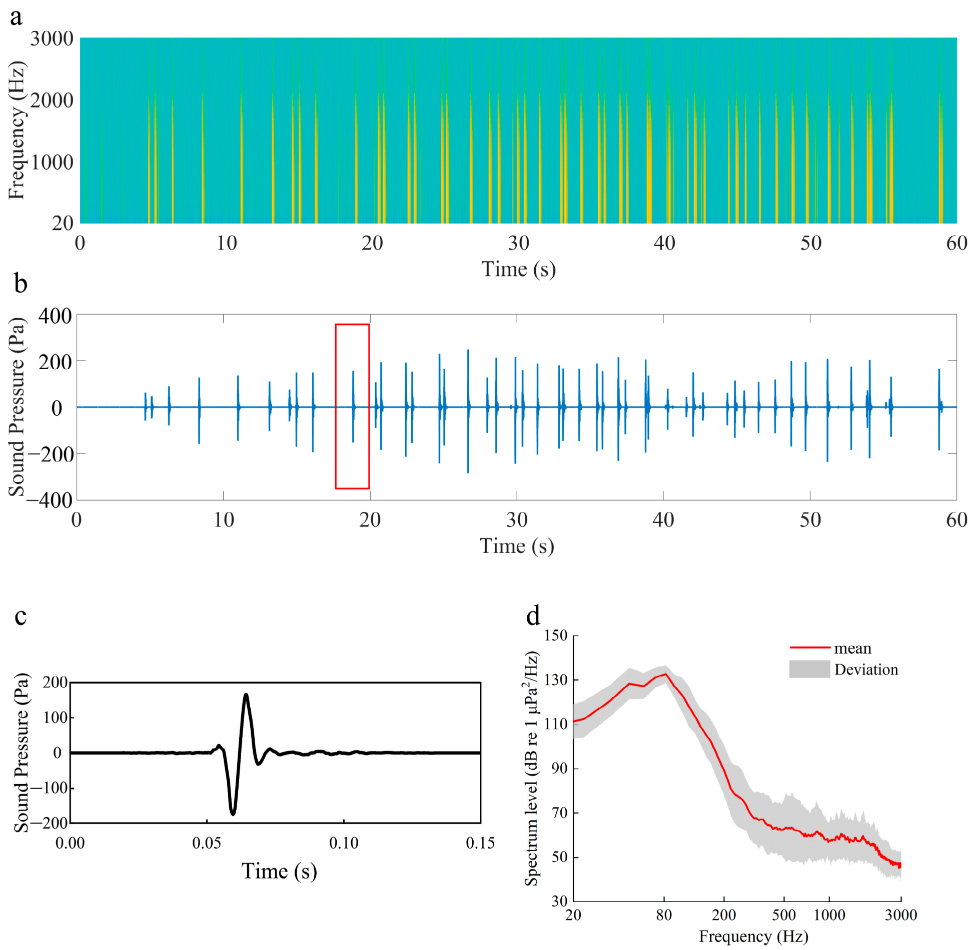

Figure 2. Spectrogram (**a**) and oscillogram (**b**) of representative single drum trains emitted by Chinese bahaba. (**c**) Oscillogram for representative individual single drum and (**d**) power spectra for the total calling signals.

A individual call of a single drum regularly consisted of 1–3 cycles with the main energies (over 80 dB re 1 $\mu Pa^2/Hz$) below 200 Hz (Figure 2c,d). The analyzed single drum of Chinese bahaba had a mean PF = 77.8 ± 16.2 Hz (n = 207), a mean −3 dB bandwidth $BW_{-3\,dB}$ = 16.5 ± 6.7 Hz (n = 207), a signal duration DUR = 61.8 ± 24.0 ms (n = 207), and a root-mean-square sound pressure level of SPL_{rms} = 150.9 ± 3.6 dB re 1 μPa (n = 207, Table 2).

Table 2. Descriptive statistics (mean ± S.D.) of four acoustic parameters of calls produced by Chinese bahaba.

Acoustic Parameters	**Calls Types**	
	Single Drum ***n*** **= 207**	**Fast Drum Trains** ***n*** **= 33**
PF (Hz)	77.8 ± 16.2	79.1 ± 8.7
$BW_{-3\ dB}$ (Hz)	16.5 ± 6.7	3.2 ± 0.9
DUR (ms)	61.8 ± 24.0	260.9 ± 42.0
SPL_{rms} (dB)	150.9 ± 3.6	160.1 ± 5.5

Compared to single drum, fast drum trains callings occurred individually during the monitoring periods (Figure 3a,b). The signals of fast drum trains commonly consisted of about 13 to 30 cycles with the main energies below 800 Hz (Figure 3c,d).

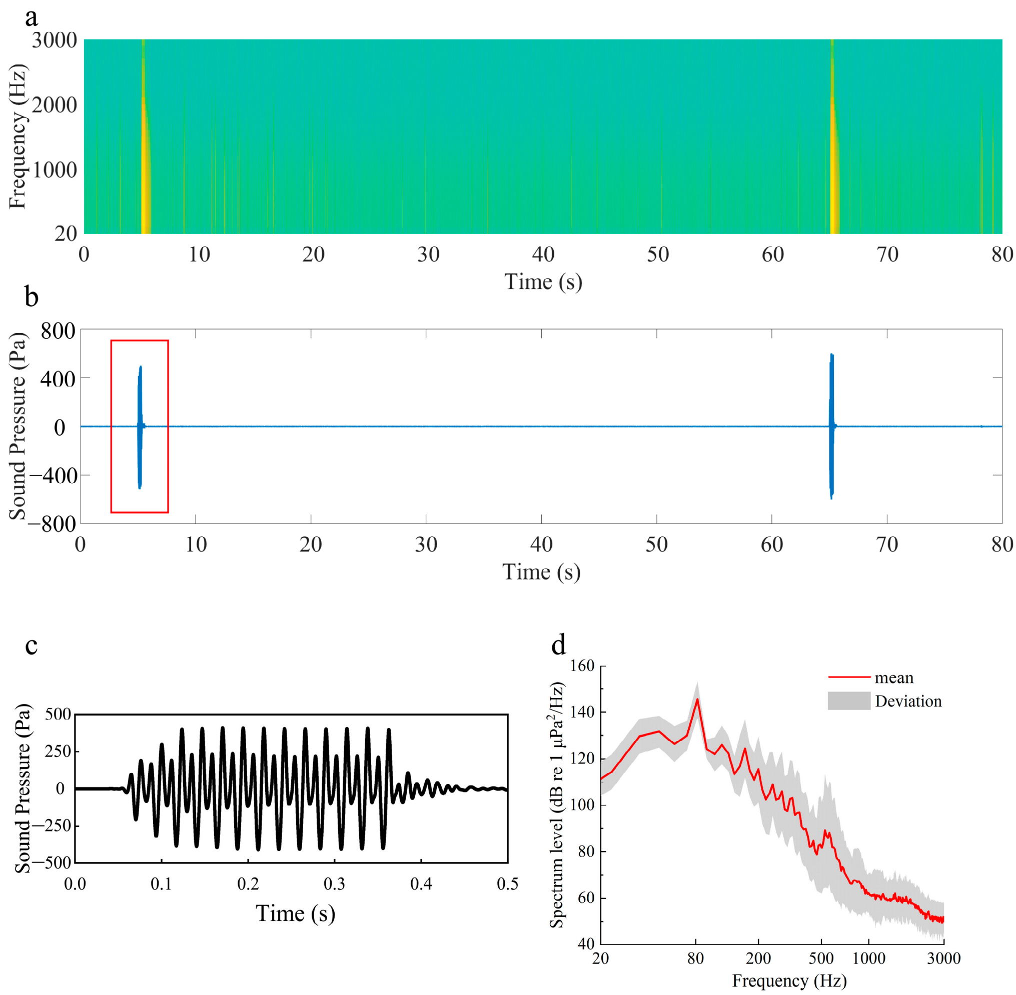

Figure 3. Spectrogram (**a**) and oscillogram (**b**) of representative fast drum trains in Chinese bahaba. (**c**) Oscillogram for representative single fast drum trains and (**d**) power spectra for the total calling signals.

The analyzed fast drum trains had a mean PF = 79.1 ± 8.7 Hz (n = 33), a mean $BW_{-3\ dB}$ = 3.2 ± 0.9 Hz (n = 33), a mean DUR = 260.9 ± 42.0 ms (n = 33), and an SPL_{rms} = 160.1 ± 5.5 dB re 1μPa (n = 33). Compared to the single drum, the fast drum trains had no significant difference in PF, while they did have significantly shorter $BW_{-3\ dB}$, longer DUR, and higher SPL_{rms} (Figure 4).

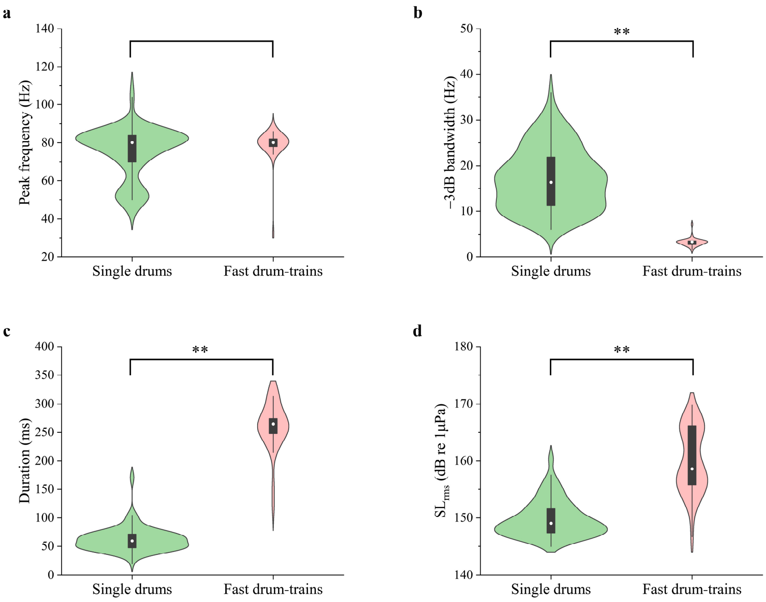

Figure 4. Violin plots of acoustic characteristics of the sounds emitted by the Chinese bahaba: (**a**) peak frequency (PF); (**b**) −3 dB bandwidth ($BW_{-3\ dB}$); (**c**) signal duration (DUR), and (**d**) root-mean-square sound pressure levels (SPLrms, ** p < 0.05).

3.2. Calling Activity Variation

Temporal variation in the calling activity of Chinese bahaba was tracked for 11 days and a significant difference in these distributions was found across the acoustic monitoring periods. The peak of calling activity of single drum was observed from 4 to 5 April while the least activity occurred on 10 April (Figure 5a). A day was split into four periods, single drum mostly peaked before dawn (period range from 0:00 to 6:00 am) and less frequently after dusk (18:00–24:00 pm, Figure 5b). In contrast, the fast drum trains calls had a high concentration on 9 April (Figure 5c) with the maximum total number of pulses of 21. Compared to temporal distributions of single drum, this calling type mostly occurred after dawn (6:00–12:00 am) and before midnight (18:00–24:00 pm, Figure 5d).

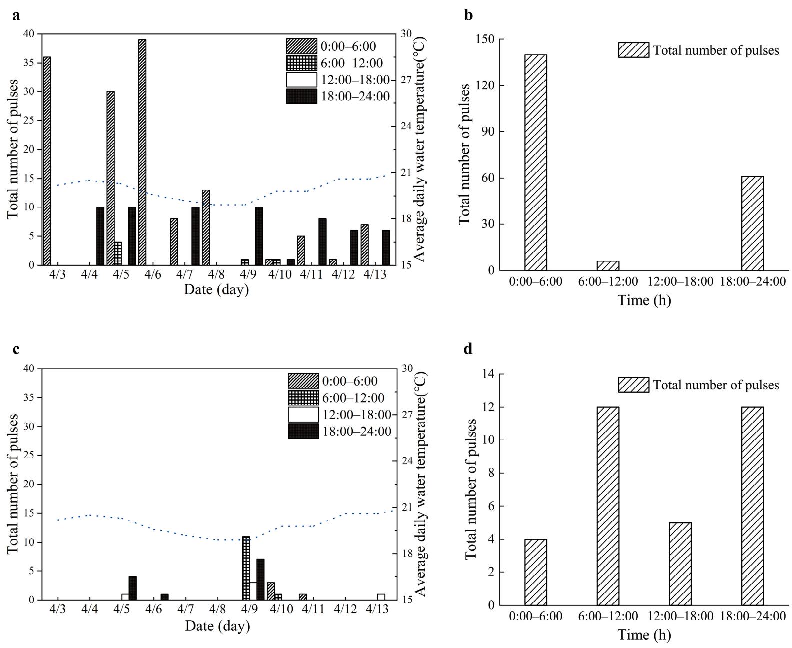

Figure 5. Temporal variation in different calling signals of Chinese bahaba: (**a**) Occurrence of single drum in four time periods from 3 to 13 April 2022, and (**b**) total number of pulses in four time periods

during acoustic monitoring. (**c**) Occurrence of fast drum trains in four time periods from 3 to 13 April 2022, and (**d**) total number of pulses in four time periods during acoustic monitoring.

4. Discussion

In the present study, continuous acoustic monitoring of Chinese bahaba was carried out during reproduction season for almost 11 days. The waveforms of the two types of drumming calls presented obvious differences in individual signals. Although both types of callings have a similar mean peak frequency of around 80 Hz, the fast drum trains callings showed a spectral variation from 50 up to 600 Hz. As another vocal Sciaenid species, the meagre could also produce two distinct sounds, described as long and short grunts, during the spawning periods [10]. Additionally, the long grunts of meagre were assumed to serve as the formation of spawning aggregation, whereas short grunts preannounce the beginning of courtship behavior [10]. Compared to the sound characterization of other Sciaenid species during the spawning period, the fast drum trains calling of Chinese bahaba was species-specific, resulting in the unusual oscillogram [4]. The key information will provide the opportunity to track and map the spawning area in the field protection habitat for this endangered species.

In terms of temporal variation, an individual call of fast drum trains observed in Chinese bahaba was much longer than the single drum call produced in the reproduction season. Similar to other vocal Sciaenidae species (e.g., shi drum and meagre), the single drum calls produced by Chinese bahaba also consisted of trains containing rapid pulses [10,28]. In terms of fast drum trains, statistical comparisons found that the changes in acoustic characteristics have significant differences among the $BW_{-3\ dB}$ and SPL_{rms} ($p < 0.05$, Figure 4), except for the PF. Change in sound production indicated that Chinese bahaba emitted a unique sound that was longer and louder during the reproduction season, maybe for the purpose of breeding. Calls of the large yellow croaker presented a higher number of pulses per call of 3.1, a shorter period of approximately 75 ms, and a higher peak frequency of up to 679 Hz during the spawning periods [15]. Additionally, this similarity was also observed in the other three cultured Sciaenid species including meagre, shi drum, and red drum, which increased their calling rate and produce longer sounds during the spawning night [7]. The difference in this temporal feature may be due in part to the ontogenetic variation in sonic muscle for different Sciaenid species. However, due to the rareness of Chinese bahaba, the reproductive behavior of this species was unclear and lacked relevant reporting. The correlation between vocalization behavior and calling function has not yet been explored in Chinese bahaba during reproduction season and needs more investigation to explain.

According to the temporal distribution results, single drum occurred mainly before dawn. However, fast drum trains mostly occurred after dawn and before midnight. The difference in the temporal distribution of call type may reflect different levels of motivation or function [29]. In the shi drum, the three call patterns (irregular, regular, and chorus sounds) also showed a significant difference in temporal distribution [30]. It seems that the variation in temporal distribution may be due in part to the species-specificity. In the present study, only 33 numbers of fast drum trains callings were extracted from the original data. Nevertheless, the recording number of single drum was greater than that of fast drum trains during the acoustic recording. Thus, evidence of the correlation between spawning events and the temporal distribution of calling activities is required more study for long-term acoustic monitoring in Chinese bahaba.

The relationship between sound production and spawning behavior has been found in other species in the Sciaenid family, suggesting that acoustic monitoring could be used to monitor reproduction. Sciaenid aquaculture has increased in the last decade, but reproduction in captivity still faces problems for these species that cannot spontaneously mature or spawn without exogenous stimulation [31,32]. More suitable management needs to be developed to observe reproductive behavior and improve the efficiency of induced spawning behavior. Our study provides the possibility of using acoustic information for potential applications in reproductive behavior monitoring of Chinese bahaba in aquaculture.

Moreover, the fishery resources of the Sciaenid family are a vital part of the world fishery economy, both in commercial catch and aquaculture. As an endemic commercial species in China, the fishery resources of Chinese bahaba have faced a high risk of extinction in the last decade due to overharvesting and habitat degradation. It is challenging to establish reproductive output for this species within the ecosystem by traditional sampling methods (e.g., plankton tows or trawl surveys). In the present study, we demonstrated that the acoustic signals of Chinese bahaba have the characteristic of variation with species-specificity during the reproduction season. Based on the monitoring of the soundscape, the characteristic sound of Sciaenid could provide vital information concerning species identification and behavior [16,33]. Monitoring the reproductive behavior of wild Chinese bahaba is an essential requirement for the effective management of this fishery resource. Our data serve as a foundation for future studies to investigate the spawning potential and fish density of Chinese bahaba through passive acoustic monitoring in the conservation area.

5. Conclusions

Understanding the variation of vocalization in Chinese bahaba provides insight into whether this species produces sound in species-specific manner, which may potentially help in species conservation and commercial management. In this study, sound production of sexually mature Chinese bahaba was recorded during the reproduction season and acoustic parameters of two distinct types of calls were addressed, showing significant differences between single drum and fast drum trains calls. A detailed description of sound production and related vocalization behavior in Chinese bahaba is still largely lacking, especially those produced by the animals from the field due to the significant decrease in numbers of this species. These acoustic data provide informative cues on the calls of the endangered species and may contribute to aquaculture management and population conservation in the future.

Author Contributions: H.H. and Y.Z. conceived the research. H.L. and Z.S. contributed to conceptualization, methodology, software, writing—including original draft preparation, reviewing, and editing. J.H., Y.S. and W.F. helped in data curation, methodology, and software. S.Z., L.Y. and K.Y. helped in the artificial breeding and cultivation of experimental animals. All authors have read and agreed to the published version of the manuscript.

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