الإنتاج الصوتي اليومي لأسماك الجربوع: تأثير درجات الحرارة وحالة الإضاءة

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المستخلص: يمكن التمييز بين إنتاج الصوت من قبل أنواع معينة من الأسماك من خلال تحليل الخصائص الصوتية التي تنتجها. وأسماك الجربوع باعتبارها واحدة من الأسماك التي تصدر أصواتا فإنها تنتج نغمات بنقره واحدة او نقرات مزدوجة أو سلسلة من النغمات ضمن خصائص معينة. وقد أثر تقلب درجات الحرارة وحالات الإضاءة خلال فترات النهار والليل على الإنتاج الصوتي اليومي لأسماك الجربوع. وعلى الرغم من انه لم يكن بالإمكان إعطاء تأثير معنوي على الخصائص الصوتية، فقد أثر على إنتاجية الصوت للأسماك. وزاد عدد الأصوات في مجموعه الأسماك نحو منتصف الليل (حالة الإضاءة هي ظلام) وفي ذروة اليوم (حالة الإضاءة هي إشراق) حيث كانت درجة الحرارة الدنيا والعظمى. وعلى النقيض من ذلك، فقد زاد إنتاج الصوت في الأسماك الفردية عندما تغيرت حالة الإضاءة من الظلام إلى الإشراق ومن الإشراق إلى الظلام.

كلمات دالة: خصائص الصوت، إنتاجية الصوت، درجات الحرارة، حالة الإضاءة.

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Characteristics of daily sound production at night (dark condition) and at day periods (light condition) of *T. jorbua* were as a response to endogenous mechanism. Ross and McKinney (1988) explained that diurnal activities of fish could be affected by photoperiod as well as the times of day are probably responsive to endogenous changes of either the endocrine or the neutrally alert mechanism. If hormones could actually modulate the neurological output of pattern generators in the brain (Demski, *et al.*, 1973), it is likely that the diurnal calls of *T. jorbua* could be also controlled by endogenous mechanism.

Conclusion

T. jorbua could generate a single click, double clicks, and even established a series of tones with in certain characteristics. Sound characteristics were influenced by both existence of fish as individual or as group, and the environmental variability. Fish as individual generates sound with intensity, frequency, and sound duration which are higher than those produced by fish as group. However, the sound productivity of individual fish is lower than those of fish as group. Although water temperature and light conditions are unable to give significant effects on the sound characteristics, it influenced the sound productivity of fish. For further research needs to examine the more effect of temperature by raising the temperature range so that the critical thermal maxima (CTM) of *T. jorbua* can be determined based on the sound characteristics generated by the fish.

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Discussion

T. jorbua like the other species of fish might produce sound with intensity, frequency and sound duration which is relatively low compared to other organisms, such as birds, bats, and sea mammals. Clicking sound that generated within certain characteristics may distinguish this species from other species of fishes. This difference is due to the different type of sound producing mechanisms and the sound generating organs (Kasumyan, 2008). The Sound of *T. jorbua* is generated by the pharyngeal teeth and swim bladder (Veerapan, *et al.*, 2009). There was no much difference in terms of sound generating organ and mechanism of sound production by other species of the same genus, i.e. *Terapon theraps* that have been studied by McCauley and Cato (2000). The sound generating organs in Terapontidae that has been explained by Schneider (1964) and Vari (1978) were a two-chambered swim bladder, the posterior chamber being approximately twice as long as the anterior, and they are connected by a narrow open tube surrounded by a sphincter muscle. Attached to the anterodorsal surface of the anterior chamber are laterally-paired extrinsic-muscles. These extend anterodorsally to attach on the posterior surface of the ventral process of the post temporal or the rear of the skull.

The existence of fish as individual and in group has significant impacts on the fish sound characteristics. Fish as individual emits sound with frequency, intensity, and sound duration more than as group. However, in terms of productivity, the fish as group produce more sounds compared to the individual fish. This was due to differences in the purpose why the sound is produced either as individual or as group. Kasumyan (2009) explained that fish emit sounds in

diverse situations in connection with the manifestation of diverse forms of behavior. Fish as group produce sound with a lot of purposes, such as spawning behavior (see: Lugli, *et al.*, 1997; Maruska, *et al.*, 2007), territorial behavior (see: Ladich and Myrberg, 2006; Henglmuller and Ladich, 1999), defensive behavior (see: Takayama, *et al.*, 2003), and aggregative behavior (see: Parmentier, *et al.*, 2003). The amount of goals of the sound produced by fish as group resulted in higher sound productivity, with lower intensity, frequency and sound duration compared to those produced by the individual fish.

Although environment variability (water temperature and light condition) was unable to give significant effect on the sound characteristics, it could influence the sound productivity of the fish. Generally, rising temperatures could cause an increase in rate of sound emissions, sound pressure level, sound duration, pulse repetition rate, and in fundamental or dominant frequency, as well as a decrease in pulse duration (Torricelli, *et al.*, 1990; Brantley and Bass, 1994; Connaughton, *et al.*, 2000). With an increase in water temperature, the rate of exchange of calcium ions in tympanic muscles was responsible to increases sound generation (Feher, *et al.*, 1998), and pulse pattern generator circuits in the central nervous system (Bass, and Baker, 1991). Feher, *et al.* (1998) demonstrated faster re-uptake of Ca^{++} at increased temperature by toadfish sarcoplasmic reticulum, which would support more rapid contraction of sonic muscles with increasing temperature. As a consequence, the schedule of their work changes substantially. The intensification of sound generation with water temperature increase takes place parallel to an increase in the behavioral activity of fish (Ladich, 1998).

Daily environment variability influenced the fluctuation of sound production that emitted by *T. jorbua*. Sound production of fish in groups 2B and 3B increased towards midnight (light condition was dark) and at peak of the day (light condition was bright)

which correspond to the water temperatures were minimum and maximum (Table 2 and Figure 3). In contrast, sound production of individual fish have increased when light condition changed from dark to light (05:00 – 07:00) and from light to dark (17.00 – 19.00).

Table 2. Daily environmental (water temperature and light conditions) variability

Time period	Water Temperature	Light Condition
00–05	26.0	Dark
05–07	26.5	dark to light
07–08	27.0	Light
08–11	27.5	Light
11–17	28.0	Light
17–19	27.5	light to dark
19–20	27.0	Dark
20–22	26.5	Dark
22–24	26.0	Dark

Figure 3. Daily sound production of the different group of *T. jorbua* that classified based on the environment variability. (a) Combination of temperature and light condition; (b) Temperature; and (c) Light condition. Number of pulse per hour with different superscripts are different at $P < 0.05$

Table 1, Sound characteristics (frequency, intensity, and sound duration) of three group of *T. jorbuia* (1, 2, and 3 specimen in an aquarium). Data is recorded in four levels of water temperature (26, 26.5, 27.5, and 28°C)

Sound Characteristics	Fish Group	Water Temperature (°C)			
		26	26.5	27.5	28
Frequency (Hz)	1	2745.70±342.41 ^b	2680.10±459.20 ^b	2841.60±635.28 ^b	3035.33±1272.58 ^b
	2	1978.30±523.02 ^a	1943.60±472.79 ^a	1952.30±451.26 ^a	1790.60±315.99 ^a
	3	1925.60±419.96 ^a	1814.60±277.97 ^a	1821.40±345.89 ^a	1579.90±383.53 ^a
Intensity (dB)	1	-29.17±4.30 ^c	-32.98±6.34 ^c	-30.55±5.31 ^c	-31.63±8.16 ^c
	2	-38.93±3.70 ^a	-38.09±4.93 ^a	-40.10±3.61 ^a	-40.10±3.65 ^a
	3	-39.16±3.45 ^a	-36.87±1.77 ^{ab}	-37.77±2.43 ^{ab}	-39.94±2.95 ^a
Duration (ms)	1	90.60±11.83 ^c	63.75±9.37 ^c	61.80±9.95 ^c	66.66±15.50 ^c
	2	42.10±5.78 ^{ab}	37.80±7.71 ^a	36.90±8.43 ^a	34.40±5.79 ^a
	3	46.50±12.43 ^b	50.50±11.45 ^b	46.90±11.80 ^b	39.70±8.17 ^{ab}

Mean sound characteristics of each fish group ($\pm$ SE, $n = 10$); $R^2 = 55.61\%$; Fish group 1, 2, and 3 (1, 2, and 3 specimen in an aquarium), means with different superscripts are different at $P < 0.05$

influenced the sound characteristics generated by fish (Table 1)

Fish sound characteristics (frequency, intensity and duration) for all of fish groups (1B, 2B, and 3B) in general showed no significant difference during the various water temperatures. Daily water temperature fluctuates between 26°C at night period and 28°C at the day period. This variability was not sufficient to provide a significant influence on the sound characteristics (frequency, intensity and sound duration). Generally, although sound characteristics were not affected by the water temperature, some differences in intensity occurred in fish group 3B. At medium water temperature condition (26.5 - 27.5°C), sound intensity of this fish group significantly increased compared to the minimum (26°C) and maximum (28°C) water temperature. Similar to the intensity, a significant difference of sound duration also occurred in fish groups 2B

and 3B. In fish group 2B, the sound duration was increased when the water temperature was minimum, whereas in fish group 3B, the sound duration decreased when the water temperature was maximum.

The existence of fish as individual and as group has a significant impact on the fish sound characteristics in a variety of water temperature fluctuation. This condition was clearly showed by the observation of three fish groups. Frequency of sound that produced by fish group 1B was obviously very different from the fish group 2B and 3B. Similar to the other characteristics, intensity and sound duration of the individual fish is different from those of fish in group. For sound duration, also the number of specimens in the group will provide a significant effect on the sound duration that they produce. This can be realized from the significant difference in sound duration produced by the three different fish groups.

has generated the sound with the particular characteristics. The existence of fish in the

water either as individual or as a group, and the environmental conditions (e.g. temperature)

Figure 2, Sound production of *T. jorbuca* that recorded in -55 dB noise level. (a), (b), and (c) respectively describes the sound characteristics (intensity in dB, and frequency in Hz) of a single click, double clicks, and multiple clicks

Data Acquisition

Passive acoustic technique was used to measure sound production of fish during the experiment realization. Common instrumentation was used to convert the sound production of fishes into a voltage that can be recorded and analyzed in a hydrophone (Mann and Lobel, 1995). The hydrophone was positioned in the center of aquarium and connected to the personal computer using data transmission wire. Data was recorded by using Wavelab Program at 24 hours and saved to storage devices. Passive acoustic systems generate large amounts of raw data. These data that are recorded contain true sounds and some noises. To analyze the true sound that produced by fish, basic analysis that including spectral analysis, envelope analysis, and sound counting were used.

Data Analysis

Twenty samples of sound that produced by *T. jorbua* for each observation period (00:00-01:00, 06:00-07:00, 12.00-13.00, and 18.00-19.00) were analyzed using two-way ANOVA (Analysis of Variance) to differentiate the sound characteristics of each fish group (1, 2, and 3 specimens in an aquarium). Sound characteristic parameters analyzed were frequency, intensity and sound duration. Acoustic response of each fish group to the daily environmental variability (water temperature and light conditions) was described by the daily fish sound productivity (number of pulses).

Results

Sound production of *T. jorbua*

Generally, *T. jorbua* generates a single click, double clicks, and even established a series of tones (Figure 2). Sound characteristics of clicking sound that produced by fish is characterized by intensity in -25 - -43 dB (noise level, -55 dB), the sound frequency in 1.2 - 4.3 kHz, and sound duration in 30 - 100 ms.

Single click (Figure 2a) that emitted by *T. jorbua* is characterized by the intensity and frequency which is lower than those of double click or multiple clicks (Figure 2b and 2c). However, for the sound duration characteristic, there was no significant difference between single click and double clicks or multiple clicks (P value = 0.12). Double click was a combination of two single clicks that have short time intervals. The first click has both intensity and frequency that are lower than those of the next click. In the other case, multiple clicks produced by this species resulted from a series of single clicks forming a tone. The time interval between one click to another was very short, therefore it could be distinguished from the other tone series. The first click of the series has a lower intensity and frequency than those of the next clicks. Variability of the intensity and frequency of each click could establish a series of tone and it could be distinguished from the other series of clicks.

Sound Characteristics of *T. jorbua*

Fish sound produced by certain species could be differentiated by the characteristics of their sound. Similar to the other species, *T. jorbua*

increases (Feher, *et al.*, 1998), and, as a consequence, the schedule of their work changes substantially, which, in turn, is reflected in most parameters of sounds produced by fish. This study aims to describe the daily sound production of *Terapon jorbuca* that impacted by water temperature and light conditions.

Experimental Method

Materials

Terapon Jorbuca as Indonesian endogenous fish is able to produce sound with specific characteristics that provides essential information regarding to their existence and behavior in the waters (Amron *et al.*, 2013, 2017). Twenty specimens of *T. jorbuca* in various sizes (60 – 80 mm) and sex which captured from natural habitat (Pelabuhan Ratu Bay – Indian Ocean) were transported to the laboratory. Fish was acclimatized in rectangular pond (5.0 m length x 0.8 m width x 1.0 m height; with water depth 0.7 m) in one month to keep fish adapt in the new environment before experiment. Pond was filled by sea water and as a fish shelter in the

bottom of the pond were placed flower pots. Fish was fed by artificial feed (Super-Vit[®]), with a chemical composition are moisture 12%; protein 30%; fat 6%; and dietary fiber 6%.

Experimental Setting

The experiment was performed in 3 small aquaria (50 cm length x 25 cm width x 30 cm height; with water depth 25 cm) (Figure 1a). Environmental conditions and feeding were set like that in the acclimation pond. The aquarium walls were covered on the outside with rubber mattress to reduce excessive light and noise from the environment, except the front of aquarium.

Fish of 6 – 8 cm TL grouped as: 1 specimen (1B), 2 specimens (2B), and 3 specimens (3B) were reared in the aquarium during 10 days without temperature treatment (daily temperature variability is 26 – 28°C) (Figure 1b). During the experiment period, the water was circulated 30 ml/s using external water pumps and filtered by external filters. Light conditions were adjusted to the environmental conditions during the day and night periods without additional lighting.

Figure 1, Experimental setting. (a) layout, and (b) design. 1B refers to one-specimen group, 2B refers to two-specimen group, and 3B refers to three-specimen group

observed becomes less apparent. Among the sound sources, fish is more dominant and complex as sound producer than the others, therefore it is very interesting to be studied.

Kaatz (2002) reported that more than 800 species of fishes from 109 families worldwide are known to be “soniferous” or able to produce sound. Commonly, most fishes generate sound with low-frequency pulses, and vary in duration, number and repetition rate (Myrberg, *et al.*, 1978). The diversity of sound that made by fishes is not as remarkable as in other organisms, such as bird, bat, and sea mammals. Most fish show poor amplitude and frequency modulation in their sounds (Wysocki and Ladich, 2003; Veerapan, *et al.*, 2009) and also fish appear to produce fewer calls (McCauley and Cato, 2000; Rice and Lobel, 2003; Amorin, *et al.*, 2006; Ladich, 2007). One of the fish species that predicted to produce sound is *Terapon jorbua* living in Indonesia.

Fishes of the family Teraponidae or terapons (thornfishes, grunters, or tiger perches) are found in the Indo-West Pacific (Nelson, 2006), Australia, New Guinea, Indonesia and the Philippines (Heemstra, 1986), Mediterranean Sea (Lipej, *et al.*, 2008), and Western Indian Ocean (Taquet, *et al.*, 2007). These species are living as demersal, schools, and catadromus fish in freshwater, brackish, and marine habitat with depth range 20 – 350 m and sea temperature 26-29°C (see www.fishbase.org). Other species of the same family, *Terapon theraps* (McCauley and Cato, 2000) can emit sound with frequencies from 50 Hz to a few kilohertz, with spectral peaks up to 30 dB above background. This sound generated by the muscle action of two

chambered swim bladder in sporadic occurred after 18:00 and increased at 20:30 to 01:00, while during the day period, there was no significant production of sound. The variation of sound production in the day and night period is caused by water environment variability such as water temperature and light conditions.

The decrease in sound productivity of *T. jorbua* with water temperature increase was highly related to changes of their behavior. One reason that is possible to describe this phenomenon is the influence of temperature on the muscle ontogeny of the fish (Johnston, *et al.*, 2009). Different temperatures lead to variation in body muscle mass (in terms of size and number of muscle fibers) that directly affect swimming ability. In the case of zebrafish, Johnston, *et al.* (2009) showed that the optimal embryonic temperature for fast muscle fiber recruitment (hyperplasia) is 26°C, as in that temperature there were 18.8% more fast fibers than at 22°C and 13.7% more fibers than at 31°C. The increase in swimming ability changed the territorial behavior to aggressive behavior. As a result, this change decreased the sound productivity.

Beside this change of sound productivity, increase of water temperature also has impacted the sound characteristics of *T. jorbua*, including intensity, frequency, and decrease in pulse duration. According to Connaughton, *et al.* (2000), sound pressure level, repetition rate, and dominant frequency of weakfish are increased, but pulse duration is decreased during water temperature increases. With an increase in water temperature, the rate of exchange of calcium ions in tympanic muscles responsible for sound generation

Daily Sound Production of *Terapon jorbua*: Impact of Temperature and Light Condition

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Abstract: Sound production by certain species of fishes could be differentiated by analyzing the sound characteristics that they produced. *Terapon jorbua* as one of soniferous fishes generates a single click, double clicks, and a series of tones within certain characteristics. Variability of temperature and light conditions at the day and night periods had influenced the daily sound production of *T. jorbua*. Although unable to be given significant effect on the sound characteristics, it had influenced the sound productivity of fish. Number of sound in fish group was increased toward midnight (light condition is dark) and at peak of the day (light condition is bright) where the temperature was minimum and maximum. In contrast, sound productivity of individual fish was increased when the light condition was changed both from dark to bright and from bright to dark.

Keywords: sound characteristics, sound productivity, temperature, light condition

Introduction

In the sea and freshwater where light does not penetrate more than a few meters below the surface because of suspended materials, biota absorption and scattering, sound has important role as transmission medium of information and communication. This is possible due to the sound waves could propagate much longer distance in the water column (Simmonds and MacLenan, 2005). Some of information regarding water phenomenon, biota and others are obtained from the analysis of the sound signal that recorded by using passive or active sonar. Nguyen, *et al.* (2009) and Liu, *et al.*

(2008) studied South China Sea circulation and multi sub-tidal internal modes generated in Hiroshima Bay by analyzing the sound travel time from the Coastal Acoustic Tomography System. Kasumyan (2008; 2009) explained the fish behavior by tracing the acoustic signal that produced by the fish. Results and information from other acoustic researches illustrate the importance of sound as a medium of underwater information and communication. However, the number of sound sources in the water either from biota, physical process as well as human activities lead the information from the sound signal that