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Characterization of Sounds of the Blackspotted Croaker *Protonibea diacanthus* (Sciaenidae) and Localization of Its Spawning Sites in Estuarine Coastal Waters of Taiwan

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Hin-Kiu Mok, Hsin-Yi Yu, Jinn-Pyng Ueng, and Ruey-Chang Wei (2009) Characterization of sounds of the blackspotted croaker *Protonibea diacanthus* (Sciaenidae) and localization of its spawning sites in estuarine coastal waters of Taiwan. *Zoological Studies* **48**(3): 325-333. The sounds produced by mature blackspotted croakers *Protonibea diacanthus* were surveyed along coastal areas adjacent to 9 major rivers in Taiwan. The sounds were composed of bursts of pulses with longer inter-pulse intervals than in other sympatric sound types recorded. Variations in the intervals and pulse numbers per call distinguished the blackspotted croaker's sounds into 2 types, one of which was rarely found. For the main sound type, the duration of calls ranged 256-820 ms, the pulse duration ranged 9-34 ms, the pulse repetition rate ranged 13.5-21.6 pulses/s, the mean inter-pulse interval was 60.3 ms, and the minimum and maximum frequencies of the fundamental frequency were 116 and 307 Hz, respectively. These sounds were found from Apr. to Aug. and were spatially restricted to the surveyed area adjacent to 2 rivers on the southwestern coast at depths of < 25 m (mostly < 15 m). A major area was located close to the largest sandbar in Taiwan. The areas where the sounds were found are considered to be the spawning grounds of this species in Taiwanese coastal waters.
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Key words: Sound, Sciaenidae, *Protonibea diacanthus*, Spawning grounds, Taiwan.

Sciaenids are common food fishes with a rather high fisheries value. *Protonibea* is one of 4 sciaenid genera in which the species can reach a maximum body size of > 1 m; the other 3 genera are the *Arygrosomus*, *Atracatscion*, and *Megalonibea* (Chu et al. 1963, Sasaki 1989). The blackspotted croaker *Protonibea diacanthus* is a demersal marine or brackish species of coastal and estuarine areas with muddy bottoms, and is even known to ascend tidal rivers. It is found in tropical regions of the Indo-West Pacific Ocean, from the west coast of the Arabian Gulf and along the coasts of India and Sri Lanka, north to Taiwan, China, and Japan, and south through the Philippines and Borneo to New Zealand and northern Australia (Froese and Pauly 2005). Its vertical distribution extends to about 60 m in depth.

Sciaenids are well known for their croaking or drumming sounds emitted during the spawning season. Sounds of several Atlantic sciaenid species recorded in lagoons or large bays were described and tracked by hydrophone to provide clues for locating the sound producers so that their spawning areas could be delimited (e.g., Mok and Gilmore 1983, Saucier et al. 1992, Saucier and Baltz 1993, Connaughton and Taylor

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1995). Fishermen in Yunlin County (where the Chosui River study area of this study is located; see below) on the west-central coast of Taiwan use a passive hydroacoustic method to track blackspotted croaker in coastal waters south of the estuary of the Chosui River (a major river in Taiwan; Fig. 1) and catch them using purse seines (Ueng 1999). They use a hydrophone to listen for the characteristic sounds (low-frequency croaks), which are believed to be emitted by the blackspotted croaker. After that particular sound is heard at a site (the starting site), the fishermen locate the approximate position of the target calling individual(s) by listening to and comparing the amplitudes of the sounds along crisscrossing tracks adjacent to the starting site. After the purse seine has been deployed to surround the target calling site, firecrackers are dropped into the water to create underwater acoustic shock waves to scare the targeted individuals into the closing purse seine. This fishing method has been quite successful; at 1 time about 70 fishing boats equipped with this fishing gear operated in the area. However, according to local fishermen, annual catches and body sizes of the blackspotted croakers have continually decline in recent years, and now only 2 fishing boats still fish with this method. This passive hydroacoustic method has not been applied to catch other sciaenids which are much smaller in maximum body size. As both sexes of the blackspotted croaker have sonic muscles, mature males and females may both be targeted by this fishing method. However, it may also be possible that females might not call, but are attracted to a male's call. An 1150 mm male and 790 mm female specimen caught by local fishermen had gravid gonads. The ovaries weighed 876.4 g and were estimated to be carrying 3,883,840 eggs. Although a few aquaculturists in southern Taiwan have successfully cultured the blackspotted croaker, the number cultured is quite low. Conservation of natural populations remains a necessity. Obviously, active management to reduce fishing pressures on mature individuals in the spawning grounds has become an urgent matter. Conservation of the blackspotted croaker can be actively pursued by banning fishing in the spawning area during the spawning season, which will require precise data on the spatial and temporal distribution and spawning season. Ueng (1999) noted this fisheries problem, and his original study in the fishing ground in Yunlin County identified discrete sites with loud fish sounds. Those sounds were likely produced by several sciaenid species common to these waters. However, additional data covering a broader region are required to understand the distribution of the blackspotted croaker's spawning grounds in Taiwan and the relative importance of each of these grounds. Subsequently, a more-thorough survey of the major estuaries in Taiwan where suitable habitats for sciaenids are present was conducted between Jan. 2000 and Dec. 2004. The purposes of this paper were to describe characteristics of the blackspotted croaker sounds and report seasonal and spatial variations in these sounds.

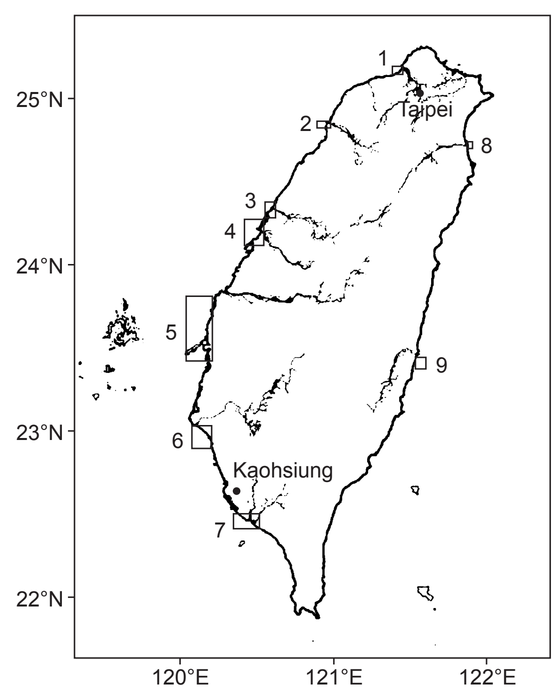

Fig. 1. Distribution of the study areas indicated by frames adjacent to the major rivers in Taiwan surveyed in the present paper. **1.** Tanshui River, **2.** Touchein River, **3.** Tachia River, **4.** Tadu River, **5.** Chosui River, **6.** Zengwen River, **7.** Kaoping River, **8.** Lanyang River, **9.** Hsiuruluan River.

MATERIALS AND METHODS

Study areas and study period

As most sciaenids are estuarine dependent, acoustic recordings were made in estuarine coastal waters of 9 major rivers along the coasts of Taiwan, including the Hsiuruluan River (24 stations), Lanyang River (32 stations), Tanshui River (54 stations), Tachia River (71 stations), Touchein River (77 stations), Tadu River (58 stations), Zengwen River (32 stations), Chosui River (197 stations), and Kaoping River (28 stations) (Fig. 1). All field recording stations were shallower than 50 m. Except for the Chosui River study area, each study area was surveyed at least 4 times on a seasonal basis (once a season). Each survey was completed in 1 evening. In total, 574 stations were recorded between Jan. 2000 and Dec. 2004. An intensive survey of the Chosui River study area was conducted in 2001 and 2004. During 2002 and 2003, this study area was monitored once every season at only a few stations where sounds had been recorded in 2001.

Sound recording and analysis

Sound recordings were made using either a B&K 8104 hydrophone (with a frequency range of 0.1 Hz-80 kHz) connected to a B&K NEXUS 2635 conditioning amplifier or a HP-A1 hydrophone (Burns Electronics, Salamander Bay, Australia; with a frequency range of 10 Hz-25 kHz). The hydrophone was connected either to a SONY stereo cassette recorder (TCD5-PROII; Tokyo, Japan) or to a JVC XM-D1 personal Mini-Disc player (Yokohama, Japan). The sound outputs from the above recorders were digitized at 16 kHz using a Cool edit 2000 software and the C-Media Electronics analog-to-digital board (CMI8338 PCI, Taipei, Taiwan; with a frequency range of 10 Hz-44.1 kHz). The B&K hydrophone was calibrated using a B&K hydrophone calibrator type 4229. The frequency of the Mini-Disc player was calibrated by a known frequency from a signal generator, and the sound pressure was calibrated using the B&K hydrophone. As has been reported, sciaenids emit sounds beginning around sunset (e.g., Mok and Gilmore 1983). Thus, field recordings began around sunset. The fishing boat engines were shut down during the recording. A hydrophone was suspended 1 m below the surface, and sounds were taped for 5-10 min depending on the quality of the signals and the state of the sea. The locality of each station was documented using a Garmin GPS II Plus system (Sijhih City, Taiwan); water depth was recorded by a depth sounder.

Acoustic data were analyzed using Avisoft-SASlab PRO software (Specht 2002). Measured sound features included the call duration, number of pulses per call, pulse interval, pulse rate, pulse frequency range, and dominant frequency.

On 2 Dec. 2005, aquaculturists allowed us to tape the sounds emitted by mature cultured individuals which they had caught and were confined underwater in a net. Sounds were also recorded in the air. The sizes (i.e., standard lengths) of the recorded mature individuals were around 57 cm.

RESULTS

Characteristics of the target croaking sound

Bursts of low-frequency staccato sounds were repeatedly heard in the Chosui River and Zengwen River study areas. Each call (or a staccato sound) contained a train of pulses (Figs. 2, 3). Calls were sorted into 2 types based on the inter-pulse interval. The main call type (type-1 call) was composed of 6-11 pulses (mode, 9) (Fig. 2, Table 1). The duration of the calls ranged 256-820 (mean, 520) ms (Table 1). These 2 sound parameters were positively correlated (Fig. 4).

Table 1. Sample size (*n*), mean, standard error (S.E.), range of the physical features of type-1 calls produced by *Protonibea diacanthus* in the wild

Sound parameter	Mean	Range	S.E.	*n*
Call duration (s)	0.52	0.256 - 0.82	0.01	226
No. of pulses/call	9.01	5 - 14	0.1	221
Pulse rate (pulses/s)	17.80	13.48 - 21.65	0.64	221
Pulse duration (ms)	14.90	9 - 34	0.31	33
Inter-pulse interval (ms)	60.27	29 - 122	0.62	33
Low frequency of the fundamental frequency (Hz)	116.07	62 - 250	1.92	223
High frequency of the fundamental frequency (Hz)	307.85	218 - 421	2.52	221
Maximum frequency (Hz)	1635.24	1343 - 1906	24.76	41

The pulse duration ranged 9-34 (mean, 14.9) ms (Table 1). The mean pulse rate was 17.8 (range, 13.5-21.6) pulses/s (Table 1). Inter-pulse intervals within the same call were quite similar (range, 29-122 ms; mean, 60.3 ms; standard error (SE), 0.62 ms; Fig. 2). The pulse frequency ranged 116.07-1635 Hz (Fig. 2. Table1). Energy was allocated in 6 or 7 frequency bands (harmonics) (Fig. 2). Fundamental frequencies ranged 116-307 Hz (Table 1). Fundamental and dominant frequencies were about the same (Fig. 2). The fundamental-frequency band had a longer duration then that of the higher harmonic bands (Fig. 2).

Of the blackspotted croaker sounds recorded at the Chosui and Zengwen River survey areas, type-2 sounds appeared only on 3 occasions (12 June 1999, 29 Apr. 2001, and 26 May 2002) from the Chosui River study area. On 1 occasion, 13 type-2 sounds were inserted among a chain of 42 type-1 sounds. The intensities of these 2 types of calls were similar and did not overlap, suggesting they were emitted by the same individual. Type-2 calls mainly differ from type-1 calls in the number of pulses and inter-pulse intervals. Type-2 calls had higher pulse numbers (range, 8-20) and shorter inter-pulse intervals (mean, 62 ms; range, 19-101 ms; SE, 0.85 s), and both parameters were more variable for type-2 call (Figs. 2, 3). Sound pressure levels ranged 133-152 dB re 1 μPa (144 ± 1.36 dB). These values can be affected by many factors including the source level and distance to the source from the hydrophone.

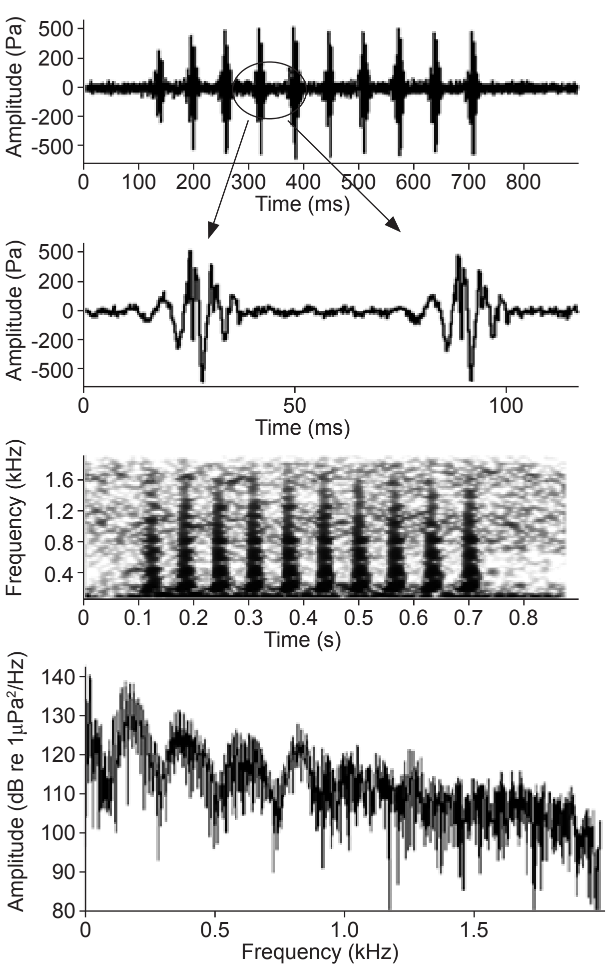

Fig. 2. Oscillogram, magnified oscillogram, corresponding sonogram, and long-term average spectrogram of a representative type-1 call emitted by *Protonibea diacanthus*. Spectrum parameters were an FFT length of 256, a frame of 50%, and a Hamming overlap of 96.87.

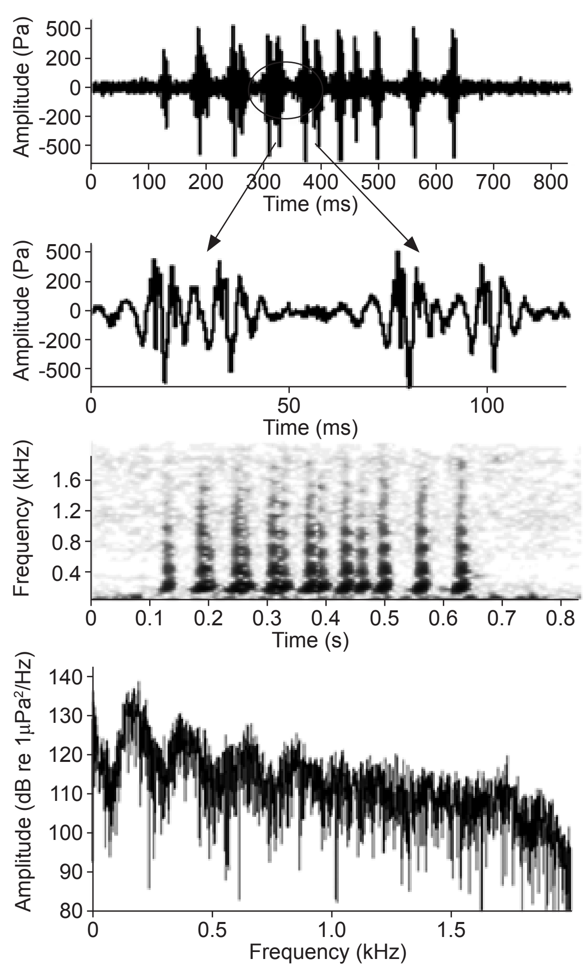

Fig. 3. Oscillogram, magnified oscillogram, corresponding sonogram, and long-term average spectrogram of a representative type-2 call emitted by *Protonibea diacanthus*. Spectrum parameters were an FFT length of 256, a frame of 50%, and a Hamming overlap of 96.87.

A sonic muscle twitch should correspond to 1 pulse in a call (e.g., Sprague 2000, Connaughton 2004). A magnified oscillogram of a pulse showed that each pulse had 3 half-cycles followed by a couple of rapidly decaying oscillations (Fig. 7).

For the 2 independent series of calls recorded from the Chosui River study area, all pulses were about the same amplitude and were therefore attributed to the same individual. Means and ranges of inter-call intervals in these 2 series were 7.38 ± 0.71 (3-35 s; n = 52 calls) and 9.75 ± 0.57 s (5-30 s; n = 55 calls; Fig. 5).

Identifying the producer of the targeted croaking sound

In Apr. 2001, with the assistance of local fishermen, we were able to locate and track the source of these low-frequency calls in the Chosui River study area. A 115 cm blackspotted croaker was then caught by purse seine set around the estimated calling site at about 6-7 m in depth. The blackspotted croaker *P. diacanthus* was therefore indirectly identified as the producer of these low-frequency staccato calls.

In total, 7 distinct sound types with variable temporal and frequency domains were recorded in these surveyed areas (Fig. 6). A longer inter-pulse interval was a diagnostic character

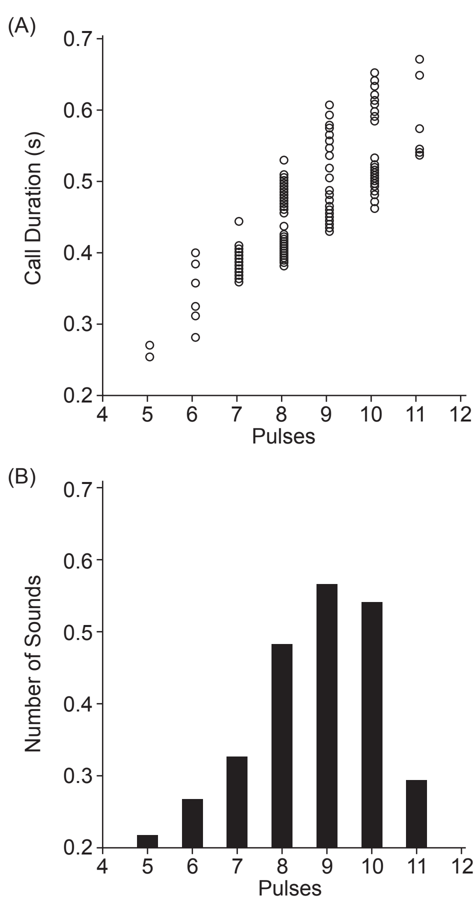

Fig. 4. Characteristics of calls emitted by *Protonibea diacanthus*. (A) Plot of the call duration to the number of pulses in a call. (B) Histogram of the number of pulses per call (N = 226 calls).

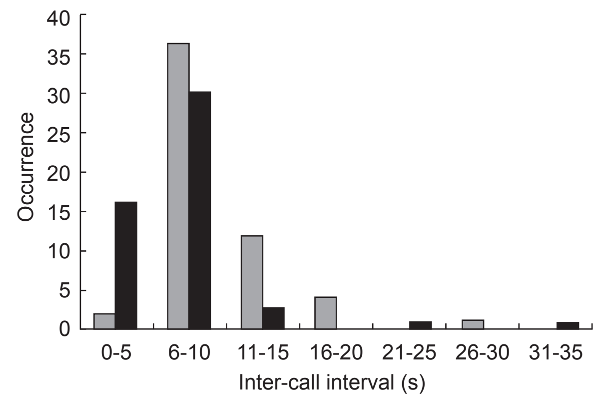

Fig. 5. Interval between 2 immediate adjacent calls in 2 series of sounds believed to be emitted by 2 different individuals (black bar, sound series recorded on 22 Aug. 2001 consisting of 52 calls; gray bar, sound series recorded on 26 May 2002 consisting of 55 calls).

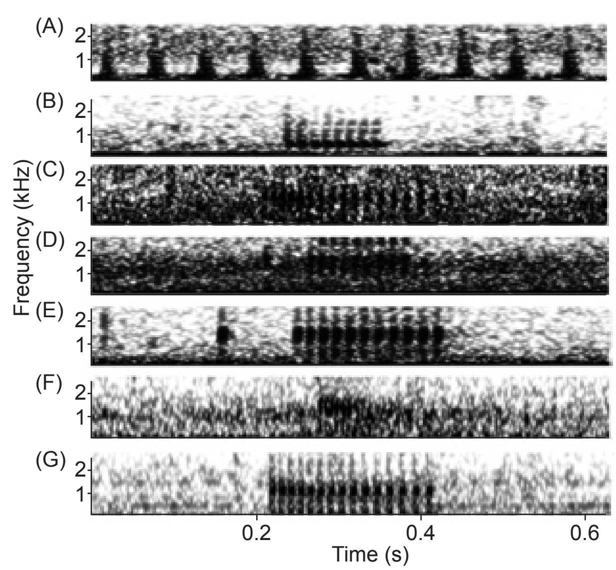

Fig. 6. Representative sonograms for the 7 types of sounds from the surveyed areas. A, Blackspotted croaker sound; B, Japanese croaker (see Ueng et al. 2007); and C, big-snout croaker (see Lin et al. 2007). The fish which produced the other 4 types (D-G) remain unknown.

distinguishing the blackspotted croaker sound from the remaining sound types (Table 2). Sounds from wild and cultivated individuals exhibited this diagnostic character (Fig. 7; inter-pulse interval of the sounds from the wild was 62 ms, and that from a 57 cm individual was 56 ms; n = 10 calls). The larger individual from the wild exhibited a lower fundamental frequency than the smaller 57 cm cultivated individual (fundamental frequency: ~156 vs. ~326.0 Hz, respectively; Figs. 2, 7).

Distribution of the blackspotted croaker's sound

Blackspotted croaker sounds were only heard in the Chosui and Zengwen River survey areas. Most recordings of blackspotted croaker sounds were from the Chosui River study area adjacent to the Wai-san-ding-chue, the largest sand barrier lagoon in Taiwan, at depths of < 15 m (Fig. 8). In the Zengwen River survey area, the sounds were recorded at 3 recording stations including an artificial reef site, at no deeper than 25 m. In the artificial-reef area (50 m in depth) in the Touchein River survey area, on the other hand, only sounds of the Japanese croaker *Argyrosomus japonicus* (Ueng et al. 2007) were heard, and no fish sounds were recorded from the other artificial reef area at 32 m deep in that study area.

Seasonal variations in the occurrence of the blackspotted croaker's sound

Blackspotted croaker sounds were heard between Apr. and Aug. (Table 3).

DISCUSSION

Lin et al. (2007) provided evidence from the big-snout croaker to support the notion that the hand-held disturbance sound agrees with those emitted under voluntary conditions. As such, the agreement between the above-mentioned sounds from the wild and those emitted by the cultivated blackspotted croaker should verify that the former were emitted by the blackspotted croaker. Additional support for the value of comparing the characteristics of the sounds emitted by the same species from the wild, and those when being held in the hand in and out of water comes from a study of Atlantic croaker *Micropogonius undulates* (Fine et al. 2004). Those authors found that sonograms of the emitted sounds in both air and water had similar pulse repetition rates and dominant frequencies, despite the pulse duration being longer for sounds in the water. When this phenomenon is extrapolated to the present study, the agreement among the exceptionally long inter-pulse interval, which is related to the pulse rate, among the target croaking sounds and those emitted by blackspotted croakers in and out of the water should serve as appropriate proof of which fish produced this sound type.

Although the type-2 call could be the combined sounds of 2 fish calling at the same time, this inference is not very likely as the intensities of the composing pulses were very similar (suggesting the calling fish should be located very close to each other; Fig. 3), and a few (1-5) shorter inter-pulse intervals only appeared in the internal section of the pulse trains (i.e., with an increased repetition rate at this particular section of the call). Figure 9 shows the difference in sound amplitude in the calls possibly made by 2 fish. If the above suspicion is true, one would expect that more (4-13) shorter inter-pulse intervals should be found in the

Table 2. Means of physical parameters of the seven types of sounds recorded in the surveyed areas. A, Black-spotted croaker sound; B, Japanese croaker (see Ueng et al. 2007); C, big-snout croaker (see Lin et al. 2007). Producers for the other four types (D-G) remain unknown. Ten calls for each sound type were analyzed

Parameter	Sound type						
	A	B	C	D	E	F	G
Duration (s)	0.62	0.24	0.26	0.25	0.40	0.07	0.27
Frequency range (Hz)	92-1156	531-1085	293-5230	322-1732	322-1203	656-1453	187-1031
Pulses/call	10	16	19	18	15	9	16
Inter-pulse interval (ms)	62	19	10	12	16	7	19

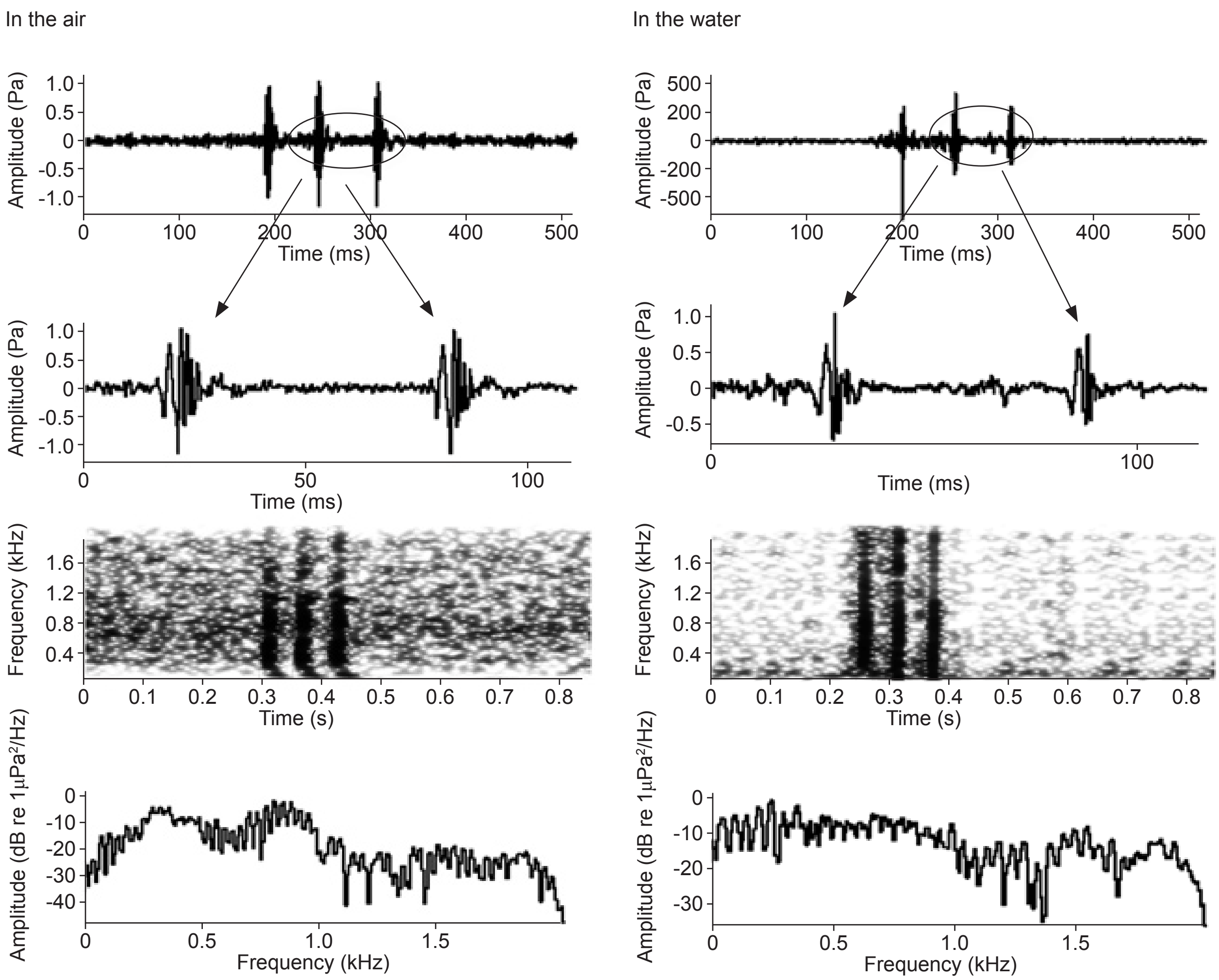

Fig. 7. Oscillograms, magnified oscillograms, corresponding sonograms, and spectrograms of disturbance calls emitted by cultivated blackspotted croakers in the air and in the water.

Table 3. Seasonal occurrence of *Protonibea diacanthus* sounds in the study areas surveyed between 2001 and 2004. Open circles indicate the absence of sounds from the field recordings; solid circles indicate the presence of sounds from the field recordings; blank cells indicate that no field recording was made. FA, fall; SP, spring; SU, summer; WI, winter

Year	2001				2002				2003				2004			
Study area	SP	SU	FA	WI	SP	SU	FA	WI	SP	SU	FA	WI	SP	SU	FA	WI
Tanshui River									○	○	○	○				
Touchein River									○	○	○	○				
Tachia River									○	○	○	○				
Tadu River													○	○	○	
Chosui River	●	●	○	○	●	●	○	○	○	○	○	○	○	○	○	○
Zengwen River					●	○	○	○								
Kaoping River					○	○	○	○								
Lanyang River													○	○	○	○
Hsiuruluan River													○	○	○	○

pulse train because each call should be composed of 5-14 pulses (Table 1; i.e., pulses related to the shorter inter-pulse intervals were made by 2 fish).

Efforts made in recording field sounds at each of the 9 study area in the present study were not equal, and the blackspotted croaker sounds being restricted to the Chosui and Zengwen River study areas might not represent the actual distributional pattern of this species in the region as a whole. However, this dataset still provides baseline information as to where to begin to protect their

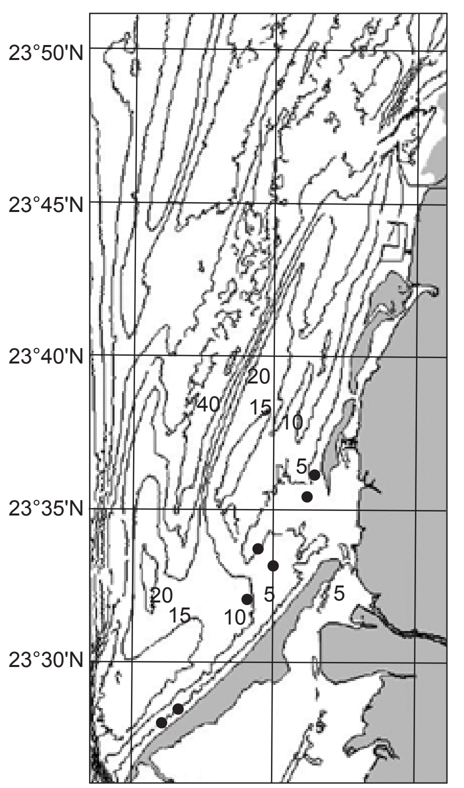

Fig. 8. Distribution of the recording sites in the Chosui River study area where sounds produced by *Protonibea diacanthus* were documented in the present study.

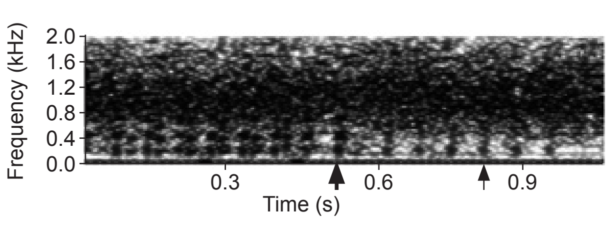

Fig. 9. Sonograms showing 2 calls probably emitted by 2 individuals as indicated by the difference in sound amplitude. Thick and thin arrows point to a pulse in each of the 2 calls.

spawning grounds. As more blackspotted croaker sounds were obtained from the former area, the question arose: What causes such a distributional preference? The Chosui River study area, where a higher concentration of blackspotted croaker sounds was present, is adjacent to the Wai-san-ding-chue. Such particular geological topographic and hydrographic characteristics may explain the preference for this area. This sand barrier has been reduced in width (east-west distance) and has progressively been shifting southward. Such changes are caused by coastal development via inland construction that has reduced the amount of efferent sand passing through the adjacent Baikong River into the lagoon region. Although overfishing has been proposed as the main factor causing the reduction in the annual catches of this species, changes in the conditions of its habitat in this major region may also be an important environmental factor.

Despite the presence of a rather consistent aggregation of mature blackspotted croakers in the above-mentioned areas, immature or juvenile fish are very uncommon in the coastal waters of Taiwan (e.g., Shao 2005). Among the landed demersal fish specimens we trawled from the Chosui River estuarine region in the summer, fall, and winter of 2004, only 1 blackspotted croaker specimen was collected in each of the fall and winter samples (both were 14.5 cm in standard length). However, most of the other 10 sympatric sciaenid species were much more abundant than the blackspotted croaker. The reasons for the scarcity of young fish remain unclear.

The type-E sound, characterized by a longer 1st inter-pulse interval compared to the following inter-pulse intervals, is made by the big-snout croaker *J. macrorhynus* (Lin et al. 2007). In addition to this sound type and type A, which belongs to *P. diacanthus*, the fish producing the remaining 5 sound types in figure 6 remain to be determined. *Arius maculates*, *Atrobucca nibe*, *Chrysochir aureus*, *Otoeithes rubber*, *Johnius amblycephalus*, *J. belangerii*, *J. tingi*, *J. sina*, *Nibea albiflora*. *Pennahia argentata*, and *P. macrocephalus* are the other 11 soniferous species known from the surveyed areas (see: Fishdb.sinica.edu.tw). Five or fewer species would be responsible for producing these sound types as a species can emit more than 1 sound type or some of these sound types may just be variants of the same type.

CONCLUSIONS

Yields of blackspotted croaker *Protonibea diacanthus* on the west coast of Taiwan have declined to a low level. The sound produced by mature blackspotted croakers is considered a possible indicator of the spawning grounds. This species produced 2 sound types, one of which was rarely found. The main type of sound is composed of bursts of pulses with approximate inter-pulse intervals which differed from other coexistent sound types in the field in having a longer inter-pulse interval. Sound energy is distributed in discrete bands with energy spreading to 1635 Hz. The sounds were recorded from Apr. to Aug. and were spatially restricted to the area surveyed adjacent to 2 rivers on the southwestern coast at depths of < 25 m. A major area was located close to the largest sand bar in Taiwan.

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