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Underwater Ambient Biological Noise in the Waters on the West Coast of Taiwan

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Abstract
Underwater ambient noise was surveyed along the shallow-water banks in the regions adjacent to the estuaries of seven major rivers on the west coast of Taiwan. Attention was paid only to the sounds which were considered to be emitted by soniferous fishes. Eight sound types were recorded from the study areas. They were compared to the hand-held disturbance sounds of nine soniferous species captured in the coastal waters of Taiwan in order to determine the origins of the sounds found in the wild. There were few cases of high matches. The sea catfish was treated as the producer of the high-frequency sound commonly occurring in these areas.

Key words: estuary, soniferous fish, Taiwan, underwater ambient noise

1. Introduction

The estuary, affected by both sea and river, is an important ecosystem in coastal regions and provides nourishment and habitat resources to marine animals. Unfortunately, many estuaries suffer from anthropogenic adverse effects as a result of river discharges containing chemical contamination. Ovefishing turns the estuary into an even more stressful places for the fishes. Generally speaking, there has been substantial trend of reduction in the abundance of estuarine fishes and an increase in the bioaccumulation of pollutants.

The western coast of Taiwan lies within the continental shelf with an average depth of over 70 meters. Several major rivers, including the Tanshui, Touchein, Tachia, Dadu, Chosui, Zengwen, and Kaoping, on the island empty onto this coast. Demersal fish species reported from sampling trawls made at the estuary of the Dadu River (Mok, pers. data) revealed that sea catfish accounted for about 23-79% of all catches, with sciaenids being the most abundant preys—a group of soniferous species.

In addition to these carnivorous fishes, some dolphin species, such as the Chinese white dolphin, the top predator in the marine food chain, also reside along the west coast.

The Chinese white dolphin (or the Indo-Pacific humpback dolphin), *Sousa chinensis*, is found in tropical and temperate coastal waters of the Indian and Pacific Oceans from northern Australia and southern China in the east, through Indonesia and around the coastal rim of the Indian Ocean to Southern Africa. They prefer shallow waters where depths are less than 20 m and they are known to enter rivers, estuaries and mangroves (Karczmarski *et al*. 2000, Hung and Jefferson, 2004). In southern China, they are present in the coastal region south of the Yangtze River and in Hong Kong and as far as the western coast of Taiwan (Jefferson and Karczmarshi, 2001). A relative large population with 1,000-1,500 individuals has been reported in the Pearl River and in the Hong Kong region (Jefferson and Hung, 2004). Along the contrary, only 60 individuals were reported in Xiamen, China. On the western coast of Taiwan, less than 100 individuals have been reported (Wang *et al.,* 2004). Due to its small population size, the Chinese white dolphin was identified as a "critically endangered" species in the IUCN Red List of Threatened Species in 2008.

The diet of the Chinese white dolphin includes squids, sciaenids, and sea catfish. In Hong Kong waters, Humpback dolphins have a diet comprised almost exclusively of fish sciaenids, with clupeiform accounting for over 93% of all prey consumed (Barros *et al.,* 2004). It is evident that dolphins forage on their prey not only by means of their active biosonar system, but also by passive means (i.e., listening to the sounds of their prey).

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The co-occurrence of the soniferous fishes with the Chinese white dolphin exhibits an ecological relationship between them; survival of the latter partly dependent on that of the soniferous fishes.

A recent public issue in Taiwan causing some hot debate is the proposed implementation of an industrial development project on the west coast of Taiwan. As the Chinese white dolphin lives in that coastal region, the anthropogenic adverse pressure associated with the industrial development there will likely damage the small dolphin population. Because of this public controversy, protecting the Chinese white dolphin has received more public attention and the current status of the soniferous prey of the Chinese white dolphin has also become a concern.

The distribution of these fishes can be surveyed by fishing or remote sensing (e.g., by fish finder or passive sonar). Both approaches share a technical bottleneck, i.e., a difficulty in obtaining a clear taxonomic characterization of either the echo signal or the acoustic signal the fish emit. Mok *et al*. (1983) applied the latter approach to survey the aggregation of vocalizing adult sciaenids in the Indian River lagoon. In Florida, U.S.A. their possible spawning sites were estimated according to the spatial distribution of particular sound types designated to a sciaenid species and also to the amplitude and occurrence (abundance of calls per unit time) of the sounds recorded. Similar methods associated with further technical improvement have been developed and applied to field fishery survey in recent years.

A survey was carried out from 2000 - 2004 in the estuaries of eight major rivers in Taiwan. The data provide some preliminary information on the ambient biological sounds in these regions as they relate to the distribution of the soniferous fishes. However, further details on the distribution of individual species remain unclear because information of their acoustic signatures is unavailable. A reliable source for such information is the data recorded from cultured species whose voluntary sounds can be obtained at various developmental and spawning stages (pre-courtship, courtship, spawning, and post-spawning stages). Lin *et al* (2007) reported that the hand-held disturbance and voluntary sounds emitted by the big-snout croaker, *Johnius macrorhynus*, shared unique acoustic characteristics in having a longer pause duration between the first and second pulse in a call (the rest of the pauses are about equal in duration). In other words, the disturbance sound is informative in revealing the species' acoustic signature. If this is a general phenomenon, one can record the disturbance sounds of the soniferous species in a target region and compare them to the sounds from the wild; any match will provide a clue as to the sound producer.

Twenty sciaenid species have been reported in Taiwanese waters (Shen, 1993). Those living in the estuaries in northern Taiwan are listed in decreasing order of abundance: *Pennaha macrocephalus, Johnius macrorhynus, J. tingi, Pennahia argentata, Atrobucca nibe, J. sina, Johnius amblycephalus, Protonibea diacanthus, Chrysochir aureus, Argyrosomus japonicus, Pennahia pawak., Nibea albiflora, Pennahia macrophthalmus, and Johnius belangeri* (personal unpublished data).

The present paper reports the wild sound types found in the estuaries of seven major rivers along the west coast of Taiwan and the disturbance sounds of nine soniferous species commonly found in the coastal waters of Taiwan. The latter data set was used to search for the possible producers of the wild sound types.

2. Materials and Methods

1) Survey areas

The widths of the mouths for the surveyed rivers, namely the Tanshui, Touchein, Tachia, Dadu, Chosui, Zengwen and Kaoping, are 1,060 m, 1,031 m, 947 m, 973 m, 1,524 m, 561 m, and 938 m, respectively (Fig. 1).

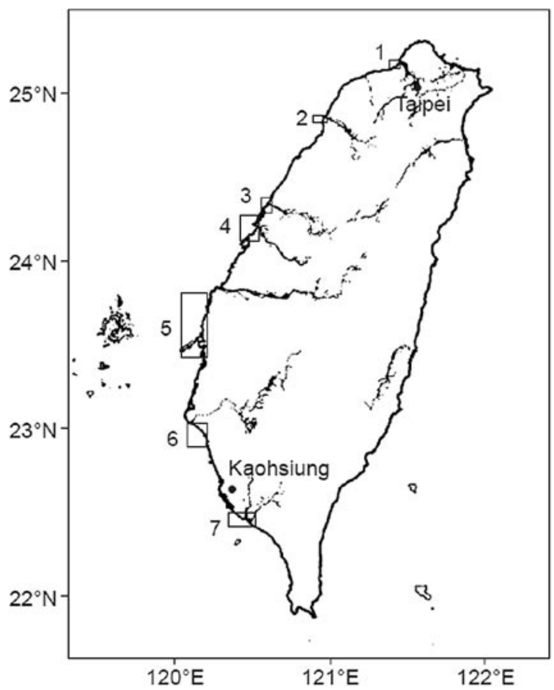

Fig. 1. Recording estuaries along the west coast of Taiwan. 1. Tanshui River; 2. Touchein River; 3. Tachia River; 4. Dadu River; 5. Chosui River; 6. Zengwen River; 7. Kaoping River.

2) Sound recording and analysis

As has been reported, sciaenids emit sounds beginning around sunset (e.g., Mok and Gilmore 1983). Thus, field recordings began at around 1,700 hr and continued until around 2,200 hr. Engines of the fishing boat were shut down prior to recording. A hydrophone was suspended to ca. 1 m below the surface, and sounds were taped for five to ten minutes depending on the quality of the signals recorded.

The sound recording system included a HP-A1 hydrophone (Burns Electronics; frequency range: 10Hz-25 kHz) connected either to a SONY stereo cassette recorder (TCD5-PROII) or to a JVC XM-D1 personal MiniDisc player. The sound outputs from the recorder were digitized at 16 KHz using a Cool Edit 2000 analog-to-digital board.

Acoustic data were analyzed using Avisoft-SASlab PRO software (Specht, 2002). Measured sound features included: the number of pulses per call, call duration, pulse repetition rate, pulse duration, pulse period (the time between the beginnings of two immediately adjacent pulses in a call), inter-pulse interval, frequency range, and dominant frequency. For the frequency-domain character and time domain-feature, 56 Hz and 224 Hz 3 dB filter bandwidths were used, respectively.

For obtaining the disturbance sounds of the soniferous fishes, live specimens were captured by hook-and-line in the coastal waters of Taiwan (mainly on the west coast). As soon as they were caught, they were put into a plastic cooler (56cm x 32 cm x 28 cm). Upon gentle touching of the abdomen of the fish, they often emitted croaking sounds which were recorded by a hydrophone placed inside the cooler at about 5 cm – 10 cm from the fish.

3. Results

1) Sound types from the wild

A total of eight sound types were recognized in the coastal regions near the seven estuaries. The following key, which is constructed based on the frequency range, call duration, inter-pulse interval, and pulse repetition rate, provided guide to the sound types.

1A. Call duration about 100 msec ....Type F
1B. Call duration much longer than 100 msec......2
2A. Maximum frequency below 1 kHz.................Type G
2B. Maximum frequency above 1 kHz.................3
3A. Frequency below 2 kHz 4
3B. Frequency above 2 kHz..................................5
4A. Pulse repetition rate low.................................Type D
4B. Pulse repetition rate high................................Type A
5A.Frequency reaching 6 kHz 6
5B. Frequency not reaching 3 kHz 7
6A. First inter-pulse interval longer......................Type B
6B. All inter-pulse intervals approximately
equal in duration..Type H
7A. First inter-pulse interval longer......................Type C
7B. All inter-pulse intervals approximately
equal in duration..Type E

Besides the above-mentioned sound parameters, the number of pulses per call is also a useful parameter that can help distinguish sound types. For example, type-D sounds are composed of fewer pulses, whereas Type-G sounds tends to contain more pulses. Intra-call variation in the inter-pulse interval is a parameter of paramount importance ; inter-pulse intervals of Type-A and G sounds tend to increase toward the end of a call. Inter-pulse interval, pulse duration, and repetition rate are important distinguishing parameters.

2) Characteristics of the sound types from the wild (Fig. 2)

Type A: Inter-pulse interval increased toward the end of a call.

Type B: First inter-pulse interval was much longer that the following ones of which the durations did not increase toward the end of the call; sound energy reached 7 kHz.

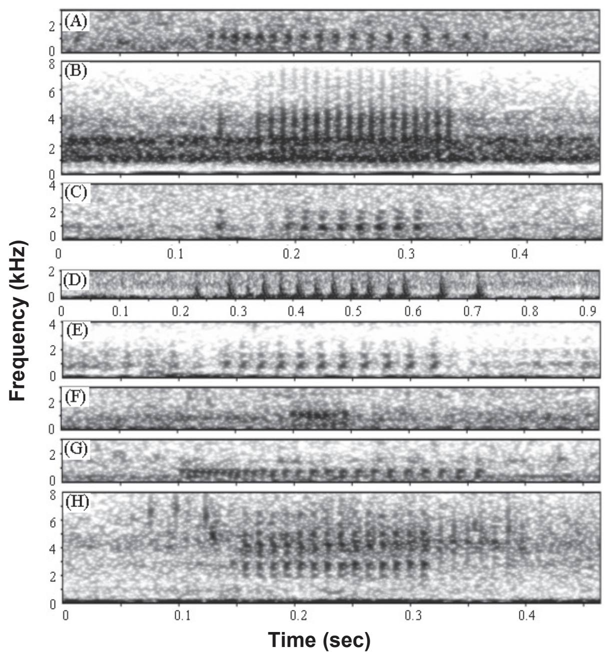

Fig. 2. Representative sonograms of eight sound types (A-H) recorded from the study areas.

Type C: First Inter-pulse interval was longer and frequency reached only 2 kHz.

Type D: Frequency below 2 KHz, pulse repetition rate reached about 28 pulses/sec; sound energy continuously extended to about 2 kHz.

Type E: Inter-pulse interval increased gradually towards the end of the call; sound energy concentrated in discrete bands.

Type F: Call duration was very short, with few pulses and a high repetition rate.

Type G: The anterior inter-pulse intervals were much shorter and lengthened toward the end of the call; number of pulses/call high (ca. 26 pulses/call).

Type H: Maximum frequency reached 8 kHz.

3) Distribution of the sound types:

The distribution of the eight sound types is shown in Table 2. Type-C sound is the most common type occurring in all seven estuaries along the western coast (Fig. 1 and Table 1). Types are listed in decreasing order of commonness: Type C, Type H, (Types B, and G), Type E, (Types A and F), Type D (Table 1).

Estuaries are listed in decreasing order of the number of sound types contained (Table 1): Chosui River (eight types), Tachia River, Zengwen River (six types), Kaoping River (five types), Dadu River (four types), Tanshui River and Touchein River (three types).

Table 1. Distribution of the eight sound types in the seven study estuaries.

Sound Type	River							Total
	Tan-shui	Tou-chein	Ta-chia	Tadu	Cho-sui	Zeng-wen	Kao-ping	
A					V	V	V	3
B			V	V	V	V	V	5
C	V	V	V	V	V	V	V	7
D					V	V		2
E	V	V	V		V			4
F			V		V		V	3
G			V	V	V	V	V	5
H	V	V	V	V	V	V		6
Total	3	3	6	4	8	6	5	

4) Distribution of soniferous species along the west coast

In the Tanshui, Touchein, and Tachia estuaries, *Pennahia macrocephalus* is the most abundant sciaenid species followed by *Johnius macrorhynus*. For the Touchein estuary, *Johnius tingi* is in third place, whereas *Pennahia argentata* is the third species in the Tachia estuary (Mok, unpublished data). In other words, *Pennahia* and *Johnius* are the two common genera along the northwestern coast. In the Chosui estuary, *Arius maculate* is the dominant species and the number of fish could be 3-25 that times of the sciaenids. *Pennahia pawak* is the most common sciaenid in this region, followed by *Johnius macrorhynus*.

5) Hand-held disturbance sounds (Figs. 3, 4, 5; Table 2)

Hand-held sounds of nine sciaenid spp., namely, *Johnius belangeri, J. distinctus, J. macrorhynus, P. argentata, P. macrocephalus, P. pawak, Atrobucca nibe, Otolithes ruber* and *Arius maculates* are described (Table 2).

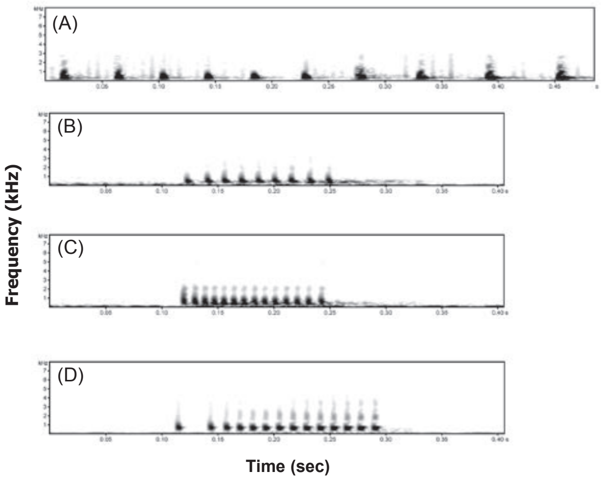

Fig. 3. Representative sonogram of A, *Atrobucca nibe;* B, *Johnius belangerii,* C, *Johnius distinctus,* D, *Johnius macrorhynus.*

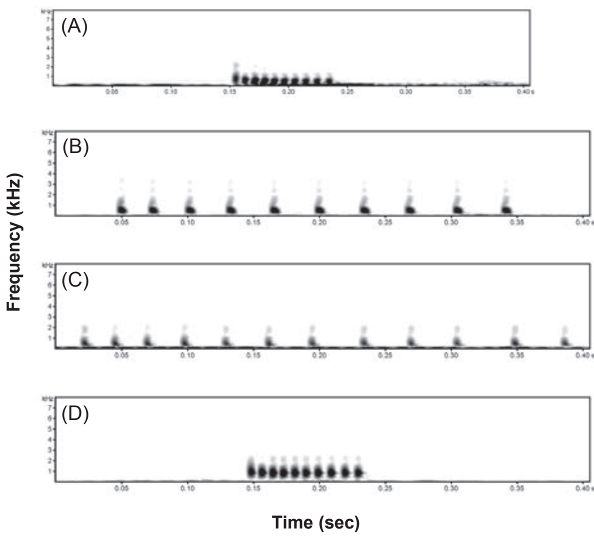

Fig. 4. Representative sonogram of A, *Otolithes ruber;* B, *Pennahia argentata;* C, *Pennahia macrocephalus;* D, *Pennahia pawak.*

The inter-pulse interval of the *Pennahia* spp. sounds increased towards the end of a call; pulse repetition rates for *P. argentata* and *P. macrocephalus* are long, whereas that of *P. pawak* is short. The call duration of *P. pawak* is also very short (Table 2).

The inter-pulse intervals of the sounds of *Johnius* spp. did not increase toward the end of a call. The intervals varied among the three species; the first interval in *J. macrorhynus* is longer than the following ones (Figs. 3, 4).

Atrobucca nibe's sound is characterized by an exceptionally long inter-pulse interval (i.e., low repetition rate; Fig. 4).

Otolithes ruber's sound is characterized by low frequencies; frequency and inter-pulse intervals slightly decreased toward the end of the call (Fig.4).

The disturbance sounds of all three *Pennaha* spp. are characterized by increasing inter-pulse intervals toward the end of the call (Table 2). Among the recorded species, the pulse repetition rates of *Pennahia argentata, P. macrocephalus,* and *Atrobucca nibe* were much longer than the others. Only the first inter-pulse interval of *J. macrorhynus* was longer than the following ones (Fig. 4).

Arius maculates emits two hand-held disturbance sounds (Lin, 2010), i .e., a low frequency, harmonic drumming sound and a high-frequency stridulatory sound composed of a train of pulses (Fig. 5).For the former sound, each drum lasted about 58.5 ms, with a fundamental frequency at about 163 Hz with the number of harmonics reaching 5; most energy was lower than 2.2 kHz. For the later sound, pulses/call ranged from 5 to 11; the repetition rate 139.3; the inter-pulse interval ranged from 0.47 to 4.33 ms, with the duration not increasing toward the end of the call; most sound energy was below 5 kHz.

4. Discussion

Spatial variation in diversity of sound types may be due to an inequality of recording effort; more time had been devoted to the Chosui River and that might have led to a higher number of sound types being recorded in that area. The low number of sound types recorded from the Tanshui River is very likely a result of the substrate characteristics as snapping sounds were predominant in many recording sites in that area. This substrate type may not be a suitable habitat for sciaenids and sea catfish. More data from these estuaries will help clarify the reason for the diversity variation.

Possible producers of the sound types:

The calls of *Nibea albiflora* were described by Takemura *et al*. (1978); its fundamental frequency is low (0.2-0.7 KHz), but the pulses could reach to about 7kHz by the amplified resonance. Despite its high-frequency sounds, this species is rare along the west coast; it

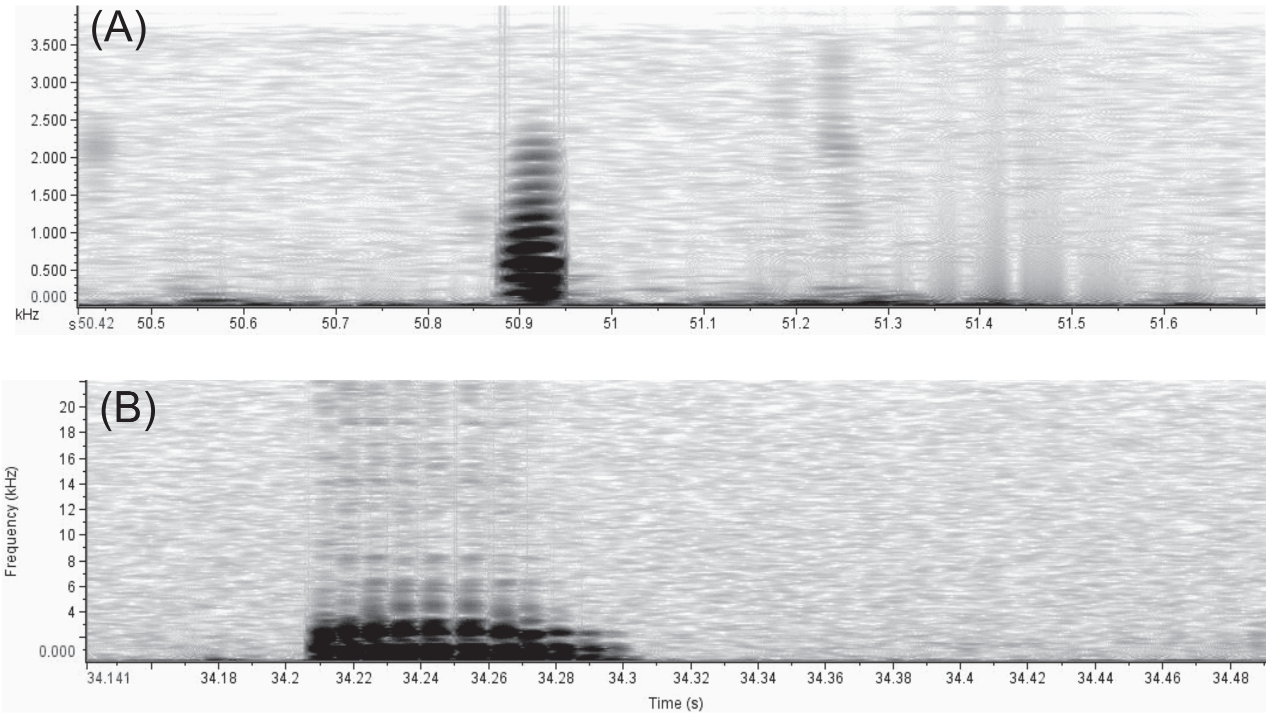

Fig. 5. Representative sonograms of the hand-held disturbance sounds produced by sea cat fish, *Arius maculatus*.
(A) Drumming sound (FFT size 512 points, time overlap 98% and a Hamming window); (B) Stridulatory sound.

Table 2. Parameters of the hand-held disturbance sounds in nine sciaenid species.

Sound parameters	*Pennahia*				*Johnius*			*Otoeithes*	*Atrobucca*
	P. anea	*P. argentata*	*P.macrocephalus*	*P. pawak*	*J.belangerii*	*J.distinctus*	*J.macrorhynus*	*O. ruber*	*A. nibe*
Fish numbers (n.)	6	11	7	10	10	24	31	1	1
Sound numbers (n.)	90	104	92	169	200	242	85	17	1
Pulse numbers (Pulses/call)	11.5 ± 8.7	11.4 ± 6.9	7.8 ± 5.5	9.2 ± 5.4	10.2 ± 4.8	12.9 ± 3.8	11.2 ± 4.3	8-13	10
Call duration (ms)	119.4 ± 106.6	352.8 ± 242.7	247.5 ± 204.8	85.8 ± 54.5	129.6 ± 44.6	132.5 ± 44.4	113.7 ± 32.0	-	44.7
Pulse duration (ms)	7.0 ± 0.6	7.3 ± 0.7	7.9 ± 0.9	6.2 ± 0.8	6.5 ± 0.8	6.4 ± 1.0	6.2 ± 0.8	5.5	5.3-7.8
Interpulse interval (IPS, ms)	3.6 ± 1.7	25.6 ± 6.2	26.7 ± 7.4	2.9 ± 1.9	6.4 ± 3.4	4.4 ± 1.9	3.9 ± 3.3	2.8-6.7	41.7-50
First IPI (ms)	2.1 ± 0.9	16.7 ± 4.5	17.3 ± 6.1	2.3 ± 1.8	7.9 ± 4.1	4.7 ± 2.9	16.0 ± 7.3	-	-
Last IPI (ms)	5.1 ±1.8	30.6 ± 6.7	30.2 ± 7.0	3.5 ± 2.2	10.4 ± 7.8	5.9 ± 2.1	4.3 ± 1.6	-	-
Repetition rate (pulses/second)	101.9 ± 11.6	35.2 ± 6.0	35.6 ± 7.4	118.5 ± 14.3	78.0 ± 17.2	99.5 ± 13.5	88.5 ±10.6	130	21.3
Peak frequency (Hz)	736 ± 115	543 ± 98	576 ± 93	736 ± 101	584 ± 181	511 ± 126	807 ± 143	354-1717	-

becomes unlikely that *N. albiflora* is the sound producer of Type-H. Due to (1) the common occurrence of *Arius maculates* on the west coast and its high sound frequency and (2) the wide distribution of the high-frequency Type-H sound on the west coast, this sound type is possibly produced by *A. maculatues,* despite the fact that its hand-held sound does not totally agree with this type of sound (Fig.5). It was reported that *A. maculates* is absent from areas south of the Zengwen River; interestingly, Type-H sound is also absent in the Kaoping River (see above) located within the area mentioned. The agreement strengthens the possibility of the above inference regarding the producer of Type-H sounds.

The hand-held and voluntary sound of *Johnius macrorhynus* is known (Lin *et al.,* 2007); it is characterized by an exceptionally long first inter-pulse pause length and a maximum frequency reaching 8 kHz—two characteristics similar to that of the Type-B sound from the field.

Type-A and Type-G sounds are characterized by an increase of the inter-pulse interval towards the end of a call—a characteristic fits that of *Pennaha* spp. The exceptionally short duration of the call and short inter-pulse interval of Type-F sound suggests that it might be emitted by *P. pawak* (Table 2) whose sound is short in duration. The frequency range, inter-pulse interval and repetition rate of Type-C sound suggests that it is emitted by one of the *Johnius* spp. The very low frequency range and repetition rate of Type-G sound make it likely to be emitted by *Otolithes ruber* (Figs. 2, 4 and Table 2).

Some sounds recorded in the Chosui River region showed much longer second or third inter-pulse intervals (unlike the long first inter-pulse interval in *J. macrorhynus*). Whether these three types belong to *J. macrorhynus* remains unknown. In the large number of sound data of Lin *et al.,* (2007) the first two conditions did not occur. A possibility exists that they are sounds produced by other *Johnius* species.

Because sciaenids are the main prey of the Chinese white dolphins, monitoring the spatial distribution, relative density, and amplitude of the possible sciaenid sounds will provide valuable information reflecting the distribution and relative abundance of the soniferous aggregations of the sciaenids. Unfortunately, the present paper can only provide preliminary data on the distribution of the sound types without any associated information on their relative abundance (e.g., number of calls/unit time, amplitude, and individual-, small-group or large-group sounds). When these data are available, a clearer picture of the food resources for the Chinese white dolphin will be revealed.

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