Studies on Underwater Sounds Produced by Japanese Horse Mackerel *Trachurus japonicus* in Net Pens at Culture Grounds in Innermost Kagoshima Bay

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(Received October 12, 1998)

The differences between swimming and feeding activity of recorded underwater sound in summer and winter produced by japanese horse mackerel in a net pen were analyzed using the one-third octave band method. The small and big-sized fish show the same curve patterns under swimming and bait-eating activity in summer, but in the term of the maximum and minimum level frequencies, it seems slightly different. The swimming sound curve pattern in summer was same as in winter, but there were some different patterns in bait-eating sound. The two respective records obtained simultaneously on the inside and outside of net pen when swimming activity were same in regard to the pattern and sound level, but the records when bait-eating activity were different.

Key words: swimming sound, bait-eating sound, japanese horse mackerel, one-third octave band analysis

It is well known that many marine fishes produce sounds when moving about in the water column. The spectrum of sound produced by marine animal is characteristic of the species, so these sounds can be used for detecting, attracting or repelling fish schools.¹⁾ A device for gathering fish schools by using underwater acoustical equipment was conceived with the idea that if fish schools could be lured to a location and driven into a fish net by emitting an effective sound, fishing efficiency could be increased.²⁾

Some series of experiments report on underwater sound produced by fishes in net pens at the culture ground have been published previously.^{3–5)} In the previous study, the different sound of yellowtail and amberjack for swimming and feeding conditions was reported.⁶⁾ However, the underwater sound of japanese horse mackerel has not been examined thoroughly.

The present study was undertaken to obtain more information on underwater sound produced by japanese horse mackerel (named “ma-aji” in Japanese). The purposes of this paper are to study characteristics of underwater sound produced by japanese horse mackerel; to examine the relationship between swimming sound and feeding sound; to compare sounds in the summer with those in the winter and finally, to contrast the recorded sound simultaneously by two hydrophones located inside and outside the net pen.

In the Kagoshima waters, japanese horse mackerel is one of main target fishes of small size purse-seine fisheries. This data could be used for identification, detecting, gathering and luring fish schools.

Materials and Methods

Research Subject

The subjects of this research were japanese horse mackerel *Trachurus japonicus* in schooling during the swimming and feeding activities. The average size and weight of the fish were shown in Table 1. The examined fishes were divided into two size categories, i.e., small size (weight 90–120 g; length 20–23 cm) and big size (weight 280–320 g; length 28–30 cm).

Research Field Condition and Net Pen

The Kurokami culture ground is situated in the eastern coastal waters of Sakurajima, Kagoshima Prefecture (Fig. 1). The net pens were laying around 0.1 nautical mile offshore with of depth about 50 m. The cubical net pen with size 8 m in length, 8 m in width and 8 m in depth is made of galvanized iron pipes and covered by galvanized iron netting panels or synthetic fiber netting that are buoyed up by foaming floats.

Table 1. Average size and amount of examined fish

Size category	Average weight	Average length	Number of fish*	
			Summer	Winter
Small size	90 g–120 g	20 cm–23 cm	20000	—
Big size	280 g–320 g	28 cm–30 cm	10000	7000

*Estimated value.

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Fig. 1. Location of Kurokami culture ground.

Fig. 2. Recording method in a net pen.

At the time underwater sound investigation was carried out, the weather and sea conditions were as follows: clear-cloudy, none wind, calm sea, water temperature of 26.8°C (in summer) and 16.3°C (in winter).

Bait for fish were moisture pellets with a diameter of about 1 cm.

Data Collecting Procedure

The underwater sound was received with a hydrophone (OKI SW 1020) which connected with underwater levelmeter (OKI ST 1020) and recorded by PCM data recorder (TEAC RD-101T). A hydrophone was hung at the depth of 3 m (when bait-eating) and 6 m (when swimming) on the inside of net pen in the summer. However, in the winter, two hydrophones were hung on the inside and outside of net pen separately, by putting 3 meters of space between them (Fig. 2).

The underwater sound was being recorded when there was no noise from boat or other noise source. The bait was spread by hand during bait-eating activity. The underwater levelmeter cut off frequency of the low pass filter was adjusted to 10 kHz and that of the high pass filter was adjusted to 10 Hz. The data recorder also recorded some use-

ful information related to the experiment.

Data Analysis Procedure

Data recorded in the net pen were examined by the one-third octave band method. In the one-third octave band analysis method, the sound and vibration signal analyzer (RION SA74A) was used. The average of five pieces data (one datum length; continuous 1 minute 7 second) was used.

Center frequencies of one-third octave band filters were from 16 Hz–8 kHz, with the minimum cut off frequency of 14 Hz and the maximum cut off frequency of 9 kHz. The reference sound pressure level was 1 μ Pa. The resultant frequency characteristics were compared, based on the respective sizes, activities of the schooled fish, season (only summer and winter) and position of where hydrophone was placed (inside and outside the net pen).

Results and Discussion

One-third octave band analysis graph of Japanese horse mackerel's underwater sound showed some curve pattern with three separated certain frequency bandwidths such as in the low frequency bandwidths, in the middle frequency bandwidths where the hollow curve that steeply decrease and becomes concave, and in the high frequency bandwidths.

Swimming Sound

Swimming sound of Japanese horse mackerel in summer showed same pattern in small-sized ones and big-sized specimens (Fig. 3). The low frequency bandwidth of both sizes appeared below 200 Hz. Small-sized fish curve in low frequency bandwidth have high level from 31.5 Hz, but big-sized ones from 40 Hz. The concave bandwidth appeared in frequency 200 Hz–1.25 kHz and has minimum level at 500 Hz for small-sized fish and at 400 Hz for big-sized ones. The minimum level frequency was higher for small-sized fish, and was lower for the big-sized ones. In the high frequency bandwidth, both sizes showed that the sound levels increase when frequencies become higher.

The maximum level frequency of small-sized Japanese horse mackerel in summer was 8 kHz, but big-sized ones was 6.3 kHz. The maximum level frequency of small-sized fish was a little higher than big-sized ones. It presumed that the small-sized fish and the big-sized ones generally produced same type of frequency under their swimming activities.

In comparing with small-sized (70 g) of yellowtails swimming sound pattern,⁶ both sized Japanese horse mackerel swimming sounds pattern have differences with yellowtail's pattern and also with red sea bream's sound under swimming activity,⁹ which is horse mackerel's swimming sound pattern showed upward curve in high bandwidth frequency. Other species reported that the swimming sound of 1.5 kg yellowtails produced the maximum level of 64 Hz,³ which this examined species was bigger than present object.

Swimming sound of big-sized ones in winter showed difference pattern with in the summer (Fig. 4). The concave curve in middle frequency bandwidth of swimming sound in winter was not clearly appeared in about 125 Hz–

Fig. 3. One-third octave band analyses of swimming sound in summer.
—○— Small size; —■— Big size; —◆— Ambient noises.

Fig. 4. One-third octave band analyses of swimming sound of big size fish.
—■— Summer (inside); —□— Winter (inside).

200 Hz. Apparently, curve of swimming sound in winter has flat curve from 100 Hz until 500 Hz, but become convex curve in summer. The other way, the winter curve sharply increased in 630 Hz to 1 kHz, but in summer, it was gradually increased until 2 kHz.

The maximum level frequency of big-sized fish in winter is at 6.3 kHz, also in summer. The minimum level frequency of concave bandwidth of big-sized ones in winter is at 160 Hz, but in summer at 400 Hz. It means that the minimum level frequency under swimming was decreased in winter.

Bait-eating Sound

The bait-eating sounds of Japanese horse mackerel in summer showed the same pattern in both small and big sized fish (Fig. 5). In the low frequency band, the big-sized sound showed a convex curve from 31.5 Hz to 50 Hz and on the contrary become concave at small-sized ones. In the middle frequency bandwidth, small-sized fish showed another convex curve from 630 Hz to 1.25 kHz and just

the opposites become concave with large specimens.

The maximum level frequencies of small and big-sized specimens in summer were same at 100 Hz. In the meantime, the minimum level frequencies of middle frequency bandwidth of big and small-sized fish in summer were also same at 315 Hz. It presumed that small and big-sized fish generally produced same type frequency under bait-eating activity.

The bait-eating sound of big-sized fish in winter showed a flat pattern, but in summer it showed curve pattern (Fig. 6). In the low frequency bandwidth, the flat pattern showed an increased level of frequency of 40 Hz.

In comparing with other species reported that the sound curve of small-sized yellowtail (fish weight about 70 g at Tarumizu culture ground)⁶⁾ and amberjack (fish weight about 3.5 kg at Higashi Sakurajima culture ground)⁴⁾ under bait eating, apparently, have same pattern with the present summer bait-eating sound curve pattern result.

According to Matsuno *et al.*,⁵⁾ the maximum level of amberjack in Akoubaru culture ground (fish weight about

Fig. 5. One-third octave band analyses of bait-eating sound in summer.
—●— Small size; —□— Big size; —◆— Ambient noises.

Fig. 6. One-third octave band analyses of bait-eating sound of big size fish.
—□— Summer (inside); ---□— Winter (inside).

500 g) were 25 Hz, 63 Hz and 6.3 kHz under bait eating activity, which is slightly same with the present result.

Swimming Sound Compare to Bait-eating Sound

The sound curve pattern of small-sized fish in summer showed same pattern under swimming with under bait-eating activities (Fig. 7). Sound level of bait-eating increased in low and middle frequency bandwidths. In low the frequency bandwidth, the sound level increased from 16 Hz until 200 Hz. In the middle frequency bandwidth, the sound level was increased from 315 Hz until 1.25 kHz. The 70 g amberjack's bait-eating sound curve also increased in the low frequency bandwidth in 16 Hz–160 Hz compared to the swimming sound curve.⁴⁾

The sound curve pattern of big-sized fish in summer also showed the same pattern under swimming during bait-eating activities (Fig. 8). The sound level of bait-eating was increased in low and middle frequency bandwidths. In the low frequency bandwidth, the sound level was significantly increased from 16 Hz until 200 Hz. In the middle frequency bandwidth, the sound level was increased from

400 Hz to 2 kHz.

In the low frequency bandwidth, the represented difference sound level during bait-eating from that during swimming of big-sized fish was bigger than of that small-sized ones. But, in the middle frequency bandwidth, the represented difference sound level during bait-eating from that during swimming of small-size fish was bigger than of big-sized ones. It presumed that big-sized Japanese horse mackerel activity during bait-eating produced higher energy than small-sized ones in low frequency bandwidth.

The overall underwater sound levels of bait-eating activity were higher than during swimming activity. This result was similar to other previous researches.^{3,5,6)}

The difference overall underwater sound of small-sized fish in summer during both activities was 4.0 dB. The difference of overall underwater sound of big-sized fish in summer during both activities was 4.6 dB. The difference of overall underwater sound of big-sized fish in winter during both activities was 9.3 dB (hydrophone was hung inside the net pen).

The sound curve pattern of big-sized fish in winter

Fig. 7. One-third octave band analyses of underwater sound of small size fish in summer.
—○— During swimming; ---●--- During bait-eating.

Fig. 8. One-third octave band analyses of underwater sound of big size fish in summer.
—■— During swimming; ---□--- During bait-eating.

Fig. 9. One-third octave band analyses of underwater sound of big size fish in winter.
—□— During swimming; ---■--- During bait-eating.

Fig. 10. One-third octave band analyses of swimming sound of big size fish in winter.
—□— Inside; ---■--- Outside.

Fig. 11. One-third octave band analyses of bait-eating sound of big size fish in winter.
—□— Inside; ---■--- Outside.

showed a different pattern during swimming from that during bait eating activities (Fig. 9). All of sound levels of the bait-eating sound curve are higher than those of swimming activity from low frequency bandwidth until 2 kHz frequencies. The bait eating sound level is greatly different from swimming sound from 16 Hz–1 kHz. The swimming sound level is slightly higher at 5 kHz–8 kHz. It may be caused by water surface ripples.

The difference in level of both activities of big-sized fish sound in winter was larger than big-sized fish sound in summer, if bait-eating activity was the same action in both seasons. It is presumed that fishes are not so active during their swimming in winter compared with in summer. This phenomenon was also confirmed by visual observation during the research done. In comparing with the other species it is reported that yellowtail were normally not active enough in water temperature of 13.5°C.²⁾

Comparing of Hydrophone Position

The curve pattern of big-sized fish sound in winter during swimming with hydrophone dipped 6 m inside net pen

and 6 m outside net pen showed the same level and pattern (Fig. 10). Overall, underwater sound of big-sized fish during swimming activity was 111.1 dB when hydrophone was dipped inside the net pen and was 110.7 dB when the hydrophone was dipped outside the net pen.

The curve pattern of big-sized fish in winter during bait-eating with the hydrophone dipped 2 m inside the net pen and 2 m outside the net pen showed same pattern (Fig. 11). The sound level of the curve pattern with the hydrophone dipped 2 m inside was higher than with the hydrophone dipped 2 m outside the net pen at all frequencies. The difference in sound levels of both curves was high in low frequency and diminished when the frequencies become high. It is presumed that fish movement was very active under bait-eating in comparison with swimming activity. This phenomenon also was confirmed by visual observation during the research done.

According to Hawkins,⁷⁾ hydrodynamic sounds are produced by fish that are actively swimming, or rapidly turning. Though much of the disturbance recorded on a hydrophone in the vicinity is generated by water turbulence, a

booming or rushing sound is often detectable at several meters.

The overall underwater sound of big size specimens during bait-eating activity was 120.4 dB when the hydrophone was dipped inside and was 108.5 dB when the hydrophone was dipped outside the net pen.

In conclusion, (1) The small and big-sized fish show the same curve patterns during swimming and bait-eating activity in summer; (2) The bait-eating sounds of Japanese horse mackerel in summer showed the same pattern in both of small and big sized fish. The bait-eating sound of big-sized fish in winter showed a flat pattern, but in summer it showed a curved pattern. The bait-eating sound of big-sized fish in winter showed a flat pattern, but in summer showed a curved pattern; (3) The sound curve pattern of small and big-sized fish in summer showed same pattern during swimming as during bait-eating activities, but the big-sized fish in winter showed a different pattern for both activities; (4) The difference in level of both activities of big-sized fish sound in winter was larger than big-sized ones sound in summer. It is presumed that fishes are not so active during their swimming in winter compared with in summer; (5) The curve pattern of big-sized fish sound in winter during swimming and bait-eating activities with the hydrophone hanging inside and outside the net pen showed same pattern.

Acknowledgments We wish to express our gratitude to the "Fishermen's Production Association", especially Mr. Masato Kawazoe and

Mr. Isamu Kawazoe for kindly providing the experimental fish.

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