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Application of broadband dolphin mimetic sonar for discriminating target fish species

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This paper based on published papers (Imaizumi et al. 2008, Matsuo et al. 2009) and include newly measured data using captive tuna.

ABSTRACT

For the acoustic species discrimination, broadband response of three tuna species, bigeye tuna, yellowfin tuna and skipjack tuna were measured by a broadband split beam sonar system. Each species was kept in an enclosure separately. Ultrasonic broadband sound (70 kHz - 140kHz) was projected nearly horizontally to the captive fish body in a floating pen. Three major echoes were detected from each fish. The delay time between earlier and last echo corresponded to the body width of the target fish. These echoes seemed to come from the left and right body surface of each fish when the acoustic beam projected transversally to the fish body. The dominant echo at the middle between body surface echoes was considered to come from the center of the body such as the swimbladder and/or the spine. As already known, bigeye tuna has swimbladder where as skipjack tuna does not. Yellowfin tuna has smaller swimblader than that of bigeye tuna. The relative intensity of the body surface echo to the body center echo was large for skipjack tuna and small for bigeye tuna. This is consistent with the large target strength of the swimbladder rather than the spine or other unidentified reflectors in the body center of the fish. This could be a key for the species discrimination. More sample size and experiment including numerical simulation is needed as the future research.

I. INTRODUCTION

Selective catch of species and size has been anticipated for the sustainable fisheries. As for the purse seine fishery at the tropica waters, to develop the method to avoid the bycatch of small sized bigeye and yellowfin tuna by purse seine operation on FADs (Fish aggregating devises) has been very serious issue for both of stocks and fishery. If one can grasp species and size composition in the fish school before the purse sein operation, it would be possible to avoid the fishing on school of undesirable composition.

Conventional echo sounders have been used for searching fish school but were not suitable to discriminate fish species remotely. It is known that dolphins can distinguish not only size of target but also thickness, material and shape of it by using their sonar system (Au 1993). Their sonar system can be characterized by its broadband frequency and short duration of sonar sound. Broadband sonar is getting popular these years (Reeder et al 2004, Stanton and Chu 2008)). It is advantageous for target discrimination by using broadband echoes from different targets (Au and Benoit-Bird 2003, 2008). The very high spatial resolution of the broadband sonar seems to be useful for the measurement of individual echo and observation of fish movement (Ito et al. submitted). Recently, we developed a dolphin mimetic sonar, which is the broadband split beam sonar system (Imaizumi et al. 2008). A trial has been made to observe the broadband echo characteristics differences among skipjack tuna and small sized bigeye and yellowfin tunas.

II. MATERIALS AND METHODS

A. Sound transmission and receiving system

The broadband sound transmitting and receiving systems were constructed (Imaizumi et al. 2008). A custom made broadband transducer and power amplifier for transmitting and receiving was used (FURUNO electric Co. Ltd., Nishinomiya, Hyougo, Japan). Computer generated broadband signal was amplified and was sent to the transmit transducer. In the receiving system, the reflected wave was received by the same transducer, and the signal was amplified by the preamplifier. The output signals were observed, measured, and transformed into digital data by PXI system (National Instruments, USA) and the data were transferred to a personal computer harddisk. The transmitting sensitivity had a peak at 118 kHz, fell off rapidly below 60 kHz, and varied as much as 5 dB in the flat area between 67 and 134 kHz Fig. 1a. The beam width of the transmit transducer was 18.82° at 60 kHz and 9.03° at 120 kHz. The product of the transmitting and receiving sensitivities had a broadband characteristics of sensitivity product 70kHz to 140 kHz at a level of -10 dB.

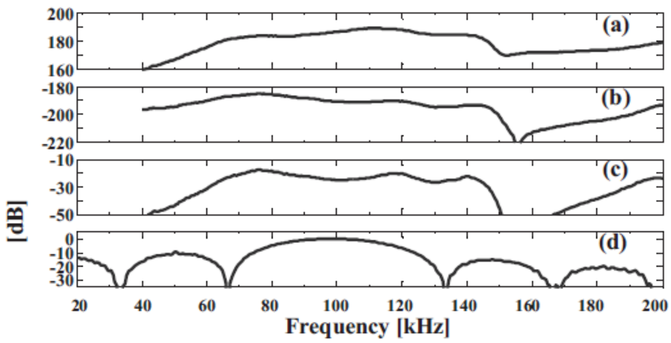

FIG.1 Frequency response of (a) transmitting and (b) receiving sound by the custom made transducer. Product of both sensitivity (c) still keeps the broadband capability comparing with the main lobe of the three waves sinusoidal tone burst (d)

Dolphin sonar sounds are composed of trains of clicks for which the click interval is generally dependent on the target range (Au 1993). The waveform is similar among the pulses (Kamminga et al. 1996). The characteristics of the sonar sound vary among the dolphin species, but they can be roughly divided into two types. The bottlenose dolphin type has a broad frequency bandwidth and is composed of a small number of cycles, whereas the finless porpoise type has a narrower and width and is composed of a larger number of cycles. The term “dolphin” represents both dolphins and porpoises in this paper. Dolphins transmit highly focused sonar sounds forward from the head (Au 1993). It is well known that both the waveform and the frequency characteristics of the sounds measured off-axis are different from those measured on-axis. The typical on-axis sonar signals of the bottlenose dolphin and finless porpoise were recorded (Nakamura and Akamatsu 2004). Based on these sound characteristics, three wave sinusoidal impulse was used as the alternative of the dolphin clicks because its mathematical expression is simple comparing with real biosonar signals at centroid frequency of 100 kHz.

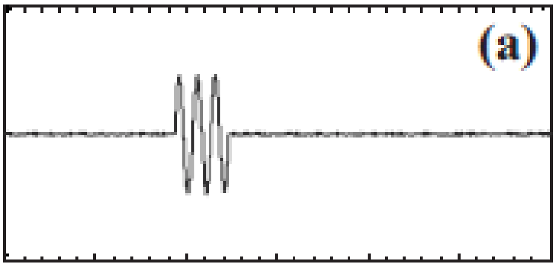

FIG.2 Waveforms of the broadband signal used for the present study.

The -3 dB bandwidth of the tone burst was 30 kHz, from 84 to 114 kHz. It is clear that the transducer system can transmit and receive the majority of the spectral content of these broadband signals. The far-field distance was computed as 1.3 m at the highest frequency of 140 kHz, which was much shorter than the separation range. Because of the transducer frequency characteristics, the incident waveforms are distorted versions of the transmitting signals.

B. Experiment site

Broadband echo measurements were conducted during April 13-18, 2010 at southern end of Amami Island, Kagoshima, Japan (28.12.52N, 129.15.08E). Experienced local fisherman who catches tuna alive for supplying aquarium exhibition was asked the fisherman to catch three tuna species, bigeye tuna, yellowfin tuna and skipjack tuna and accommodate fish in each pen (FIG.3). Each pen has iron pipe frame structure sized 8 x 8 m square on the sea surface from which net enclosure was hanged so as its bottom to be approximately 5 m in depth. Beside the three pens, 12 m square flat pontoon was settled asfor the platform of a transducer and the data acquisition systems. The transducer was fixed at the end of an iron pipe. The other end of the pipe was fixed on the frame of the pontoon. The depth of the transducer was fixed at 3.8 m from the water surface. The direction of the transducer was adjusted to the center of each pen except for the skipjack’s one.

Recording of broadband echo was continued for over two hour for each species to obtain large number of echo traces. During measurement, fish behavior was monitored by an underwater video camera, which was installed in the text enclosure.

Approximately 30 to 50 individuals were contained in each pen. At the end of the experiment, all of the fish was captured for the measurement of folk length, body depth and body width. Average folk length of the bigeye, yellowfin and skipjack tuna were, 51.5, 41.4, 41.6 cm, respectively (Table 1). Twenty fish were preserved to measure the length of the swim bladder using X-ray image that was not finished yet. In table 1, ration of individuals having swimbladder was indicated. Two of two bigeye tuna had swimbladder and two of 21 yellowfin tuna were confirmed to have swimbladder. The volume of the swimbladder of bigeye tuna was known to be larger than that of yellowfin tuna (Bertrand and Josse 2000).

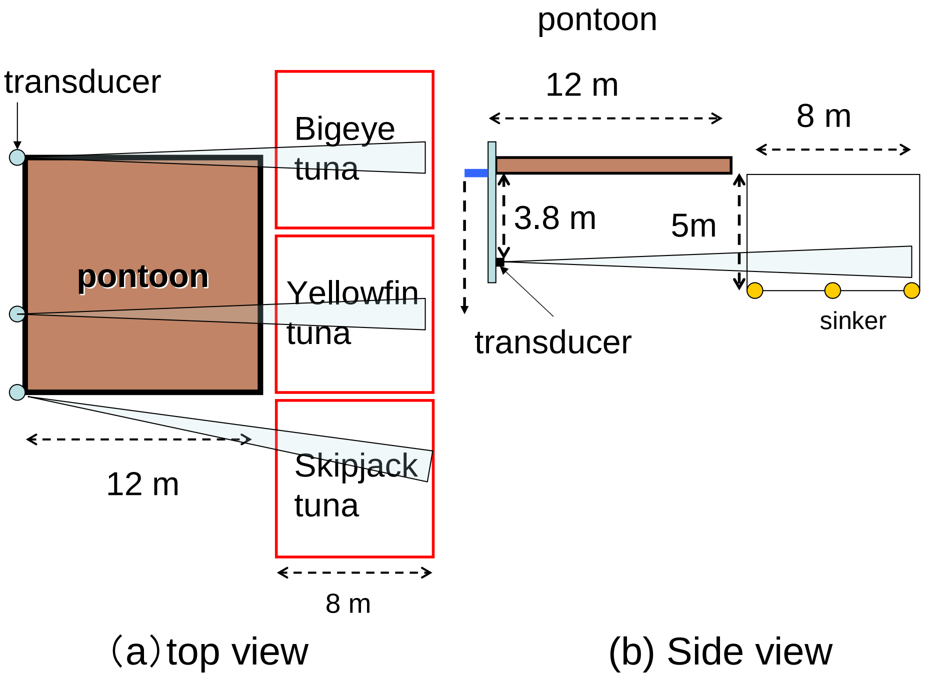

FIG.3 Three net pens were fixed right next each other beside the pontoon. Each pen had single species of fish bigeye tuna, yellowfin tuna and skipjack tuna. They swam in circle and the acoustic beam was projected horizontally from the transducer as shown in blue long triangles. The position of the transducer was adjusted to point the beam to the center of each enclosure except for skipjack tuna. Because of the location of the skipjack pen, the acoustic beam axis was at an angle.

Table 1. Folk length, body depth and body width of three tuna species used for the measurement.

Species	N	Folk Length (cm)			Body depth (cm)			Body width (cm)		
		Range	Average	Std	Range	Average	Std	Range	Average	Std
Bigeye tuna	12	44.5-57.2	51.5	3.4	11.1-15.1	13.9	1.1	6.7-9.2	8.2	0.8
Yellowfin tuna	21	38.3-46.0	41.4	1.9	9.3-11.2	10.0	0.5	5.8-7.9	6.6	0.5
Skipjack tuna	20	38.2-44.7	41.6	1.8	8.3-10.2	9.4	0.5	5.7-7.3	6.4	0.5

C. Signal processing

To estimate its temporal structure of a fish, the echo-envelope pattern was extracted. As shown by the solid curve of Fig. 4, this envelope pattern was calculated by the cross-correlation function between the incident wave and echo waveform (Oppenheim and Schafer, 1975). The temporal highlight structure was computed by extracting the local peak from the envelope pattern.

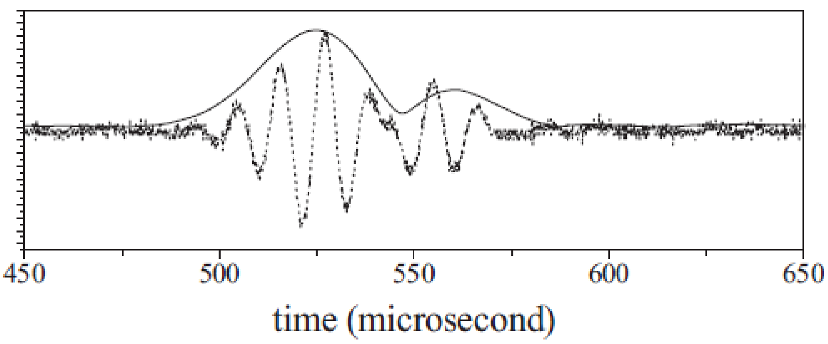

FIG.4 Envelope extraction of the echo was conducted by cross correlation between incident and

received sound.

III. RESULTS AND DISCUSSION

All of the three fish species swam in circle in the pen. The echogram showed sinusoidal pattern of the fish movement (FIG.4). Ordinate shows the distance from the transducer. The line appeared at 14 m is the nearer net of the enclosure from the transducer. The appeared at 20.5 m is the opposite side of the net. In between the net, which is the inside of the enclosure, periodical echo traces can be observed. Since the fish swam in circle, strong echo came back when the fish pass through the acoustic beam perpendicular to the beam axis at 15 m and 19 m distance. Skipjack tuna appeared always to be approaching to the sound source. It is because the beam axis covered the half side of the enclosure unlike the case of other two species (FIG. 5).

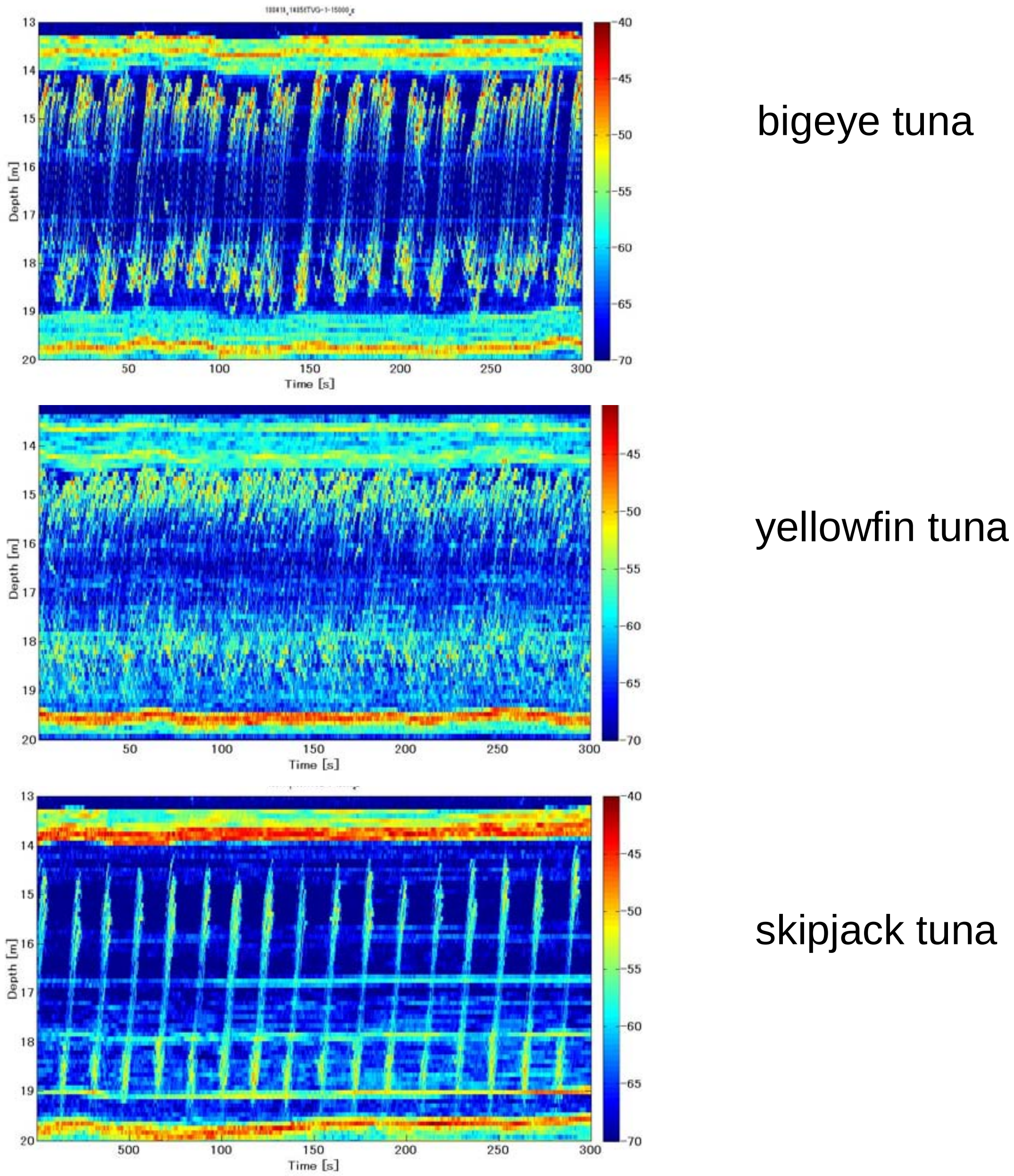

FIG.5 Echogram of bigeye tuna, yellowfin tuna, and skipjack tuna Each trace corresponds to individual fish except for skipjack tuna. Skipjack tuna swam in a group, which echogram showed a

trace of group behavior.

The echogram and the envelope pattern of individual fish was shown in FIG. 6. The echogram showed the echo came from single fish and no contamination of echo from other fish occurred. The abscissa shows ping number of each sound transmission, which produces every 50 ms. The ordinate shows the time of received sound in micro second.

The envelope pattern showed the triple peak structure. The strong horizontal echo of bigeye tuna seemed to come from the swimbladder. There were two other echoes before and after the echo of the swimbladder in bigeye tuna. These side robes were observed approximately 30 microseconds (45 mm) upper and lower from the main echo of the swimbladder. The separation is calculated 90 mm assuming 1500 m/s sound speed in the body of the fish. Note that the acoustic beam traveled fish body transversely. This suggests that the two side robes came from the surface of the fish body since the actual body width of samples fish was 82 mm (Table 1). This may be an acoustic cue to identify the fish body width remotely using broadband sonar systems.

Yellowfin tuna and skipjack tuna showed triple peaks structure, too. But their side robes shown as white arrows were much larger than that of bigeye tuna. The intensity of the main echo at the center line was used as the reference for these figures. This means the relatively smaller echoes came from the body center. This is consistent with that yellowfin tuna and skipjack tuna have small or no swimbladder.

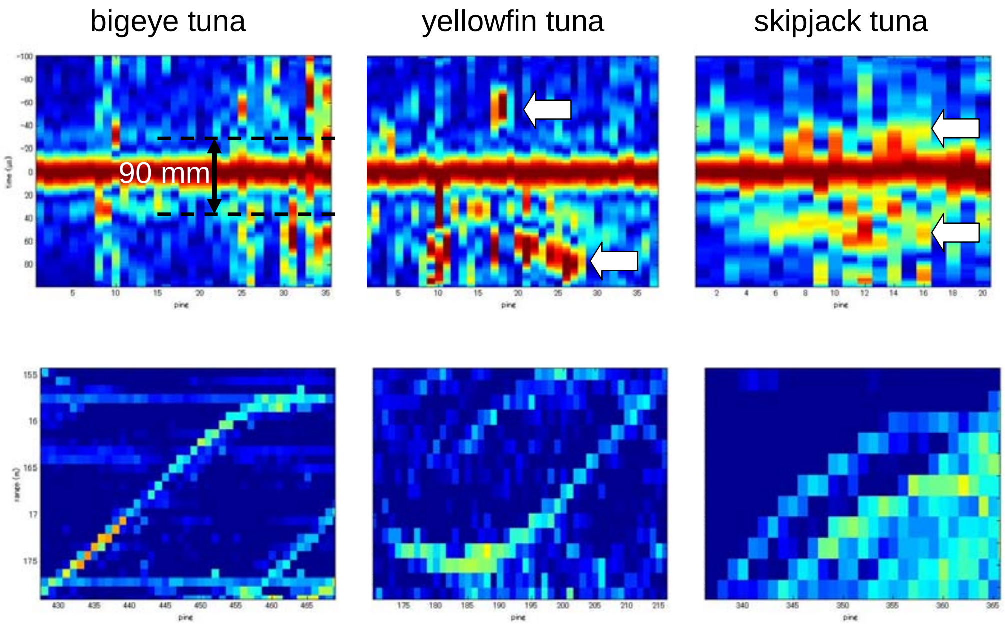

FIG. 6 Envelope (top) and echogram (bottom) patterns of three tuna species. Red center line of the envelope pattern indicate the swim bladder or spine, which are the major reflectors at the center of the fish body. There are two side robes above and below of the center. These side robes seemed to come from the both sides surface of the fish body. Intensity of the side robes were stronger for a yellowfin tuna and a skipjack tuna than that of a bigeye tuna.

IV. CONCLUSION AND FUTURE WORKS

The broadband echo sounder system provided precise image of individual echogram of three tuna species that provide underwater movement, fish body width and may be species as well. The high spatial resolution of the present dolphin mimetic sonar can be used for the direct counting of the target species as well as the underwater behavioral observation. Three major echoes were detected from a fish. The delay time between earlier and last echo corresponded to the body width of the target fish.

These echoes seemed to come from the left and right body surface of each fish when the acoustic beam projected transversally to the fish body. Dominant echoed at the middle between body surface echoes was considered to come from the center of the body of each fish. Suspected reflectors were the swimbladder and the spine. As already known, bigeye tuna has swimbladder where as skipjack tuna does not. Yellowfin tuna has smaller swimblader than that of bigeye tuna. The relative intensity of the body surface echo to the body center echo was large for skipjack tuna and small for bigeye tuna. This is consistent with the large target strength of the swimbladder rather than the spine or other unidentified reflectors in the body of the fish. This could be a key for the species discrimination. Using split beam system, relative angle of the incident sound wave to the fish body can be calculated. This parameters will be helpful to reconstruct 3D echo envelope image of each fish. For the discrimination of fish species, it is important to show the probability of classification. To do this, more sample size and experiment including numerical simulation is needed.

V. ACKNOWLEDGEMENTS

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