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Acoustic characteristic of the large jellyfish *Nemopilema nomurai*

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The jellyfish *Nemopilema nomurai* has occurred in large numbers in Japan and Korea and has had on a negative effect on coastal fisheries in this region. Data on the abundance and distribution of jellyfish are needed to forecast when and where they will occur in coastal areas. Acoustic techniques are commonly used to study the distribution and abundance of fish and zooplankton. However before such surveys can be conducted, the acoustic characteristics of the target species must be known. In this study, the density of and speed-of-sound in jellyfish were measured to clarify their acoustic characteristics using a theoretical scattering model. The acoustic characteristics were estimated with the distorted-wave Born approximation (DWBA) model using these material properties and the shape of free-swimming jellyfish.

Material and methods

Sound speed in jellyfish

The experiments were conducted at Yosu in Korea in August and at Tottori in Japan in October 2005. The live jellyfish were captured by the scoop net and their bell diameter were from 24 cm to 85 cm. Sound speed is determined by measuring the direct travel times for sound between the two transducers of the tank, called time-of-flight method (Kogeler *et al*., 1987).

To conduct the measurements of large jellyfish, a specially designed tank was used. The tank was 30 cm in diameter, and the height was adjustable from 10 to 30 cm in 5 cm increments. Two 400 kHz transducers are placed facing vertically each other, one as a transmitter and the other as a receiver (Fig.1). The tank were filled with only jellyfish when the travel times for sound in jellyfish was measured. The temperature in jellyfish was measured using the thermometer (CUSTOM,CT-800WP) while the measurement. The travel times for sound in only jellyfish and only seawater were measured.

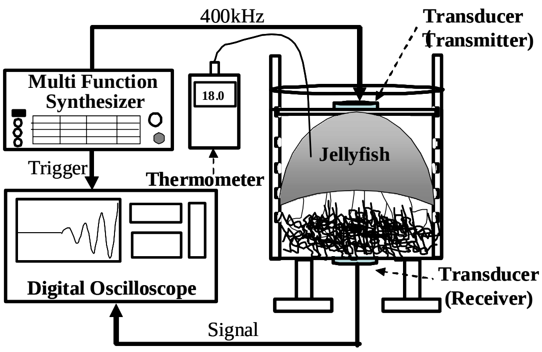

Fig. 1 The apparatus used to measure sound-speed of jellyfish.

These experiments gave values for the travel times for sound in sea water (T_{sw}), and for the jellyfish only (T_{jelly}). The sound-speed contrast (h) is defined as the ratio of these values using expression (1).

$$h = \frac{C_{jelly}}{C_{sw}} = \frac{T_{sw}}{T_{jelly}} \quad \cdots\cdots (1)$$

The sound speed in the seawater (C_{sw}) in the tank was estimated from measurements of temperature and salinity and using the equation of Mackenzie (1981). All the jellyfish were alive during the experiments.

Density of jellyfish

A dual-density method (Chu and Wiebe, 2005) was used to estimate the density of jellyfish. The advantage of the dual-density method is that it can avoid the uncertainty introduced by water unavoidably adhering to the animals, that occurs with the traditional method involving displacement volume and weight measurements. There were four steps in completing. (i)

Measuring the densities of the seawater ρ_{sw}, (ii) Adding the v_{sw} liter seawater to a pre-weighed empty container. (iii) Jellyfish mixture to a container and measuring the total weight of the container plus the mixture and obtaining the net weight of the mixture w_1 by subtracting the weight of the container. (iv) Adding the v_w liter distilled water v_2 to the container and measuring the total net weight of the new mixture w_2. ρ_m was estimated using expression (2) in order to exclude the influence of the water with jellyfish. The density of the jellyfish can be determined by solving these equations.

$$\rho_m = \frac{\rho_{sw}v_{sw} + \rho_w v_w}{v_{sw} + v_w} \quad \cdots\cdots \quad (2)$$

$$w_1 = v_{sw}\rho_{sw} + v_j\rho_j \quad \cdots\cdots \quad (3)$$

$$w_2 = (v_t - v_j)\rho_m + v_j\rho_j \quad \cdots\cdots \quad (4)$$

$$v_t = v_{sw} + v_w + v_j \quad \cdots\cdots \quad (5)$$

$$v_w = (w_2 - w_1)/\rho_m \quad \cdots\cdots \quad (6)$$

$$\rho_j = \frac{w_2 - (v_t - v_j)\rho_m}{v_j} = \frac{w_2 - (w_2 - w_1)[(\rho_m/\rho_w)(\rho_{sw} - \rho_w)/(\rho_{sw} - \rho_m))]}{v_t - ((w_2 - w_1)/\rho_w)((\rho_{sw} - \rho_w)/(\rho_{sw} - \rho_m))} \quad \cdots\cdots \quad (7)$$

Target strength of *Nemopirema nomurai*

The TS of jellyfish were tried to estimate using these results of the sound speed and density using DWBA model (McGehee *el al.*1998), simplicity. The shape of jellyfish to estimate TS was used to the photograph which was taken by the underwater video camera which was located in the tank where there is jellyfish in. The shape of jellyfish was digitized from this photograph.

Results and discussion

Fig.2 shows the results of sound speed measurements. Triangles show the results for the Yosu experiment, and circles show those at Tottori.

The open symbols are the data of the live jellyfish and black symbols are for the dead jellyfish. The speed of sound in sea water where the jellyfish were captured was showed the dashed line. The speed of sound in jellyfish were nearly sea water and there is no difference between the live state and dead state.

Fig.3 shows the results of density measurements. The density of seawater surrounding the jellyfish lived was showed the broken line. The density of the damaged jellyfish are heavier than the other jellyfish. And also the density of the dead jellyfish were tended to be heavier than the live one.

Fig.4 shows that the relationship between the swimming angle and the estimated TS by DWBA model. The density and speed of sound contrast used in the model computation was 1.013 and 1.001, respectively. The incident angle assumed that the 180 degree correspond to sound impinging on the bell of jellyfish. The peak of TS was at 0 and 180 degree and TS decrease dramatically with the incidence angle changing. Especially, TS drop suddenly at 120 kHz and 200 kHz with the slight incident angle changing.

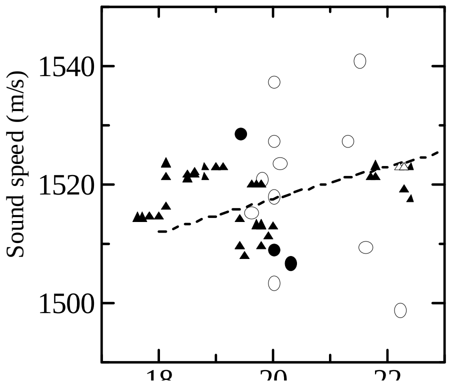

Fig. 2 Relationship between temperature and sound speed. The broken line is sound-speed of seawater (31.5PSU). Tottori: Live ○, Dead ● Yosu: Live △, Dead ▲

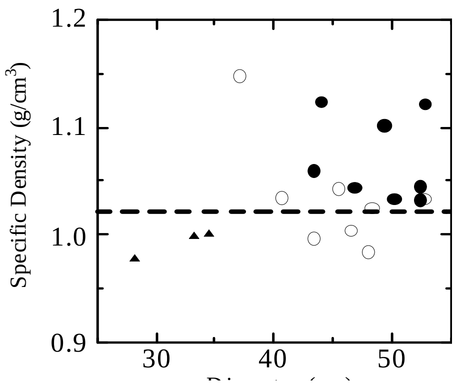

Fig. 3 Relationship between diameter and specific density. The broken line is density of sea water ($1.021 g/cm^3$, 20℃, 31.5PSU) Tottori: Live ○, Dead ● Yosu: Live △, Dead ▲

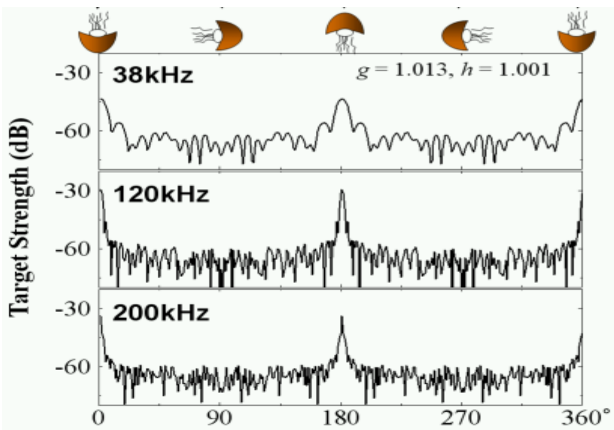

Fig.4 Relationship between the swimming angle and the estimated TS by DWBA model.