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Target-strength Measurements of Sandfish *Arctoscopus japonicus*

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Abstract – The goal of this study was to estimate the target strength (TS) of the sandfish *Arctoscopus japonicus* using *in-situ* and *ex-situ* methods with an echosounder. For the *in-situ* TS measurement, the survey was conducted by taking hydroacoustic measurements at 38 and 120 kHz and using a coastal gill net, in Goseong, in the northeastern sea of Korea in early December 2009. *Ex-situ* measurement of TS used live specimens and the tethering method, and was conducted at 120 kHz. The distribution of fork length (FL) was bimodal: 14.6–19.8 cm (n = 241 individuals, mean = 17.0 cm) for males and 16.3–24.5 cm (n = 105 individuals, mean = 19.6 cm) for females. The *in-situ* TS ranged from -79.8 to -59.1 dB (mean = -74.3 dB for males and -64.1 dB for females) at 38 kHz and -79.9 to -56.2 dB (mean = -74.3 dB for males and -64.1 dB for females) at 120 kHz. The mean TS of females was approximately 10 dB higher than that of males at each dominant frequency. The female *ex-situ* TS values ranged from 68.5 to -54.6 dB, and those of males was from -67.7 to -59.3 dB. The mean TS value for females was 2.9 dB higher than that of males. These results may be used in echo-integration surveys of sandfish to estimate their abundance and seasonal distribution.

Keywords – Target Strength, hydroacoustics, *in-situ*, *ex-situ*, *Arctoscopus japonicus*

1. Introduction

Arctoscopus japonicus is a cold-water sandfish found in the eastern sea of Korea, the northern sea of Japan, around the Kamchatka Peninsula, and along the Alaskan coast. Its seabed consists mostly of areas with sand or muddy sediment, such as that found on the continental shelf and at water depths of 100–200 m (Lee et al. 2009; Yang et al. 2012). Annually during the winter season, the sandfish migrates to the northeastern sea of Korea, where it spawns in seaweed-rich areas at a depth of 2–10 m (Lee et al. 2006; Yang et al. 2012). This species is managed within the total allowable catch (TAC) system in force in Korea, which requires an accurate assessment of resources to regulate exploitation, because the number of fish has fallen dramatically since 1970.

The stock biomass and seasonal migration may be surveyed using echosounders. First, estimates of the volume backscattering coefficient (s_V; m^2 m^{-3}) are made using *in-situ* sandfish. Then, the integrated s_V (s_a; m^2 m^{-2}) is converted to a number density using an estimate of the mean backscattering cross-sectional area (σ_{bs}; m^2) for sandfish. Target Strength ($TS = 10 \log(\sigma_{bs})$; dB re 1 m^2) depends on the acoustic frequency and incidence angle, and the target size, shape, and morphology; particularly whether or not the fish has a swim bladder (Nakken and Olsen 1977; Foote 1980; Mukai and Iida 1996; Horne 2003). Models of versus acoustic frequency (f; Hz) and fish length (L; cm) may be used to identify the s_V from target scatterers, and their sizes. Models of TS (f, L) may be theoretical, or based on split-beam echosounder measurements of live or dead *ex-situ* fish, or *in-situ* fish. For example, Saito (2004) measured at $f = 38$ kHz($TS_{38\,\mathrm{kHz}}$) for suspended, quick-frozen sandfish. Seseo (2005) measured $TS_{38\,\mathrm{kHz}}$ for *in-situ* sandfish in deep water, during day and night. The TS of sandfish relies on fewer assumptions than other approaches. However, there is a need to quantify $TS_{38\,\mathrm{kHz}}$ and $TS_{120\,\mathrm{kHz}}$ of sandfish in the shallow spawning areas off Korea.

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2. Material and Methods

TS of *in-situ* sandfish

TS of spawning sandfish was measured in the 14-m deep coastal region of Go-seong, which lies in the northeastern sea of Korea on December 7–8, 2009. A single gill net was cast at each of the five stations in the survey area on December 7, 2009 and these were retrieved on December 8 to identify species distribution and biological characteristics, such as fork length (FL; ± 1 mm), weight (w; ± 1 g), and sex. The mesh size of these gill nets was 39.4 mm and their length was 55 m. The nets contained 100 meshes.

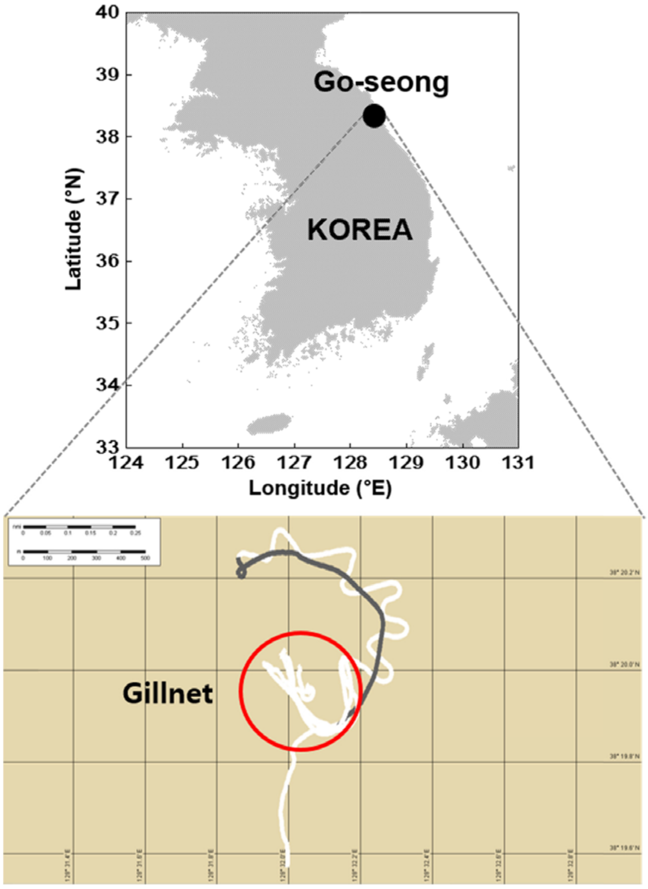

Fig. 1. Study area for the acoustic and fishing-gear survey. The black line defines the survey line used to collect the acoustic data. The coastal gill nets were installed in the circled region

An echosounder system (EK60, Simrad Kongsberg Maritime AS, Norway), operating at 38 and 120 kHz, was installed on the side of the fishing boat (1.3 tons), and acoustic data were collected from 18:40 to 20:00 after sunset at the locations where the coastal gill nets had been cast in the survey area. This was the period when the fish were most active (Fig. 1). The depth of the survey area was in the shallow water, within 14 m. Table 1 shows the system parameters used, and they are adjusted for collection of acoustic data for sandfish.

TS of *ex-situ* sandfish

TS of *ex-situ* sandfish was measured in a seawater acoustic tank (5 m × 5 m × 5 m) at the Institute of Fisheries Science, Chonnam National University, Korea, in March 2015. Sandfish were caught in trap nets in Ohori-hang, located in the northeastern sea of Korea. Then, the live sandfish were moved to the experimental location in seawater in large plastic buckets with an air supply. The sandfish were also kept in fish tanks (ø 5.0 × 1.0 m) for a few days. TS measurement of sandfish was made with a frequency (120 kHz) split-beam echosounder system (EK60, Simrad Kongsberg Maritime AS, Norway). The temperature and salinity in the acoustic tank were measured (YSI30, Yellow Springs, Ohio, USA) before and after the TS measurement. The echosounder was calibrated using a 23 mm diameter copper sphere (Table 1) and the sphere was also used to confirm the system gain before and after TS measurement.

The live sandfish were tethered with monofilament lines. Horizontal lines were connected to the mandible and tail, the vertical lines were tied to weights at both ends, and the

Table 1. System parameter settings for the EK60 echosounder, used for acquiring sandfish acoustic data

Parameter	Settings		
	In-situ		*Ex-situ*
Transducer type	ES38-12	ES120-7C	ES120-7C
Absorption coefficient (dB/m)	0.007659	0.040980	0.033345
Transducer gain (dB)	19.0	25.1	27.0
Two-way beam angle (dB re 1sr)	-15.5	-20.8	-20.0
Major Axis 3 dB beam angle (degrees)	12.15	6.37	6.39
Minor Axis 3 dB beam angle (degrees)	11.82	6.35	6.42
Transmitted power (W)	1,000	500	300
Transmitted pulse length (ms)	0.256	0.256	0.256

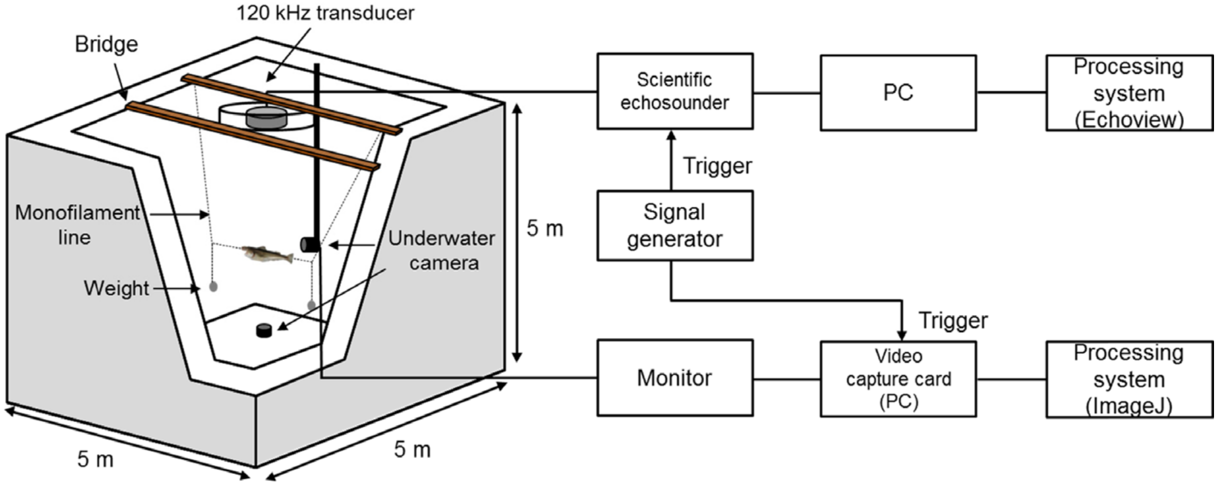

Fig. 2. Experimental diagram for TS measurements of sandfish using 120 kHz split-beam echosounder

horizontal and vertical lines were connected to each other and positioned at a depth of 3.5 m in the center of the acoustic tank. During measurement, fish behavior and swimming orientation were monitored with a seawater camera installed at the bottom and on the side of the acoustic tank. Video data were recorded as .jpg files at 0.5 sec intervals and were synchronized with acoustic data using the trigger of the video capture card (VCE-pro, ImperX, USA), which was connected to the side camera. The fork length of fish that was used in the experiment was 20.0 cm for females and 17.5 cm for males.

Data analysis

The acoustic data were analyzed with a single-target detection function using acoustic-analysis software (Echoview V 4.7, Echoview Software Pty Ltd., Australia). To detect single targets, the parameter settings for single target detection were equal to those used for single target detection in the *in-situ* and *ex-situ* TS experiments (Table 2). The tilt angle on each frame obtained in the *ex-situ* experiments was analyzed using photo editing software ImageJ (ImageJ 2009).

Table 2. Parameters for single-target detection, used in the post-processing program

Parameter	Settings
TS threshold (dB)	-80
Pulse-duration determination level	6.0
Minimum normalized pulse duration	0.1
Maximum normalized pulse duration	1.5
Maximum beam compensation (dB)	4.0
Maximum standard deviation (degrees)	0.3

3. Results

***In-situ* TS of sandfish**

A total of 346 sandfish (241 males and 105 females) were caught in the coastal gill nets. Their fork length displayed a bimodal distribution and had approximate values of 14.6–19.8 cm (mean = 17.0 cm) for males, and 16.3–24.5 cm (mean = 19.6 cm) for females. The male fork-length distribution was narrower. The mode values for the male and female distributions were 17 and 21 cm, respectively (Fig. 3). Fig. 4 shows the relationship between the fork length and total weight of the sandfish. Males showed a higher correlation with $W = 0.0118FL^{2.8698}$ ($R^2 = 0.74$), whereas the females exhibited $w = 0.0208FL^{2.7098}$ ($R^2 = 0.61$).

The sandfish histograms obtained at 38 and 120 kHz are shown in Fig. 5. These distributions display two modes over

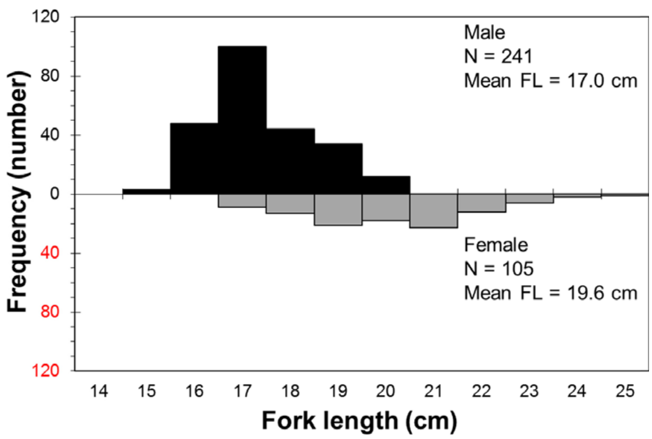

Fig. 3. Fork length of sandfish caught using a coastal gill net in Go-seong, Gangwon, Korea in early December 2009

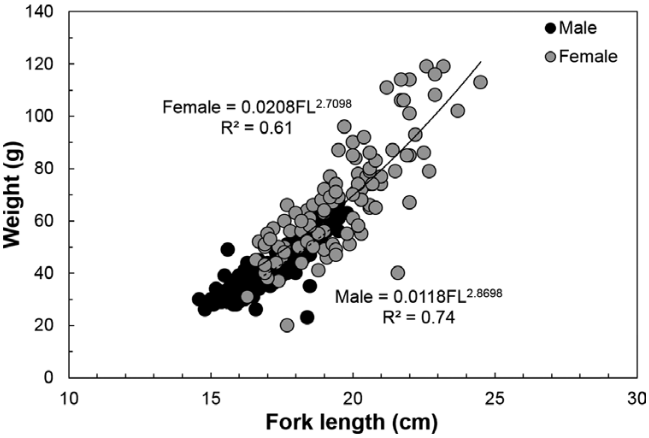

Fig. 4. Relationship between fork length (cm) and total weight (g) of sandfish caught using a coastal gill net in Go-seong, Gangwon, Korea in early December 2009

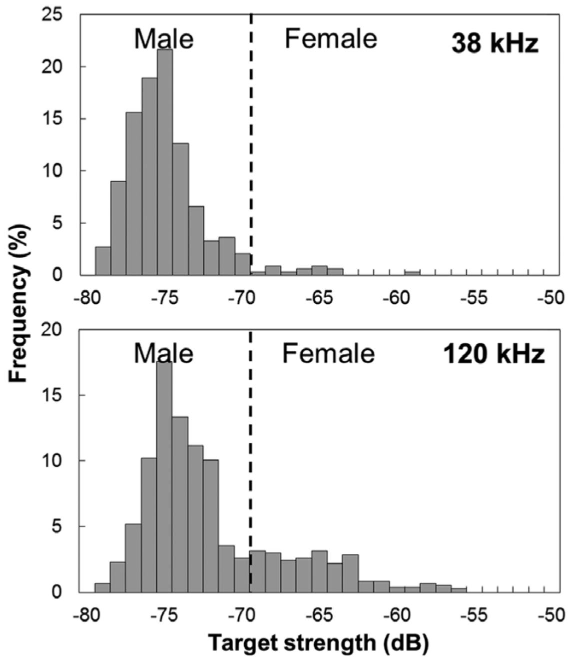

Fig. 5. TS distributions for single targets, measured at 38 and 120 kHz

the range -79.9–-59.1 dB at 38 kHz and -79.9–-56.2 dB at 120 kHz. These bimodal distributions bear some similarity with the size distribution in Figure 2. It was therefore concluded that the lower-TS mode (< -70 dB) corresponded to males, and the higher TS-mode (> -70 dB) to females. At 38 kHz, the mean TS for males was -75.3 dB and the mean TS for females was -65.1 dB. The corresponding mean values at 120 kHz, were -74.3 and -64.1 dB for males and females, respectively. Females, thus, had a mean value that was approximately 10 dB above that of the males at both frequencies.

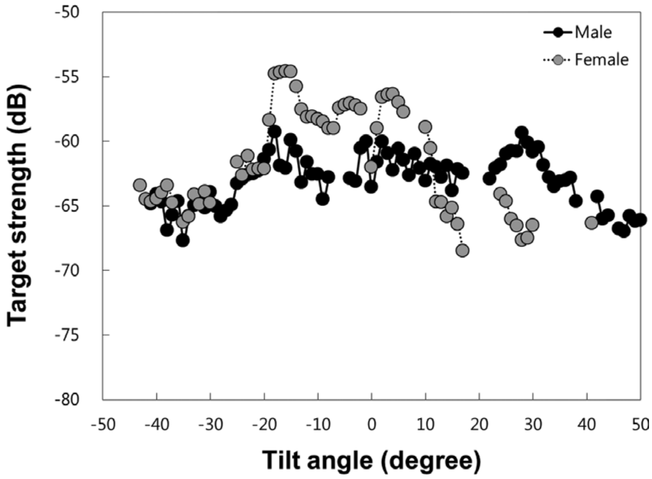

Fig. 6. TS variations for the sandfish as a function of the fish tilt angle, measured *ex-situ* at 120 kHz. Positive angles correspond to "head up" and negative angles to "head down"

***Ex-situ* TS sandfish**

The female *ex-situ* TS values ranged from 68.5 to -54.6 dB, and those for males ranged from -67.7 to -59.3 dB. The maximum value was at a tilt angle of approximately -15° (i.e., on the negative side of the horizontal axes). In addition, the mean *ex-situ* TS values for body tilt angles between -30° and 30° were -59.0 dB for females and 61.9 dB for males. Thus, the mean TS value for females was 2.9 dB higher than that of males (Fig. 6).

4. Discussion

These results suggest that the female sandfish carried mature spawns, consistent with the fact that the survey period coincided with spawning. In accordance with the fork length, the spawning number of sandfish was: Female FL = 0.4693 $BL^{2.6825}$. The weight of the eggs during spawning accounted for one third of the fork length (Lee et al. 2006). Yang et al. (2008) reported relationships between the fork length and weight as for males and for females caught off the coast of Gangwon. These results agree with those of the present study in that the females grew faster than did the males.

Fig. 7 compares the mean TS values for male and female sandfish in this study with earlier results. Saito (2004) measured the TS value with an *ex-situ* method using fast-frozen sandfish *in-situ* collected in the field. The results demonstrated a length–TS relationship in the form: $TS_{38\ kHz} = 20\log(FL) - 74$, which resulted in values approximately 17 dB higher than our observations. However, Saito (2004) noted the potential

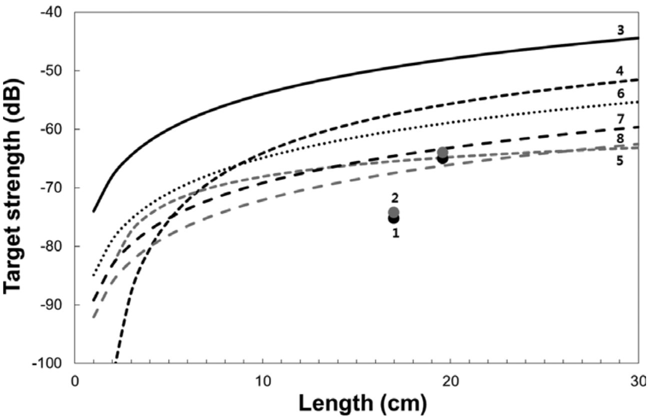

Fig. 7. Mean *in-situ* estimates of the TS sandfish at 38 and 120 kHz, and the relationship between the length and TS of fish without a swim bladder, obtained from another study. These are represented by the dots and lines shown in black for 38 kHz and grey for 120 kHz. (1), (2) Target strength data at 38 and 120 kHz for sandfish *in-situ* TS measurements, obtained in this study; (3) plot of target strength at 38 kHz for quick-frozen sandfish, measured by the *ex-situ* method (Saito 2004); (4), (5) modelling results for the lanternfish by Yasuma et al. (2006) at 38 and 120 kHz, respectively; (6) data for the Atlantic mackerel, measured *ex-situ* at 38 kHz (Edward et al. 1984); (7), (8) Model TS plots of adult sandeel obtained at 38 and 120 kHz by Yasuma et al. (2009), respectively

effects of frozen samples and attached air bubbles when measuring TS. The TS measurements for dead and living orange roughy (*Hoplostethus atlanticus*) illustrated that dead specimens produce higher TS values (1.9–9.8 dB difference) than live ones owing to air bubbles attached to the frozen dead specimens. This confirmed earlier findings, in which TS values differed between dead and live specimens (McClatchie et al. 1999). Seseo (2005) reported significantly higher *in-situ* TS values at 38 kHz (-57.8 to -33.0 dB) than those found in our study, despite a similar sandfish length distribution. Although the sandfish has no swim bladder, Saito (2004) and Seseo (2005) reported a similar TS value in fish with a swim bladder. Various studies investigated the TS values for other species lacking a swim bladder. The relationship between the length and TS of these fish is expressed as $TS_{38\,\mathrm{kHz}} = 20\log(L) - 84.9$ for Atlantic mackerel (*Scomber scombrus*) (Edwards et al. 1984). For lanternfish (*Stenobrachius leucopsarus*) it is $TS_{38\,\mathrm{kHz}} = 32.1\log(L) - 64.1$ and $TS_{120\,\mathrm{kHz}} = 15.5\log(L) - 67.8$ (Yasuma et al. 2006). Furthermore, the relationship between the length and TS of adult Japanese sandeel (*Ammodytes personatus*) was $TS_{38\,\mathrm{kHz}} = 20\log(L) - 89.2$ and $TS_{120\,\mathrm{kHz}} = 20\log(L) - 92.1$ (Yasuma et al. 2009). Foote (1980) reported standardized TS values by squaring the length of pelagic fish ranging from -90 to -80 dB. These results indicate that fish without a swim bladder display a significantly lower TS value than fish with a swim bladder. Yasuma et al. (2008) confirmed that the TS value for fish without a swim bladder was more than 10 dB lower than that for fish with a swim bladder. The present study also showed that the TS for sandfish is similar to that for sandeels, which do not have a swim bladder. In addition, Safruddin et al. (2013) showed that the average swimming tilt angle of the Japanese sandeel (*Ammodytes personatus*, with no swim bladder) was 20.4 ± 18.5°. Kubilius and Ona (2012) also reported similar (23.7 ± 18.2°) and quite variable natural swimming angles for the lesser sandeel (*Ammodytes marinus*), also a bladderless and negatively buoyant fish, that needs to continually swim to maintain constant depth. This is because it must swim with a positive body tilt angle to stay at a constant depth.

The absence of the swim bladder in the sandfish may result in its swimming tilt angle varying more in the sound field. The *in-situ* TS values may also be lower.

The female sandfish examined in this study had larger fork lengths and higher TS values than did the male. This was because the survey period coincided with spawning, and therefore the female sandfish likely carried mature spawns. The ratio of dorsal-profile area (cm^2) to fork length (cm) was 2.6 for females and 2.0 for males; in the lateral view, these ratios are 1.6 and 1.1, respectively (Fig. 8).

Kloser and Horne (2003) demonstrated differences in the TS values obtained for female and male orange roughy, as well as concomitant differences in the ratio of the sound speed and density in the gonads. They argued that these factors influenced the TS values. The density ratio for *Palaemonetes pugio* was 1.030–1.063 (1.045 ± 0.009) during spawning; after spawning, it decreased to 1.019–1.057 (1.034 ± 0.010). Such changes in the density ratio were caused by size, feeding conditions, female fecundity, sex, and maturity (Forman and Warren 2010). In the present study, the TS corresponding to each sex was measured by distinguishing the sex of the sandfish caught, based on the fork-length distribution. Future studies must assess the TS values of each female and male and establish the density and sound-speed ratios using *ex-situ* methods.

The present study established the TS value and characteristics of sandfish at 38 and 120 kHz. These results may be useful in the analysis of acoustic survey data for the estimation of sandfish biomass.

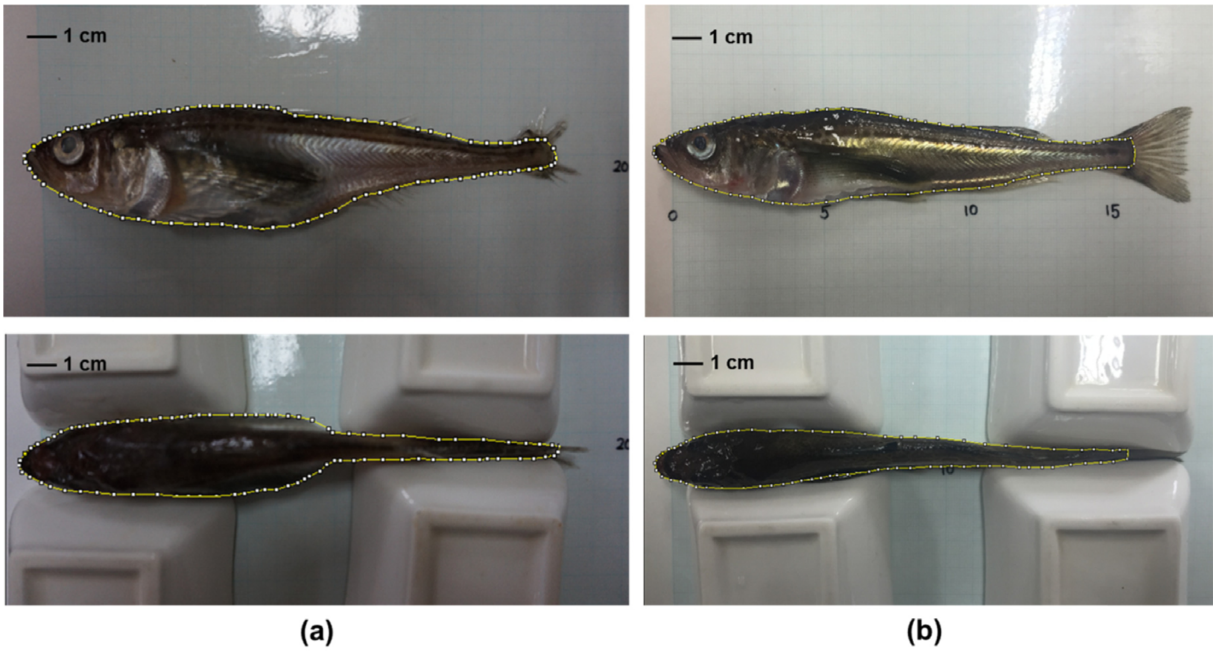

Fig. 8. Images of (a) female and (b) male, taken from the lateral and dorsal perspectives of the fish used for TS measurements. The outlines indicate the lateral and dorsal profiles for each sample

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