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Ex Situ Target Strength Measurements of Rockfish (*Sebastes schlegeli*) and Striped Beakperch (*Oplegnathus fasciatus*)

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Abstract: The rockfish (*Sebastes schlegeli*) and striped beakperch (*Oplegnathus fasciatus*) were released in marine ranching areas in Korea, Japan, and China to maintain fishery resources in coastal areas. To estimate the density and biomass of fishery resources, the target strength (TS) of target marine organisms is needed to scale integrated volume backscattering coefficients. In this study, the target strength–length (TS–L) relationship for live rockfish and striped beakperch was derived using ex situ methods at a frequency of 200 kHz. The TS-L function for rockfish and striped beakperch can be expressed as $TS_{Avg.}$ = 20logTL − 69.25 (R^2 = 0.35) and $TS_{Avg.}$ = 20logFL − 67.01 (R^2 = 0.31), respectively. These results can be used to assess the growth, density, and abundance of the two species using acoustics.

Keywords: target strength; *Sebastes schlegeli*; *Oplegnathus fasciatus*; ex situ

Key Contribution: This study measures the TS–length relationship that can be applied to improve acoustic estimates of rockfish (*Sebastes schlegeli*) and striped beakperch (*Oplegnathus fasciatus*).

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Citation: Yoon, E.; Oh, W.-S.; Lee, K. Ex Situ Target Strength Measurements of Rockfish (*Sebastes schlegeli*) and Striped Beakperch (*Oplegnathus fasciatus*). *Fishes* **2024**, *9*, 371. https://doi.org/10.3390/fishes9100371

Academic Editor: Vincent Kerzérho

Received: 19 July 2024
Revised: 4 September 2024
Accepted: 17 September 2024
Published: 24 September 2024

1. Introduction

Fishery resources are an important food source for humans. However, in recent years, they have been declining because of global warming, marine pollution, and overfishing. Marine fish farming technology made significant advancements in the 2000s to sustainably utilize and increase fishery resources [1]. Coastal aquaculture is an environmentally friendly production system that maximizes the potential of the ocean to produce fishery resources sustainably [2]. The fish typically used in marine ranching and coastal aquaculture include rockfish, striped beakperch, red sea bream, and olive flounder.

Of these, rockfish belong to the Scorpaeniformes order and Scorpaenidae family, whereas striped beakperch belong to the Perciformes order and Oplegnathidae family. Both species are mainly found in artificial reefs in coastal areas of Korea, Japan, and China [2–4]. These two fish species have been released in marine ranches in Korea.

Among the various methods for measuring fishery resources, acoustic measurement techniques can provide a quantitative assessment of these resources over a wide area within a short period. These methods are used to measure the growth, behavior, and density of target organisms in aquaculture [5–7]. Resource management will be efficient if the acoustic characteristics of the fish species released and raised in these marine ranching are identified and the acoustic resource survey is carried out smoothly.

Information on the target strength (TS; dB re 1 m^2) of the target species is essential to determine the body length and density of the target organism using acoustics [8–10].

This parameter is often expressed in terms of TS, where TS = 10 $\log_{10}\sigma_{bs}$ [11–13] and σ_{bs} is the backscattering cross-section of the fish. The TS–length (L, cm) equation can be expressed as $\text{TS} = a\log L + b$, where the slope a and intercept b are generally assumed to be species-specific constants. The backscattering cross-section is proportional to the length squared, a is normally close to 20, and $\text{TS} = 20\log L + b_{20}$, where L is the length in cm and the intercept, b_{20}, is in dB. Field-measured TS values were input into the TS–L equation to determine the body size of the target fish using acoustics. In addition, TS and the volume backscattering strength (Sv; dB re 1 m^{-1}) can be converted into volumetric number densities that can subsequently be used to provide population estimates (e.g., abundance, number of animals) [14]. Fish TS is influenced by length [15], tilt angle [16], frequency of use [17], water depth [18], swimming bladder shape [19], and the contrast of sound speed and density [20]. Methods for measuring TS can be divided into experimental and theoretical methods [21]. Methods used to measure TS include (i) experimental methods of ex situ measures of dead or live fish [22–25] and in situ measures of swimming freely in their natural habitat [26–28]; and (ii) theoretical methods involving acoustic models [16,29].

Rockfish and striped beakperch are demersal fishes. Several studies have been conducted on the distribution and biomass of demersal fish using acoustic measurements [30–33]. Therefore, demersal fish TS has been studied, including for Atlantic redfish, Atlantic croaker, white perch, orange roughy, and yellow croaker [25,31,34,35]. In previous studies on rockfish, TS was measured using the cage method [36] at frequencies of 38, 70, 120, and 200 kHz, and the suspension method was used at frequencies of 70 and 120 kHz [37]. In addition, the TS functional expressions were derived for a narrow size range (25.8–29.5 cm) for frequencies of 38, 70, and 120 kHz using the suspension method [38]. The striped beakperch TS field equation has only been reported for frequencies of 70 and 120 kHz using the ex situ method [29]. Previous TS studies of rockfish and striped beakperch were conducted using the ex situ method, which can measure TS according to the known size, thereby obtaining reliable values.

Frequencies of 38, 70, 120, and 200 kHz are commonly used in scientific echosounders. However, in the field, smaller vessels often favor the use of 200 kHz owing to its smaller transducer size and reduced near field [36,39]. To date, there has been limited research on the TS–L relationship at 200 kHz in rockfish and striped beakperch. Therefore, this study aims to derive the TS–L relationship equation at 200 kHz using ex situ methods.

2. Materials and Methods

2.1. Fish Sample

The rockfish and striped beakperch used in this study were purchased from a fish market in Yeosu, Jeollanam-do. Sampling was conducted by placing ice packs at the bottom of an icebox to keep the samples alive. Transparent sample bags were filled with seawater to prevent the samples from being exposed to bubbles, maintained in a state similar to their original condition, and transported to the experimental site. Sampled fish were acclimatized for 2–3 days in rearing tanks (∅ = 5 m, H = 1 m).

2.2. Experimental System Setup and Data Analysis

TS measurements of 30 individual rockfish and 20 individual striped beakperch using the ex situ method were performed in a seawater acoustic tank (5 m (L) × 5 m (W) × 5 m (H)) located at the Institute of Fisheries Science, Chonnam National University (Figure 1). Immediately before measurements, each live fish was temporarily anesthetized (MS-222) without air exposure. Four strands of monofilament, needle, and pendulum were used to measure the TS, as shown in Figure 1. One end of the monofilament line (0.2 mm diameter) was threaded through a needle and attached to the snout of the fish, whereas the other end was attached to a longer monofilament line with additional weight. The two monofilament lines were connected to both sides of the longer monofilament line to ensure that the sample was positioned approximately 3.0–4.0 m below the transducer. Sample echograms of the rockfish are shown in Figure 2.

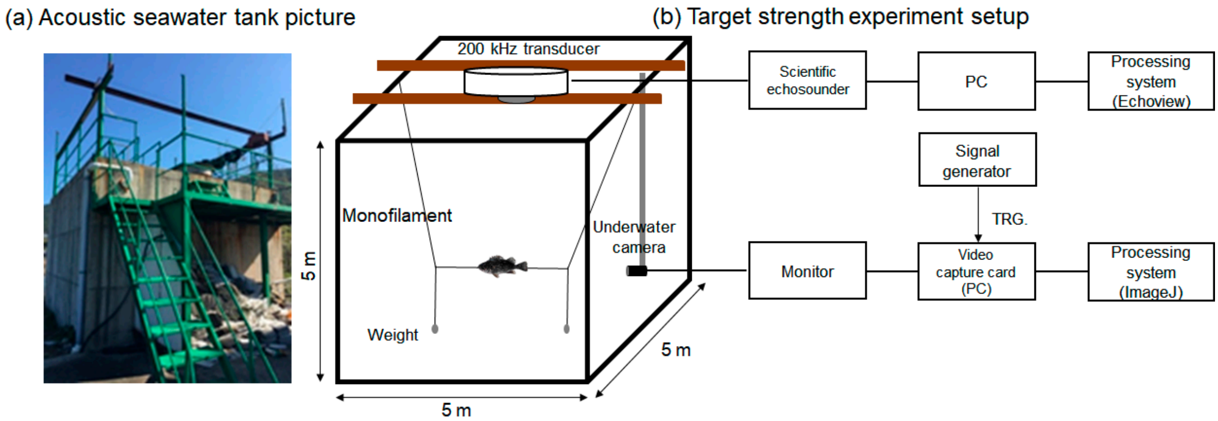

Figure 1. Photographs of (**a**) the seawater acoustic tank used to measure fish-specific TS and (**b**) an illustration of the experimental setup.

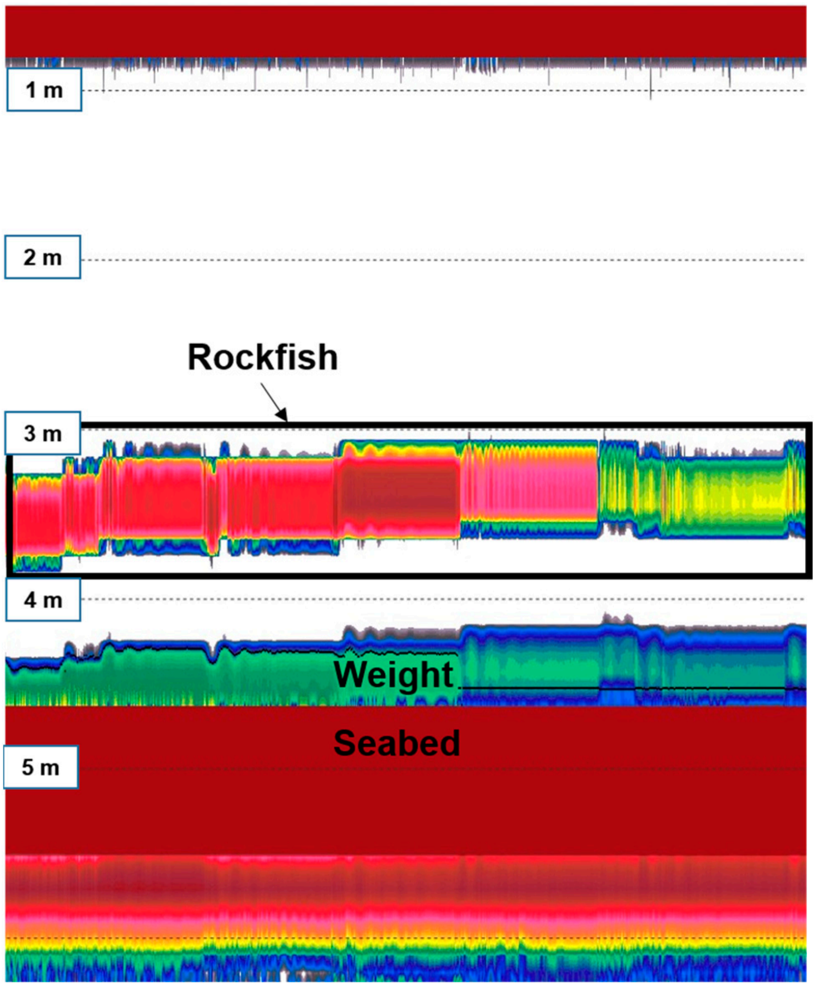

Figure 2. Sample echograms of rockfish. Fish signal was fully separated from weight and seabed.

The TS of the fish was measured using a scientific echosounder (EK80, Simrad, Horten, Norway) with a system frequency of 200 kHz, a transducer utilizing a 3 dB beam width of 7.1°, and power output of 105 W (Figure 1). The pulse duration and ping rate were set to 0.512 ms and 2 ping/s. Before the TS experiments, the temperature and salinity of seawater in the acoustic tank were measured with an YSI 30 M instrument (YSI, Yellow Springs, OH, USA) to calculate sound speed. During the TS experiments, the seawater tank temperature and salinity were 15.9 °C and 32.6 psu, respectively, resulting in sound speeds of around 1506.7 m/s. The system was calibrated using a 38.1 mm tungsten carbide sphere according to the method of [40], and the results are listed in Table 1. The TS was measured from −60° to 60° in 1° intervals. The tilt angles of the samples were measured using an underwater camera (T-water-7000DX, WIRELESS TSUKAMOTO, Suzuka-shi, Mie-prefecture, Japan) installed on the side of the tank. A video capture card (VCE-Pro, ImperX, Boca Raton, FL, USA) was connected to a signal generator (WF1944A, NF Electronic Instruments, Kohoku-ku, Yokohama, Japan), and a square-wave trigger signal was generated from the signal generator and driven in the external trigger mode with a pulse interval of 0.5 s. An image of the change in the tilt angle of the sample was saved on a computer using the trigger function of the video capture card. Furthermore, the pulse interval of the sonar was set to 0.5 s to synchronize the TS data with the images of the swimming behavior of the samples. After the experiments, the lengths (cm) and weights (g) of the samples were measured using a length board and scale.

Table 1. Parameter setting of the scientific echosounder to measure the target strength of black porgy and striped beakperch.

Parameters	Values
Two-way beam angle (dB)	−20.70
Transducer gain (dB)	26.24
3 dB beam angle (athwart/along) (deg.)	6.61/6.58
Absorption coefficient (dB km^{-1})	6.40
Sound speed (m s^{-1})	1506.7
Power (W)	105
Pulse length (ms)	0.512

The acquired TS data were later played back in the laboratory using acoustic analysis software (Echoview Version 8, Echoview Software Pty Ltd., Hobart, Australia). TS signal analysis involved the extraction of fish signals using the single-target detection (split-beam method) function and the fish signal detection layer. The tilt angle of the fish was measured using ImageJ software version 1.51 (National Institute of Health, Bethesda, MD, USA) with 0° for horizontal, minus (−) for head down, and plus (+) for head up. TS data and fish tilt angle data were matched one to one.

The average TS values were obtained using the probability density function (PDF) by assuming the average tilt angle and standard deviation of common fish as −5° and 15° [18], respectively, as shown in Equations (1) and (2). The TS of each tilt angle calculated every 1° was changed to the scattering cross-section and multiplied by the PDF of each posture angle −5° ± 15°, and the average TS was calculated as the sum.

$$\sigma_{bs} = \int_{-\pi/2}^{\pi/2} \sigma(\theta) f(\theta) d\theta \quad (1)$$

$$\text{TS}_{Avg.} = 10 log_{10} \sigma_{bs.} \quad (2)$$

Here, $\sigma(\theta)$ is the backscatter cross-sectional area at θ for each tilt angle, and $f(\theta)$ is the frequency of occurrence of each swim angle.

To determine the swim bladder angle, the fish used in the experiment were flash-frozen using dry ice and alcohol to maintain a condition similar to their natural state for X-ray imaging and then transported to the laboratory. X-rays were acquired in the lateral and dorsal views of the fish, and the swim bladder angle was determined in the lateral view (Figure 3).

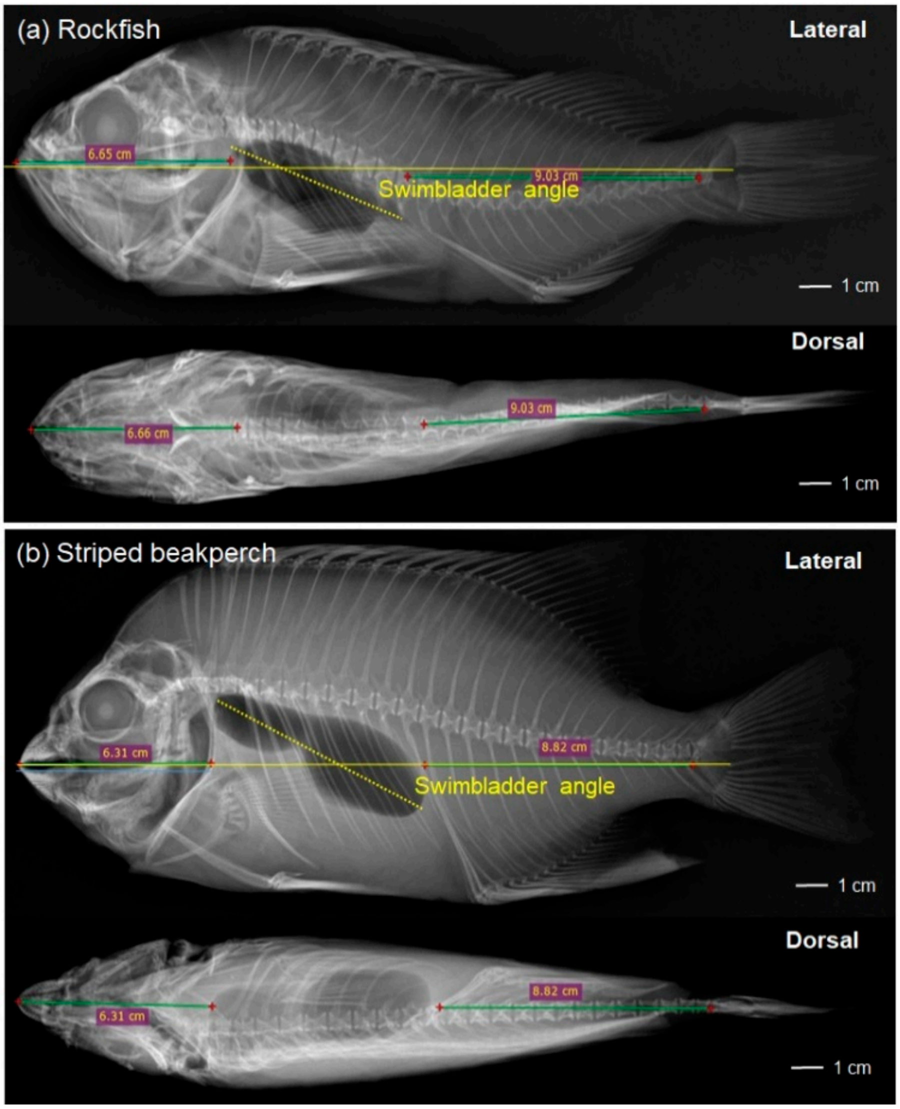

Figure 3. An example of ventral and dorsal X-ray images of (**a**) rockfish (TL = 25.5 cm) and (**b**) striped beakperch (FL = 25.3 cm). The yellow dotted line indicates the tilt angle (θ) of the swim bladder from the centerline between the anterior and posterior margins according to the fish body.

3. Results

3.1. Length–Weight Relationship of Rockfish and Striped Beakperch

The total length of 30 individual rockfish ranged from 11.3 to 27.8 cm, and the weight ranged from 18.6 to 310.6 g. The fork length of 20 individual striped beakperch ranged from 20.8 to 35.8 cm, and the weight ranged from 260.4 to 1290.6 g. Length–weight relationships were calculated using the equation $W = aL^b$ [41], where W is the total weight of the fish in g, L is the total length of the fish in cm, a is the intercept, and b is the slope of the above linear regression (Figure 4). The regression models fit to the relationship between length and weight for rockfish and striped beakperch used in the experiment were $W = 0.0241TL^{2.7880}$ (R^2 = 0.98) and $W = 0.0814FL^{2.6725}$ (R^2 = 0.82).

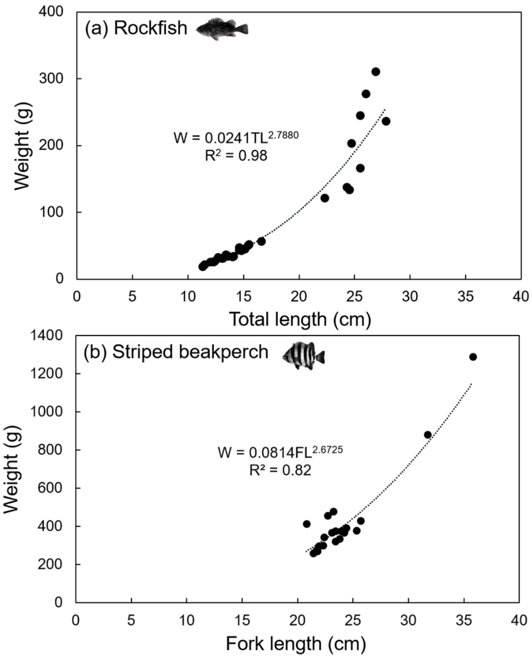

Figure 4. The relationship between length and weight for rockfish (**a**) and striped beakperch (**b**). The length of the rockfish represents the total length, and the length of the striped beakperch represents the fork length.

3.2. TS Based on the Tilt Angles of Rockfish and Striped Beakperch

The averaged TS value for the 30 individual rockfish as a function of tilt angle was the highest at −39.7 dB at a tilt angle of −23°. The rockfish had a swim bladder angle of 11–26°, with a mean angle (±S.D.) of 19 ± 4°. The maximum TS for each rockfish occurred in the tilt angle range from −31 to −6°, and the average value (±S.D.) of the tilt angle was observed to be −20 ± 6° (Figure 5a).

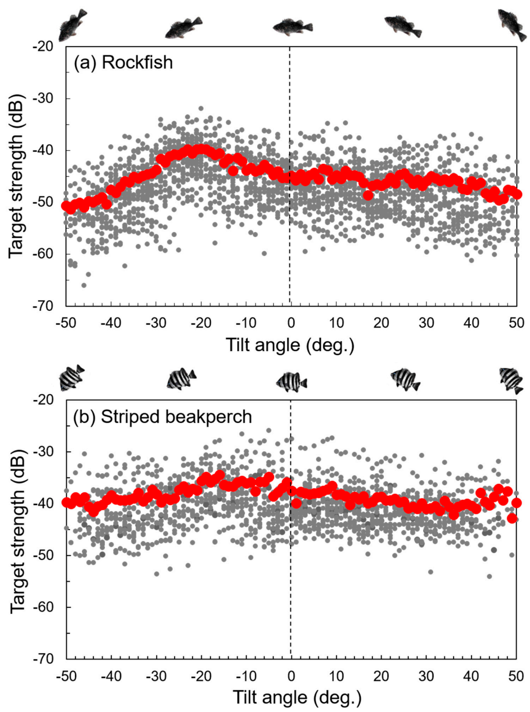

Figure 5. TS (gray circles) and average TS (red circles) as function of tilt angle for rockfish (**a**) and striped beakperch (**b**).

The averaged TS value for the 20 individual striped beakperch as a function of tilt angle was the highest at −34.4 dB at a tilt angle of −16°. The striped beakperch had a swim bladder angle of 20–32°, with a mean angle (±S.D.) of 25 ± 3°. The maximum TS for each striped beakperch occurred in a tilt angle range from −30 to −4°, and the average value (±S.D.) of the tilt angle was observed to be −15 ± 7° (Figure 5b). This indicates that the tilt angle was in the negative direction (Figure 5). In both fish species, it was found that the tilt angle was head down and the slope of the swim bladder was horizontal, indicating a high TS value.

3.3. TS Functional Expression Based on Length of Rockfish and Striped Beakperch

The maximum TS values of rockfish ranged from −44.4 to −31.8 dB, and the average TS value of rockfish was from −52.1 to −39.0 dB. With a predefined slope of 20, the TS-L relationships are as follows (Figure 6a):

$$TS_{Max.} = 20\log TL - 63.02 \text{ (95\% CI: } -63.96 \text{ to } -62.09, R^2 = 0.25, \text{RMSE} = 2.535) \quad (3)$$

$$TS_{Avg.} = 20\log TL - 69.25 \text{ (95\% CI: } -70.19 \text{ to } -68.32, R^2 = 0.35, \text{RMSE} = 2.308). \quad (4)$$

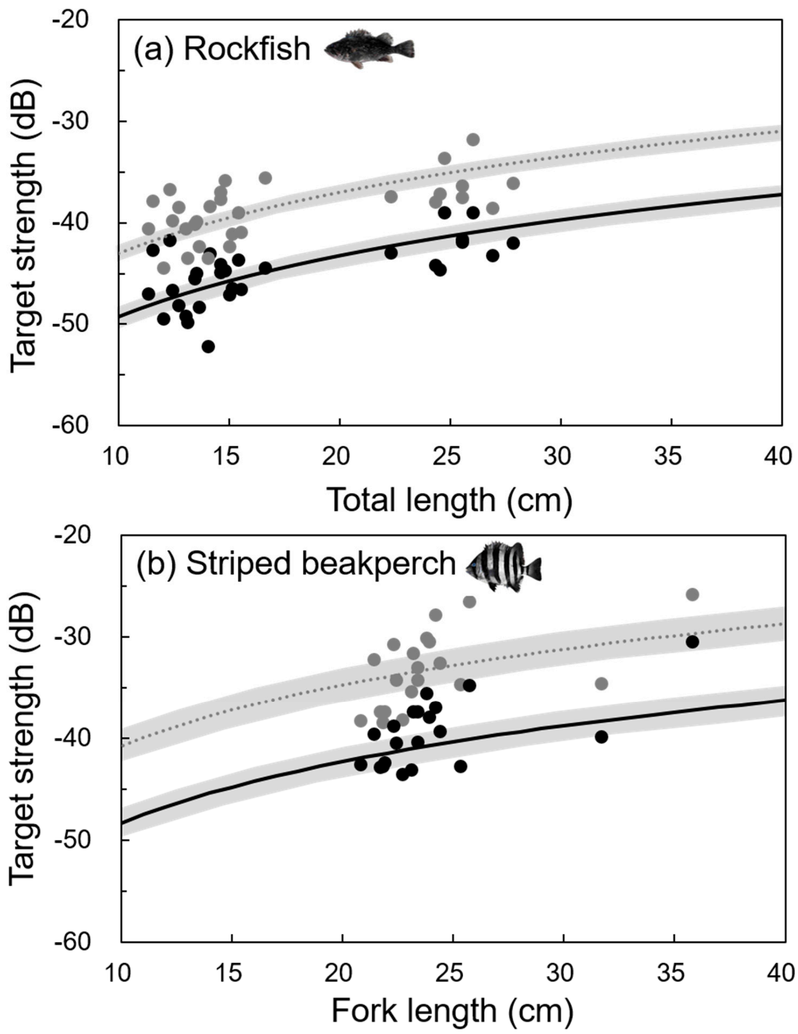

Figure 6. The relationship between the maximum TS and the average TS and length for rockfish (**a**) and striped beakperch (**b**). The gray circles represent the maximum TS values, and the black circles represent the average TS. The lines represent TS = 20logL + b_{20}. The gray dotted line indicates the least-squares regression of the maximum TS, and the black solid line indicates the least-squares regression of the average TS, whereas the gray shaded areas represent the 95% Confidence Interval.

The maximum and average TS of striped beakperch ranged from −38.4 to −25.8 dB and from −43.5 to −30.5 dB, respectively. With a predefined slope of 20, the TS-L relationships are as follows (Figure 6b):

$$TS_{Max.} = 20\log FL - 60.76 \text{ (95\% CI: } -62.33 \text{ to } -59.18, R^2 = 0.23, \text{RMSE} = 2.704) \quad (5)$$

$$TS_{Avg.} = 20\log FL - 67.01 \text{ (95\% CI: } -68.32 \text{ to } -65.69, R^2 = 0.31, \text{RMSE} = 2.816). \quad (6)$$

4. Discussion

Previous studies on the length–weight relationship of rockfish yielded the formulas $W = 0.015TL^{3.015}$ [42] and $W = 0.0087TL^{3.226}$ [43]; this study had a significantly higher *a* value, whereas the *b* value was higher in previous studies. For striped beakperch, the formula $W = 0.0579FL^{2.7223}$ [4] exhibited a lower *a* value in a previous study, whereas the *b* value was higher in a previous study. In general, the fish had *a b* value between 2.5 and 3.5. It varies depending on the fish ecology and environment, and is particularly related to gender, growth stage, diet, and spawning. When the *b* value is greater than 3 ($b > 3$), this indicates positive allometric growth, in which body weight increases faster than body length. When the *b* value is less than 3 ($b < 3$), this suggests negative allometric growth, where body weight increases more slowly than body length. When the *b* value is equal to 3 ($b = 3$), this signifies that the fish had isometric growth [44,45]. In this study, the value of *b* was <3 for both rockfish and striped beakperch, indicating negative allometric growth.

A typical acoustic transducer has a near field of several meters [46]. The near field of 200 kHz frequency used in this study was calculated to have a range of 0.59 m, whereas the far field extended to 1.18 m. The fishes were securely positioned at a depth of 3.0 to 4 m, ensuring that the TS experiments were conducted without interference from the far field. Furthermore, the beam width of the frequency employed in this study allows for the detection of fish up to 37–50 cm in depth at the 3.0-to-4.0 m range. The maximum length measured for the specimens in this study was 35.8 cm, which was within the detection range of the beam width.

The body shape and swim bladder morphology of scorpionfish, red sea bream, azurio tuskfish, filefish, and bambooleaf wrasse inhabiting the Jeju Sea marine ranching area differed for each fish species [29]. The angle of the mackerel swim bladder was 6–13° [47], and that of the black seabream was 16–24° [48]. Therefore, the swim bladder angle is positive for surface, mesopelagic, and demersal fishes [49–53]. The swim bladder has a positive inclination toward the body axis, which results in a maximum TS value when the angle between the incident wave and swim bladder is perpendicular to the fish, that is, when the tilt angle of the fish has a negative inclination [54]. In this study, both rockfish and striped beakperch exhibited high TS values when the swim bladder angle was horizontal.

Previous studies on the TS of rockfish have reported results for frequencies of 38, 70, 120, and 200 kHz, and the b_{20} using the cage method for specimens with a total length of 9.8–23.8 cm was observed to be −67.7 dB at a frequency of 38 kHz, −74.3 dB at 120 kHz, and −72.8 dB at 200 kHz, which is approximately 2 dB lower than the results of this study at a frequency of 200 kHz [36]. This could be attributed to the fact that the tilt angle of the rockfish used in this study was $-5 \pm 15°$, and when the TS of a free-swimming specimen was calculated using the cage method, the fluctuation in the tilt angle was large. The b_{20} at 38, 70, and 120 kHz for 14 rockfish of body length between 25.8 and 29.5 cm was measured using the ex situ method, and values of −67.1, −68.6, and −69.9 dB, respectively, were observed, which are similar to the 120 kHz values in this study [38]. In general, almost all species have swim bladders, and such fish generally show relatively strong signals in the low-frequency range of ≤38 kHz due to resonance, rather than in the high-frequency range. The b_{20} using the ex situ method for rockfish with a total length of 17.5–32.0 cm was observed to be −71.29 dB at a frequency of 70 kHz and −66.88 dB at 120 kHz [37]. A major factor in TS versus fish length regressions is swimming angle. Previous studies have not clearly shown the swimming angle of rockfish. However, in the present study, which is both accurate and reliable compared to previous research, it can be observed that the

b_{20} value at a frequency of 200 kHz is higher than that at 70 kHz and lower than that at 120 kHz.

In this study, TS experiments were conducted on a variety of sizes for rockfish, ranging from 11.3 to 27.8 cm in length, but for striped beakperch, the TS value for small individuals ranged from 20.8 to 35.8 cm, which is insufficient. The value of R^2 of the TS-L regression line was low. In the future, experiments on TS values of small objects will need to be conducted and supplemented.

Previous studies on the TS of striped beakperch have reported results at frequencies of 70, 120, and 200 kHz. The b_{20} was calculated using the ex situ method for striped beakperch with a mean fork length of 19.13 cm and it was observed to be −71.59 dB at a frequency of 70 kHz and −67.92 dB at 120 kHz, which is approximately 1 dB higher than the 200 kHz result used in this study [29]. A previous study calculated the length-dependent b_{20} using the ex situ method for striped beakperch with a fork length of 17.8–21.0 cm and it was observed to be −72.97 dB at a frequency of 200 kHz, which is approximately 7 dB lower than the results of this study and significantly lower than the results of [55]. In a previous study, the sample size of five fish did not allow for a wide range of fish lengths to be tested; therefore, comparison with the results of this study is somewhat difficult [55].

It is difficult to directly compare the TS of rockfish and striped beakperch because of their different length measurement positions. The TS value was higher for the striped beakperch than for the rockfish. In this study, the average TS values for both species differed significantly, although the same tilt angle was used. In general, the TS signal of fish with a swim bladder is strongly influenced by the size of the swim bladder, with more than 90% of the difference in the density ratio between gas and water affected by the swim bladder. The swim bladder volumes of rockfish and striped beakperch with similar body lengths showed that the striped beakperch was larger than the rockfish (Figure 3), which is believed to have affected the TS values of both fish species. In addition, TS impacting factors include the developmental stages of reproductive organs (or gonadosomatic indices like calculated for other species specific TS-L relationships), swim bladder inflation, and behaviors (e.g., particular orientation distributions one might expect in situ) [18,19,56].

A previous study lacked the use of 200 kHz echosounders to analyze the TS of rockfish and striped beakperch, instead focusing on 38, 70, and 120 kHz transducers. The relative contributions of resonant scattering in fish are significant at lower frequencies. However, in the field of a variety of fish, various frequencies are used to identify the species. Therefore, in this study, TS information for 200 kHz was needed to identify fish species in the field using acoustic measurements and to calculate the biomass of present species.

In this study, we collected rockfish and striped beakperch TS data over various lengths using ex situ methods, enabling us to derive highly accurate TS data (i.e., accurate tilt angle adjustment) and to derive a highly accurate TS–length relationship. However, our analysis did not apply the TS-L functional formula by utilizing the natural swimming angle of rockfish and striped beakperch. It is necessary to obtain measurements of the swimming angle on the spot. In addition, TS is greatly affected by swim bladders; in this study, the swim bladder angle was measured, but the swim bladder volume was not measured. In the future, it is necessary to measure the swim bladder volume and analyze the TS value accordingly.

However, our analysis did not fully account for the moving posture angle and swimming speed of school swimmers. For fish species that swim in schools in the wild, it is necessary to obtain measurements in schooling conditions.

In conclusion, in this study, the TS results for live rockfish and striped beakperch of different sizes were used to derive TS–L relationships, which were used as a basis for the growth, density, and abundance assessment of both species.

5. Conclusions

Ex situ measurements of TS–length were made for 30 rockfish and 20 striped beakperch at 200 kHz. With a predefined slope of 20, the TS vs. log(L) relationships were

$TS_{Avg.}$ = 20logTL − 69.25 for 30 rockfish and $TS_{Avg.}$ = 20logFL − 67.01 for 20 striped beakperch. This information will be useful in improving the accuracy of rockfish and striped beakperch biomass estimates and identifying fish species.

Author Contributions: Conceptualization, E.Y.; methodology, E.Y.; software, W.-S.O.; validation, E.Y.; formal analysis, W.-S.O.; investigation, E.Y.; resources, K.L.; data curation, W.-S.O.; writing—original draft preparation, E.Y.; writing—review and editing, W.-S.O.; visualization, K.L; supervision, K.L.; project administration, K.L.; funding acquisition, W.-S.O. All authors have read and agreed to the published version of the manuscript.

Funding: This study was supported by the National Institute of Fisheries Science (No. R2024001), Korea, and this research was supported by "Development of Advanced Science and Technology for Marine Environmental Impact Assessment" of Korea Institute of Marine Science & Technology Promotion (KIMST) funded by the Ministry of Oceans and Fisheries (RS-2021-KS211469).

Institutional Review Board Statement: Ethic Committee Name: Chonnam National University Laboratory Animal Research Center. Approval Code: CNU-IACUC-YS-2021-8. Approval Date: 25 October 2021.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available, because the data form part of an ongoing study.

Acknowledgments: We would like to thank the students of the Chonnam National University and researchers of Fisheries Resources Research Center for helping with the experiment. We are grateful to the two anonymous reviews that helped improve this paper.

Conflicts of Interest: The authors declare no conflicts of interest.

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