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# Sound properties produced by Korean rockfish *Sebastes schlegelii* in relation to body and swim bladder size

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ABSTRACT: The aim of this study was to understand the relationship between acoustic characteristics and body size of Korean rockfish *Sebastes schlegelii* in order to better estimate the body length of *S. schlegelii* by passive acoustic techniques. In this study, *S. schlegelii*, with a body length ranging from 21.7 to 24.8 cm (mean ± SD = 23.33 ± 0.93 cm) and a body weight of 144.2 to 250.3 g were selected as subjects. The aim was to explore the relationship between the acoustic characteristics of the fish and their standardized lengths through aquarium experiments. The vocalization frequency exhibited a main peak at around 150 Hz, a sub-peak at approximately 100 Hz, and the primary vocalization band extended from 100 to 350 Hz, with a pulse duration of 15.2 ± 2.4 ms. The results indicated that the peak frequency was negatively correlated with the standardized length, swim bladder length, width, and height ($p < 0.001$). This research contributes to the understanding of the relationship between acoustic properties and body size and suggests the potential utility of passive acoustic monitoring techniques for estimating the body lengths of target species.

KEY WORDS: *Sebastes schlegelii* · Acoustic characteristic · Swim bladder · Passive acoustics monitoring

## 1. INTRODUCTION

Acoustic signal communication in fish is ubiquitous in nature (Looby et al. 2022). Certain fish transmit information through vocalizations, which include acoustic communication between conspecifics, courtship calls during reproduction, schooling signals, alarms for predator avoidance, and tentative calls made during foraging (Myrberg & Lugli 2006). For instance, the spotted toadfish *Porichthys notatus* emits a 'buzzing' sound during courtship, which can last up to 2 h and may be repeated throughout the night's courtship activities (Tripp et al. 2021). The 'grunts' made by the large yellow croaker *Larimichthys crocea* during feeding are single pulses, while the 'gurgles' during spawning are mostly double or triple pulses (Ren et al. 2007). Fish vocal behavior also manifests in situations of antagonistic encounters and territorial defense (Hallacher 1974, Fletcher 1983). Furthermore, some fishes with awareness of territory protect their territories through vocal behavior (Ladich 1989), such as Scorpaeniformes marbled rockfish *Sebasticus marmoratus* (Zhang et al. 2013) and black rockfish *Sebastes vulpes* (Matsubara et al. 2018).

Different fish species are capable of producing a variety of sounds, and the principles and methods of their vocalization vary (Wall et al. 2012). Certain species with swim bladders utilize the contraction and

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vibration of their swim bladders and associated muscles to generate sound (Tavolga 1971, Kaatz 2002, Ladich et al. 2011, Ladich 2014). Among many species, members of the *Sebastes* genus, such as *S. atrovirens*, *S. carnatus, S. chrysomelas, S. melanops, S. nebulosus, and S. schlegelii*, are all capable of producing sounds (Hallacher 1974, Fletcher 1983, Nichols 2005, Song et al. 2023). Comparative classification of swim bladder muscles in Scorpaeniformes fishes reveals that the swim bladder muscles of *Sebastes* can be divided into 2 groups: the first group, with muscles attached to the shoulder girdle bone, includes species like *S. levis*, *S. crocotulus*, and *S. constellatus* (Širović & Demer 2009); the second group, without attachment to the shoulder girdle bone, includes *S. nebulosus*, *S. caurinus*, *S. maliger*, and *S. marmoratus* (Nichols 2005, Zhang et al. 2016). It is hypothesized that all rockfish species possessing swim bladder muscles are capable of vocalization (Hallacher 1974).

Passive acoustic monitoring (PAM) is a non-invasive and non-damaging observation method that operates without noise input (Cato et al. 2005). PAM is versatile, used not only in research areas such as fish population assessment, monitoring fish habitat conditions, and locating spawning fish (Lindseth & Lobel 2018, Hossain & Hossen 2019, Matsubara et al. 2023) but also in efficiently collecting various types of underwater acoustic data produced by organisms. This includes fish vocalizations (Aalbers & Drawbridge 2008, Anderson et al. 2008, Picciulin et al. 2020), marine mammal vocalizations (Stimpert et al. 2011, Zhang et al. 2016, Sills & Reichmuth 2022), and sounds associated with various behaviors in marine invertebrates (Fish 1966, Berk 1998, Patek 2002). *S. schlegelii*, a major economic fish species predominantly found in the Bohai Sea, Yellow Sea, and East China Sea, exhibits a correlation where larger swim bladder sizes correspond to lower vocalization frequencies (Dobrin 1947, Fish & Mowbray 1970). Vocalizations in *Sebastes* and other rockfish species are primarily produced through the swim bladder and its muscles (Hallacher 1974), suggesting that the acoustic properties of *S. schlegelii* may change with growth as the swim bladder and its muscles increase in size.

In this study, we utilized the PAM technique to record the sounds of *S. schlegelii* in an experimental tank, described the acoustic characteristics of their vocalizations, and investigated the relationship between body length, swim bladder size, and vocal characteristics. This research provides data to support the use of PAM in identifying the distribution and size of the *S. schlegelii* population in natural settings.

## 2. MATERIALS AND METHODS

### 2.1. Materials

The *Sebastes schlegelii* used in this experiment were captive-bred individuals acquired in Dalian, Liaoning Province, China. They were temporarily housed in open cylindrical glass fibre reinforced plastic tanks (∅ 100 × H 90 cm) for 7 d and fed with sinking granular baits (∅ 5.0 mm) at 8:00 h daily. Water was changed daily, with half of the tank's volume replaced each time. Ten experimental fish were randomly selected and individually housed in cylindrical acrylic tanks (∅ 50 × H 60 cm) at a water temperature of 20.46 ± 0.32°C for 1 d. The standard length (SL) of these fish ranged from 21.7 to 24.8 cm (mean ± SD = 23.33 ± 0.93 cm) (Table 1), and the body weight varied between 144.2 and 250.3 g (mean ± SD = 197.28 ± 37.75 g) (Table 1).

### 2.2. Methods

Vocalizations were recorded for each experimental fish using an AQH20k-1062 hydrophone (sensitivity: −193 dB re 1 V μPa$^{-1}$, Aquasound) connected to a professional recorder. The recordings were saved offline in WAV format with a 16-bit rate and a sampling frequency of 96 kHz. Before starting the recordings, it was necessary to switch off the oxygenation pump and other noise sources to minimize external noise interference. Following the recordings, the experimental fish were anesthetized using MS-222. Once the fish entered a deep anesthesia phase (characterized by complete loss of body balance and occasional belly-up posture) (Guan et al. 2011, Xiao et al. 2023), they were placed on a homemade fixation bracket.

Table 1. Standard length, body weight and swim bladder size in each *Sebastes schlegelii*

| No. | Standard length (cm) | Weight (g) | Swim bladder | | |
|---|---|---|---|---|---|
| | | | Length (mm) | Width (mm) | Height (mm) |
| 1 | 21.7 | 144.2 | 32.3 | 18.1 | 19.6 |
| 2 | 21.8 | 145.6 | 33.1 | 18.6 | 18.9 |
| 3 | 22.1 | 160.4 | 35.7 | 19.2 | 19.8 |
| 4 | 22.8 | 166.7 | 36.1 | 19.5 | 19.5 |
| 5 | 23.3 | 210.5 | 37.8 | 21.2 | 21.8 |
| 6 | 23.3 | 213.6 | 39.4 | 23.2 | 22.1 |
| 7 | 23.7 | 222.5 | 39.8 | 24.1 | 23.8 |
| 8 | 23.8 | 213.6 | 39.4 | 23.2 | 22.1 |
| 9 | 24.4 | 245.4 | 41.3 | 25.6 | 25.8 |
| 10 | 24.8 | 250.3 | 42.2 | 26.1 | 25.9 |

High-definition X-ray images were then taken of each fish's swim bladder, and measurements of the swim bladders' length, width, and height (mm) were recorded as shown in Fig. 1.

### 2.3. Data processing

Sound files were parsed and processed using iZotope RX 5 Audio Editor and AQ Level Meter1607 to generate frequency profiles. Statistical analyses exploring the relationships between sound characteristics, SL, and swim bladder size were conducted using goodness-of-fit tests.

## 3. RESULTS

### 3.1. Measurement of swim bladder size in experimental fish

Swim bladder lengths ranged from 32.3 to 42.2 mm, widths from 18.1 to 26.1 mm, and heights from 19.6 to 25.9 mm. There was a significant positive correlation between swim bladder length and SL, with a high coefficient of determination ($R^2$ = 0.949, $p < 0.001$, goodness-of-fit test; the $R^2$ is for the model's goodness-of-fit, and the p-value is for whether the model as a whole is linearly significant, for post-hoc testing, the p-value suffices) as shown in Table 1 and Fig. 2.

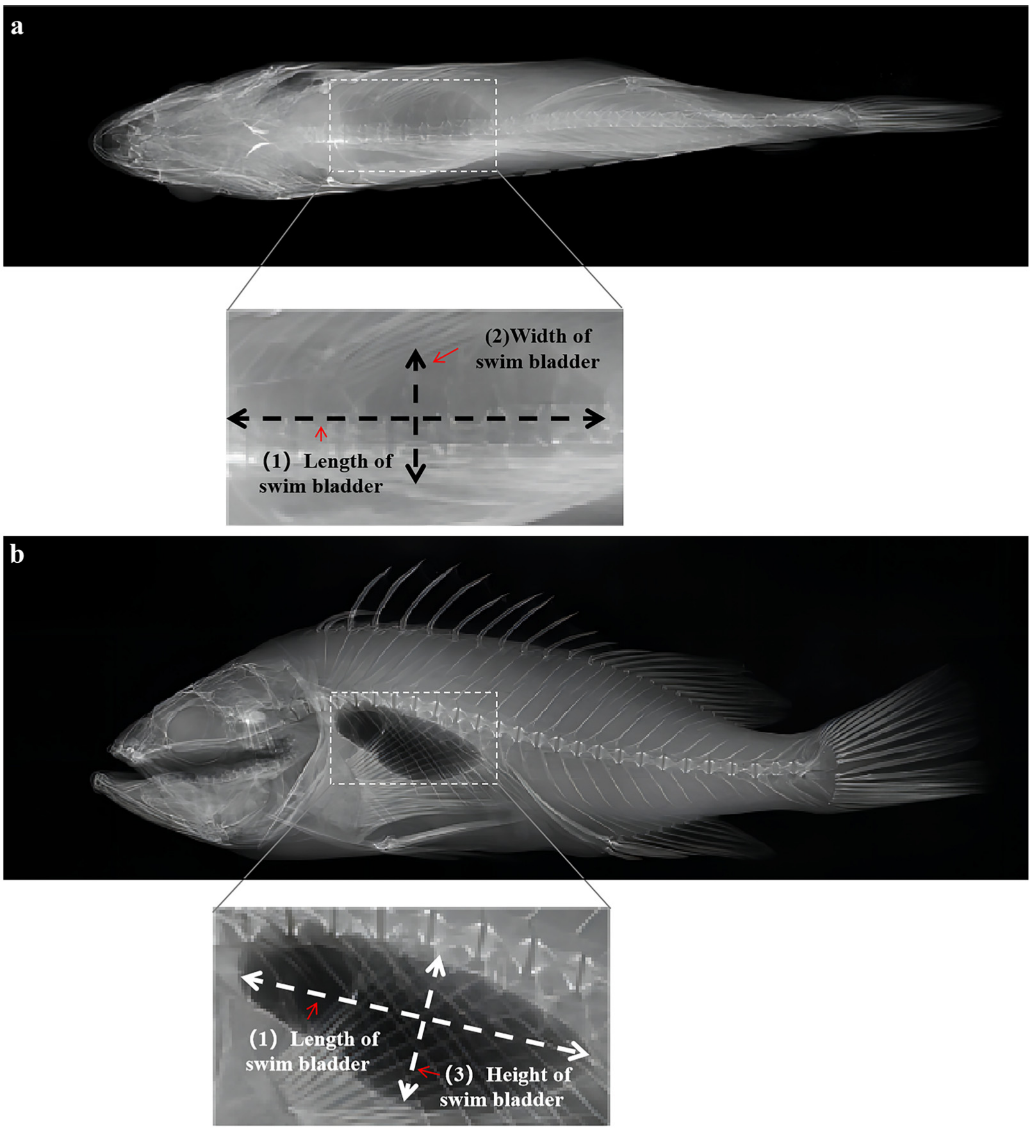


Fig. 1. Swim bladder of the *Sebastes schlegelii.* X-ray image of *S. schlegelii.* (a) Top view; (b) side view. Dashed lines with arrows: (1) length, maximum length of swim bladder in the cephalad and caudal direction of the fish; (2) width, maximum vertical aspect of swim bladder measured from the dorsal side; (3) height, maximum vertical aspect of swim bladder measured from the lateral side

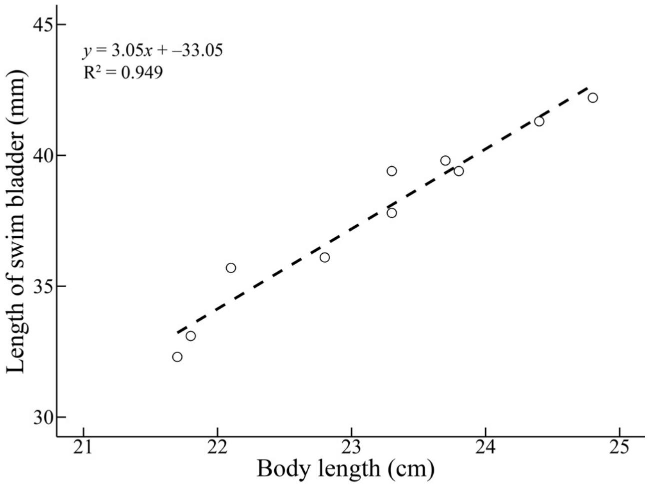


Fig. 2. Relationship between standard body length and length of swim bladder

### 3.2. Acoustic characteristics of *Sebastes schlegelii*

The 'cooing' sound produced by *S. schlegelii* consists of several individual pulses, as shown in Fig. 3a, with a pulse duration of 15.2 ± 2.4 ms, as shown in Fig. 3b. The main peak of the vocalization frequency for *S. schlegelii* is approximately 150 Hz, with a subpeak around 100 Hz. The primary vocalization frequency band ranges between 100 and 350 Hz, as shown in Fig. 4.

### 3.3. Relationship between sound properties, SL, and swim bladder length

The highest mean peak frequency observed was approximately 260 Hz, with the shortest mean pulse duration around 0.012 s. Conversely, the lowest mean

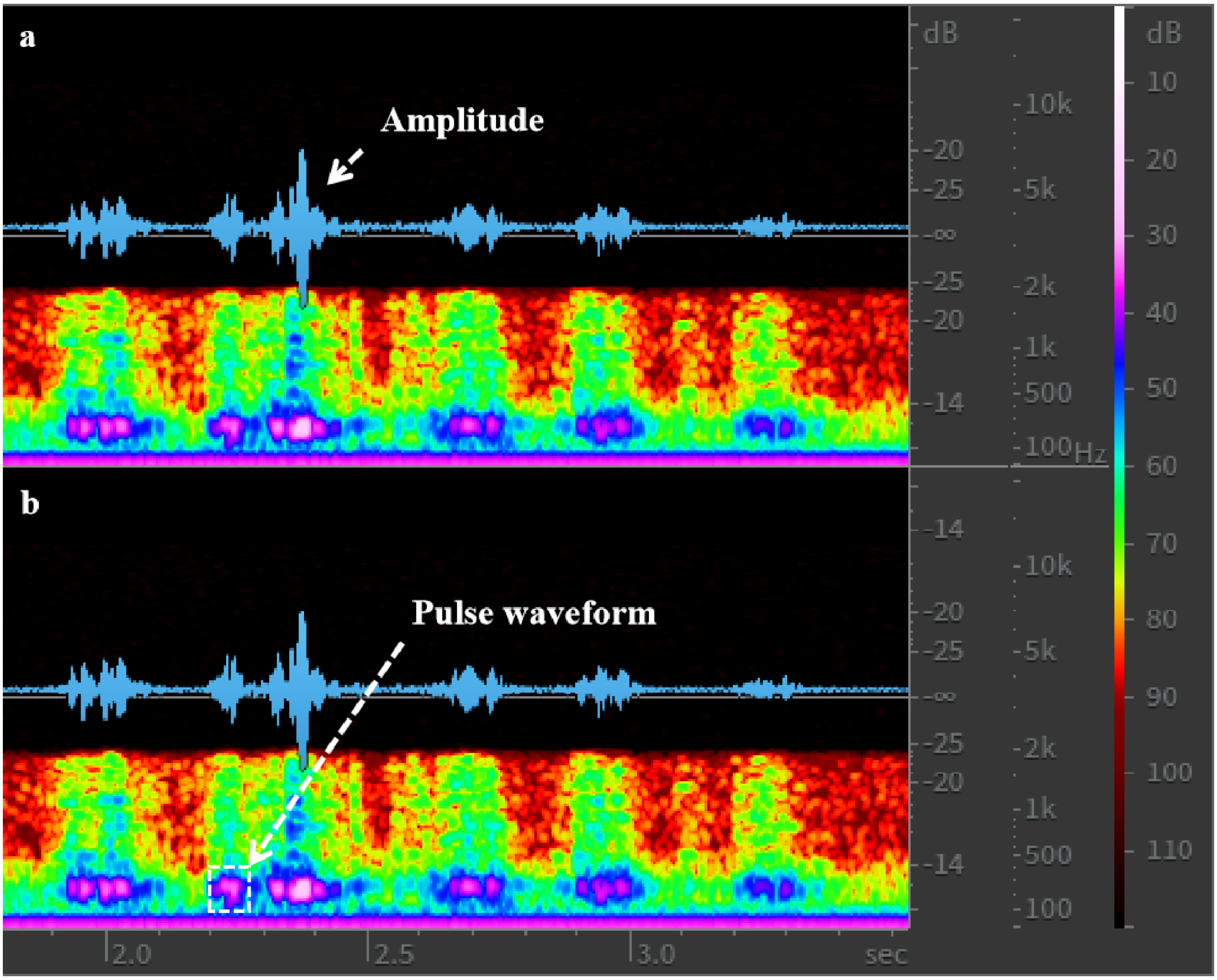


Fig. 3. Analytical graph of *Sebastes schlegelii* vocalisation audio. (a) Amplitude indicated by white arrow; (b) single pulse waveform indicated by white arrow

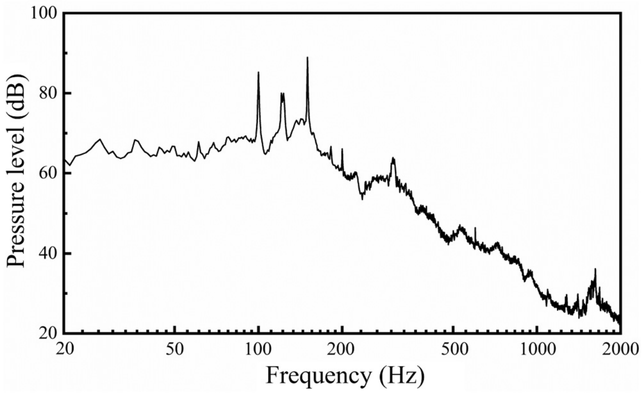


Fig. 4. Spectrogram of individual vocalisations of *Sebastes schlegelii*

peak frequency was about 140 Hz, with the longest mean pulse duration approximately 0.019 s. Peak frequency showed a significant correlation with SL ($R^2 = 0.923$, $p < 0.001$) (Fig. 5a), swim bladder length ($R^2 = 0.954$, $p < 0.001$) (Fig. 5b), swim bladder width ($R^2 = 0.914$, $p < 0.001$) (Fig. 5c), and swim bladder height ($R^2 = 0.776$, $p < 0.001$) (Fig. 5d); all correlations were negative. No significant correlation was found between peak frequency and pulse duration ($R^2 = 0.771$, $p > 0.05$) (Fig. 5e).

## 4. DISCUSSION

Many fish species are capable of producing a wide variety of sounds, and the mechanisms of vocalization vary among them (Wall et al. 2012). In this study, *Sebastes schlegelii* vocalized primarily in the frequency band between 100 and 350 Hz. In contrast, captive rockfishes vocalized within the frequency range of 70 to 500 Hz (Širović & Demer 2009), and white-edged rockfish also vocalized within this same range (Matsubara et al. 2023), supporting the research viewpoint that vocal characteristics can vary significantly even within closely related species. Additionally, pulse durations varied among species, with *S. schlegelii* showing pulse durations of 0.0152 ± 0.0024 s, *S. taczanowskii* ranging from 0.001 to 0.022 s (Matsubara et al. 2023), and *S. marmoratus* at 0.0326 ± 0.0026 s in the present study (Zhang et al. 2013). These results indicate that the spectral characteristics of *S. schlegelii*'s vocalizations are distinct, despite the similarity in body structure among fishes of the same population and genus. By spectral comparisons, it is possible to distinguish other *Sebastes* species. Hallacher (1974) hypothesized that all fishes of the genus *Sebastes* with swim bladder muscles are capable of vocalizing due to the ability of the swim bladder muscle to drive vocalization through contraction (Tavolga 1971, Kaatz 2002). The frequency bandwidth of vibrational sounds produced by the swim bladder ranges from 50 to 1500 Hz, while that of friction sounds extends from 50 Hz to 10 kHz (Fish 1954). Most friction sounds are impulses, whereas vibrational sounds from the swim bladder may be pulses, pure tones, continuous tones with frequency and amplitude variations, or a mixture of tones, which relate to the structure of the swim bladder and its mechanism of sound production (Demski et al. 1973). In this experiment, the specific dimensions of the swim bladder were obtained through the X-ray image acquisition method. However, this technique was not effective in capturing relevant data on the swim bladder muscle. High-resolution CT (HRCT) utilizes the penetrative capabilities of X-rays to image the internal structures of organisms, offering high-resolution imaging that can clearly delineate both large differences in density between soft tissues and bone structures, as well as subtle differences within soft tissue structures and organs, typically without overlap between these structures (Zhang 2013). This technique has proven effective in detailing the structure and arrangement of the swim bladder and swim bladder muscle (Carpenter et al. 2004, Yang et al. 2021). For future studies, combining anatomical methods with computed tomography could more accurately obtain data on the swim bladder and swim bladder muscle of target fish species, and more precisely explore the relationship between vocal frequency and the size of these structures in fish.

PAM, also known as passive sonar, operates without a specialized acoustic source transmitting system. It detects underwater targets by receiving noise radiated by the targets themselves, which is used to determine the state and nature of the target for localization, tracking, and identification (Cato et al. 2005, Song et al. 2023). Capturing the vocal audio of target species through PAM and exploring the relationship between their vocal characteristics and features such as swim bladder and SL are crucial for estimating the length composition of these species (Anderson et al. 2008, Song et al. 2023). Our results indicate that SL is positively correlated with swim bladder size, whereas peak frequency is negatively correlated with SL, swim bladder length, and swim bladder height, both of which have been confirmed in vocalization studies of various fish with swim bladders (Dobrin 1947, Fish & Mowbray 1970, Colleye et al. 2009, Amorim et al. 2013). These relationships between the sound characteristics of *S. schlegelii* and SL suggest that PAM can be effectively used to estimate its length composition.

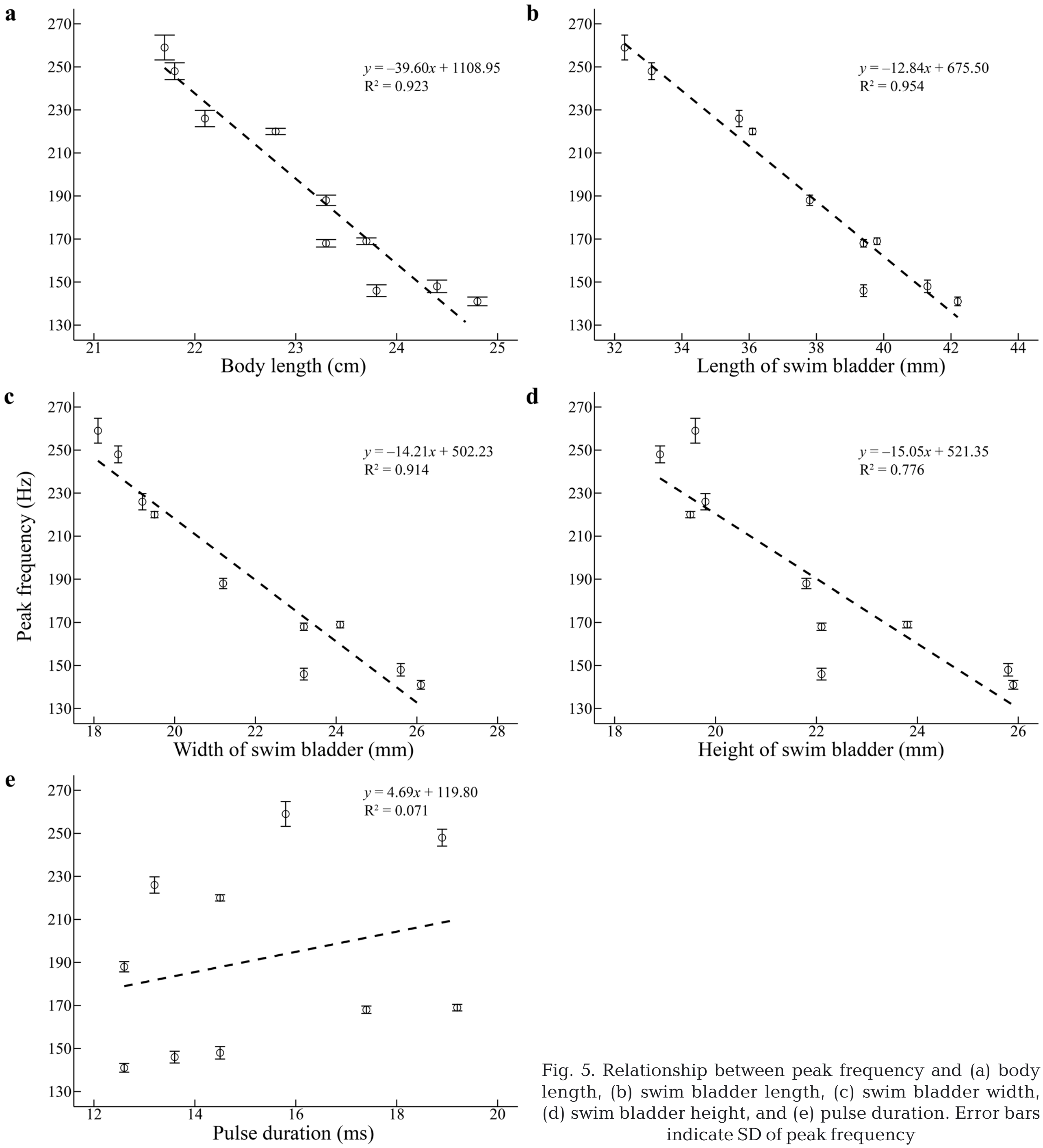


Fig. 5. Relationship between peak frequency and (a) body length, (b) swim bladder length, (c) swim bladder width, (d) swim bladder height, and (e) pulse duration. Error bars indicate SD of peak frequency

However, some studies have shown that in fish from the group Sciaenidae, measuring 20–25 cm, there are very subtle changes in peak frequency of their vocalizations with SL (Connaughton et al. 2000, Tellechea et al. 2010). The standard body length of the experimental fish in this study fell within this range (20 to 25 cm), yet the peak frequency varied significantly, likely due to differences in swim bladder structural characteristics among different fish populations (Ramcharitar et al. 2006, Ren et al. 2007). As the experimental fish in this study all had body lengths greater than 20 cm and lacked acoustic data from *S. schlegelii* with smaller body lengths, further research aimed at using PAM to estimate length composition should involve setting up multiple body length gradients for acoustic characterization of *S. schlegelii*.

This approach would enable a more precise extension of the range of estimated length compositions.

The samples selected for this experiment were all farmed individuals, whose vocal characteristics may not be representative of wild populations (Matsubara et al. 2023). Additionally, the vocal data collected were from a single individual and did not include acoustic communication exchanges between groups displaying different behavioral outputs, such as spawning (Ramcharitar et al. 2006, Ren et al. 2007, Aalbers & Drawbridge 2008), competition for bait (Song et al. 2023), disturbance responses (Heyd & Pfeiffer 2000), and territorial defence (Fletcher 1983, Zhang et al. 2013). Moreover, fish vocalizations are also diurnally and seasonally related (Montie et al. 2015), and some species exhibit changes in acoustic properties during the mating period (Luczkovich et al. 2008, Amorim et al. 2013), making the selection of specific seasons and time periods for monitoring essential. Therefore, comprehensive studies on the acoustic characteristics of *S. schlegelii* should include comparisons of acoustic traits between farmed and wild individuals, evaluations of vocal characteristics among individuals and groups across different seasons and periods, and assessments of vocal variations among individuals of different SLs.

*Ethics*. All animal procedures were performed in accordance with the institutional guidelines for the care and use of laboratory animals at Dalian Ocean University, Dalian, China, and were compliant with animal ethics standards.

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