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Age and Growth of Japanese Anchovy (*Engraulis japonicus*, Temminck & Schlegel, 1846) in Coastal Waters around Shandong Peninsula, China

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Abstract: Japanese anchovy (*Engraulis japonicus*) is a small pelagic fish with commercial and ecological importance. In spite of its importance, in recent years, specific research on anchovy in the Shandong Peninsula area has been relatively scarce and outdated. This study aims to estimate the age and growth characteristics of anchovy through year-round seasonal sampling from 2016 to 2017, utilizing length–frequency and otolith microstructure analysis. The higher coastal abundance and larger size observed in the spring and summer suggest a potential peak spawning period for anchovies dominated by larger-sized individuals. Based on otolith analysis, anchovies range in age from 0 to 4 years, with a limited presence at age 0 and dominance in the age-1 group. The length–weight relationship (LWR) equation shows hyper-allometric growth for each season, with a mean relative condition factor (K_n) of 1.025 ± 0.005, indicating good health. Additionally, the von Bertalanffy growth equation of can be expressed as $L_t = 154.40\,[1 - e^{-0.604\,(t\,+\,0.965)}]$, suggesting a medium growth rate (K = 0.604). These findings contribute to the understanding of anchovy age and growth patterns, emphasizing the continuous need for research and monitoring to support rational and sustainable fisheries management and conservation efforts.

Keywords: biological parameter; Japanese anchovy; otolith microstructure; spatial–temporal distribution; von Bertalanffy model

Key Contribution: This research not only provides information about seasonal changes in distribution but also offers insights into the age and growth patterns of *E. japonicus*. These findings hold significant implications in terms of enhancing sustainable anchovy population management and conserving marine ecosystems in the Shandong Peninsula.

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1. Introduction

Small pelagic fish (SPF) play a crucial role in marine ecosystems by regulating biomass, influencing fishery yields, facilitating nutrient transfer, and impacting predator–prey dynamics in aquatic food webs [1–5]. These fishes are characterized by short lifespans, rapid growth, high mobility, and schooling behavior, making them responsive to environmental variability and susceptible to large-scale fishing efforts [6,7]. Due to their responsiveness to environmental changes, small pelagic fishes have been highlighted in prior studies as crucial indicators of ecosystem health and climate change [5,8,9]. Despite their significance in practical fisheries management, our understanding of small pelagic fish population growth still needs to be explored [10]. Therefore, to ensure their sustainability, it is critical to understand the fundamental aspects of their biology to assess survival, recruitment, and population dynamics in fisheries management [11,12].

Japanese anchovy, *Engraulis japonicus* (hereafter referred to as anchovy), is a typical small pelagic fish widespread throughout the northwest Pacific, especially in the China Seas [13,14]. Anchovy serves as the most abundant small pelagic fish and a crucial prey species for many other fishes, while also holding significant commercial value [3,4,15–17]. However, since the 1980s, the anchovy population has experienced significant fluctuations. The highest landing was recorded in 1998, with a total landing exceeding 1300 thousand tons. However, under the high fishing pressure of the early 2000s, particularly since 2003, the landing continued to decrease until 2009 (Figure 1), and anchovy spawning stock biomass (SSB) in the Yellow Sea during the early 2000s declined significantly from 1.3×10^6 tons to 0.2×10^6 tons, as estimated through acoustic methods [15,18,19]. There is also a phenomenon of catch composition characterized by miniaturization, early sexual maturity, and decreasing catch per unit effort (CPUE) [16,20,21]. In recent years, the anchovy landings gradually increased until 2015, followed by a subsequent decrease. Nevertheless, despite this decline, annual landings have consistently maintained a high yield of 600 to 800 thousand tons, which is the second highest in China's marine fishery. Notably, among these landings, those from Shandong Province have significantly impacted the total anchovy landings in China, accounting for approximately 60% of the total [22] (Figure 1).

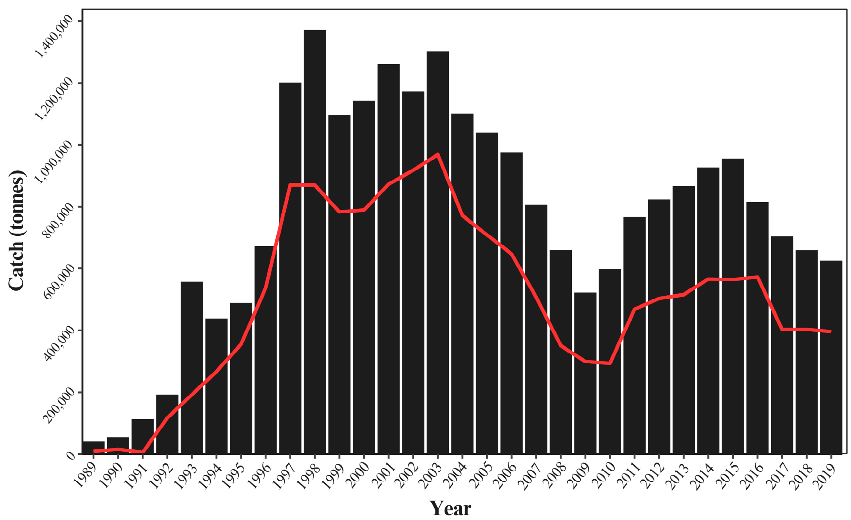

Figure 1. The annual landing of *Engraulis japonicus* in the China Sea and Shandong Province (red line) from 1989 to 2019 (The data can be accessed from the FAO and China Fisheries Statistical Yearbook).

Every year, anchovies migrate from their wintering grounds to an inshore area for spawning, typically from April to May, with the spawning period lasting until September [17]. Anchovy can undergo multiple-batch spawning during the spawning period. After laying their eggs, they disperse to forage for food in the surrounding areas. There are several traditional spawning grounds for anchovies along the coast of the Shandong Peninsula (Figure 2), which play a pivotal role as both spawning and feeding grounds for the anchovy population [17,23,24]. Several studies have been conducted to investigate the biological information of anchovies around these areas [14,25–28]. However, these studies are relatively limited and dated, emphasizing the need for further studies to address knowledge gaps.

The estimation of fish age has traditionally involved examining calcified structures like otoliths, scales, and other skeletal parts. However, otolith remains the preferred structure due to its simplicity, high accuracy, and minimal need for specialized equipment [29,30]. Otoliths are small calcareous structures found in the inner ear of fish that function as valuable repositories of their life history [31,32]. Unlike other structures, otoliths possess resistance to reabsorption and continuous growth, providing critical insights into fish life and growth, thus making them indispensable tools in ecological fish studies [29,33–35].

Various innovative methods using sophisticated technology have been employed in fish age determination [31,36,37]. However, this approach incurs significant costs and cannot be universally applied to all species. Despite these challenges, otolith microstructure analysis remains the most commonly used and reliable approach for age determination in teleost fishes [34]. The analysis provides a powerful tool for gathering essential biological data particularly well-suited for investigating the age, growth, and survival rate of early-stage fish [38,39]. Otolith microstructure analysis has become increasingly crucial in studying various aspects of fish populations, including early life history, fish distribution, age structure, and growth, with applications spanning across China and other countries [10,14,25,40–42].

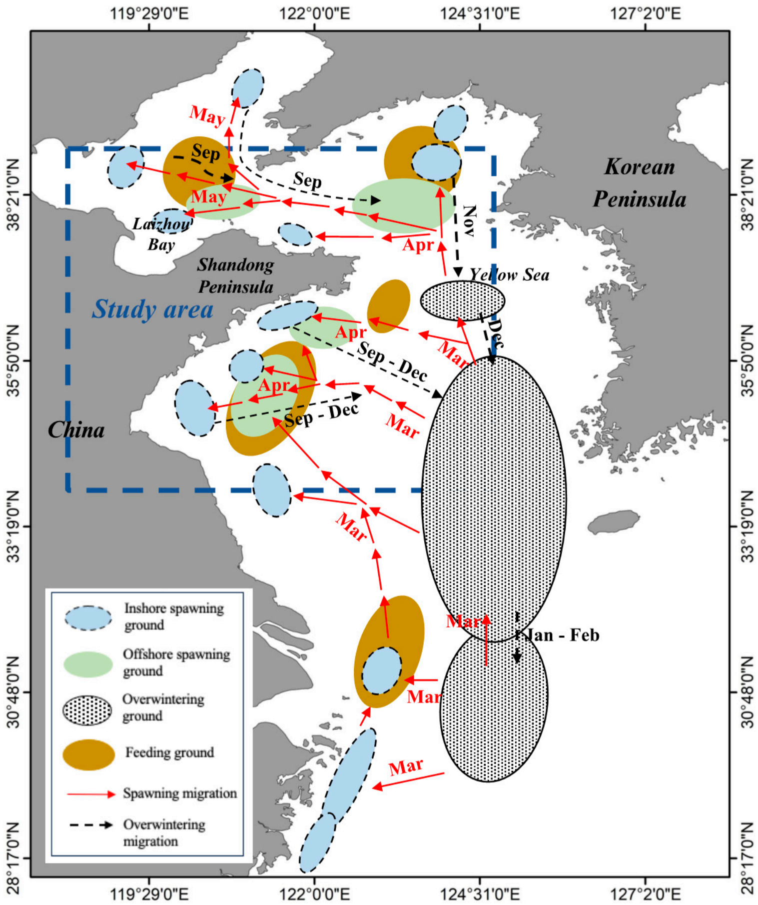

Figure 2. Migration routes of anchovy illustrated based on Zhang et al. [17]. The blue square delineates the study area, with the wintering migration routes indicated by black arrows and the spawning migration routes denoted by red arrows.

This study aims to provide essential insights into the biological aspects of anchovies in the coastal area of the Shandong Peninsula based on year-round seasonal trawl data. This includes estimating age, length–weight relationships, and population growth parameters. The findings of this study will establish the foundation for more in-depth biological research, potentially providing valuable insights to improve the effectiveness of fisheries management and preserve marine ecosystem health in China.

2. Materials and Methods

2.1. Survey and Sample Processing

Surveys were conducted in the coastal waters of the Shandong Peninsula, covering the area between 118°20′–123°50′ E and 35°00′–38°30′ N. They were divided into the following three regions: Laizhou Bay (area A), northern Shandong Peninsula (area B), and southern Shandong Peninsula (area C) (Figure 3). The anchovy samples were collected using a bottom trawl operated at a speed of approximately 3 knots for one hour. The trawl net has an opening width of about 20 m with a height of about 2 m and a mesh size of 1.5 to 1.8 cm. A total of 651 stations were conducted throughout four seasons (Table 1), with 54 trawls in autumn, 14 in winter, 37 in spring, and 83 in summer.

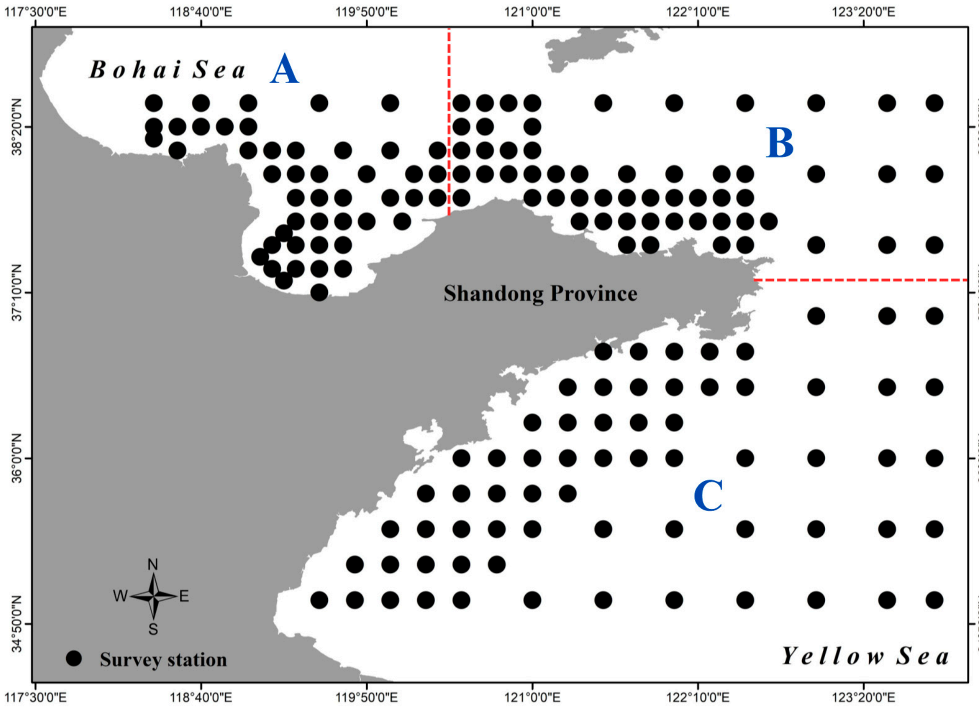

Figure 3. Survey stations located in the coastal waters of the Shandong Peninsula from autumn 2016 to summer 2017. The Shandong Peninsula is divided into three distinct regions: (A) Laizhou Bay, (B) the northern region of the peninsula, and (C) the southern region of the peninsula (separated by the red dotted line). Sampling for autumn was conducted in October 2016, winter in late December 2016 to early January 2017, spring in May 2017, and summer in August 2017.

Table 1. Seasonal variations of survey and sampling data for *Engraulis japonicus* were collected in the coastal waters of the Shandong Peninsula from autumn 2016 to summer 2017.

Season (Time Collection)	Total Number of Survey Stations	Anchovy Occurrence Station (Anchovy Measurement Station)	Number of Anchovies (ind.)	Total Length (Length Range) (mm)	Wet Weight (Weight Range) (gram)	Frequency of Occurrence (%)	Mean CPUE (kg/km^2)
Autumn (October)	160	54 (19)	243	98.63 ± 30.18 (35–165)	9.01 ± 6.19 (0.27–24.89)	33.75	2020.29 ± 113.28
Winter (late December to early January)	166	14 (11)	91	106.98 ± 26.09 (60–162)	7.71 ± 5.97 (0.79–25.51)	8.43	248.03 ± 46.14
Spring (May)	161	37 (33)	287	126.75 ± 13.66 (26–161)	12.01 ± 4.56 (5.56–30.25)	22.98	1356.37 ± 99.54
Summer (August)	164	83 (74)	880	113.06 ± 16.55 (39–159)	7.08 ± 3.60 (0.35–22.06)	50.61	31,436.93 ± 1469.03
Total	651	188 (137)	1501	112.97 ± 21.34 (26–165)	8.37 ± 4.84 (0.27–30.25)	115.77	35,061.62 ± 1727.99

A total of 1501 anchovy samples were randomly selected from different stations and used for biological measures in this study. The examination comprised 243 individuals in autumn, 91 in winter, 287 in spring, and 880 in summer (Table 1). The total length (TL) and body weight (wet weight, WW) were measured to the nearest 0.1 mm and 0.01 g, respectively. Additionally, 582 subsamples were randomly selected from the summer cruises and used for age estimation, with 322 samples collected from area B and 260 samples from area C.

2.2. Data Analysis

2.2.1. Assessment of Anchovy Biomass

In this study, the anchovy biomass was assessed by calculating the catch per unit effort (CPUE) (kg/km^2), which was determined using the following formula:

$$\text{CPUE}\ (\text{kg}/\text{km}^2) = \frac{\Sigma\ catch\ (\text{kg})}{\Sigma\ t\ (\text{h}) \times speed\left(\frac{\text{kn}}{\text{h}}\right) \times net\ width\ (\text{km})} \quad (1)$$

CPUE represents the average catch per unit of time (kg/km^2); Σ catch refers to the total catch recorded at each station (kg), while Σ *t* (h) represents the duration of trawl operation at each station. The trawl *speed* per hour (kn/h) requires conversion to kilometers by multiplying it by a factor of 1.852 km. Finally, *net width* (km) signifies the width of the net utilized as the sampling gear during data collection.

2.2.2. Size Distribution and Length–Weight Relationship

The anchovy growth pattern was estimated by determining the length–weight relationship (LWR) parameters. The LWR is a valuable predictor of fish growth, biological health, and aquatic ecosystem conditions that vary between species due to environmental factors, seasonal fluctuations, and geographic location [39,42]. The LWR parameters are expressed by the following equation [43]:

$$\text{WW} = \text{a} \times \text{TL}^{\text{b}} \quad (2)$$

Equation (2) can alternatively be represented in a logarithmic form, which is often used to convert the relationship into a linear form and simplify statistical analysis. The log-transformed formula is as follows [43]:

$$\ln(\text{WW}) = \ln(\text{a}) + \text{b} \times \ln(\text{TL}), \quad (3)$$

WW represents the weight (g), while TL indicates the total length (mm), 'a' represents the intercept value, and 'b' represents the slope value. The goodness of fit was evaluated by calculating the coefficient of determination (R^2) [43].

To estimate the growth pattern of anchovy, the regression coefficient (b) was compared to the theoretical isometric growth coefficient using the mathematical equation of Student's *t*-test [44]. The allometric coefficient (b) reflects the type of mass growth relative to length. If the exponent b = 3 (isometric), fish tend to have the same shape, while if b > 3 (positive allometric) or b < 3 (negative allometric), fish tend to become slightly fatter or more streamlined.

2.2.3. Relative Condition Factor

The seasonal variations of the relative condition factor (K_n), which reflects the interaction of biotic and abiotic factors influencing the physiological condition of fish, were determined using Le Cren [45] formula:

$$K_n = \frac{WW}{WW'} \quad (4)$$

WW represents the actual weight of the fish, while *WW′* is derived from the length–weight relationship (LWR) for each season. A one-way ANOVA was employed to explore seasonal variations in K_n values, followed by Tukey test when necessary. The coefficient of determination (R^2) was also utilized to assess the predictive quality of the linear regression model.

2.2.4. Age Estimation

Age estimation was conducted using anchovy sagittal otoliths, which were resin-embedded on plastic molds and subsequently polished to improve the visibility of the annual increments. Photographs of the otoliths were taken at 200× magnification using photomicrographic equipment (OLYMPUS BX53,Tokyo, Japan). Under transmitted light, the otolith sections displayed a distinct pattern of translucent and opaque bands (Figure 4). For Japanese anchovy, a translucent band appears before the opaque band, and each opaque band was identified as an annulus ring [46]. The formation of annulus was proven to occur between May and September, with predominant occurrences in June and August, as indicated by marginal increment analysis [46–49]. This suggests that the timing of annual ring formation in anchovies corresponds with their spawning period, indicating a correlation between annulus formation and spawning events. Therefore, the age of anchovies was determined by counting the opaque bands, considering the date of birth (1st June) based on the spawning period of anchovies (typically occurring between May and August) and the capture date [46,50].

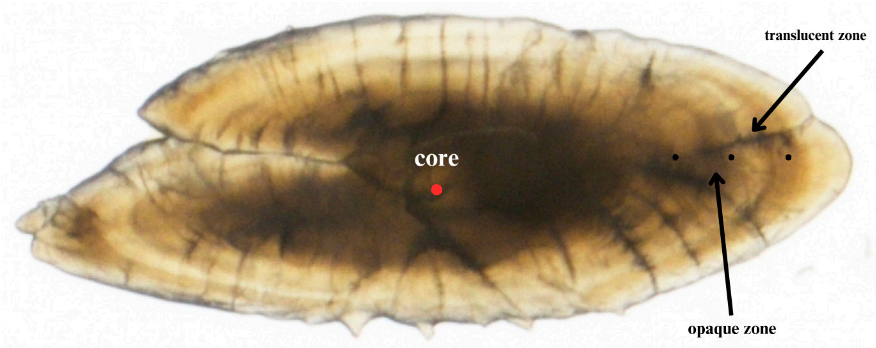

Figure 4. A digital photograph an anchovy sagittal otolith (TL = 144 mm, 3 years old) shows annual increments. Red dots mark the core, while black dots indicate the increments.

Since the maximum age of anchovies is 4, with the majority being 0–1 years old, the accuracy of age estimation methods using average percent error (APE) and coefficient of variation index (CV) calculations could lead to significant discrepancies. Therefore, anchovy otoliths were blindly read twice monthly, and conflicting results were evaluated by experienced readers. When the same reading occurred at least 2 out of 3 times, it was considered as the age determination [51–53]. This approach involved excluding individuals with inconsistent or inaccurate aging results. Following this, the chi-square test was employed to evaluate the difference in the age distribution between the two regions during the summer.

2.2.5. Growth Parameters

The growth parameters of anchovy were evaluated using the von Bertalanffy growth function, a widely accepted approach in fisheries research due to its incorporation into early stock assessment models [54,55].

$$L_t = L_\infty \left[1 - \mathrm{e}^{-\mathrm{K}\,(\mathrm{t}\,-\,\mathrm{t}_0)}\right] \tag{5}$$

L_t is the length at age t, L_∞ is the theoretical asymptotic length, K represents the growth coefficient, and t_0 denotes the theoretical age when L = 0. The von Bertalanffy growth function (VBGF) was applied using the FSA package in R software 4.3.2 (R Core Team, 2018) [56].

3. Results

3.1. Spatial–Temporal Distribution

During the 2016–2017 survey in the coastal waters of the Shandong Peninsula, anchovy had an overall occurrence frequency of 28.87% across all stations. The seasonal occurrence frequency of anchovy was as follows: summer (50.61%) > autumn (33.75%) > spring (22.98%) > winter (8.43%). Similarly, the highest biomass was observed in summer (average, 31,436.93 kg/km^2), followed by autumn, with a biomass of 2020.29 kg/km^2, while during the winter, anchovy biomass was notably low, at only 248.03 kg/km^2 (Table 1; Figure 5).

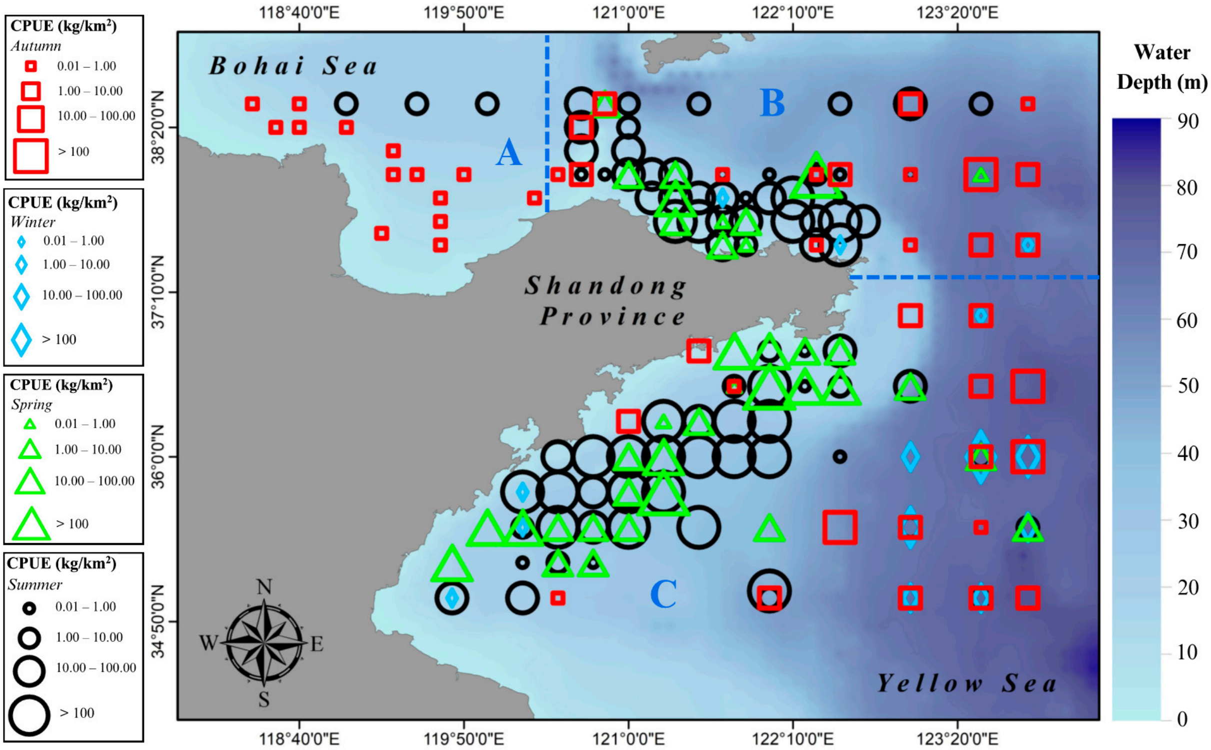

Figure 5. Japanese anchovy distribution throughout the Shandong Peninsula during the study period. Symbols at specific stations might overlap, since anchovies were encountered multiple times during sampling across various seasons. The size of the symbols indicates the biomass of anchovies.

The spatial distribution of anchovy showed distinct seasonal variation. In spring and summer, the coastal areas along the Shandong Peninsula, specifically in area B and area C, serves as a primary aggregation area, suggesting the potential for inshore spawning activities (Figure 5). In autumn, the primary distribution areas tend to shift from inshore to offshore areas. The Laizhou Bay inshore areas (area A) also have a higher presence of anchovies, though with low abundance. The anchovy biomass declines notably in the inshore areas during the winter, and the central Yellow Sea becomes the primary distribution area.

3.2. Seasonal Variation Pattern of Length and Length–Weight Relationship

The observed total length of anchovies ranged from 35 to 165 mm across all seasons, with an average length of 112.97 ± 21.34 mm (Table 1; Figure 6). Seasonal variations in anchovy size distribution were evident. During spring and summer, larger individuals of anchovy are predominant, especially in the spring, when many individuals exceed 90 mm in length. The average length of these larger individuals reaches 126.75 ± 13.66 mm, with the dominant length group falling within the range of 120 to 130 mm. In summer, the dominant length group shifts slightly to 110–120 mm, and the average length decreases to 113.06 ± 16.55 mm. Smaller individuals (approximately 39–95 mm in length) were observed during this season. The length distribution of individuals in autumn was more evenly spread, characterized by a dominant length of 120–130 mm, with an average length of 98.63 ± 30.18 mm. Autumn exhibits a higher proportion of smaller individuals with lengths of less than 90 mm. As winter set in, the average individual length was 106.89 ± 26.09 mm, with the larger individuals predominating in the 100–110 mm range and the smaller individuals predominating in the 60–70 mm range.

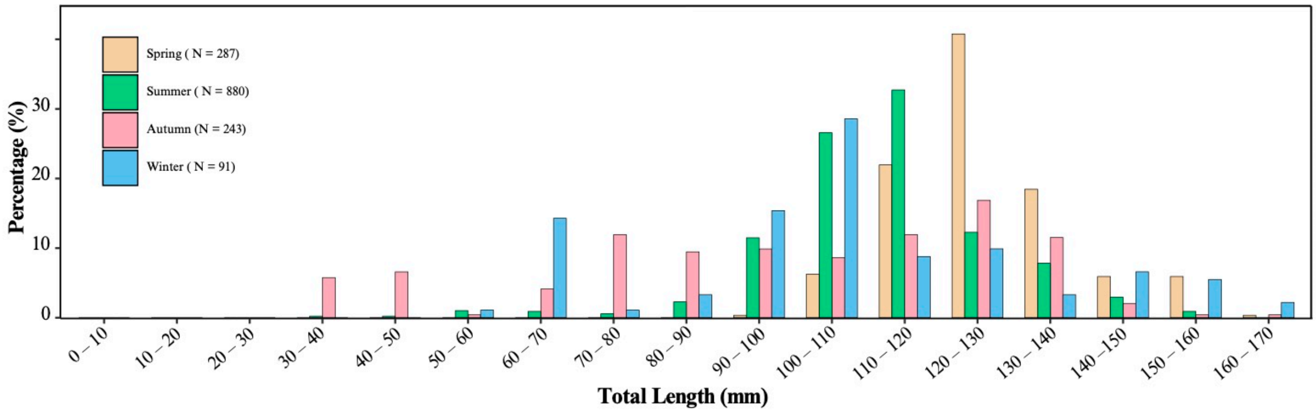

Figure 6. The frequency of length distribution of anchovy from four seasons in the Shandong Peninsula.

The length–weight relationship of anchovy showed an exponential correlation (Table 2; Figure 7). The all-season LWR is defined by the equation WW = 0.0054 $L^{2.9626}$ (R^2 = 0.8743). There are evident variations in the length–weight relationship across different seasons. The value of b is larger than 3 in all seasons and significantly different from 3 ($p < 0.05$), which indicates positive allometric growth or hyperallometric growth. The average relative condition factor (K_n) value was 1.025 ± 0.017, with the highest value recorded in Autumn 2016 (1.052 ± 0.287). A one-way ANOVA analysis revealed no significant seasonal variations ($p = 0.0519 > 0.05$).

Table 2. Details of the LWR parameter and the mean value of K_n of anchovy in four seasons from Shandong Peninsula coastal waters.

Season	Length–Weight Relationship (LWR) Parameters			K_n
	a	b	R^2	
Autumn	0.005153	3.066	0.953	1.052 ± 0.287
Winter	0.003171	3.197	0.908	1.016 ± 0.155
Spring	0.002445	3.372	0.971	1.018 ± 0.151
Summer	0.003516	3.188	0.802	1.015 ± 0.165

3.3. Age Estimation and Growth Parameter

During the summer, age estimation in both the northern Shandong Peninsula (area B) and the southern Shandong Peninsula (area C) revealed a minimum age of 0 years and a maximum recorded age of 4 years. The highest-frequency age group was 1 year in both areas (Figure 8). In area B, there were very few anchovies in the younger class (age 0). In area C, the age group of adult anchovies (age 4) was less prevalent. The chi-square test indicated that the age frequency distribution of anchovy differed significantly between the two areas ($\chi^2 = 26.85$, $df = 4$, $p < 0.05$).

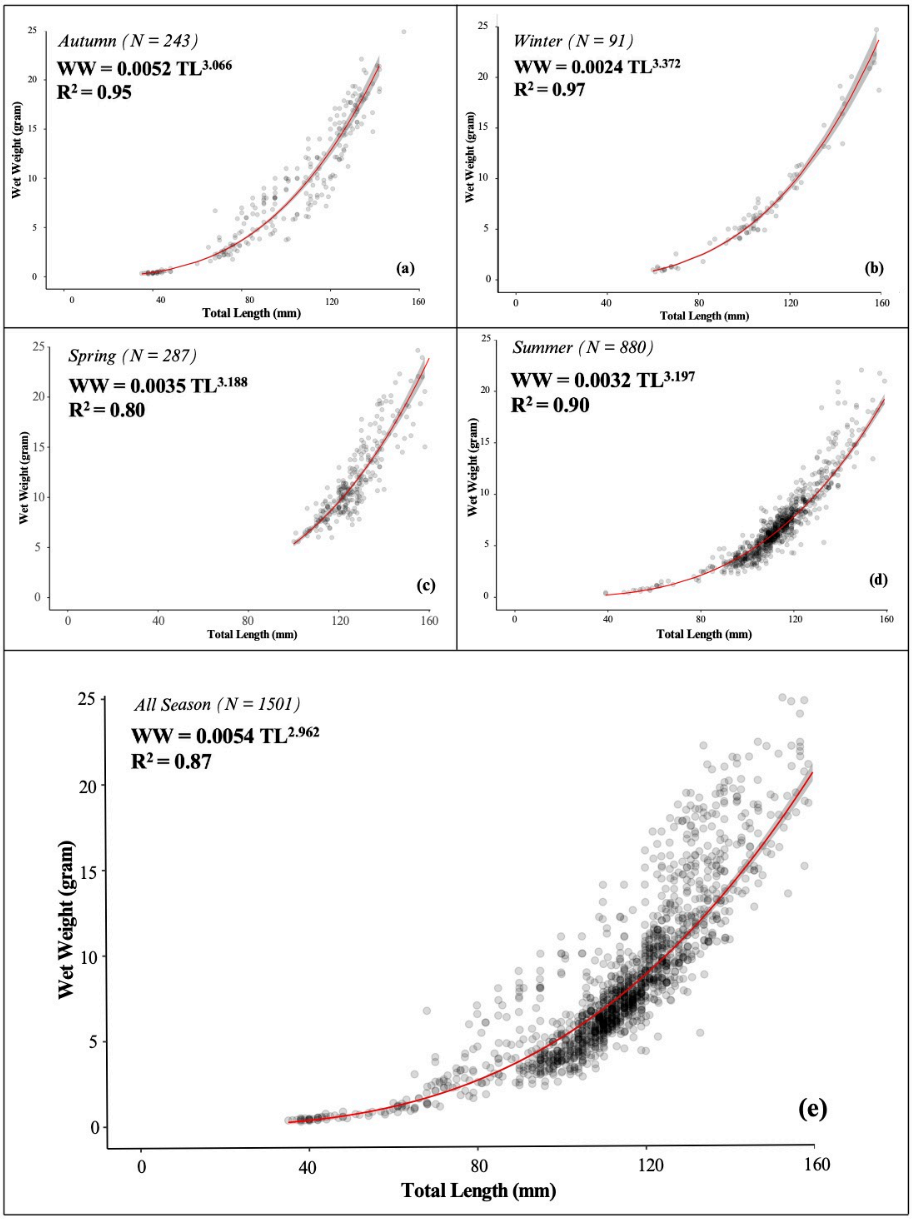

Figure 7. Japanese anchovy length–weight relationship (LWR) in Shandong Peninsula coastal waters: (**a**–**d**) seasonal LWR and (**e**) all-season LWR.

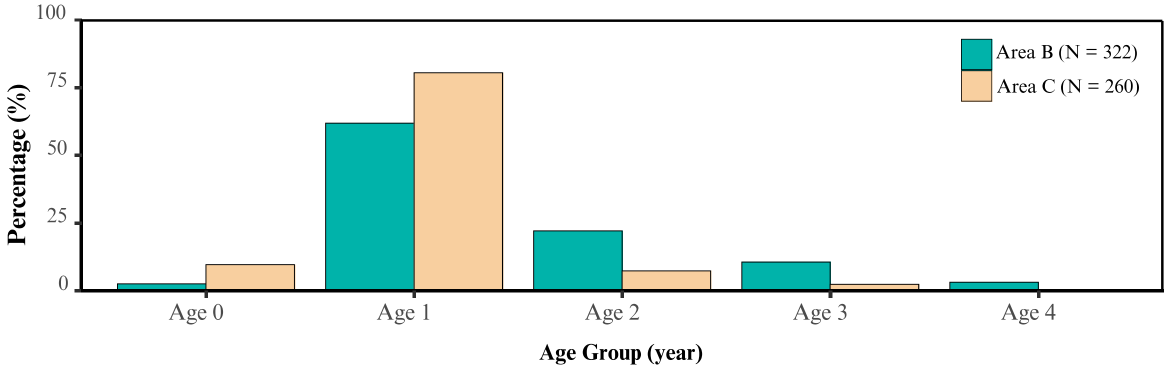

Figure 8. Frequency distribution of anchovy age in the coastal waters of the Shandong Peninsula during the summer of 2017.

The von Bertalanffy model was fitted to the length-at-age data, resulting in an estimated asymptotic length (L_∞) of 154.40 mm and a growth coefficient (K) of 0.604/year. The theoretical age at which fish length would be zero (t_0) was estimated at −0.965 years. Therefore, the von Bertalanffy growth equation for anchovy is represented as follows: $L_t = 154.40\ [1 - e^{-0.604\ (t\ +\ 0.965)}]$ (Figure 9). The relationship between the number of annual growth rings and fish body length shows a logarithmic growth pattern. Furthermore, the coefficient of determination (R^2) for the von Bertalanffy model was 0.7817, indicating a strong fit of the model to the observed data.

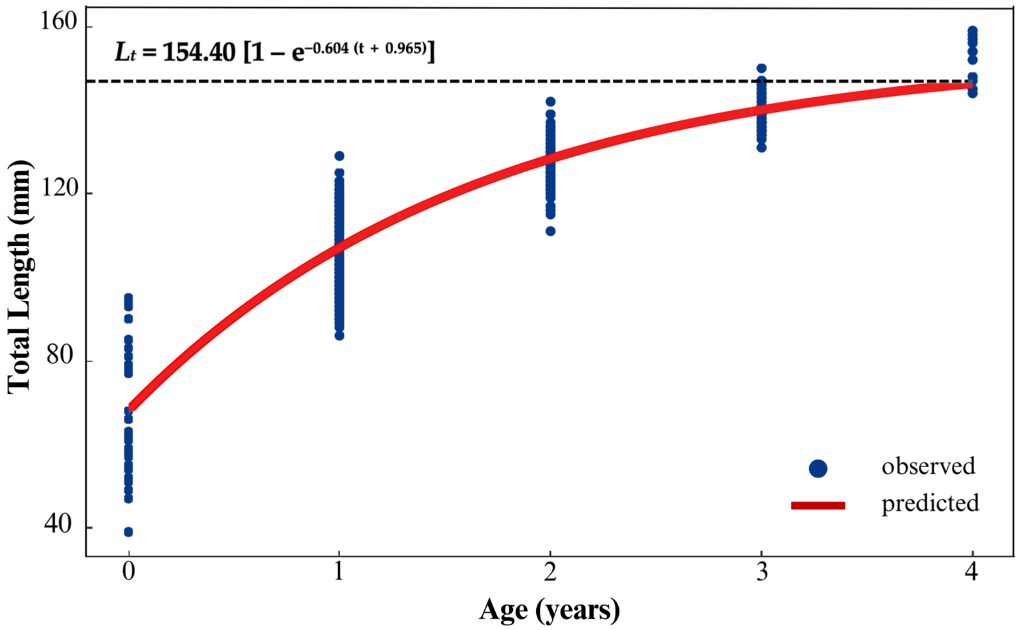

Figure 9. The von Bertalanffy growth curve of anchovy from the coastal waters of the Shandong Peninsula.

4. Discussion

4.1. Spatial–Temporal Distribution of Japanese Anchovy

The coastal Yellow and Bohai Seas serve as traditional spawning grounds for Japanese anchovy [17]. In the early spring, as the temperatures of coastal waters rise, anchovies migrate from their wintering grounds to the coastal area to spawn (Figure 2) [57–60]. Anchovies have a prolonged spawning period [39], with the primary spawning season occurring in late spring until early summer [17,25,61,62]. During this primary spawning period, spring and summer show higher adult abundance and larger sizes, ranging from 90 to 150 mm, with average total lengths of 126.75 ± 13.66 mm and 113.06 ± 16.55 mm, respectively (Figure 5; Figure 6). Conversely, autumn and winter exhibit a significant prevalence of smaller-sized anchovies, particularly noticeable during autumn, with sizes ranging from 30 to 50 mm. This suggests recruitment events occurring within the existing population [63,64]. The size dominance observed in each season aligns with Zhu et al. [27], who found that larger anchovies were more common in spring, whereas sizes ranging from 20 to 70 mm were dominant in winter.

Japanese anchovy has a relatively short lifespan with rapid growth. Generally, anchovies live for up to three years, with a few individuals surviving up to four years [25,27,61]. In our survey area, anchovy age estimation ranges from age 0 to age 4, with the age-1 group being predominant. The age-1 group accounts for 50% of the population in area B and 75% in area C. Anchovy stocks in area B consist of individuals aged 1 to 4, while the stocks in area C mostly consist of individuals aged 1 to 3. Anchovies reach sexual maturity quickly and can spawn by the age of one year. Their reproductive capacity increases between ages 1 and 2, while the peak of the reproductive capacity period occurs between ages 2 and 3 [60]. Previous studies showed that the early spawning stock of anchovy is primarily composed of large individuals [25,61], and the population spawning in summer is dominated by small individuals aged 1–2 years [27]. This pattern supports the body length distribution of anchovies observed in this study (Figure 6).

The presence of age-0 individuals in both locations suggests the possibility of these areas serving as nursery grounds during that period [3,7]. The northern Shandong Peninsula exhibits a higher number of individuals ranging from age 1 to age 4, while in the southern Shandong Peninsula, the population consists of anchovies aged from 0 to 1. This divergence might be attributed to temporal variations in the anchovy spawning period influenced by environmental conditions and migration patterns [17,39]. The frequency of small-sized anchovies in these areas has also increased compared to the anchovy population in 1991. This phenomenon indicates a trend of miniaturization within the anchovy population [61] attributed to environmental pressure [65], fishing pressure [16], and climate change effects [66].

Nonetheless, it is important to note that this study was limited to a one-year survey, focusing only on the summer samples without conducting gonad analysis on the anchovy samples. Consequently, data on sex and spawning ratios across different age groups are unavailable. The subsample from summer was selected to represent the period when anchovy reproduction activity tends to peak. However, due to sample limitations, the age study only utilized samples from areas B and C. Supplementing ages from other seasons will provide better insights into anchovy information.

4.2. Growth Pattern

The total length (TL) of anchovies observed in this study ranges from 35 to 165 mm, with the majority falling within 110–120 mm (Figure 6). These findings are consistent with previous studies conducted in the Yellow Sea, which reported length variations in anchovies ranging from 40 to 165 mm, with a mean length of 119 mm and a maximum length reaching 160 mm [25,27,67]. Similar results from studies in other locations, such as Korea and Japan, also suggest that anchovy populations typically range from 80 to 140 mm, with a maximum length of 140 mm [68,69].

The LWR analysis reveals that anchovies in the Shandong Peninsula display a positive allometric growth pattern (Figure 7a–d), indicating that the anchovy experiences a proportionally more significant increase in weight compared to length, reflecting favorable prey and growth conditions [70]. Positive allometric growth ($b > 3$ in LWR) has also been observed in anchovy populations across various sea areas [26,27,39,71,72]. The mean relative condition factor (K_n) is a factor that can assess the overall health and physiological state of fish populations [73,74]. In this study, the K_n value was 1.025 ± 0.017, indicating that the anchovy population in the Shandong Peninsula generally exhibits good health and well-being [45,75,76]. The highest K_n value was recorded during autumn (1.052 ± 0.287), suggesting an improved condition of the fish population during that season. The higher K_n value in autumn may also indicate preparation for overwintering, as anchovies typically reduce their feeding activity during the overwintering period [27,77]. Conversely, the lower K_n value in spring and summer may suggest anchovies invest more energy in reproduction and growth. This variation in K_n value could reflect that anchovy is an "income breeder" species [78,79], i.e., spawning depends on energy obtained from pre-spawning feeding rather than energy accumulated in the body [71,76,80].

Anchovy exhibits an allometric relationship based on the von Bertalanffy growth parameters, demonstrating rapid growth during the first year of life, followed by a slower and more controlled growth rate (Figure 9). This corresponds with the concept of autocatalytic growth, which suggests that growth increases, then slows down until the fish reaches a certain length and becomes a constant [55,81]. The asymptotic length (L_∞) for anchovy derived from the von Bertalanffy growth equation was 154.40 mm. Pauly and Morgan [82] suggest that infinite length (L_∞) can be utilized to determine the optimal size for fishing in a particular body of water. Compared to results from another study (Table 3), our findings for the L_∞ of anchovy in the study area closely correspond with those reported in the East China Sea and Yellow Sea (155 mm) by Iversen et al. [25]. However, there is a difference when compared to the studies conducted by Liang and Pauly [83] and Zhu et al. [27], possibly due to geographical variations and seasonal fluctuation. The population used in this study was from the summer samples, whereas both previous studies used an anchovy population from winter samples.

Table 3. Growth parameters of *E. japonicus* in diverse locations within China and the surrounding waters.

Location	L_∞ (mm)	K (/Years)	t_0 (Years)	References
Coastal waters of Shandong Peninsula (summer stock)	154.40	0.604	0.965	This study
Chinese waters	184	0.51		[83]
Yellow Sea (wintering stock in 2001)	190.1	0.47	0.06	[27]
Yellow Sea (wintering stock in 2004)	172.7	0.61	0.17	
East China Sea (spring stock)	53.22	0.019	2.80	[26]
East China Sea (late summer stock)	42.17	0.024	3.10	
East China Sea and Yellow Sea	155	0.6	1	[25]

The growth coefficient (K) of anchovies calculated in this study was 0.604, which falls within the category of medium growth according to the classification proposed by Sparre and Venema [55]. This relatively higher growth coefficient (K) value suggests that the maximum asymptotic length will be attained more quickly, a characteristic often observed in fish species with short life cycles [84]. Compared with previous studies (Table 3), our findings show a growth coefficient (K) value consistent with those reported previously. Nonetheless, a study by Chiu and Chen [26] reported low growth coefficient (K) values for two anchovy stocks from the East China Sea, which might be attributed to differences in fishing gear affecting the variations of fish caught.

5. Conclusions

This study provides fundamental and valuable insights into the distribution, growth patterns, and age composition of Japanese anchovy (*Engraulis japonicus*) in the coastal waters of Shandong Peninsula, China. Anchovy distribution is primarily concentrated in the coastal area during spring and summer. Age estimation from the summer samples revealed anchovies ranging from age of 0 to age of 4, primarily consisting of individuals aged 1. Positive allometric growth trends were observed seasonally, with larger individuals predominating in the spring and summer. The von Bertalanffy growth equation (L_t = 154.40 [1 − $e^{-0.604\ (t + 0.965)}$]) indicates an estimated asymptotic length (L_∞) of 154.40 mm and a medium growth rate (K = 0.604). To ensure the sustainability of this species, the implementation of several strategies, such as size restrictions, identification of optimal fishing seasons, and regular monitoring, could be pursued. These actions could significantly impact fisheries management and marine ecosystem preservation in the Shandong Peninsula.

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