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Age and Growth of Japanese Mackerel in the High Seas of the Northwest Pacific Ocean

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Abstract

Japanese mackerel (*Scomber japonicus*) is one of the important economic species in the pelagic light seine fishery in China, but few studies have been reported on the age, growth and management recommendations of Japanese mackerel in the high seas of the northwest Pacific Ocean. In this study, we fitted expressions for the relationship between fork length and body weight of Japanese mackerel based on fork length and body weight data of Japanese mackerel in the high seas of the Northwest Pacific Ocean from 2018 to 2019, and calculated growth parameters and growth characteristics of Japanese mackerel von Bertalanffy growth equation by identifying otolith age data combined with the least squares method. The results showed that the relationship between fork length and body weight of Japanese mackerel in the open sea of the Northwest Pacific Ocean was $W = 2.0 \times 10^{-6} L^{3.289}$ ($r = 0.9764$, $n = 2833$); the growth parameters were $L = 447.61_{\infty}$, $K = 0.264$, $t = -1.06_{0}$; the growth rate reached the maximum when the bodyweight growth rate was 122 g/yr, at which the inflection point age was 3 years old, the inflection point body weight was 310 g, and the inflection point length was 309 mm. We recommend 2 years of age start fishing with a fork length of 250 mm (±10 mm). The growth parameters of Japanese mackerel in the open sea of the Northwest Pacific Ocean were not significantly different from those of the Japanese mackerel population on Japan's coast ($P > 0.05$), Finally, based on the knowledge of biological research and resource evaluation, we suggest that the age of opening trap should be 2 years old and the length of fork should be 250 mm (±10 mm).

Keywords

Northwest Pacific High Seas, Japanese Mackerel, Growth Parameters,

Fisheries Management

1. Introduction

Japanese mackerel (*Scomber japonicus*) is an oceanic warm-water pelagic fish, one of the important economic species of China's pelagic light seine fishery, mainly living in the northwest Pacific Ocean, divided into the Pacific group system and the Tsushima group system [1] [2] [3]. With Japanese mackerel being the main species caught, accounting for 50.2% of the total catch [4]. According to the statistics of The North Pacific Fisheries Commission (NPFC), the total catch of Japanese mackerel in the western Northwest Pacific Ocean from 2017 to 2019 showed a slightly decreasing trend for three consecutive years, and the reasons for the decree sing catch are still unclear, Japanese mackerel is the main species caught in the light seine in the North Pacific Ocean, and NPFC is very concerned about its resources. The research in this paper can provide basic data for NPFC's management of its resources [5]. The study of individual growth patterns of fish is the basis for studying the changes in the number of resource groups and their rational use, and growth increases the total amount of resources, which is one of the main factors affecting the number of resource groups. There have been many studies in the literature on the quantity, distribution and biology of Japanese mackerel in the offshore waters of China and Japan [6]-[15]. The only reports on Japanese mackerel in the high seas of the Northwest Pacific Ocean are Zhuang Zhidong *et al.* [16]. who studied the feeding habits, gonad maturity and fork length-body weight relationships of Japanese mackerel in the high seas of the Northwest Pacific Ocean in autumn; Dai [4] and Xu [5] who studied the distribution of Japanese mackerel in the high seas of the Northwest Pacific Ocean and the environmental characteristics of the fishing grounds; and a few studies who studied the environmental factors affecting the resources and parental replenishment of Japanese mackerel in the Pacific group [1] [17] [18]. In general, studies on the biology of Japanese mackerel fisheries in the high seas of the Northwest Pacific are rare [19] [20]. It is known that only a few scholars have partially studied the age and growth of Japanese mackerel Japan's coast [11] [12], and few studies have been reported on the age, growth and management recommendations of Japanese mackerel in the high seas of the Northwest Pacific Ocean.

Since the Japanese mackerel fishery is of great relevance to the expansion of China's high seas fishery and the improvement of the capacity building of the high seas fishery stock assessment system, and the strengthening of the research on the biological characteristics and stock growth of this fishery stock can provide the preliminary basic data for China's active participation in the assessment of mackerel resources in the Northwest Pacific Fisheries Commission. In this paper, the age determination and growth characteristics of Japanese mackerel in the high seas of the Northwest Pacific Ocean from 2018 to 2019 were analyzed to provide a reference basis for resource assessment and fisheries management.

2. Materials and Methods

2.1. Material Sources

Japanese mackerel in the high seas of the Northwest Pacific Ocean, randomly collected by fishing vessels, were studied in the sampling area of 39 - 44˚N, 147 - 154˚E, and the sampling period was from April to December (fishing season) in 2018 and 2019. Samples were taken four times a month, 100 tails were taken each time, if the number of tails was less than 100, and all samples were taken totaling 2833 tails (Frozen and shipped back to the lab via transport ship). The fishing date, latitude and longitude of each sampling location were recorded, and the samples were numbered and registered. The sampling area is shown in **Figure 1**.

2.2. Fork Length-Weight Relationship

Body length, fork length and full length of Japanese mackerel were measured by tape measure (accurate to 1 mm); body weight was measured by electronic balance (accurate to 0.1 g, Error range in ±0.1 g). The differences between fork length and body weight of Japanese mackerel by sex were examined by analysis of covariance (ANOVA), and then the fork length-weight growth relationship was fitted by power function [21] [22], as shown in Equation (1).

$$W_i = a \times L_i^b \tag{1}$$

L_i denotes the mean fork length (mm) of the *i*th fork length group, W_i is the mean weight (g) corresponding to L_i, *a* is the condition factor for growth, and *b* is the power index coefficient.

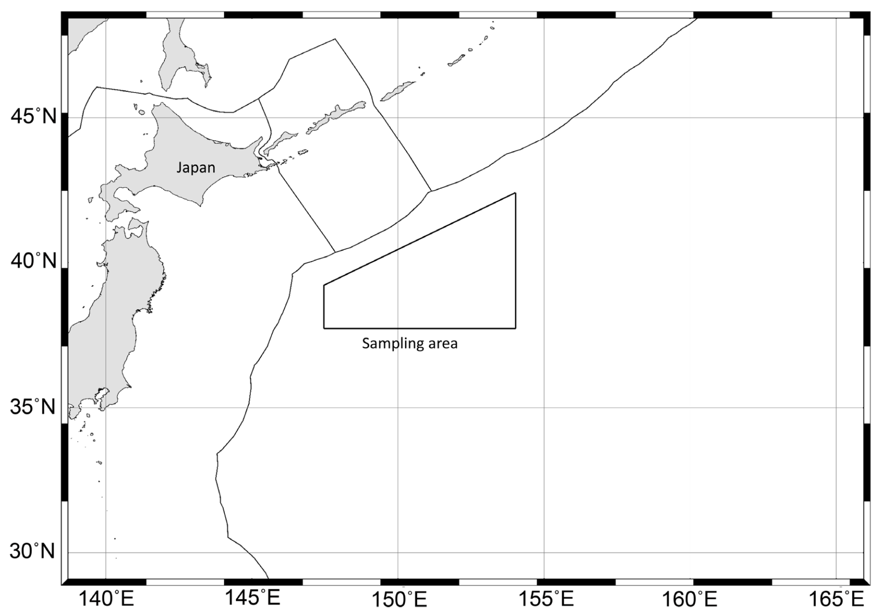

Figure 1. Schematic diagram of sampling location.

2.3. Age Identification

During the life cycle of teleosts, the inner cavity of the skull is lined with carbonate deposits of "small stones" called otoliths. The main mineral component of otoliths is $CaCO_3$, and fish rely on otoliths to distinguish sounds and maintain body balance [23]. Otoliths are used to identify the age of fish because the rate of $CaCO_3$ deposition in otoliths varies with season, water temperature and physiological changes during the development of individual fish [24], resulting in a regular distribution of opaque zone and translucent zone around the core of otoliths, with one layer of transparent zone plus one layer of opaque zone being 1 age. In this paper, the cross-section of Japanese mackerel otoliths was used as a basis for age identification. The polished otoliths were photographed under a 100× light microscope (model: Olympus BX53), and the annual diameter and otolith diameter on the otolith photographs were measured by the measurement software Image J. The Dahl-Lee hypothesis was used to derive the fork length conversions for each age group of Japanese mackerel [25] [26]:

$$\frac{L_i}{R_i} = \frac{L}{R} \tag{2}$$

where L_i is the back-calculated fork length (mm) of the ith age or annual whorl of Japanese mackerel; L is the fork length (mm) of that individual; R_i is the ith annual whorl diameter, which refers to the straight-line distance (mm) from the core point of the otolith to the ith annual whorl of the otolith, and the whorl pattern is measured by the outer edge of the opaque band; R is the otolith diameter, which refers to the straight-line distance (mm) from the core point of the otolith to the outermost edge. The schematic diagram of otolith chronology measurement is shown in **Figure 2**.

To enhance the accuracy of age identification, the otoliths used for age reading should be relatively transparent in cross-section, with the whorls clearly visible, and as much as possible, the secondary whorls should be brought together in

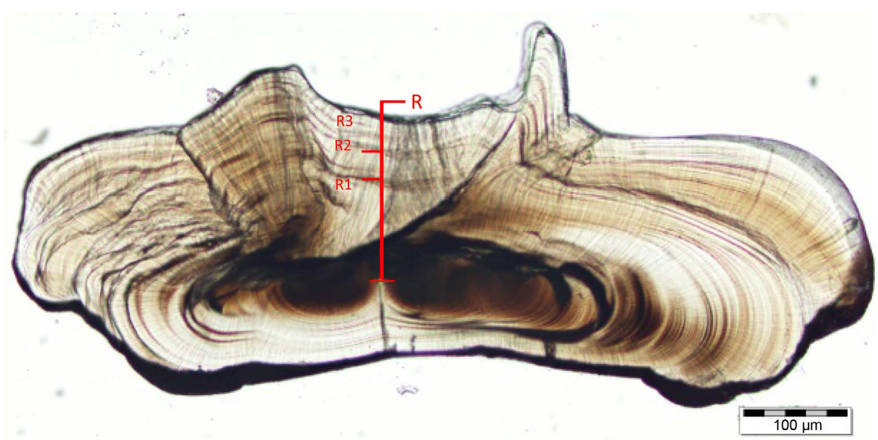

Figure 2. Schematic diagram of age determination of Japanese mackerel otoliths (fork length of this individual is 309 mm, age 3^+).

one place during the polishing process to reduce the interference with age identification. When measuring the diameter of the whorls on the photographs of the otoliths, the alternating zone between the transparent and opaque bands in transmitted light was used as the location of the annual whorls, and the diameter of all the secondary whorls, annual whorls and interfering whorls was recorded [26]. Each otolith age reading was performed independently of each other by two persons with solid otolith reading experience, and the age identification was considered reliable if the judgment was consistent or re-reading or discarding the sample if it was inconsistent.

2.4. Growth Parameters

In fisheries research, the von Bertalanffy growth equation can elucidate the age-dependent variation of length and weight of fish, and the growth process can be fitted with the data of minimum parameters. The equation is generally used to fit and describe the growth pattern of fish, and the least squares method is used to determine the optimal growth parameters for the von Bertalanffy growth equation [21] [27].

Fork length growth equation.

$$L_t = L_\infty \times \left\{1 - e^{\left[-K \times (t - t_0)\right]}\right\} \tag{3}$$

Weight growth equation.

$$W_t = W_\infty \times \left\{1 - e^{\left[-K \times (t - t_0)\right]}\right\} \tag{4}$$

L_t and W_t denote the fork length (mm) and weight value (g) of Japanese mackerel at age t; L_∞ and W_∞ denote the ultimate fork length (mm) and ultimate weight (g) of Japanese mackerel; t_0 denotes the age when the theoretical fork length (L_t) or weight (W_t) is equal to zero, often a negative number; K is the average curvature of the growth curve, indicating the relative rate of convergence to the asymptotic value.

3. Results

3.1. Fork Length and Weight

It was found that there was no significant difference in fork length and body weight between male and female Japanese mackerel individuals ($P > 0.05$). The relationship between fork length and body weight was expressed as $W = 2.0 \times 10^{-6} L^{3.289}$ ($r = 0.9764$, $n = 2833$), where the growth condition factor a was 2×10^{-6} and the power index coefficient b was 3.289 (**Figure 3**).

3.2. Growth Equation

3.2.1. Age Identification and Fork Length-Age Conversion Table

The total number of samples used for otolith age identification in 2018 and 2019 was 317, including 5 at age 0^+, 92 at age 1^+, 170 at age 2^+, 44 at age 3^+, and 6 at age 4^+. Fork lengths and age back-calculations were performed according to the

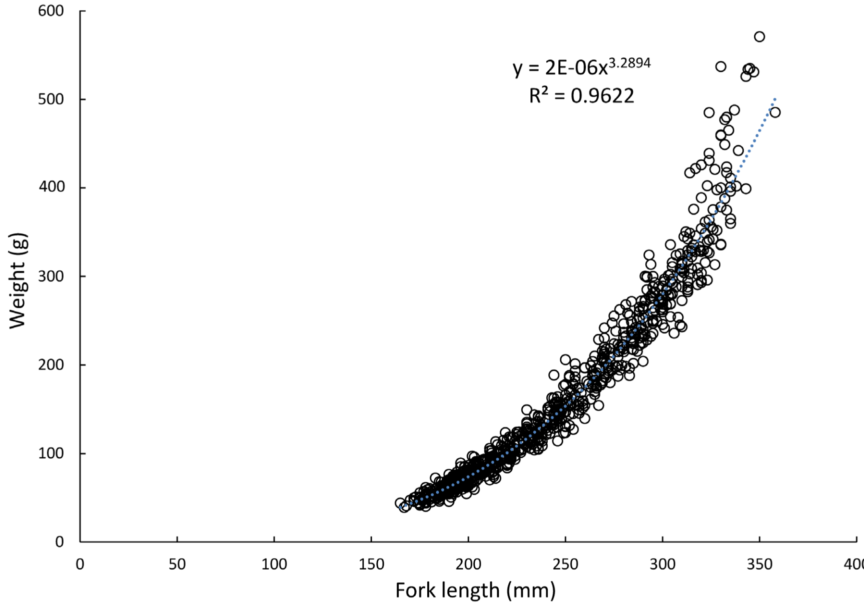

Figure 3. Relationship between fork length and body weight of Japanese mackerel in the Northwest Pacific.

otolith wheel diameter, and the corresponding average back-calculated fork lengths for each age were 187.83 mm at age 1^+, 248.38 mm at age 2^+, 294.01 mm at age 3^+, and 318.46 mm at age 4^+, as shown in **Table 1**.

3.2.2. Growth Parameter Estimation

Based on the age and corresponding fork length data listed in **Table 1**, the growth parameters of Japanese mackerel were obtained as L_∞ = 447.61 mm, K = 0.264, and $t_0 = -1.06$, respectively, using the least squares method to estimate the von Bertalanffy growth equation.

3.3. Growth Rate and Growth Inflection Point

The weight growth equation is:

$$W_t = 1046.74 \times \left\{1 - e^{\left[-0.264 \times (t+1.06)\right]}\right\}^{3.289} \tag{5}$$

The weight growth rate of Japanese mackerel with age as well as weight change curve can be plotted from the weight growth equation (**Figure 4**). From **Figure 4(a)**, it can be seen that during the period from 0 to 8 years of age, the body weight growth rate was the smallest at age 0, at 37.33 g/yr, but the body-weight growth acceleration (slope of the curve d^2Wt/dt^2) was the largest at this time, and the Japanese mackerel grew the fastest. The body weight growth rate continued to increase from 0 to 3.1 years of age, which is the rapid growth period of Japanese mackerel, and the bodyweight growth acceleration was 0 at 3.1 years of age when the bodyweight growth rate reached the maximum value of 122 g/yr. Thereafter, the bodyweight growth rate gradually decreased from 3.1 to 8 years of age, indicating that the growth and development of Japanese mackerel entered a slow growth period.

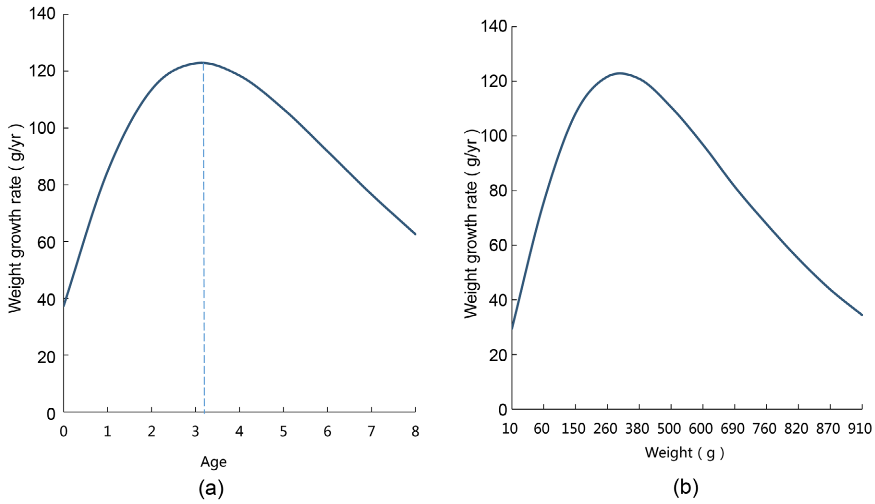

Figure 4. Bodyweight growth rate curve of Japanese mackerel ((a) is the bodyweight growth rate curve of Japanese mackerel with age; (b) is the bodyweight growth rate curve of Japanese mackerel with bodyweight).

Table 1. Back-calculated fork lengths corresponding to different ages of Japanese mackerel in the North Pacific high seas.

Age/Fork length	L_1 (mm)	L_2 (mm)	L_3 (mm)	L_4 (mm)
1	187.00			
2	185.89	247.85		
3	192.64	251.81	302.72	
4	185.77	245.48	285.29	318.46
Average	187.83	248.38	294.00	318.46

As can be seen from **Figure 4(b)**, the body weight growth rate also showed a trend of accelerating and then decelerating in the range of body weight change from 0 to 910 g. When the bodyweight growth acceleration was 122 g/yr, the corresponding body weight was 310 g. Then the bodyweight growth acceleration became negative and the bodyweight growth rate decreased gradually, and the Japanese mackerel body weight increased slowly. When the weight growth acceleration was 122 g/yr, the corresponding weight was 310 g. Then the weight growth acceleration became negative, the weight growth rate gradually decreased, and the weight gain of Japanese mackerel became slower. Therefore, the inflection point weight of Japanese mackerel in this study was 310 g, the inflection point age t_p = 3.1 years, and the inflection point fork length L_p = 309 mm.

4. Discussion

4.1. Relationship between Fork Length and Body Weight

The relationship between fork length and body weight of pelagic fishes has been shown to be a power function [21] [22] [23] [24] [25], and in this study, we also found a significant relationship between fork length and body weight of Japanese mackerel ($R^2 = 0.9764$, n = 2833). It is generally believed that the power index in the relationship between fork length and body weight can be used to determine whether the fish is growing at the same rate if the power index is $2.5 < 3 < 3.5$, it means that the fish is growing at the same rate, which means that the growth rate of the individual in the three directions of length, width and height is close to each other in the process of growing from small to large [21].

4.2. Reliability of Otolith Age Identification

Most pelagic fish age identification is based on otoliths, and the resin-embedded otolith molds are polished to a thickness of about 0.2 mm by a grinding and polishing machine, and the age is identified and the whorl diameter is measured under an optical microscope, based on this age identification method it is easier to determine the actual age composition of the fish [6] [25] [27], but there is sometimes some error in the accurate interpretation of the otoliths [28]. To enhance the accuracy of age determination, the otoliths used for age determination should be relatively transparent in cross-section and the whorls should be clearly visible, and as much as possible, the miscellaneous whorls should be brought together in one place during the polishing process to reduce the interference with age determination. When measuring the whorls on the otolith photographs, the alternating transparent and opaque bands in transmitted light were used as the location of the annual whorls, and the whorls of all the secondary whorls, annual whorls, and interfering whorls were recorded [29]. In this study, the average fork length values corresponding to the age back-calculation (with a margin of error of ±2 cm) were determined as the fork lengths corresponding to different ages of Japanese mackerel. All data were observed and recorded by two researchers with experience in age identification, and the age-fork length data recorded by the two researchers were compared, and the error range of ±1 cm for each age corresponding to the fork length was considered as the same data, and the data table of age-fork length relationship was finally obtained.

To verify the accuracy of otolith age identification, the growth curves of Japanese mackerel in this study were compared with those of Japanese mackerel from the Pacific group studied previously using F-test [29]. The results showed that there was no significant difference between the growth curves derived from the otolith age identification and the equations of the production curves of Japanese mackerel from different seas (**Table 2**, **Figure 5**). Therefore, it can be seen that the age identification of the present study has high reliability.

4.3. Growth Parameters

Comparing the results of the present study with the results of the growth equation parameters of Japanese mackerel in Japan's coast (**Table 3**) derived by Kawashima, Tokuei and others, we found that the limiting fork length L_∞ of Japanese mackerel in the North Pacific high seas was higher than the results of

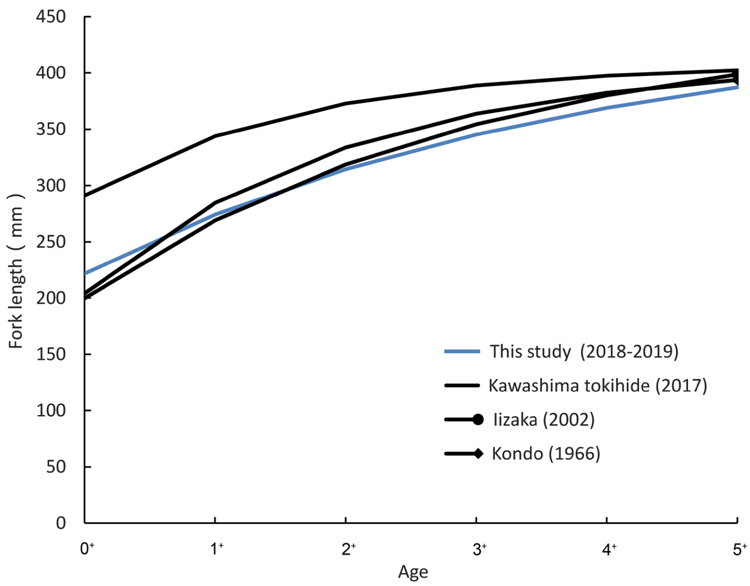

Figure 5. Comparison of the growth curves of the Japanese mackerel Pacific group.

Table 2. Significance analysis of the differences in growth curves among different samples of the Japanese mackerel Pacific group lineage.

	Tokifusa (2017) [29]		Iizuki (2002) [30]		Keiichi (1966) [31]	
F-test F-test	F-value	P-value	F-value	P-value	F-value	P-value
In this study	1.254	0.395	0.626	0.292	0.528	0.228

Table 3. Comparison of parameter estimates for the growth equation of Japanese mackerel von Bertalanffy.

Researchers	Analysis Method	Parameter		
		L_∞ (mm)	K	t_0
This study (2021)	Otoliths Otolith	447.6	0.2641	−1.59
Tokifusa (2017) [29]	Otoliths Otolith	408.1	0.6	−1.082
Iizuki (2002) [30]	Fish Scale Scale	411.6	0.49	−0.4
Keiichi (1966) [31]	Fish Scale Scale	446	0.33	−0.8

Tokifusa [29] and Iizuki [30], but similar to the results of Keiichi [31]. The K and t_0 values in this study were small among all studies, which proved that the growth and development of Japanese mackerel in the North Pacific open sea were slower than those on Japan's coast.

4.4. Growth Inflection Point of Japanese Mackerel

The growth rate of fish reflects how fast or slow the fish increases in length or weight throughout its life. After understanding the growth rate of fish in each life stage, the period of fast growth to slow growth can be appropriately selected and utilized to maximize the fishery resources [21]. Wang Kai *et al.* analyzed the fishery resources of Japanese mackerel in the East China Sea according to the B-H (Beverton-Holt) dynamic integrated model, and suggested that the age at harvesting was 1.22 years old and the fork length at harvesting was 247 mm [7]; Liu Yong *et al.* studied that the inflection point age of Japanese mackerel in the north of the east China sea and the south of the yellow sea is 2.7 years, the inflection point weight is 450 g, and the inflection point fork length is 320 mm [3]. In this study, the inflection point age of Japanese mackerel in the high seas of the Northwest It can be seen that there are some differences in the growth process of Japanese mackerel population in different sea areas and different ages, and the age of inflection point of Japanese mackerel tends to become larger with the increase of latitude. In fishery, the fishing standard can be formulated comprehensively with reference to a series of factors such as growth characteristics, natural mortality, fishing mortality, environmental factors, space-time conditions, utilization rate of dominant groups and economic benefits [3] [21]. Finally, combined with the data obtained in this paper, we recommend 2 years of age to be start fishing with a fork length of 250 mm (±10 mm). This suggestion will provide a biological reference for the follow-up resource assessment and fishery management of Japanese mackerel in the high seas of the Northwest Pacific.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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