

Communication

First Data on the Age and Growth of Schmidt's cod *Lepidion schmidti* (Moridae) from Waters of the Emperor Seamounts (Northwestern Pacific)

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Abstract: This study presents the first data of growth and age of Schmidt's cod *Lepidion schmidti*, a rare and poorly studied member of the Moridae family (Gadiformes, Teleostei). The research was focused on the Emperor Seamounts area with the aim of investigating the age, growth rates, and longevity of this species. The analysis involved examining annual growth increments on sagittal otoliths. Data were taken from longline catches in 2014 and 2016, resulting in the collection of 140 individuals and the use of 70 otoliths for age determination. The results revealed that Schmidt's cod can live for up to 49 years, with a mean age of 31.5 years in the catches. The relationship between body weight and total length was described by a power function, indicating positive allometric growth. The most suitable growth model for this species was determined to be the Von Bertalanffy growth equation. These results provide valuable insights to add to the limited knowledge of growth and age in the Moridae family and emphasize the long lifespan and slow growth of Schmidt's cod.

Keywords: longline catches; biological parameters; stocks; benthopelagic fish; bycatch; lifecycle; deep-sea fish; otoliths



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1. Introduction

Since the development of deep-sea fishing and increased research on deep-sea fish, it has been hypothesized that the most demersal fish species exhibit slow growth and long lifespans. However, specific age estimates have remained controversial for many years due to difficulties in interpreting age determinations [1–3]. Researchers have not reached a consensus on the regularity of ring formation on fish hard structures under conditions of large-scale temporal and spatial homogeneity of environmental factors at depths exceeding 500 m, which implies significant stability in deep-sea ecosystems [4]. By now, it has been demonstrated that calcified structures of deep-sea fish show annual growth increments. This has been evidenced by limited studies involving tagging and recapture of deep-sea fish, particularly sablefish *Anoplopoma fimbria* [5,6], as well as more extensive studies comparing the number of zones in otolith cross-sections with radiometric age estimates based on the Pb-210/Ra-226 isotopes ratio [1,3,7–9]. These comparisons have helped optimize the methodology for counting annual rings on otoliths, enabling the acquisition of reliable age data, even for long-lived fish species, using current otolith preparation and growth increment counting methods [6,10].

The family Moridae (order Gadiformes) includes 18–19 genera and over 100 species, six of which have been described in the past decade [11–13]. *Lepidion* is one of the oldest genera in the family with fossil representatives recorded from the Middle Miocene (11.6–16.0 Ma) [12,14–16], and is represented by nine valid species that live in deep waters over the continental slopes and seamounts around the world [12,14–16]. Schmidt’s cod, *L. schmidti* (Figure 1A), is a rare and poorly studied member of the genus [12,13], found in the North Atlantic, southwestern Indian Ocean, and northern and southwestern Pacific [16–19]. On the Emperor Seamounts, it is found alongside its congener, *L. inosimae* [14,15]. Schmidt’s cod lives at depths of 375–2404 m, with an optimal habitat range of 900–1200 m [20]; it does not form dense concentrations and has no commercial value [11,21].

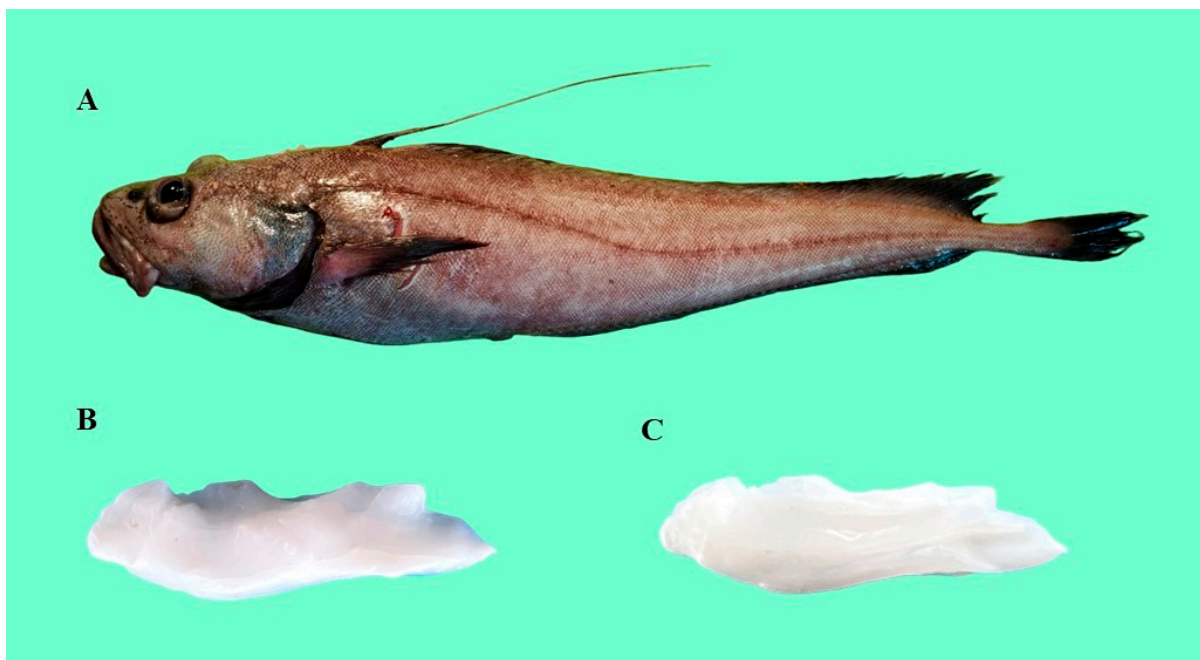


Figure 1. (A) Habitus of Schmidt’s cod *Lepidion schmidti* from the Emperor Seamounts (TL = 51.7 cm), (B,C) External appearance of its otoliths (photos by the authors).

Lepidion schmidti has been poorly studied, and there are currently no publications documenting age and growth of this species. Although there are over 100 species in this family, data on age and growth have only been published for a few, including the common mora *Mora moro* [22,23], longfin codling *Laemonema longipes* [24], red cod *Pseudophycis bacchus* [25–27], blue antimora *Antimora rostrata* [28–35], and Pacific flatnose *A. microlepis* [36–38]. Among the nine valid species in the genus *Lepidion*, information on growth and age is available for the North Atlantic codling *L. eques* only [33].

The objective of this study is to provide the first data on the growth and age of *L. schmidti* from the Emperor Seamounts area based on the analysis of growth increments on sagittal otoliths.

2. Materials and Methods

This study is based on the materials from the catches of *Lepidion schmidti* during the longline commercial fishery off the Emperor Seamounts (Figure 2) on board the commercial longliner “Palmer” (owned by LLC “Yuzhny Krest”, Petropavlovsk-Kamchatsky, Russia) in May–July of 2014 and 2016 at depths ranging from 401 to 1062 m. The fishing was conducted at seamounts: Koko, Lira, Ojin, Nintoku, Jingu, Kammu, T363 + A. *L. schmidti* was only caught sporadically in 2014 off Jingu and Ojin seamounts, while in 2016 it was caught only off Koko Seamount (24.7 individuals per 1000 hooks) and Lira Seamount (6.8 individuals per 1000 hooks). The fishing was done using Mustad (Gjøvik, Norway)

bottom longlines (No. 14 hooks), with Pacific squid (*Todarodes pacificus*) and Pacific herring (*Clupea pallasii*) used as bait at 1:1 ratio. A total of 140 individuals were collected and subjected to biological analysis on board the vessel using standard methods [39]. Due to technical reasons, otoliths (sagittae) (Figure 1B,C) for age determination were collected from 70 individuals. Only one pair exhibited a weakly calcified otolith with a modified shape, while the remaining otoliths had a shape as described in the literature [40].

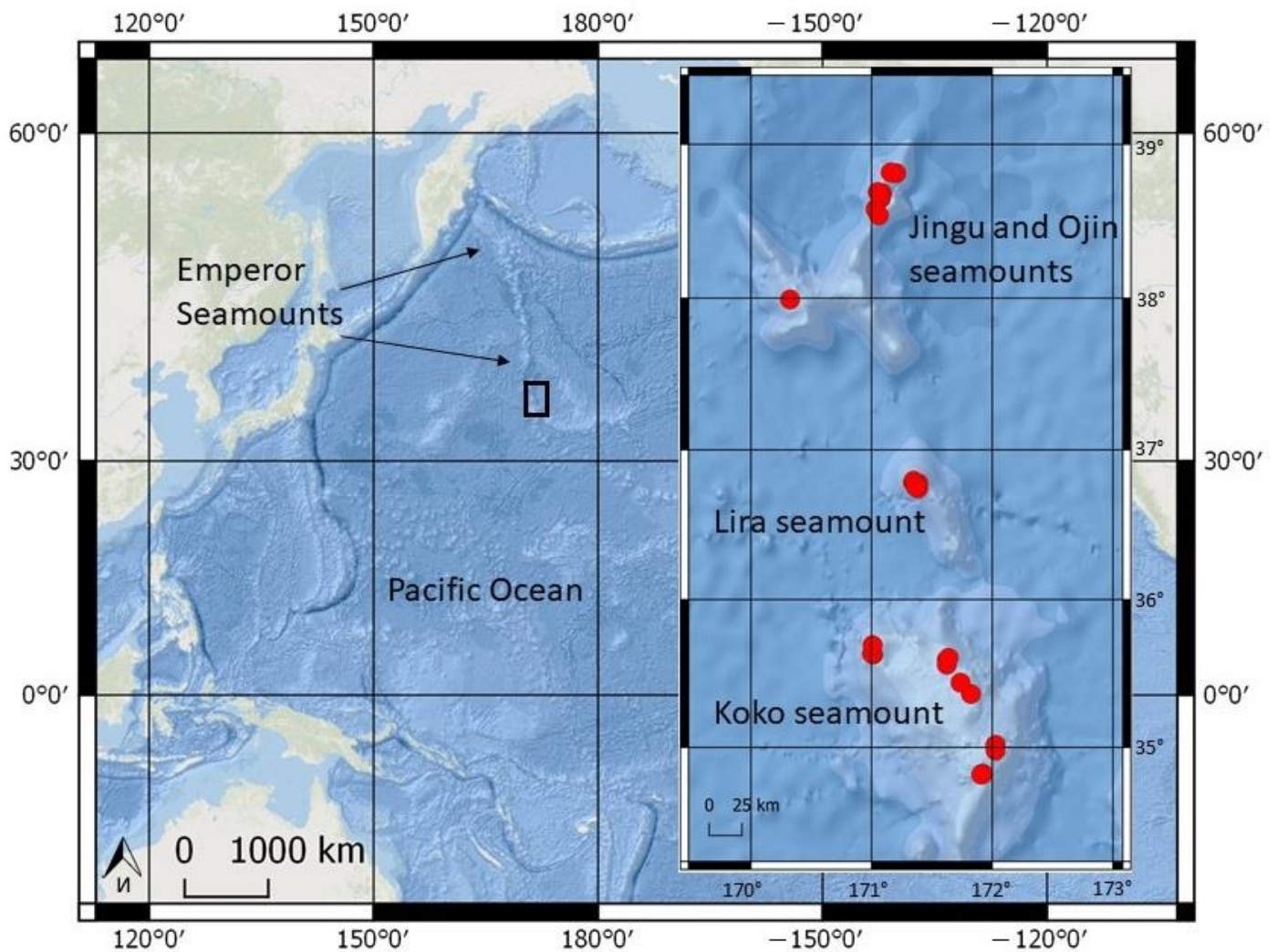


Figure 2. The sites (red circles) where otoliths of *Lepidion schmidti* in the waters of the Emperor Seamounts were collected.

Two species of the genus *Lepidion* inhabit the Emperor Seamount Chain area, namely, *L. enosimae* and *L. schmidti* [16,41]. During the fieldwork period, significant attention was paid to accurate species identification of the fish captured. Information from various sources [15,17,19,21,41] was used for species identification, taking into account distinct external morphological features of both species.

The age of *L. schmidti* was determined using a method specifically developed for some long-lived deep-water fish species [6,10]. This method has been successfully used to determine the age of other members of the Moridae family, such as *Antimora* spp. [30–32,34,35,37,38,42]. The otoliths were sectioned to the center, then heated in the flame of an alcohol burner, and polished on abrasive disks with aluminum-oxide or silicon-carbide coating with a grain size of 0.1–0.9 μm (Buehler, Lake Bluff, IL, USA). Age was determined by counting annual rings on photographs of polished otolith cross-sections (Figure 3) using Adobe Photoshop CS6 ver. 13.0 \times 64 software (Adobe System, San Jose, CA, USA). The sections

were photographed in glycerin under a Motic SMZ-143 microscope camera (Motic, Hong Kong, China) at magnifications of $\times 2$ –8, depending on the size of the otolith.

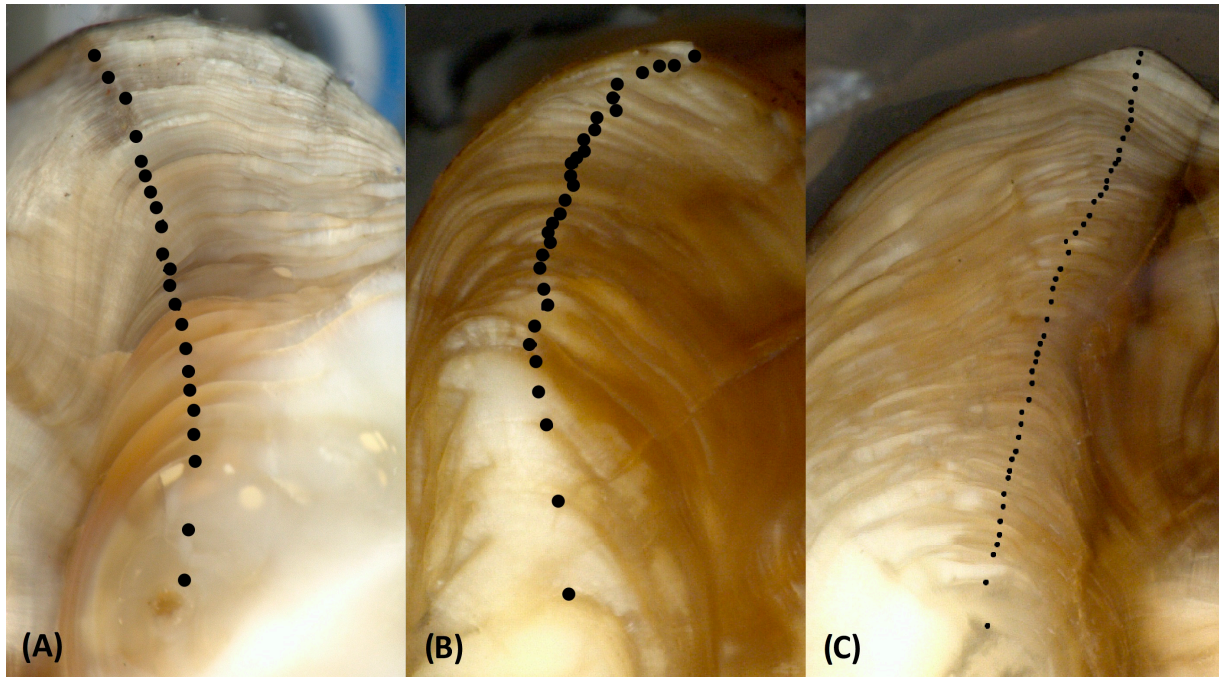


Figure 3. Cross-sections of otoliths of Schmidt's cod *Lepidion schmidti* from waters of Emperor Seamounts: (A)—TL 48.5 cm, 22 years; (B)—TL 61.5 cm, 31 years; (C)—TL 112 cm, 49 years (dots indicate annual growth zones, TL is total length).

The differences in TL, body weight, and age values of males and females were tested using the Shapiro–Wilk test with a significance level of $p \leq 0.05$. The test results showed that TL and body weight do not follow a normal distribution, while the age was normally distributed. Thus, the Mann–Whitney U-test was used to compare TL and body weight, and the Student's *t*-test was used to compare age of males and females.

Based on the obtained age and length data, a size–age key was constructed [43], which was used to estimate the age composition of the entire catch. To describe the growth of the studied species, the most suitable function was chosen using the Akaike information criterion (AIC) [44], comparing linear, power, and logistic functions, Gompertz curve, and Von Bertalanffy growth equation (VBGE). The mean specific rate of linear growth was estimated using the formula [45,46]:

$$C = \frac{\ln(L_{n+1}) - \ln(L_n)}{t_{n+1} - t_n},$$

where L_{n+1} and L_n are the mean lengths of fish at the ages of t_{n+1} and t_n respectively.

Statistical analysis of the results was performed using MS Excel (Microsoft, Redmond, DC, USA) and PAST version 3.14 software [47].

3. Results and Discussion

Due to the selectivity of the longline fishing gear, the catch was dominated by large fish with a TL ranging from 40 to 112 cm, and an average of 60.7 ± 0.9 cm. The most abundant individuals in the catch had a body length of 56 to 65 cm, while smaller fish (<46 cm) and longer fish (>70 cm) were rare (Figure 4). Males and females had different body length ranges and mean lengths, with males ranging from 43.5 to 85.0 cm (mean 59.0 ± 1.2 cm) and females ranging from 42.0 to 112.0 cm (mean 61.3 ± 1.3 cm). However, no statistical differences were found between TL of males and females in the catches ($U = 2009$; $Z = 0.7875$; $p = 0.431$)

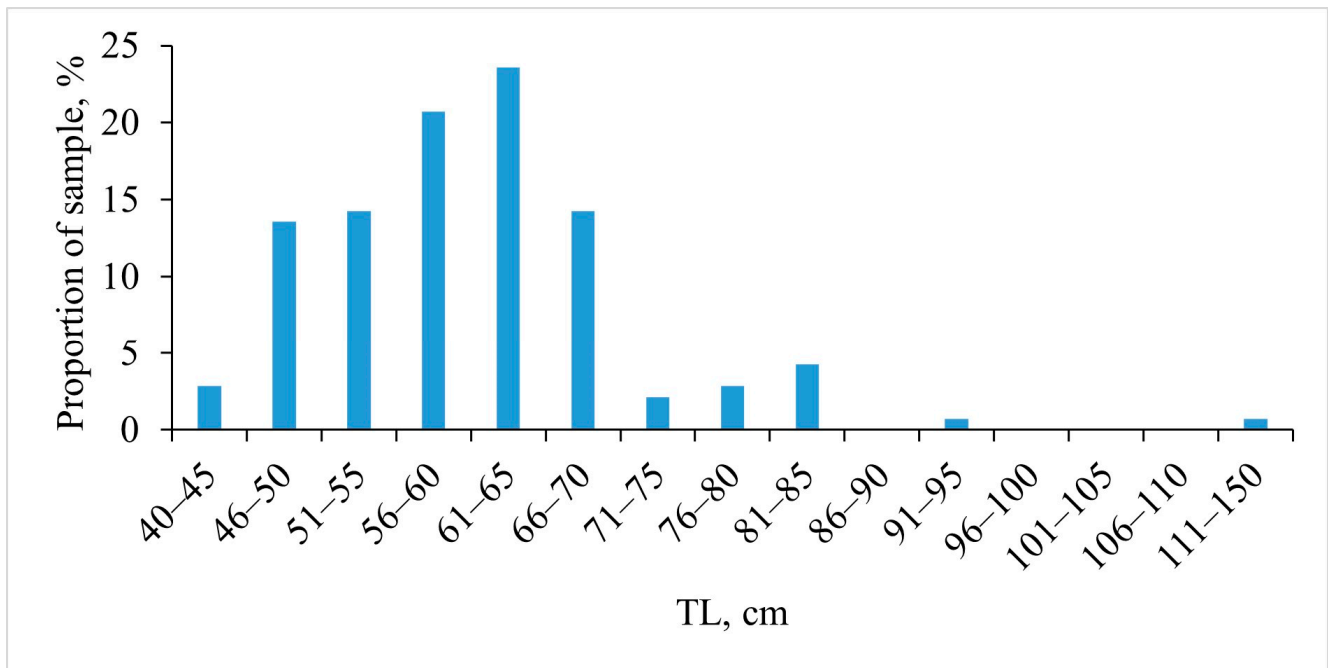


Figure 4. Size composition of Schmidt’s cod *Lepidion schmidti* in longline catches from off the Emperor Seamounts.

The body weight of *L. schmidti* in the catches ranged from 0.5 to 14.7 kg, with mean 1.8 ± 0.1 kg. Most individuals in the catch (76.5%) had a body weight ranging 0.5 to 2.0 kg, while fish weighing 2.0 to 2.5 kg composed 12.1% of the catches, and the other size groups were represented by single individuals only (Figure 5). Meanwhile, the maximum and mean body weight in the catches were larger in females compared to males, ranging from 0.5 to 14.7 kg (mean 1.9 ± 0.2 kg) and 0.5 to 4.4 kg (mean 1.5 ± 0.1 kg), respectively, but no statistical differences were found between body weight of males and females in the catches ($U = 1915.5$; $Z = 1.2091$; $p = 0.227$).

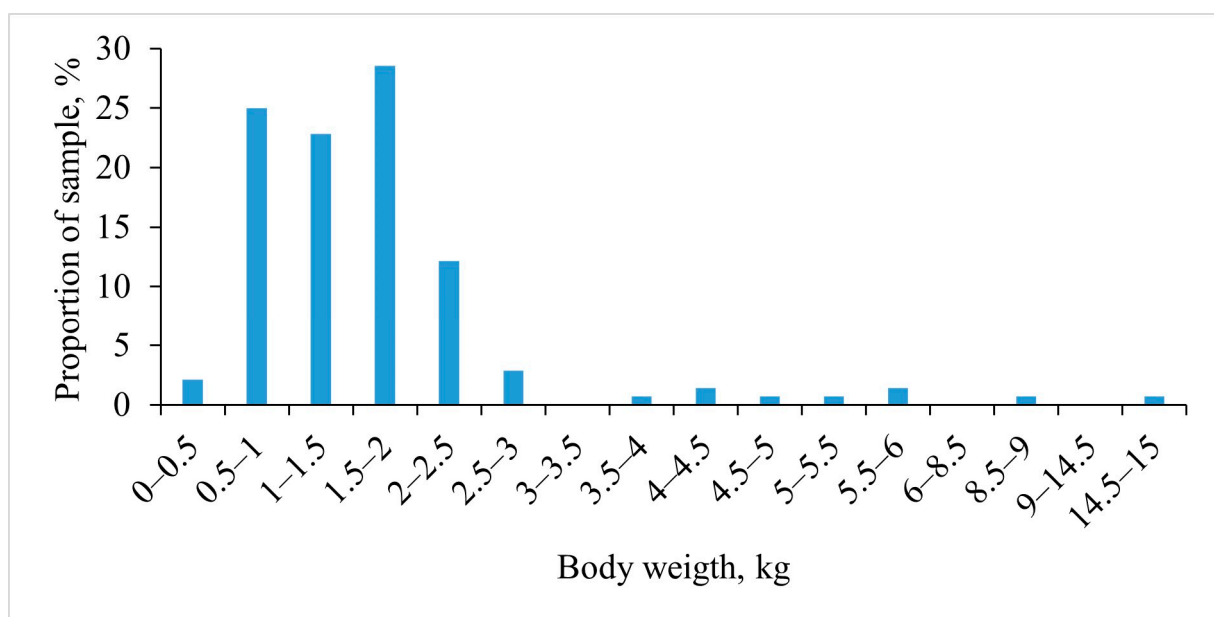


Figure 5. Distribution of Schmidt’s cod *Lepidion schmidti* in longline catches from off the Emperor Seamounts by body weight.

The proportion of males in the catches was 41.8% of the total number of fish, while females accounted for 58.2%, and immature individuals were not recorded.

The relationship (LWR) between body weight (W , g) and total length (TL, mm) of *L. schmidti* is well described by a power function: $W = 1.8 \times 10^{-6} TL^{3.323}$ ($R^2 = 0.93$) for the total sample; $W = 2.2 \times 10^{-6} TL^{3.333}$ ($R^2 = 0.96$) for males; and $W = 1.3 \times 10^{-6} TL^{3.390}$ ($R^2 = 0.94$) for females (Figure 6). In all cases, the value of the power coefficient b in the LWR equation exceeds 3, which may indicate positive allometric growth of the species in the studied area [48]. No differences were found between LWR parameters of males and females in the catches due to the absence of statistical differences in the TL and the body weight between both sexes. In the literature, this relationship for the species considered is given only for trawl catches from New Zealand waters and is described by the equation $W = 4.6 \times 10^{-3} TL^{3.218}$ [49]. The power coefficient b is close to that for our sample, while the values of linear coefficient a differ significantly, which is most likely due to the different size range of fish in the samples.

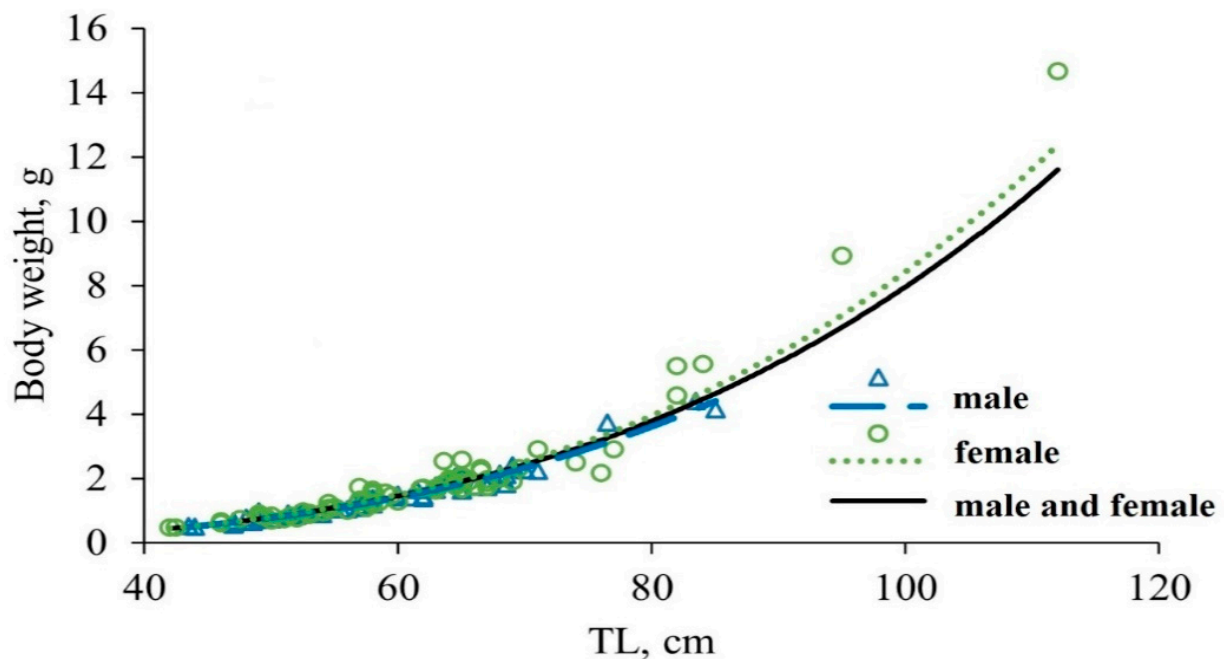


Figure 6. Relationship between body weight (W) and total length (TL) of Schmidt's cod *Lepidion schmidti* from longline catches in waters of the Emperor Seamounts.

The age of *L. schmidti* in our samples varied from 22 to 49 years, with a mean age of 31.5 ± 0.7 years. The minimum, maximum, and mean age values of males and females were quite similar. Thus, the age of males ranged from 22 to 41 years with a mean value of 31.9 ± 0.9 years, while for females these values were 22–49 years and 31.3 ± 1.0 years, respectively. There were no statistical differences in the age of males and females in the study sample ($t = 0.39036$, $p = 0.697$). Therefore, the longevity of *L. schmidti* is much longer than what is known from the literature for its congener, *L. eques*, which has a maximum age of 13 years corresponding to the total length of 33.2 cm [33]. For other representatives of the genus, the data on lifespan and growth are lacking in the literature. However, among representatives of the Moridae family, long-lived species are known, such as *Antimora* spp. and common mora *Mora moro* [22,29,32,50].

The comparison of AIC values indicates that both VBGE and the linear function provide the best fit for describing fish growth in the sample, although VBGE values are slightly higher (Table 1). The high AIC values obtained for the linear function and the significantly overestimated L_{∞} values (Table 2), which represent the asymptotic length of the fish, are likely attributed to the absence of small fish in the samples and a poorly pronounced deceleration of growth in large mature individuals (Figure 7). Similar overestimations

of L_{∞} values have been observed in studies of the age of other morids [28,30,31]. The specific growth rates of the studied species between 30 and 45 years of age remain relatively constant (Figure 8). The observed increase in growth rate after 45 years is probably an artifact resulting from the small number of largest fish in the samples and warrants further investigation. It should be noted that previous studies describing growth of morids have used the VBGE without comparing it to results obtained using other functions [23,24,27].

Table 1. Akaike Information Criterion (AIC) values for different growth functions of Schmidt’s cod *Lepidion schmidti* from the Emperor Seamounts waters (maximum AIC values are given in bold).

Function	AIC
Linear: $TL = at + b$	3112.2
Power: $TL = at^b + c$	2742.1
VBGE: $TL = L_{\infty}(1 - e^{-k(t-t_0)})$	3123.3
Logistic: $TL = \frac{a}{1+be^{ct}}$	2856.2
Gompertz: $TL = ae^{be^{ct}}$	2907.6

Table 2. Parameters of the VBGE and linear function for males and females of Schmidt’s cod *Lepidion schmidti* from waters of the Emperor Seamounts.

Sex	VBGE				Linear		
	L_{∞}	k	t_0	R^2	a	b	R^2
All specimens examined	2225.3	0.0007	−6.2	0.7	1.4	15.5	0.7
Males	984.5	0.0017	−5.0	0.7	1.6	9.7	0.7
Females	2758.6	0.0006	−6.4	0.7	1.6	11.1	0.7

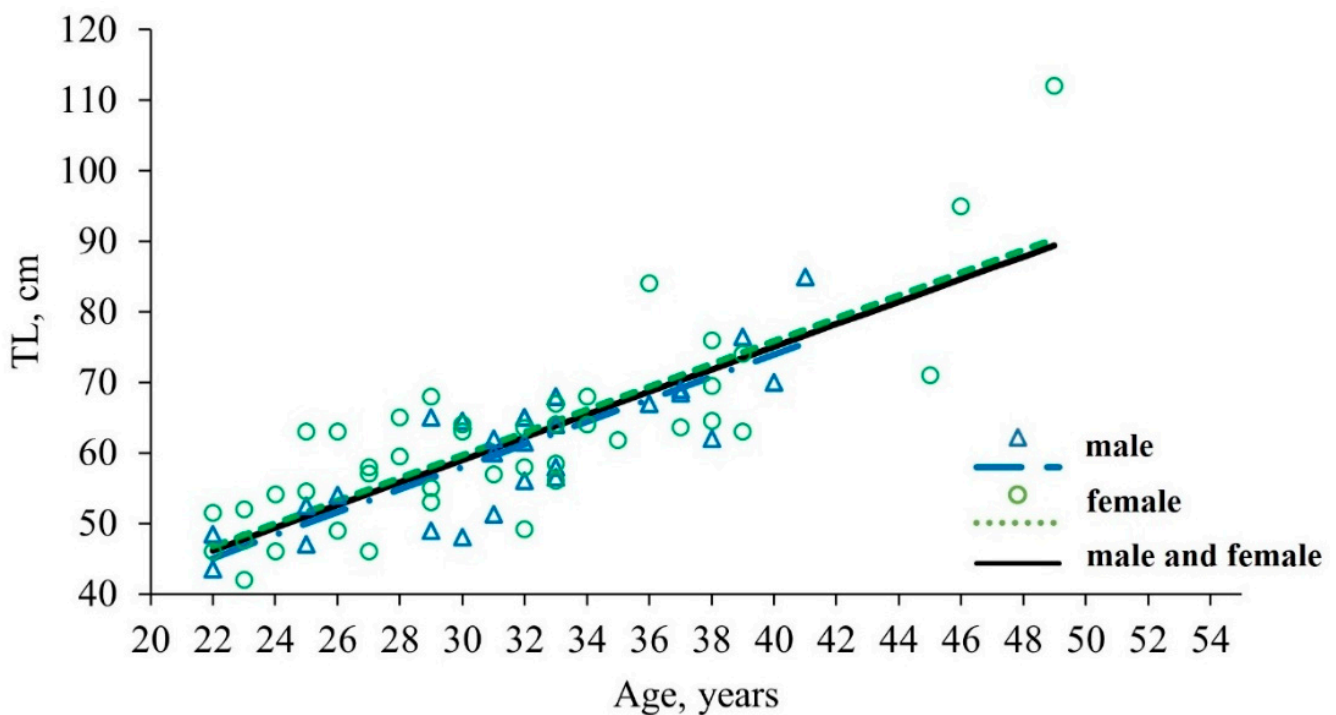


Figure 7. Growth curves of Schmidt’s cod *Lepidion schmidti* from waters of the Emperor Seamounts calculated based on the VBGE.

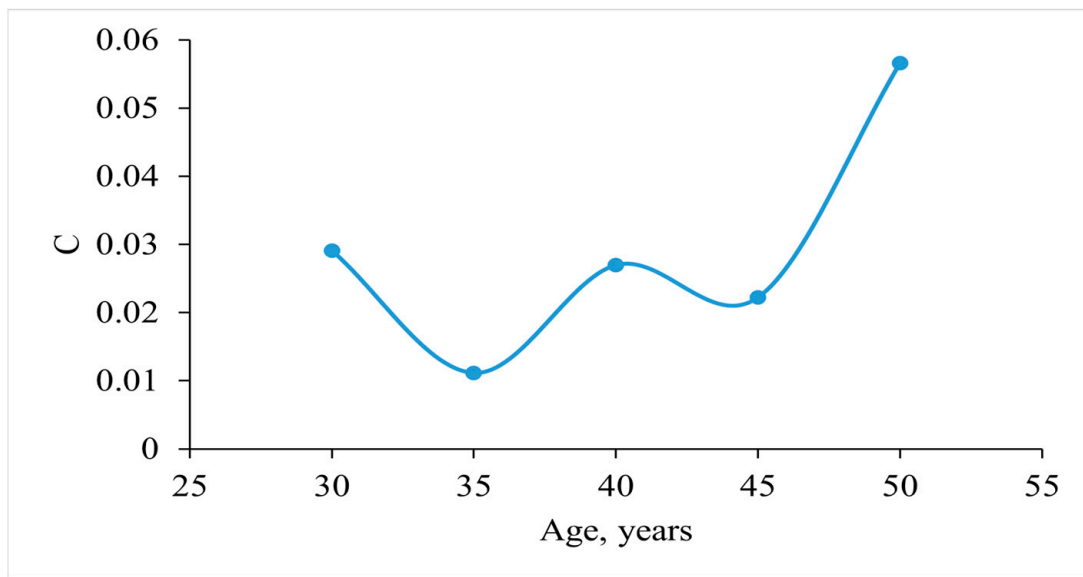


Figure 8. Specific growth rate of Schmidt’s cod *Lepidion schmidti* from waters of the Emperor Seamounts.

The growth curves of males and females in the examined samples are nearly identical (Figure 7), and the difference in L_{∞} values in the VBGE (Table 2) can be attributed to the larger maximum size and age of the females. However, due to the limited number of largest fish, it is challenging to assess the disparities in maximum size and age between individuals of different sexes.

The analysis of the age structure of catches (Figure 9), determined via the size–age key using selected age estimations, showed that the most abundant age groups were individuals aged 32 and 34, each comprising 10% of the total catch. No fish younger than 22 years were found in the catches, while individuals aged 22 accounted for slightly less than 6% of the catch. Fish older than 39 years were only sporadically encountered in the catches.

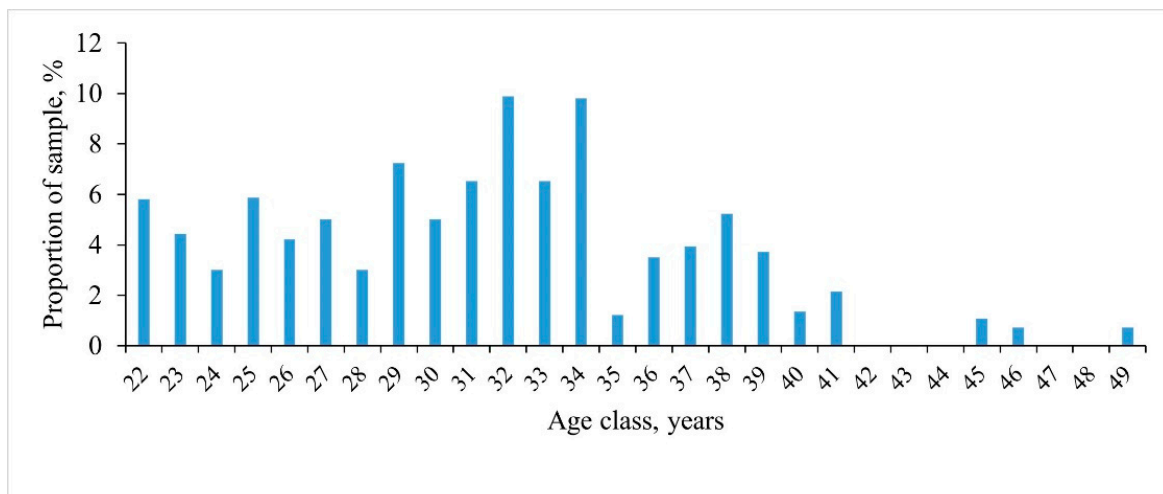


Figure 9. Age composition of Schmidt’s cod *Lepidion schmidti* in the longline catches from the Emperor Seamounts waters.

4. Conclusions

Schmidt’s cod *Lepidion schmidti* is a long-lived and slow-growing deep-water benthopelagic fish. To provide a more detailed description of its growth characteristics, an analysis of otoliths from individuals younger than 22 years and older than 40 years is necessary. The

capture of large *L. schmidti* individuals from an already rare species through longline fishing can have a negative impact on the condition of the population, as long-lived deep-water fish species are highly vulnerable to fishing pressure due to their biological characteristics such as long lifespan, slow growth rates, and low reproductive capacity [1,51–54].

According to the literature, the lifespan of morids can vary greatly. For example, *Pseudophycis bachus* has a maximum known age of 5 years [25–27] and can be considered a species with a short lifespan. *Lepidion eques*, *Laemonema longipes*, and *Physiculus cyanostrophus* have showed maximum lifespans of 13, 17, and 18 years, respectively [23,24,55], and can be classified as species with a moderate lifespan. *Antimora* spp. and common mora *Mora moro* are considered long-lived species [22,29,32]. Our data on the growth of *L. schmidti* also indicate that this species belongs to the group of long-lived morids.

There are indications in the literature that within a same taxonomic group, the metabolic rate might decrease, resulting in slowed growth and increased lifespan for deep-water species. Some authors explain this phenomenon as a result of the extreme conditions of the deep-sea affecting their metabolism [56–58]. However, it has been shown for many species that low temperatures, oxygen deficiency, and other environmental factors in mesopelagic fish are compensated by the organisms and do not affect the metabolic rate and growth rate [59–64]. The slow metabolism, slow growth rates, and longer lifespan are adaptations to the deep-sea environment, which can be partially explained by the „visual interactions hypothesis,” which states that the metabolic rate decreases with decreasing animal locomotor activity [65–70]. Undoubtedly, further research is needed to confirm this theory with an example of morids. However, the fact that *P. bachus* occurs at depths ranging from 5 to 700 m and has a significantly shorter life cycle than the deeper *Antimora* spp., *M. moro*, and *L. schmidti* may indicate the influence of the deep-sea environment on slowed growth rates and increased lifespan in morid fish.

It is also important to highlight the significance of validating age determinations in deep-water fish. Among all morids, age determination using otoliths has been confirmed by radiometric methods for *M. moro* only [71], and the correlation between the number of rings on vertebrae and otoliths has been shown for Pacific flatnose *Antimora microlepis* [42]. Therefore, to obtain a comprehensive understanding of *L. schmidti* growth, it is necessary to analyze otoliths from age groups not covered in this study (younger than 22 years and older than 40 years) and validate age determinations via radiometric methods. This, along with studying the growth and age of other morid species, can become a promising topic for future research.

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