A Preliminary Study of the Age and Growth Patterns of a Sea Toad, *Chaunax abei* Le Danois, 1978, in Suruga Bay, Japan

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Abstract

Chaunax abei Le Danois, 1978, is a bottom-dwelling species caught by bottom trawls in Suruga Bay. In the present study, we assessed the age and growth pattern of *C. abei* from Suruga Bay during the period of 2021–2022 for the first time. The total length (*TL*) of the population ranged from 37.4–268.8 mm (mean ± SD: 124.7 ± 3.64 mm), and the fish weight (*W*) between 1.11–491.75 g (mean ± SD: 58.40 ± 7.25 g). The length-weight relationship was estimated as $W = (2.07 \times 10^{-5})TL^{2.996}$ ($r^2 = 0.937$). Age determination was based on annual growth ring counts of transverse sections of the sagittal otoliths and age ranged from 1 to 12 years, with the majority of fish aged 4 (32.79 %) years old. The von Bertalanffy growth function was used to model the growth, and the parameters were found as: TL_∞ = 468.1 mm, K = 0.056 year^{-1}, t_0 = -0.402 year. This research provides the first results on the growth of *C. abei* and enriches the regional fisheries biology database. Furthermore, it presents the primary population data on the growth patterns of one of the chaunacid species.

Keywords: Chaunacidae, sea toad, bottom-dwelling species, growth curve, otoliths

Introduction

The family Chaunacidae (coffinfishes or sea toads) has two genera, *Chaunacops* and *Chaunax* and is represented by 29 species worldwide (Caruso, 1989; Ho et al., 2013; Ho and McGrouther, 2015; Ho and Ma, 2016; Quattrini et al., 2017; Fricke et al., 2018, 2019). Members of the family are considered benthic species, living at reported depths from 90 to over 2200 m with nearly global distribution, albeit absent from both polar regions (Lundsten et al., 2012). The chaunacid anglerfish genus of *Chaunax* is a group of medium-sized demersal fishes which inhabit sandy to rocky bottoms in the warm waters of all major oceans and the Mediterranean Sea (Ho and Ma, 2016). Generally, they are moderately sized (up to 400 mm in *TL*) with various colour patterns, with or without spots on the dorsal body (Rajeeshkumar et al., 2020). Chaunacid species have an important role in marine food webs and the ecology of benthic ecosystems, as predators, feeding on other fish (Masuda and Allen, 1993).

In the genus *Chaunax*, only three species inhabit Suruga Bay, which is located on the Pacific side of central Japan: *Chaunax penicillatus* McCulloch, 1915, *Chaunax abei* Le Danois, 1978 and *Chaunax fimbriatus* Hilgendorf, 1879. Especially, *C. abei* has round green spots in opposition to round and irregular yellow on the body surface in *C. fimbriatus* (Lee and Kim, 1999). Thus, it is distinguished with obvious phenotypic colouration from other sea toads in Suruga Bay. Even though *C. abei* has been reported from different marine areas, no study has been conducted yet to examine its age and growth characteristics. This is understandable because of the rarity of individuals and the difficulty in obtaining a sufficient number of fish, and *C. abei's* restricted distribution range which only occurs in the southern part of the Japan into the South China Sea (Nakabo, 1993). In addition, the consumption of Chaunacid species is quite rare, because they are not a high proportion of trawl catches, poor supply, and the lack of demand. *Chaunax abei* is deemed to be a by-catch species by fishers. Also, it is considered a non-economically important asset and often discarded species in Suruga Bay, despite its biogeographic importance to Asia. Yet, the current knowledge of this species is incomplete and lacking, especially on the population biology of this fish species.

In anglerfish (Lophiidae: Lophiiformes) species, calcified structures such as otoliths and the illicium (modified first dorsal fin ray) are frequently utilised to determine age. Particularly for the species of Lophiidae, a significant number of researchers have established a standardised aging approach using the illicium, drawing insights from the outcomes of workshops and published research findings (Landa et al., 2002; Garcia-Rodriguez et al., 2005; Takeya et al., 2017; Şenbahar and Özaydın, 2020; Erasmus, 2021). In particular, some fishery-targeted species are avoided to remove their heads in order to maintain commercial value, even if their otoliths are desired for use (Takeya et al., 2017). In Chaunacid species, a single ray in the anterior dorsal fin forms the illicium which fitted into a scaleless U-shaped depression (or rostral chamber) (Smith and Heemstra, 1986; Caruso and Pietsch, 1987; Ragonese and Giusto, 1997). However, the illicium of these species adequately short in terms of length unlike the Lophiids and a methodology to examine this structure is not well established yet. Furthermore, no verification data has been published to show how annual increments have been on in illicium of Chaunacids. On the contrary, the otolith is one of the only two calcified structures known to grow continually throughout the lifetime of fish, even when somatic growth ceases (Maillet and Checkley, 1990), and there is no resorption even during periods of starvation (Campana and Neilson, 1985). Once deposited some elements are not reworked because the otoliths are metabolically inert. Thus, it may be possible to access the life history information retained in the otolith across the entire lifetime of the fish (Fowler et al., 2004). The estimation of the age and growth of a sea toad has been attempted for the first time in this study. Therefore, we decided to conduct this research with otolith which is a well-known and studied calcified structure in terms of determining the age and growth of fishes.

Materials and Methods

Ethical approval

No live animals were used in this study. Fish sampling was carried out in accordance with the guide for the care and use of laboratory animals from Tokyo University of Marine Science and Technology. Throughout the start to end of this research (including laboratory works), there was no ethical contravention.

Sampling and measurement

A total of 133 *C. abei* individuals were obtained from the seasonal bottom trawls between April 2021 and December 2022 from Suruga Bay (Fig. 1). All samples were collected by fishermen on the ship deck, and we received them on the Heda port (Heda, Numazu City, Shizuoka Prefecture, 34°58'18"N-138°46'37"E). We had planned to collect as many *C. abei* as possible from local fishers in the region, spanning all seasons and as many months as possible. However, this species was not consistently encountered during fishing operations and fishing restrictions. Thus, samples were restricted to three seasons (Autumn, Winter, and Spring) per year due to commercial fishing regulations imposed by Numazu in the Shizuoka Prefecture. Consequently, trawl fishing was prohibited in Suruga Bay from May to September (NCOTS, 2022). These factors led to a study with a limited sample size. Therefore, *MGI* (Marginal Growth Increment) values could be reported only for the months/season of April 2021 (Spring), October 2021 (Autumn), April 2022 (Spring), and December 2022 (Winter). The samplings were collected from trawls, constructed of 27.5 mm mesh size throughout, conducted in depths of 254–324 m. In the laboratory, total length (*TL*, mm) and total weight (*W*, g) of all individuals were taken. The lengths of the samples were measured with a 1 mm precision with a digital calliper (Mitutoyo-CD-S20C, Japan) and weighed with an electronic scale (As One-AXA30002, Japan) with 0.01 g sensitivity.

Fig. 1. Sampling area of *Chaunax abei* in Suruga Bay, south-eastern Japan.

Length-weight relationship (LWR)

The functional relationship between the total length and weight of the samples were determined through the log linear regression equation:

$$W = aTL^b$$

where *a* and *b* are regression parameters. The 95 % confidence interval (CI) was estimated for parameters *a* and *b* (Froese, 2006). The overall analyses were performed in Microsoft Office Excel and R software v.4.3.1 (R Core Team, 2023). The student *t*-test was applied to determine the growth type of the samples, the equation:

$$t = \frac{b-3}{SE_{(b)}}$$

where *t*: *t*-test value, *b*: slope and $SE_{(b)}$: the standard error of the slope (Sokal and Rohlf, 1987). The hypothesis of isometric growth was tested by Student's t-test (Ricker,

1975) was carried out to determine if the (*b*) coefficient was different from "3" (if $b = 3$, isometric growth and $b \neq 3$ allometric growth). It was not possible to determine the sex of individual fish due to poor preservation of samples and therefore, only one relationship was determined for both sexes combined.

Otolith preparation and age reading

The pair of sagittae otoliths were extracted from the otic capsules of the specimens and cleaned with ethanol and distilled water. After that, they were stored dry separately within microtubes. The left otolith of each pair was used in sectioning for age estimation (n = 122) following the transversal cross-section methodology of Strüssmann et al. (2020). This method uses a new embedding material of ultraviolet (UV) cured resin instead of traditional epoxy resin and hardeners. Three major steps were carried out in preparing and sectioning each side of the otolith (anterior and posterior): embedding, grinding and polishing. Before starting the embedding process, the otolith was mounted on a reference-lined guiding block that is made of the same resin with a small droplet of UV-cured resin (Tama-Koubou and UV-Craft, Japan). In the embedding phase, the semi-transparent embedding silicon mold was used, and the molds were filled with UV-cured resin. A commercial UV nail-gel-curing lamp (UV lamp 365 nm, 9W × four lamps) was used to harden the resin inside the molds for ~15 min. The grinding and polishing proceedings were applied to the mounted otolith block, starting from the outer side and proceeding to the core of the otolith. These processes were carried out with a semiautomatic lapping wheel (Doctor-lap ML-182, Maruto Instrument, Japan) with sandpaper starting of 120-grit, 400-grit, 800-grit, 1200-grit, 2400-grit, and 4000-grit, respectively. Finally, the finished surface of rounded resin block was polished via a diamond polisher (Struers LaboPol-4, Denmark) with 1-µm diamond paste (Struers DP-Paste P, Denmark) with a slow dripping cooling-lubricating agent (Struers DP-Lubricant Blue, Denmark) for 20 min. This completed the preparation for one side of the otolith. Afterwards, the otolith was re-embedded from the polished side and the same procedures were applied to the reverse side of the otolith. The thickness of each otolith section was 50–100 µm.

The sectioned otoliths were initially observed under a wide zoom stereo microscope (Olympus-SZX10, Japan) and then under a binocular microscope (Olympus-BH2, Japan) equipped with a colour camera (Artray, Japan) and linked to an otolith micro-increment analysis system (Ratoc System Engineering Co. Ltd., Japan). Age readings were accomplished by counting opaque zones (OZ) on sectioned otoliths on images. Age readings were accomplished by counting opaque zones (OZ) on sectioned otoliths and performed two times by one operator at a different time on images. In rare cases of discrepancy between the reading results, additional counts were carried out and the revised final result was accepted. Overall, 8.27 % (n = 11) of otoliths were discarded with this context. In rare cases of discrepancy between the reading results, additional counts were carried out and the revised final result was accepted. Overall, 8.27 % (n = 11) of otoliths were discarded with this context, leaving 122 otoliths for the estimation of growth.

On the otolith marginal analyses, otoliths were examined by photographing method to detect the marginal growth increment (*MGI*). To confirm the annual ring formation, we calculated the seasonally changes in the *MGI* of samples during Spring 2021–December 2022 using the following equation:

$$MGI = \frac{R - r_{max}}{r_{max} - r_{max-1}}$$

where *R* is the median otolith radius, r_{max} is the distance from the core to the inner edge of the maximum OZ (the outermost opaque zone), and $r_{\text{max-1}}$ is the distance from the core to the inner edge of the immediately preceding OZ (Yokota et al., 2014). The distance measurements (µm) on otoliths were performed with Fiji software (Schindelin et al., 2012) on the images (Fig. 2).

Estimation of age and growth

The von Bertalanffy growth function (vBGF) equation (von Bertalanffy, 1938) was used to estimate the length-at-age based on the otolith-based age estimation of *C. abei* using the equation:

$$TL_t = TL_\infty\left(1 - \exp\left(-K(t - t_0)\right)\right)$$

where TL_t is the mean total length of fish at age "t" (mm, *TL*), TL_∞ is the theoretical asymptotic total length (mm), *K* is the instantaneous growth coefficient (year^{-1}), *t* is age of fish (year), and t_0 is the theoretical age of fish before hatching (year). These parameters were estimated by using the "fishmethods" package by Nelson (2023) in R software v.4.3.1 (R Core Team, 2023).

Results

Over the study period, a total of 133 fish samples were collected, each displaying varying *TL* and *W* across different years and seasons (Table 1; Fig. 3). In the Spring of 2021 (n = 12), the *TL* displayed a range in size from 40.59 to 262.64 mm, with a mean *TL* (± SE) of 131.10 mm ± 17.90 and the *W* values ranged from 2.04 to 491.75 g (mean = 81.67 ± 39.34 g) (Table 1). In Autumn 2021, the *TL* ranged from 73.45 to 208.63 mm (mean = 129.29 ± 15.82 mm) and the *W* ranged from 5.99 to 269.42 g (mean = 66.87 ± 32.55 g). In the Spring of 2022, only two fish were caught and they ranged from 113.72 to 116.52 mm (mean = 115.12 ± 1.40 mm). *W* values ranged from 28.35 to 31.71 g (mean = 30.03 ± 1.68 g). The greatest number of fish came from the Winter of 2022 (n = 111), when the *TL* ranged from 37.44 to 268.75 mm (mean = 123.81 ± 3.80 mm) and *W* varied from 1.11 to 461.12 g (mean = 55.79 ± 7.31 g) (Table 1).

The length-weight relationship estimated for both sexes was highly significant with length accounting for 93.7 % of the variation in weight (Table 2). The slope of the line was 2.99 and determined to be isometric: $b = 2.996$, which did not differ significantly from 3 (Table 2; Supplementary Fig. 1).

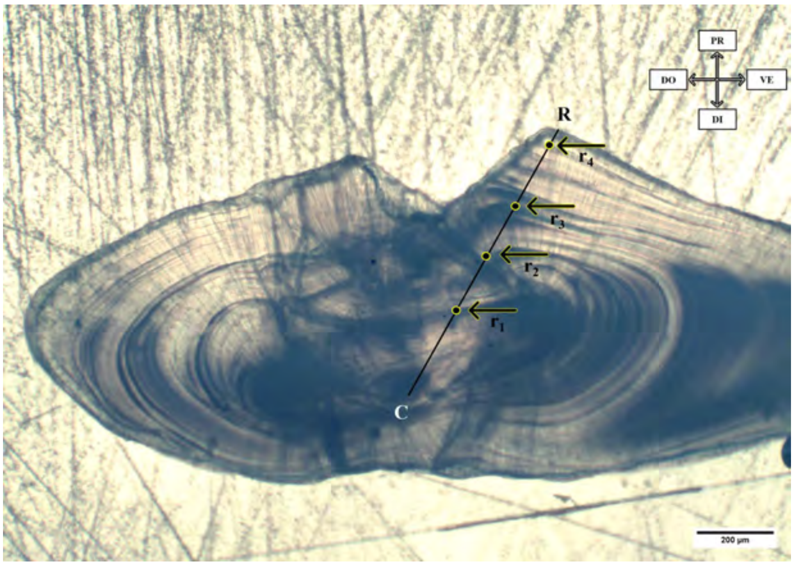

Fig. 2. Cross-sectioned otolith of *Chaunax abei* showing four opaque zones (r_i). R: otolith median radius (distance from core to edge); C: core (nucleus); black line (R to C) used for MGI method; yellow dots indicate the opaque zone (black bands), total length = 95.3 mm, otolith length = 4.87 mm, R = 797.51 μm, 4 years old, DO: dorsal; VE: ventral; DI: distal; PR: proximal.

Table 1. Total length (*TL*), and weight (*W*) data of *Chaunax abei*.

	Month/Season	*TL* (mm)				*W* (g)		
		n	L_{min}	L_{max}	L_{mean} ± SE	W_{min}	W_{max}	W_{mean} ± SE
2021	April 2021 (Spring)	12	40.59	262.64	131.10 ± 17.90	2.04	491.75	81.67 ± 39.34
	October 2021 (Autumn)	8	73.45	208.63	129.29 ± 15.82	5.99	269.42	66.87 ± 32.55
	Total	20	40.59	262.64	130.38 ± 12.18	2.04	491.75	75.75 ± 26.39
2022	April 2022 (Spring)	2	113.72	116.52	115.12 ± 1.40	28.35	31.71	30.03 ± 1.68
	December 2022 (Winter)	111	37.44	268.75	123.81 ± 3.80	1.11	461.12	55.79 ± 7.31
	Total	113	37.44	268.75	123.66 ± 3.73	1.11	461.12	55.33 ± 7.18
	Overall	133	37.44	268.75	124.67 ± 3.64	1.11	491.75	58.40 ± 7.26

SE: standard error.

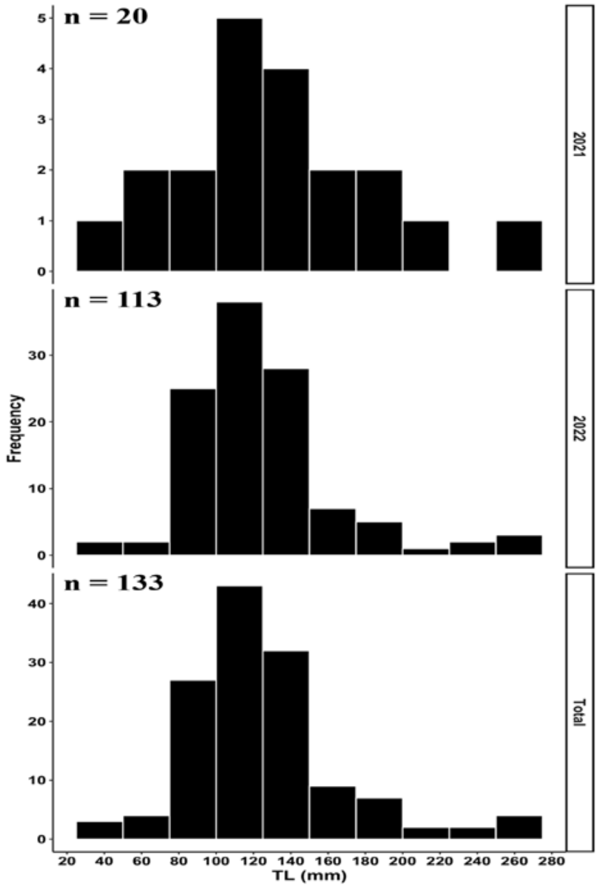

Fig. 3. Length distributions of *Chaunax abei* from Suruga Bay, south-western Japan for 2021, 2022 and both years combined.

Table 2. Summary of the length weight relationship for *Chaunax abei* from Suruga Bay, south-western Japan.

n	*a*	*b*	95% CI of *a*	95% CI of *b*	SE(b)	r^2	*t*-test	Growth type
133	2.0678 × 10^{-5}	2.996	0.000010–0.000039	2.863–3.298	0.067	0.937	-0.052	Isometric

a: intercept, *b*: slope, SE: standard error.

There were strong positive relationships between fish *TL* and median otoliths radius (*R*) and between TL and otolith length (*OL*) (r^2 = 0.927 and r^2 = 0.951, respectively) (Fig. 4) and the observed ages of fishes based on annual ring formation (see Discussion) were divided into 1 to 12 distinct yearly age classes and the most common age class identified was age-4 with 32.79 % (n = 40) (Supplementary Fig. 2).The age-length key from the interpretation of estimated ages from otoliths is shown in Table 3.

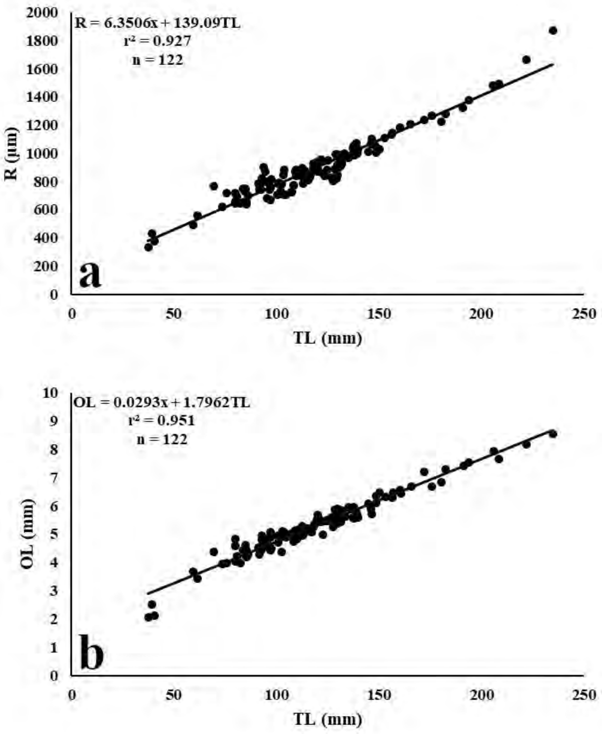

Fig. 4. The relationship between fish total length and otolith sizes. a: total length (*TL*) vs median otolith radius (*R*) and b: *TL* vs otolith length (*OL*) for *Chaunax abei* in Suruga Bay, south- western Japan.

The mean *MGI* for April 2021 (Spring) was 0.493 µm ± 0.176 (mean ± SD, µm), while for October 2021 (Autumn) it was 0.301 ± 0.184 µm (Fig. 5). In 2022, the mean MGI in April (Spring) was 0.461 ± 0.023 µm and in December (Winter), it was 0.446 ± 0.211 µm. The growth parameters estimated from the von Bertalanffy growth function were: TL_∞ = 468.1 mm, *K* = 0.056 year^{-1}, t_0 = -0.402 year (Fig. 6).

Discussion

Age data is crucial for understanding the life history of fish. Also, the accuracy of age determination relies on the size of the samples and how the growth zones on the otoliths are interpreted (Filiz et al., 2006). This study presents the life history and demographic characteristics of *C. abei* in Suruga Bay, south-western Japan, along with the first-ever population data conducted within the Chaunacid species.

From our sample of 122 fish that could be aged, we found 12 age groups with a maximum age of 12 (i.e. 1–12 opaque zones). The vast majority of the fish (n = 72, 59 %) were within the range of 90.0 to 134.9 mm and age-4 (n = 40) and age-5 (n = 32), and caught in depths of 254–324 m. The scarcity of smaller individuals (<100 mm) as well as larger ones (>200 mm) in the sampling periods could be attributed to the selectivity of fishing gear or the inclination of fish towards specific bathymetric environments. JAMSTEC (2023) reported that 33.3 % of the total individuals examined in their fish database (9 out of 27) demonstrated a predominant occurrence depth between 276–326 m, which is similar to the range of depths where our fish were collected. The congruence between the observed depth ranges in both cases provides insights into the general habitat preferences for the population of *C. abei* in the Pacific waters of Japan. Also, the limited occurrence of larger individuals in the current study may suggest a proclivity for inhabiting deeper waters, a trend commonly observed in other anglerfish species (*Lophius* sp.) (Carlucci et al., 2009).

The length-weight relationship (LWR) is an important tool which helps to know especially to understand the growth pattern (Kumar et al., 2022) and measurements of biomass (Froese, 1998; González Acosta et al., 2004; Şenbahar et al., 2020) in fish populations. The slope (*b*) in an LWR serves as an allometric growth factor and indicates variability in growth and development (Froese, 2006). The population of *C. abei* showed a tendency towards isometric growth, indicated by a growth coefficient (*b* = 2.996) (Table 4). This aligns closely with the precalculated value (*b* = 3.02) from the Bayesian LWR based on the (sub)family-body shape data from FishBase (2023) (Table 4).

The *MGI* for *C. abei* varied among the seasons and notably, December 2022 (Winter) had the greatest variation in *MGI* because of the much greater number of individuals obtained than in other sampling periods (Fig. 5). The varying *MGI* values across the seasons conformed with the anticipated natural increment hypothesis which mentioned by Campana (2001), that posits that due to the annual growth layer formation,

Table 3. The estimated von Bertalanffy parameters and age-length key for *Chaunax abei* in Suruga Bay, south-western Japan, determined from the interpretation of estimated ages from otoliths.

TL_∞(mm)	468.1												
K(year^{-1})	0.056												
t_0(year)	-0.402												
	Age (year)												
TL (mm)	0	1	2	3	4	5	6	7	8	9	10	11	12	Total
30.0–44.9		3												3
45.0–59.9			1											1
60.0–74.9			1	2										3
75.0–89.9				12										12
90.0–104.9					25									25
105.0–119.9					15	8								23
120.0–134.9						24								24
135.0–149.9							14							14
150.0–164.9							2	4						6
165.0–179.9								1	2					3
180.0–194.9									2	2				4
195.0–209.9											2			2
210.0–224.9												1		1
225.0–239.9													1	1
Mean	-	39.11	60.38	80.84	102.45	124.47	142.52	159.96	177.80	192.61	207.22	222.10	234.92	
SD	-	1.58	1.41	5.05	7.15	5.95	5.62	3.30	4.67	2.06	1.98	-	-	
n	-	3	2	14	40	32	16	5	4	2	2	1	1	122

TL_∞: theoretical asymptotic total length, K: instantaneous growth coefficient, t_0: theoretical age of fish before hatching, *TL*: total length, SD: standard deviation.

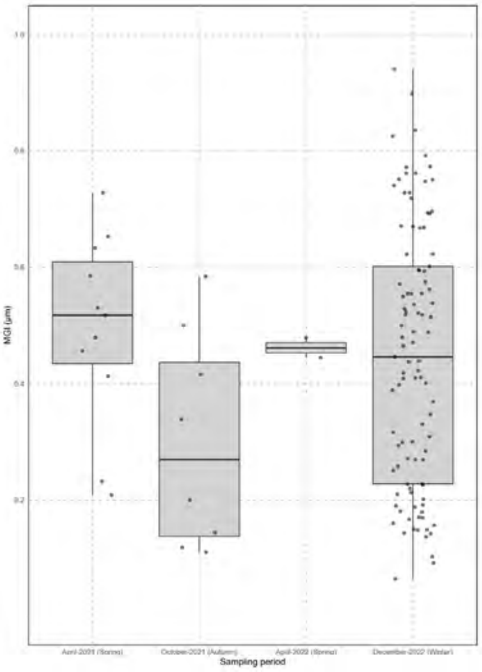

Fig. 5. Box plots of the marginal growth increment (*MGI*) estimated for the different seasonal sampling periods for *Chaunax abei*, south-western Japan. Mid-line: mean/median, box: 25 to 75 percentiles, whiskers = 5 and 95 percentiles.

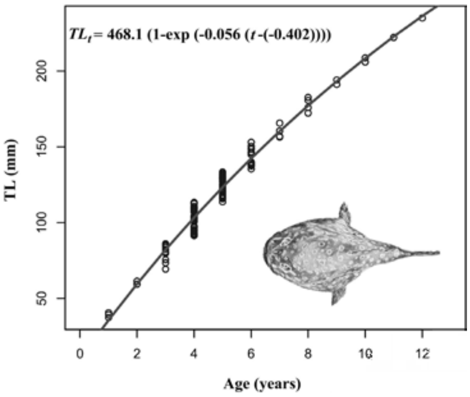

Fig. 6. The von Bertalanffy growth curve (vBGC) fitted to length-at-age classes for *Chaunax abei* from Suruga Bay, south-western Japan.

Table 4. Comparative length-weight relationships (LWR) of Lophiiformes species inhabiting the inland seas and bays connected to Pacific Ocean and the Bayesian LWR based on the subfamily body-shape data from FishBase (2023).

Species	Author	Sex	Area	n	*a*	*b*	r^2	Growth
Lophius litulon	Yoneda et al. (1997)	♀	E China Sea and Yellow Sea	302	4.01×10^{-5}	2.850	0.98	(-) allometric
		♂		512	3.44×10^{-4}	2.470	0.96	(-) allometric
	Cha et al. (1998)	♀	NW waters of Korea		8.9×10^{-3}	3.303		(+) allometric
		♂			3.29×10^{-2}	2.775		(-) allometric
	Kawano (2011)	♀	SW Japan Sea	249	9.74×10^{-6}	3.077	0.96	Isometric
		♂		83	5.5×10^{-5}	2.781	0.91	(-) allometric
		♀♀		332	1.09×10^{-5}	3.056	0.95	Isometric
	Sun et al. (2021)	♀	Yellow Sea	239	2×10^{-6}	3.333	0.90	(+) allometric
		♂		635	1×10^{-5}	3.033	0.82	Isometric
Chaunax abei	FishBase (2023)	♀♂	Bayesian LWR from (sub) family-body shape		1.905×10^{-2}	3.020		Isometric
	Present Study	♀♂	Suruga Bay	133	2.07×10^{-5}	2.996	0.93	Isometric

a: intercept, *b*: slope, r^2: coefficient of determination.

the average advancement of the outermost layer would display a sinusoidal pattern when plotted against the yearly seasons. We were not able to confirm that the opaque zones were laid down annually because samples could not be obtained in many months, and this also did not allow us to determine when the opaque zones are delineated. However, as other Lophiiformes species form an annual opaque zone, it is possible that this also applies to *C. abei*. Additionally, otolith growth is related to an increase in fish size and generally follows an allometric increase in dimensions (Chilton and Beamish, 1982; Tuset et al., 2003). Therefore, for the increase in the consistency of validation of ageing structure, growth related variation of age at a given otolith properties were evident in Figure 7. The otolith height (*OH*, mm) ($r^2 = 0.847$), otolith length (*OL*, mm) ($r^2 = 0.917$), median otolith radius (*R*, µm) ($r^2 = 0.938$) and otolith weight (*OW*, g) ($r^2 = 0.945$) show a positive and strong correlation with advancing age, indicating a gradual increase in these dimensions as the estimated age in years increases (Supplementary Fig. 3).

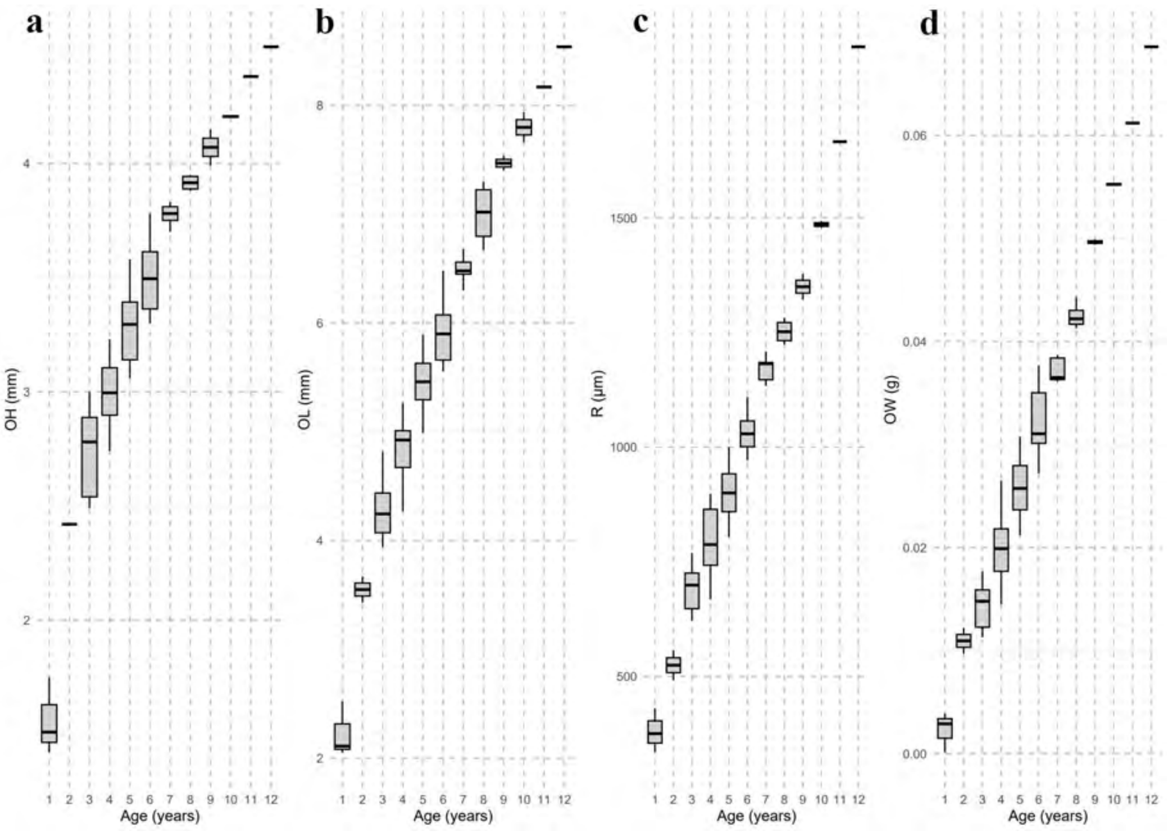

Fig. 7. Increment of otolith features by age classes. a: age vs otolith height (*OH*), b: age vs otolith length (*OL*), c: age vs median otolith radius (*R*) and d: age vs otolith weight (*OW*).

To assess the growth pattern and population characteristics specific to *C. abei*, an evaluation was conducted by comparing the findings with reports on *Lophius litulon*, another Lophiiformes species investigated in the same Pacific waters as the current study (Table 5). The overall results indicated that there is a significant divergence of theoretical asymptotic length between *L. litulon* and *C. abei* (TL_∞ = 468.1 mm). This is an expected result as Chaunacid species are already known for smaller size than *Lophius* species. Also, this should be considered as a family-type specific feature for Chaunacids in terms of maximum attainable size. Furthermore, the obvious slower growth rate observed in both species is a notable characteristic. However, *C. abei* (K = 0.056 year^{-1}) exhibited an even slower growth pattern than ever reported for *L. litulon* (K = 0.06 to 0.18 year^{-1}, Table 5). Korostelev et al. (2023) postulated that within certain *Moridae* species, a potential reduction in metabolic rate could contribute to decelerated growth and an extended lifespan in deep-water species. Some researchers attribute this phenomenon to the impact of the extreme conditions prevalent in the deep-sea environment on their metabolic processes. Additionally, Pauly (1998) reported that as temperature rises, metabolic rates also increase, and growth is constrained by respiratory metabolism. Thus, this emphasizes the intricate link between the environment, metabolic processes, and the growth patterns of species in the deep sea. Also, deep-sea environments generally tend to favour the survival of species with low energy requirements. Long and Farina (2019), based on observations from remotely operated vehicle (ROV) videos, that Chaunacid species exhibit notably low metabolic rates and also an extremely slow, high-volume gill ventilatory cycle. Consequently, the slow growth rate of *C. abei* may be directly linked to its low metabolic activity.

Table 5. Comparative growth parameters of Lophiiformes species inhabiting the inland seas and bays connected to Pacific Ocean.

Author	Yoneda et al. (1997)		Cha et al. (1998)		Sun et al. (2021)		Present study
Species	*Lophius litulon*		*Lophius litulon*		*Lophius litulon*		*Chaunax abei*
Methodology	Vertebrae		Vertebrae		Otolith		Otolith
Area	E China Sea and Yellow Sea		NW waters of Korea		Yellow Sea		Suruga Bay
Sex	♀	♂	♀	♂	♀	♂	♀♂
TL_∞ (mm)	1547	1130	827.3	1276	765	579	468.1
K (year^{-1})	0.064	0.080	0.183	0.122	0.102	0.162	0.056
t_0 (year)	-0.345	-0.401	-0.643	-0.385	-1.106	0.718	-0.402

TL_∞: theoretical asymptotic total length, K: instantaneous growth coefficient, t_0: theoretical age of fish before hatching.

This paper aimed to provide age and growth of *C. abei* by utilising otolith observations. Such information is significant, particularly given the difficulty in estimating the age of sea toads. However, as it was difficult to obtain large numbers of sample in the different months, the estimates in this study should be regarded as preliminary. We also noted while the fish grow, the larger plain zones move toward each other on sectioned otoliths. Thus, it becomes more difficult to detect true opaque zones, as previously noted for Lophiidae species by Tsimenidis and Ondrias (1980). In future studies, it is important to not only focus on otoliths but also on other calcified structures (illicium and vertebrae).

Conclusion

There is limited information available regarding the fisheries biology of deep-sea fishes in the inner part of the Kuroshio Current, mainly due to the lack of fisheries data. Obtaining a sufficient number of samples in order to represent the fish population of Suruga Bay was a major challenge encountered throughout this study. Our study reveals that *C. abei* exhibits a slower growth pattern and follows an isometric growth type. Nevertheless, we believe that this study will contribute significantly to advancing our understanding of the biological characteristics of *C. abei*.

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Conflict of interest: The authors declare that they have no conflict of interest.

Author contributions: Ahmet Mert Şenbahar: Conceptualisation, methodology, writing-original draft. Eto Akira: Collected data and review. Masashi Yokota: Writing-review and supervision.

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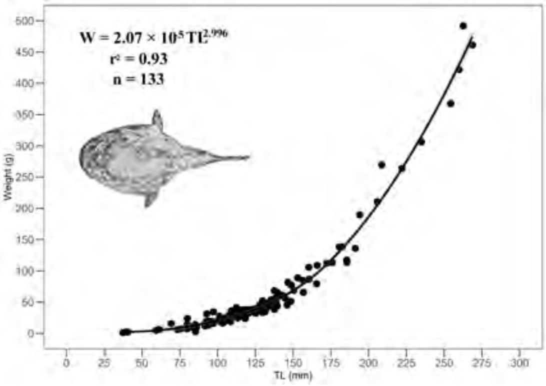
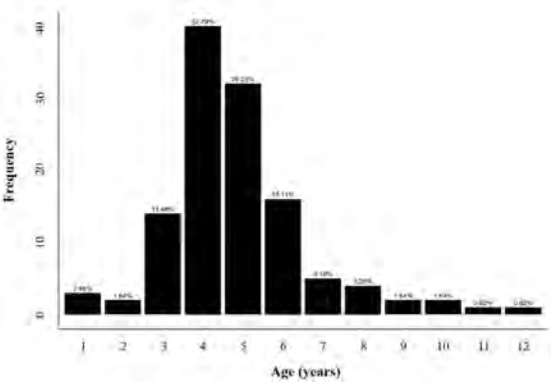
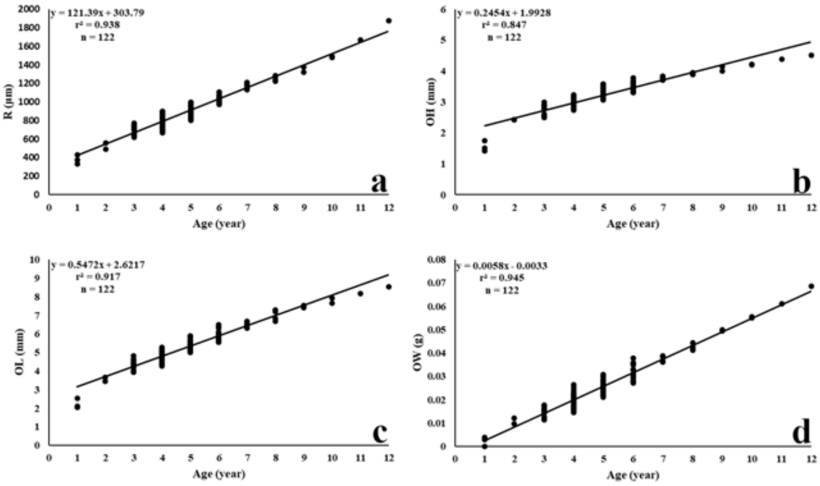


Supplementary Fig. 1. The total length (*TL*) – weight (*W*) relationship for *Chaunax abei* from Suruga Bay, south-western Japan.



Supplementary Fig. 2. Age frequency distribution for *Chaunax abei* from Suruga Bay, south-western Japan. n = 122.



Supplementary Fig. 3. Correlation of age and otolith properties for *Chaunax abei* from Suruga Bay, south-western Japan (A: age vs median otolith length (*R*), B: age vs otolith height (*OH*), C: age vs otolith length (*OL*) and D: age vs otolith weight (*OW*).