

Growth, sex ratio, and maturation rate with age in the blackspot tuskfish *Choerodon schoenleinii* in waters off Okinawa Island, southwestern Japan

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Abstract The growth, sex ratio with age, and age at sexual maturation were determined based on sectioned otoliths in 257 specimens of the blackspot tuskfish *Choerodon schoenleinii* collected in waters off Ryukyu Island. Opaque rings observed by reflected light in the sectioned otoliths were found to form once a year from January to July. The three growth parameters of the von Bertalanffy growth equation were $L_{\infty} = 68.1$ (cm), $k = 0.263$, and $t_0 = -0.023$ (year). The age at which the sex ratio reached 50% by sexual transition was about 6.15 years, and the age at which 50% of females were sexually mature was approximately 2 years. The oldest specimen among the samples was 17 years old.

Keywords *Choerodon schoenleinii* · Otolith · Growth · Sex ratio with age · Okinawa

Introduction

The blackspot tuskfish *Choerodon schoenleinii* is a large labrid species distributed in the tropical western Pacific

region [1]. Because the species is commercially important, many studies on its settlement area, growth, and feeding behavior from the larval to juvenile stages [2, 3], reproductive cycle, sexual maturation, and sexual transition based on body size [4] have been carried out in Okinawa, southwestern Japan. Because of the species's importance, stock enhancement is being tried [5]. Studies of home ranges and diel movement patterns [6], and otolith microstructure [7] using hatchery-reared individuals have also been carried out. According to these studies, the species exhibits protogynous hermaphroditism in accordance with changes in body color, like many other labrid species. Juveniles of the species inhabit sea-grass beds in the innermost areas of relatively large gulfs. The major habitats of the species in its adult stages are also restricted to the adjacent regions [8]. The major habitat of the Japanese species is very similar to that of the species in Australia, and extensive research into reproductive biology, sexual transition, growth [9], and habitat partitioning [10] have also been carried out at Shark Bay, a large gulf on the west coast of Australia, where only recreational fishing of the species has been conducted [9].

The species is caught primarily by night spire fishing, which captures the target after confirmation of the species and body size. The characteristics of the fishing gear itself allow only those fish within the size limit of the target species to be captured. A local rule restricting the capture of this species [heavier than 1 kg body weight; approximately 36 cm total length (L_T)] has been established at the northern area of Okinawa Island. The annual catch of the species in Okinawa prefecture in the past two decades has fluctuated between 20 and 40 mt, however, no decreasing trend has been observed (Ebisawa, unpublished data). The peaked body size in catch at about 28 cm L_T , in areas where the body-size restrictions have not been introduced,

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seems to be too smaller for the species which attains at about 70 cm L_T at the maximum; thus, the stock is determined to be non-rationally used even decrease in catch is not observed (Ebisawa, unpublished data).

For stock assessments or to determine the effect of stock management, analyses based on the age composition in the catch are necessary, and it is important to carry out growth studies and to examine the relationship between sexual maturation/transition and age. The present study reveals the growth of the species based on sectioned otoliths and analyzes the relationship between age and sexual maturation/transition, primarily using specimens from the same source as a previous study [4] with additional specimens collected thereafter. The results are compared to those of Shark Bay populations in order to elucidate the biological profiles of the species under different environments.

Materials and methods

The specimens for this study were 247 individuals among 289 specimens collected from 1986 to 1990 [4], and 35 newly collected specimens gathered from 2000 to 2006. The major fishing sites of the specimens were Nakagusuku Bay, Kin Bay, and the Haneji area of Okinawa Island (Fig. 1). Most of the specimens were purchased from commercial fishermen conducting night spire fishing. A pair of otoliths (sagittae) was removed from each individual after measurement of the total length (L_T) and body weight (W_B), and determination of the sex by the external appearance of the gonad. The gonad was later prepared for histological observation in order to determine both the sex and the stage of ovarian maturation; these results have already been reported by Ebisawa et al. [4]. Sex ratio (R_S) at each age was calculated based on the number of females in the total, which included female, male, and

hermaphrodite individuals in each same-integer age group. The rate of ovarian maturity (R_{OM}) in each age group was determined based on the number of mature females among whole females obtained during the most active spawning period, which is from February to May [4]. Maturity stages from early peri-nucleolus to yolk vesicle were defined as immature, and those from yolk globule to atretic were defined as mature. The smallest two specimens, otolith observations of which appear in the “Results” section, are excluded from these analyses owing to the lack of histological observations of their gonads.

Preparation and observation of otoliths

Each otolith was embedded in epoxy resin, transversely sectioned about 450 μm thick with the core included, mounted on slide glass with a medium (Eukitt; O. Kindler) and covered with a cover glass. Reflected light observation with a binocular microscope revealed translucent and opaque zones alternating around a central opaque area (Fig. 2a). The opaque zones outside of the central opaque area were counted as growth rings; the observer was blinded to the details of the specimen (body size, month collected, sex). Whether the outermost edge was opaque or translucent was also determined. Otolith pictures were recorded at the first observation using a Polaroid PDMC-Ie with 1600 \times 1200 pixels and 24-bit color. A second observation was carried out by the same reader based on the otolith picture without the reader being provided with the previous data. When the number of growth rings matched between the first and second readings, no further readings were carried out; when the numbers disagreed, two additional readings from the otolith picture were performed. When a total of three readings agreed, the number of growth rings was considered to be determined; if three concurring readings were not obtained, the otolith was excluded from later analysis. Measurements of the otolith

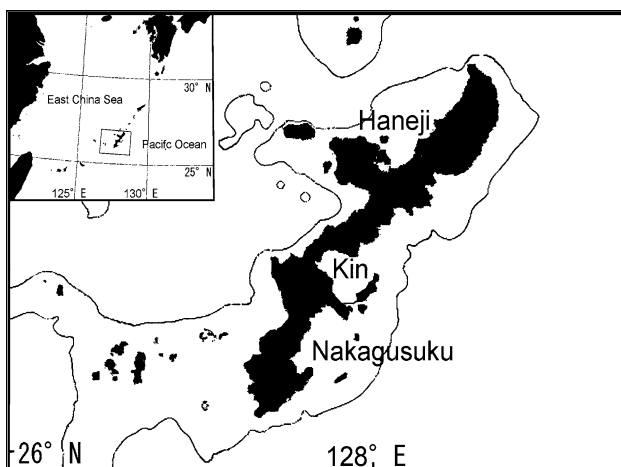


Fig. 1 Map of the Okinawa Islands with 200-m depth contour, and the locations where the specimens were collected

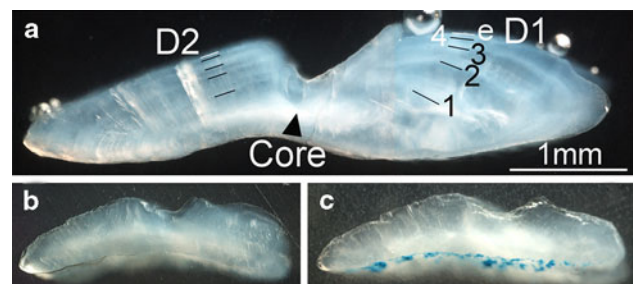


Fig. 2 Sectioned otolith of *Choerodon schoenleinii* from **a** a 46.2 cm L_T specimen collected January 11, 2002; **b** the smallest specimen, 9.2 cm L_T , collected January 1, 2005; and **c** a 10.6 cm L_T specimen collected May 4, 2005. All magnifications are equal, as shown by the 1-mm scale bar. The innermost four growth rings in **a** are identified by a line and a number. *e* Outer edge of the otolith, *D1* point at which the marginal growth index was obtained

growth ring for the analysis of the marginal growth index (MGI) were conducted at the second reading from otolith pictures. MGI was calculated as $X0/X1$ where $X0$ is the distance from the start of the outermost growth ring to the outer edge of the otolith (distance between lines “4” and “e” in Fig. 2a) and $X1$ is the distance from the start of the inner growth ring to the outer edge of the previous translucent zone (distance between lines “3” and “4” in Fig. 2a) at area D1 of the otolith. In case these measurements at the area D1 were difficult, they were carried out at area D2.

The age of each specimen is given as follows. Birth month was defined as February, which is the start of the most active spawning period of the species in the Okinawa area [4]. The decimal part of the age is the proportion of a year from the birth month to the month in which the specimen was collected. Details of the growth ring formation are explained further in the “Results” section, but it should be noted that the birth month is included in the period at which growth ring is formed. Thus, the integer part of the age is given as the number of growth rings minus one for specimens that had a newly formed growth ring but that were collected before the birth month (Fig. 3b, c; dots encircled by solid line) and is given as the number of growth rings plus one for those that had not yet started to form new growth rings but were collected after the birth month (Fig. 3d; dots encircled by broken line). In all other cases, the integer part of the age is given as the number of growth rings. Growth parameters in the von Bertalanffy growth equation were estimated by nonlinear regression (SPSS for Windows, release 7.5.2, SPSS) in the data sets of age and L_T for the specimens.

Results

Period of growth ring formation

Monthly changes in both MGI and the condition of the otolith edge were as follows. Otoliths with translucent edges in the single-growth-ring group were obtained continuously from July to January; their MGI values were the lowest in July with continual increases thereafter (Fig. 3a). In the two-ring group, otoliths with a growth ring on their edges were obtained from January to July, and those with translucent edges from June to January (Fig. 3b). Increases in MGI values were continuous from the minimum values of the otoliths with growth rings at their edges collected in January to the maximum values of those with translucent edges collected in December and January, in the two-ring group. Although monthly changes in groups with three and more rings were almost identical, earlier emergences of otoliths with growth rings at their edges collected in

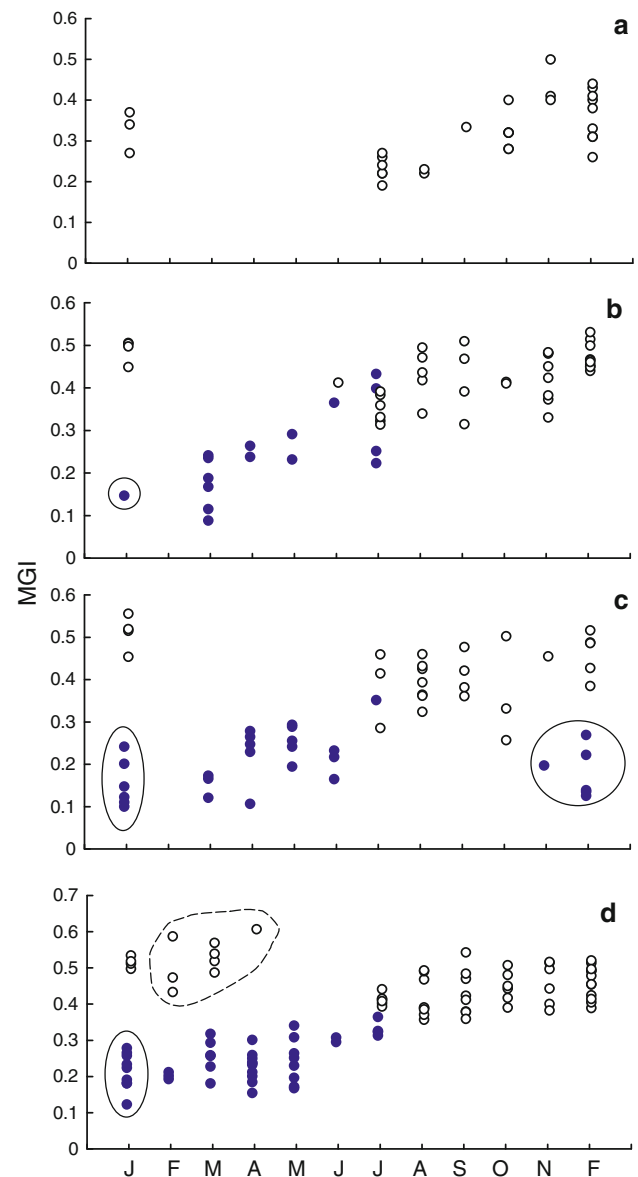


Fig. 3 Monthly changes in marginal growth index (MGI) in **a** the single-growth-ring group; **b** the two-ring group; **c** the three-ring group; and **d** a mixed group with four and more growth rings. A *solid circle* indicates an otolith with a growth ring at its edge; an *open circle* indicates one with a translucent edge. The significance of the *solid* and *broken encircling lines* is explained in the text

November and in December in the three-ring group were the exception. Therefore, all otoliths with low MGI values collected from January to July had a growth ring at their edge, while the edges of the otoliths collected from August to October showed a translucent zone. Thus, the growth ring was determined to be formed annually from about January to July.

In one of the smallest otoliths (9.2 cm L_T), which was obtained in January 2005, about two-thirds of the central area was opaque (Fig. 2b), and in another specimen

(10.6 cm L_T) obtained in May 2005, half of the central area was opaque while the outer areas were translucent (Fig. 2c).

Determination of age and growth parameters

Specimens whose integer ages differ from the number of growth rings are circled in Fig. 3. Those whose integer age is the same as the number of growth rings minus one are circled by a solid line, including 1 specimen with two rings collected in January (MGI = 0.15: Fig. 3b), 11 specimens with three rings gathered from November to January (MGI < 0.3: Fig. 3c), and 6 specimens with four and more rings collected in January (MGI < 0.3: Fig. 3d). Those whose integer age is the same as the number of growth rings plus one are circled by a broken line, including eight specimens with four or more rings collected between February and April (MGI > 0.4: Fig. 3d). The integer ages of all other specimens were the same as the number of growth rings. The three parameters of the von Bertalanffy growth equation were obtained as follows:

$$L_{\infty} = 68.1 \text{ (cm)}; \quad k = 0.263;$$

$$t_0 = -0.023 \text{ (year)} \quad (r^2 = 0.86)$$

Increases in body size were obvious up to 6–7 years of age, but ceased thereafter. Body sizes of males were larger than those of females in all same-age groups (Fig. 4).

Sex ratio and ovarian maturity rate in each age group

Average $L_T \pm$ SD for each age group, sex ratio (R_S), and ovarian maturity rate (R_{OM}) are shown in Table 1. All individuals aged 1 and 2 years were female. Hermaphrodite and male individuals appeared at 3 years of age and older. The average L_T of males was considerably larger than that of females. R_S decreased to 50% at 6 years of age, fluctuated from 0 to 75% between 7 and 11 years of age probably due to the small sample sizes, and decreased to

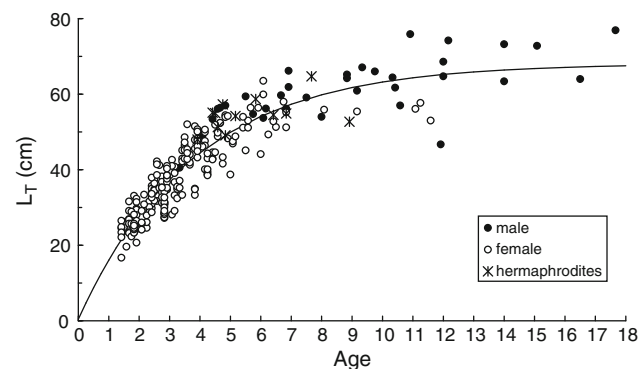


Fig. 4 The von Bertalanffy growth curve fitted to observed total length (L_T) and age in *Choerodon schoenleinii*

Table 1 Average L_T (cm) \pm SD for each sex, sex ratio (R_S), rate of ovarian maturity (R_{OM}), number of total specimens in each integer age group (n1), and number of female specimens obtained at the spawning period (n2)

Age	L_T (cm)			R_S	n1	R_{OM}	n2
	Female	Hermaphrodites	Male				
1	25.6 \pm 3.3			1.00	41		
2	32.7 \pm 4.5			1.00	70	0.91	11
3	41.5 \pm 6.1	48.0	40.5	0.96	49	1.00	13
4	46.0 \pm 5.0	53.6 \pm 3.7	54.0 \pm 3.1	0.70	37	1.00	12
5	49.9 \pm 5.3	56.5 \pm 3.2	57.1 \pm 3.3	0.73	15	1.00	4
6	53.9 \pm 5.9	54.7 \pm 0.3	58.5 \pm 4.3	0.50	18	1.00	3
7		64.7	59.1	0.00	2		
8	55.9	52.7	61.1 \pm 6.2	0.20	5		
9	55.4		64.7 \pm 3.3	0.25	4	1.00	1
10			64.8 \pm 8.0	0.00	4		
11	55.6 \pm 2.4		46.7	0.75	4	1.00	2
12			69.2 \pm 4.8	0.00	3		
13					0		
14			68.3 \pm 6.9	0.00	2		
15			72.8	0.00	1		
16			64.0	0.00	1		
17			76.9	0.00	1		

0 between 12 and 17 years. The age at which R_S was 50% was 6.15 years by fitting the logistic equation in R_S of each age class, omitting the extreme values of 0 and 75% of 7 and 11 year olds, respectively. R_{OM} was 90% in 2 year olds, reaching 100% in 3 year olds. R_{OM} in 1 year olds was not obtained because no specimens were obtained during the most active spawning period from February to May.

Discussion

Opaque zones were found to be formed in otoliths during the winter period in *Choerodon schoenleinii*, which is in contrast to many other species, in which translucent zones are formed during the winter period [11–19]. In a previous study using oxytetracycline (OTC) marking, in the congeneric *C. rubescens* in western Australia, opaque zone formation was determined to occur during the spring and summer, based on the location of opaque, translucent, and OTC marks in the otoliths, though the minute specific analytical data for this determination were not provided [20]. Another study found that, in the four species of the genus *Choerodon*, including *C. schoenleinii* in western Australia, MGI values, measured according to a baseline defined as the outermost zones of successive opaque edges, reach minimum in November/December [9], indicating that translucent zone formation begins in the summer, although

the author states that opaque zone formation takes place in the summer [9]. Opaque zone formation has been confirmed to occur during the winter in some Labridae, such as *Thalassoma lunare*, which is found in tropical eastern Australia [21], and during the spring in three species of Labridae in temperate eastern Australia [22]. Thus, the opposing periods of opaque zone formation as seen in *C. schoenleinii* are not specific to the labrid species.

The first growth ring is determined as the innermost opaque band outside of the central opaque area in the present study. In the otoliths of the two smallest specimens obtained in the present study, a 9.2 cm L_T specimen obtained in January shows a translucent zone one-third of the diameter of the otolith outside of the opaque central area, and a 10.6 cm L_T specimen obtained in May has a translucent zone about half of which is outside the central area. Accordingly, the central opaque area seems to be formed until approximately December in specimens of about 90 mm L_T . Settled juveniles in the sea-grass bed grow from about 20 mm L_T on average in May to about 70 mm L_T in August, and the larger individuals attain about 100 mm L_T by August/September [2]. Therefore, the smallest specimen in the present study (9.2 cm L_T , obtained in January) clearly belongs to the 0 integer age group, although it would have reached 1 year of age the following February. The 10.6 cm L_T specimen obtained in May has to belong to the 1 integer age group even though the first growth ring was not confirmed, since it was collected after February, the designated birth month of the species in the present study. There were no otoliths with a growth ring at their edges in the 1 integer age group collected from July to January. Thus, the first growth ring seems to be formed during the relatively short period from spring to early summer, shortly after the major spawning period from February to May.

The biological parameters of age in the species of the Okinawa population (hereafter termed Opop) differed greatly from those of the Shark Bay population [9] (hereafter termed SBpop). The growth of Opop was significantly faster than that of SBpop, although the maximum size and maximum ages in the two populations were approximately equal (Fig. 5; Table 2). While the body size at which 50% of females reached ovarian maturity (L_{OM50}) was almost equivalent between two populations, the age of 50% ovarian maturity (A_{OM50}) was younger in Opop due to differences in growth rate (Table 2). In addition, the great difference in female sexual maturation between the two populations has existed. Rate of sexual maturation in female ranged between 40–60% at 4–8 years of age and attained 100% at 9 and 10 years of age, although the sample sizes at the latter two age classes are very small in the SBpop. Therefore, A_{OM50} (3.45) indicated by Fairclough is obtained along with the determination of 50% of

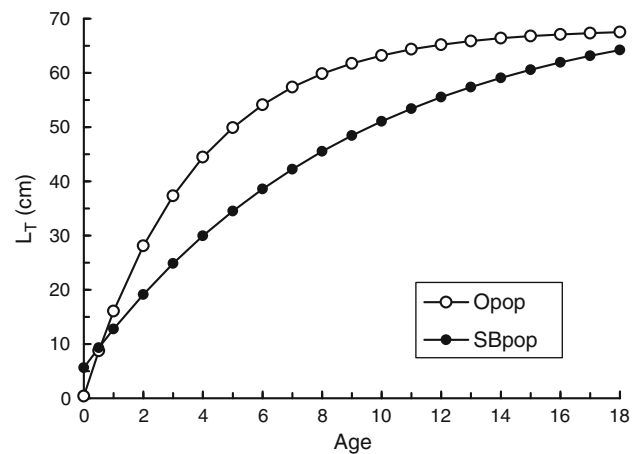


Fig. 5 Growth curve of *Choerodon schoenleinii*. Open circles represent the Okinawa population, solid circles the Shark Bay population according to Fairclough [9]

Table 2 Comparison of biological parameters in *Choerodon schoenleinii* between the Okinawa population (Opop) and Shark Bay population (SBpop) by Fairclough [9]

	Opop	SBpop
L_∞	68.1	73.4
k	0.263	0.111
t_0	-0.023	-0.72
Maximum age	17	16
A_{OM50}	<2.0	3.45
L_{OM50}	~24.0	25.3
A_{RS50}	6.15	10.37
L_{RS50}	54.6	55.6
L_T of the smallest male	40.5	52.1
Age of the youngest male	3	7
Number of males in total specimens	47/289	8/575

A_{OM50} and L_{OM50} age and total length (L_T) at which 50% of females are sexually mature; A_{RS50} and L_{RS50} , age and L_T at which sex ratio reaches 50%

ovarian maturation at 4–8 years of age as fully mature; thus, about 25% of female sexually mature at 3.45 years of age. Therefore, the A_{OM50} in the SBpop become much greater if the same criteria of A_{OM50} employed in the present study applied. In contrast, about 90 and 100% of females at 2 and 3 years old, respectively, were sexually mature in Opop. The age at which the sex ratio reached 50% (A_{RS50}) was lower in Opop, and the number of males out of the total number of specimens in SBpop was significantly smaller. One of the plausible reasons for the extremely smaller number of males in the SBpop could be biased sampling, because only a few specimens of larger body size were collected. However, the age of the youngest male in the SBpop was 7 years old, whereas it was

extremely younger at 3 years old in Opop (Table 2). The age of emergence of the youngest male was lower under higher fishing pressure in comparison with the congeneric *C. venustus* experiencing lower fishing pressure in adjacent regions [23]. On the contrary, in a comparison of the body size and age of the youngest male between two populations of the congener *C. rubescens*—one experiencing low fishing pressure and higher growth due to high productivity at the area and the other experiencing higher fishing pressure—the body size of the smallest male was smaller at the area of higher fishing pressure. However, the age of the smallest male was older there because of the slower growth rate. In addition, A_{RSS0} was younger at the lower fishing pressure area. These contradictory findings indicate that the reason for the sexual and maturational differences between SBpop and Opop can not yet be determined. The reason for the difference seems to be linked not only to environmental factors, such as biology, genetics, population density, food availability, antibiotics, water temperature, and water flow, but also artificial factors, such as fishing pressure and methods. If the effect of the artificial factors is not small, management strategies for the species should be developed by that take these factors into consideration.

Assuming a normal distribution around the calculated body size at age using the given mean square obtained during the estimation of the growth parameters, the percentage falling below the size restriction (<36.0 cm L_T) as currently enforced at the northern area of the Okinawa Island is 100% at 1 year, 78% at 2 years, and 22% at 3 years. In hermaphroditic species, size-selective fishing makes the proportion represented by the second sex significantly smaller compared to dioecious species [24, 25]. If the size-at-sex-change is flexible, the side effects of size-selective fishing are small [26, 27]. In many labrid species, a harem social structure, in which the disappearance of the male induces the sexual transition of the apex female into male in the harem, has been reported [28–30]. Therefore, if this type of social structure exists in *C. schoenleinii*, size-selective fishing of larger individuals does not necessarily lead to a shortage of males in the population. The specimens in the present study were obtained before the introduction of size-selective fishing at the study site. This size restriction is currently conducted at Haneji, but not yet at Kin and Nakagusuku. It is therefore necessary to obtain growth rate, age, and body size of both sexual maturation and sexual transition, before and after the introduction of the body-size-restrictive fishing at Kin and Nakagusuku areas in order to fully elucidate the effects of size-selective fishing.

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