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Growth and Reproductive Characteristics of the Roughear Scad *Decapterus tabl* in the East China Sea

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Abstract

The species of the genus *Decapterus* are important for fisheries in western Japan, but few in number and reports on their biological characteristics remain limited. This is the first report on the growth and maturation of the roughear scad *Decapterus tabl* in the East China Sea. The growth model of the roughear scad was estimated as follows: $FL_t = 390\{1 - \exp[-0.56(t + 0.36]\}$ $(1 < t < 8)$ using otolith annual rings that were formed once a year. The spawning period was from May to July, while the 50% maturation gonad somatic index GSI_{50} was calculated as 3.80 for female using logistic regression. The minimum length over the GSI_{50} was 274 mm, meaning a first spawning age of 2 years old in the East China Sea.

Discipline: Fisheries
Additional key words: Carangidae, growth, maturation, otolith

Introduction

The present study aims to determine the growth and maturation of the roughear scad *Decapterus tabl* off southern Kyushu, Japan. The family Carangidae such as *Trachurus japonicus*, *Seriola* spp., *Decapterus* spp. includes many important species for fishery in Japan, especially landings of jack mackerel *Trachurus japonicus*, which is the largest among the Carangidae species family. Scad *Decapterus* spp. are distributed in the southern area of the East China Sea, and are also important fish for fisheries in southern Japan. Catches of scad landed in the East China Sea and Sea of Japan by Japanese fisheries ranged from 7 to 77 thousand tons[24], and have been decreasing in recent years. There is therefore a need to manage stocks of scad, the first step of which for management involves assessing the stock. Biological characteristics such as growth and reproduction are necessary for stock assessment. The biological characteristics of round scad *Decapterus maruadsi,* shortfin scad *Decapterus macrosoma*, mackerel scad *Decapterus macarellus* and red scad *Decapterus akaadsi* in the East China Sea have already been reported[3,12,18], but not roughear scad, Indian scad *Decapterus russelli* and amberstripe scad *Decapterus muroadsi*. Landings of the roughear scad in Kagoshima prefecture over the last decade ranged from 185 to 1666 tons, while the catch of the roughear scad exceeded that of round scad [24].

Conversely, many species belong to the family Carangidae in the East China Sea and we studied the biological characteristics for the Carangidae[6,12,18-20,25,26]. Significant variations in the biological characteristics among Carangidae species have been observed. We compare the biological characteristics between roughear scad and other Carangidae species in the East China Sea.

Materials and Methods

1. Collection and measurements of samples

A total of 3695 roughear scad specimens obtained from

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2006 to 2011 in the waters off southern Kyushu were analyzed (Fig. 1a). Specimens were commercially caught by large-sized purse seiners and rod and line fishing, mainly off southern Kagoshima prefecture. In particular, specimens were caught in the waters near Tanegashima, Yakushima and Amami-Oshima islands (Fig. 1b). Specimens were measured to the nearest millimeter of fork length (FL) and to the nearest gram of body weight. The gonad weight was measured to the nearest 0.1 g after determining the sex, and small pieces of the gonad were fixed in 10% formalin for histological observation. The gonad somatic index (GSI) was calculated as follows:

$$GSI = \frac{GW}{(BW - GW)} \times 100$$

where BW and GW are body weight and gonad weight, respectively.

2. Age determination

A total of 134 specimens of the roughear scad were used to determine the age. Sagittal otoliths were removed, washed in freshwater and dried, with remaining otoliths burned at 200 °C for 30 minutes in a drying oven (DO-300A, AS ONE, Osaka, Japan), embedded in resin (Struers, EpoFix Resin) and sectioned transversely (thickness 0.2–0.3 mm) using a micro-cutter (MARUTO MC-201) and grinding machine (MARUTO ML-180). Sectioned otoliths were then observed under a digital microscope (Nikon, E-LV100D, Tokyo, Japan). We counted the number of opaque rings on the otolith and recorded whether an opaque or translucent zone occurred on its outer margin (Fig. 2a). The monthly ratio of individuals with an opaque zone ($R_{opaque,\ m}$) was calculated as follows:

$$R_{opaque,\ m} = \frac{n_{opaque,m}}{n_m}$$

where $n_{opaque,m}$ and n_m represents the number of individuals with an opaque zone on the outer margin of the otolith and the total number of specimens per month m, respectively.

The age was determined for each fish based on the number of ring marks (annuli) on the sectioned otolith, assuming a hatch month of June, which approximately corresponds to the middle of the spawning period (see Results). To describe the growth of males and females, von Bertalanffy growth equations were fitted to the observed FL values at age t, using nonlinear least square regression for both sexes. The growth equation is as follows:

$$FL_t = FL_\infty \{1 - \exp[-k(t - t_0)]\}$$

where FL_t represents the fork length (mm) at age t and FL_∞, k and t_0 represent the asymptotic fork length, growth coefficient, and hypothetical age at fork length equal to zero, respectively.

The parameters for contaminated normal distribution were estimated by the maximum likelihood method using

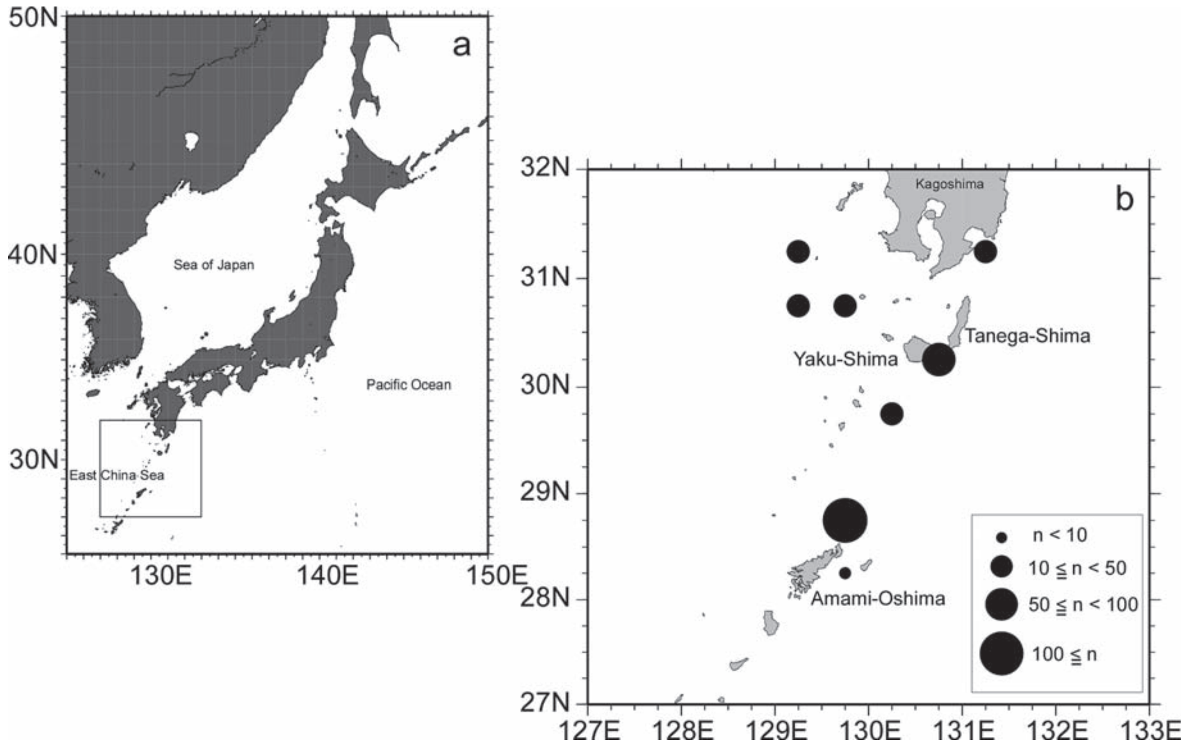

Fig. 1. Study area in Japan (a) and enlarged map of the survey area (b)
The size of the circle indicates the number of fish caught at each site in the present study.

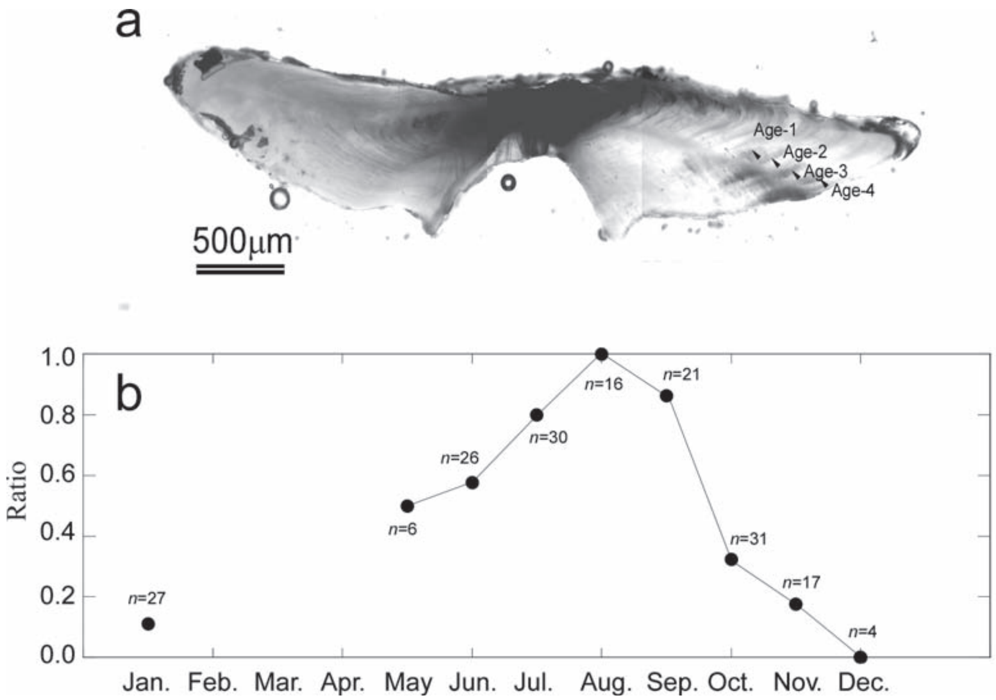

Fig. 2. Section otolith of the roughear scad (a), and monthly changes in the ratio of the roughear scad individuals with an opaque zone on the outer margin of the otolith (b)
Black arrows indicate ring marks in figure 2a.

the body size frequency[7]. The main assumption when analyzing length frequency information is that observable modes in data relate to distinct cohorts[7].

3. Histological observations

The fixed ovaries were dehydrated and embedded in methacrylate polymer resin (Technovit 7100, Heraeus Kulzer, Wehrheim, Germany) and sections 2 or 3 μm thick were stained using 0.5% toluidine blue solution or embedded in paraffin, while those 5 or 6μm thick were stained using Myer's hematoxylin and eosin. The stained sections were then observed under an optical microscope and the most advanced oocyte stages were recorded. The stages of oocytes were classified as perinucleolus, yolk vesicle, early yolk, mid-yolk, late yolk, germinal vesicle migration, hydration, atresia and the presence of any postovulatory follicles was recorded, and this classification was already reported for shortfin and mackerel scad in the East China Sea[18]. A total of 158 females were examined in the present study. Only specimens exceeding the minimum size (274 mm *FL*), which equates to sexual maturity (see Results), were used to examine the seasonal changes in gonad condition. The ovaries could be divided into six stages of maturity based on the development of the most advanced oocytes and their histological characteristics following the previous study[18].

1. Immature stage (Im), only previtellogenic oocytes were present, including those in the perinucleolus and yolk vesicle stages.
2. Developing stage (D), the most advanced oocytes are at the early- or mid-yolk stages.
3. Vitellogenic stage (Vi), the most advanced oocytes are at the late yolk stage, which marks the end of vitellogenesis.
4. Mature stage (M), the most advanced oocytes are at the germinal vesicle migration or hydration stage. Degenerated old postovulatory follicles occurred in some ovaries at the start of the germinal vesicle migration.
5. Spawning stage (Sp), yolked oocytes and newly postovulatory follicles are present. Most postovulatory follicles disappear from the ovaries before the developing oocytes attain the germinal vesicle migration stage.
6. Resting stage (Re), all yolked oocytes are degenerating (atretic stage) and non-yolked oocytes are present.

Sexually mature females were defined as individuals with ovaries at the Vi, M or Sp stages. To estimate the *GSI* at 50% maturity (GSI_{50}), a logistic function was fitted to the rate of mature fish for each *GSI* class at 0.5 intervals using a generalized linear model[16], except in the Re stage. The logistic equation was as follows:

$$MR = \frac{\exp(\alpha + \beta GSI)}{1 + \exp(\alpha + \beta GSI)}$$

where *MR* is the maturation rate and α and β represent coefficients.

Results

1. Growth of the roughear scad

Most specimens collected from July to September had an opaque zone on the outer margin of the otolith, and a translucent zone from October to January, although the results from February to April were absent (Fig. 2b). In the present study, rings on the otolith were assumed to be formed once a year, and the number of rings was considered the age number.

The relationship between age and *FL* is shown in Fig. 3. Given the lack of significant differences in the growth of males and females (F-test, $p > 0.05$) [1], all individuals were pooled to estimate the growth model. The growth model of the roughear scad was estimated as follows:

$$FL_t = 390\{1 - \exp[-0.56\,(t + 0.36)]\}\ (1 < t < 8)$$

where FL_t represents the fork length (mm) at age t. The theoretical fork lengths at ages 2, 3, 4 and 5 using the growth model were 286, 330, 356 and 371 mm, respectively.

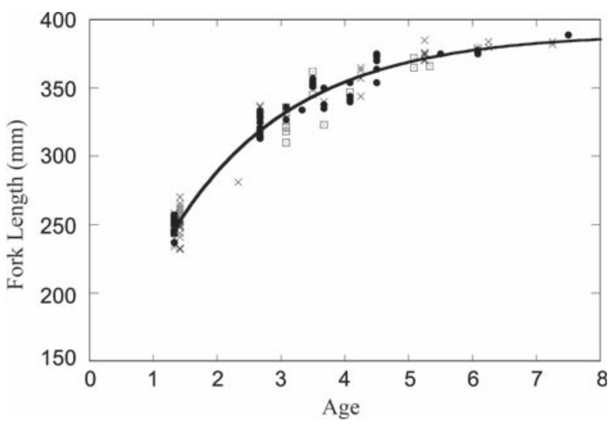

Fig. 3. Growth model of the roughear scad, solid line, □, ● and X represent von Bertalanffy's growth curve, male, female and unidentified gender individuals, respectively

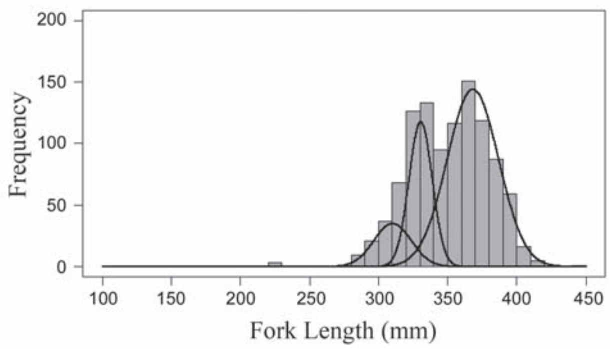

Fig. 4. Histogram of the fork length of the roughear scad during spawning periods, with solid lines indicating a mixture of normal distribution of fork length

The frequency of the fork length of the roughear scad from 2006 to 2011 during spawning periods is shown in Fig. 4. Here, three modes were estimated using data on size frequency during spawning periods (from May to July). The estimated modes using spawning periods was 310, 330 and 368 mm, while similar results were obtained using the Hasselblad method[1]. Therefore, the roughear scad was caught mainly over 2 years old during the spawning period based on the results of the age-length relationship and size frequency data.

2. Reproduction of the roughear scad

The mean *GSI* value in males and females peaked in May, reaching 3.45 and 4.05, respectively (Fig. 5). The low values of the mean *GSI* (< 1) in males and females were observed from August to March and August to April, respectively. The most advanced stage of the ovary from August to April was Im (immature) or D (developing) stage (Fig. 6). The Vi (vitellogenic), M (mature) and Sp (spawning) stages were observed in May, June and July, while the Re (resting) stage was observed during June to July. Therefore, we consider the spawning season of the roughear scad to be from May to July (Fig. 7).

The mean *GSI* in Im, D, Vi, M, Sp, and Re was 0.44,

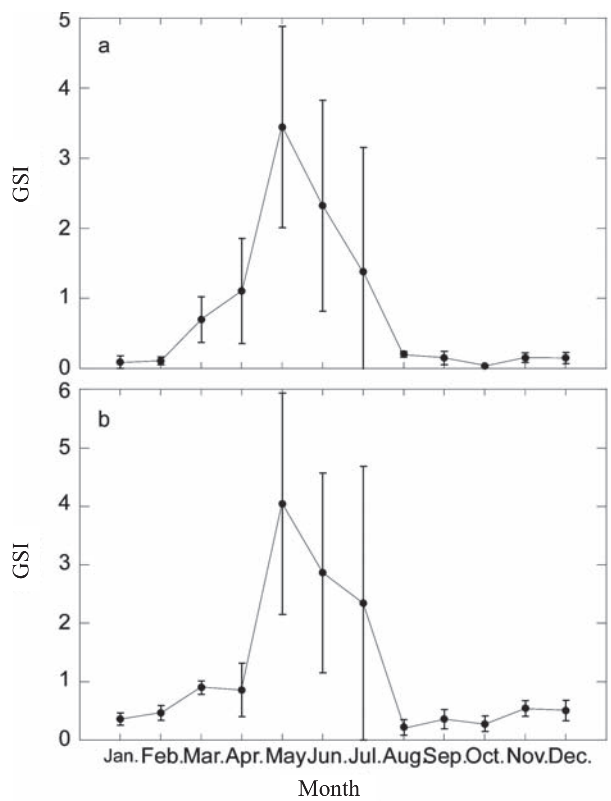

Fig. 5. Monthly changes of GSI in males (a) and females (b)
Closed circles and vertical bars indicate mean and SD of GSI, respectively.

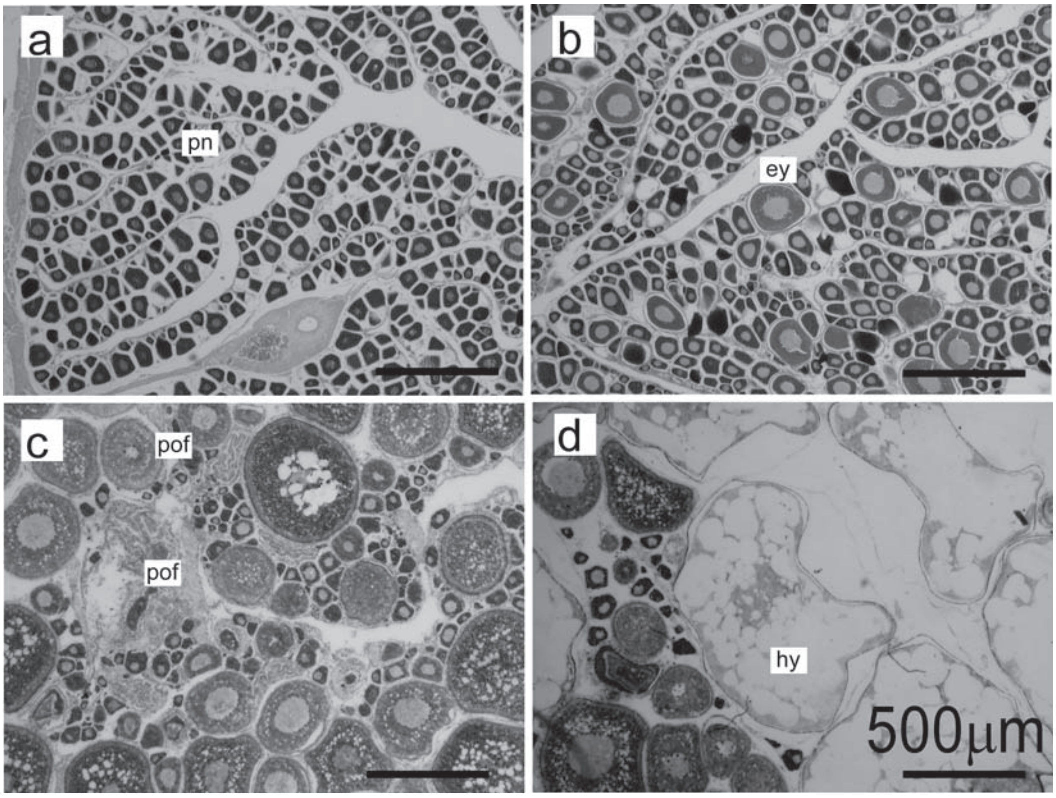

Fig. 6. Photomicrograph of ovaries at different developmental stages in *D. tabl*
a: immature stage, b: developing stage, c: vitellogenic stage and d: mature stage, ey: early yolk oocyte, hy: hydration oocyte, pn: perinucleolus oocyte, pof: postovulatory follicle. Bars indicate 500µm.

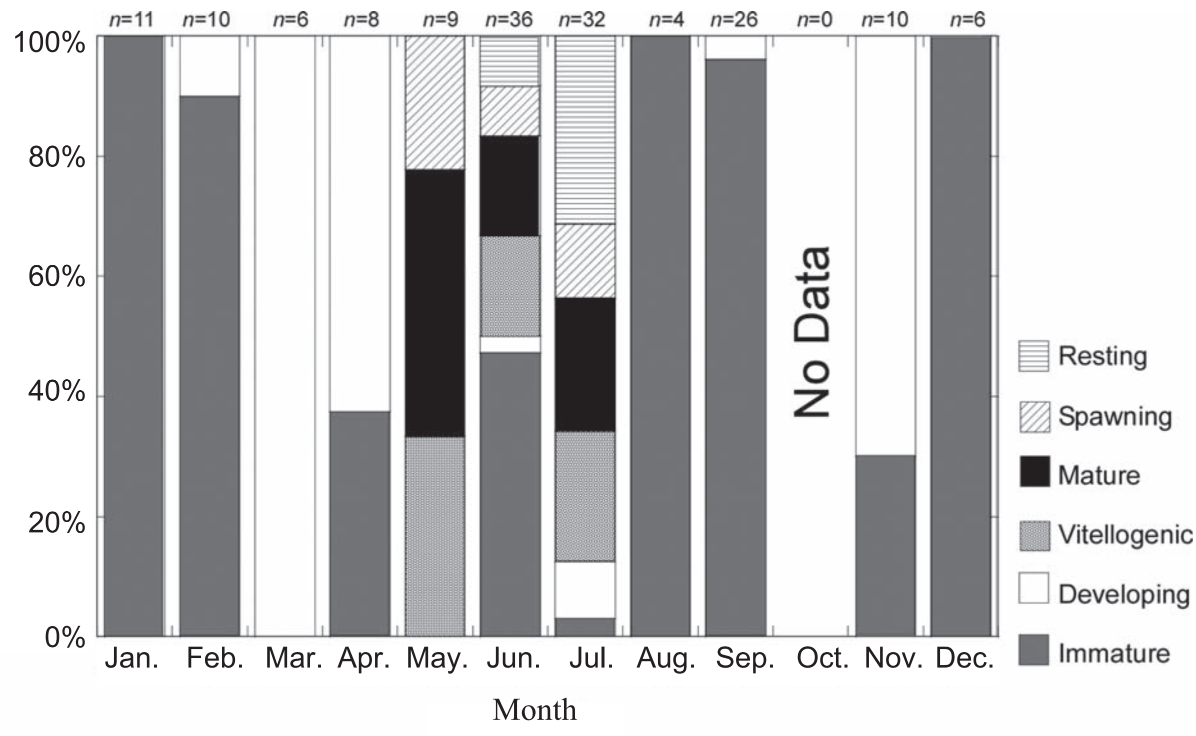

Fig. 7. Monthly frequency of the most advanced oocytes of the roughear scad

0.77, 3.18, 6.65, 3.76 and 1.43, respectively (Fig. 8a). The relationship between *GSI* and maturation rate (*MR*) was as follows:

$$MR = \frac{\exp(-5.065 + 1.332GSI)}{1 + \exp(-5.065 + 1.332GSI)}$$

GSI_{50} was calculated as 3.80 using this regression (Fig. 8b). The minimum length over the GSI_{50} was 274 mm (Fig. 8c) in the East China Sea, therefore the first spawning age was considered to be 2 years old using the results of the growth model.

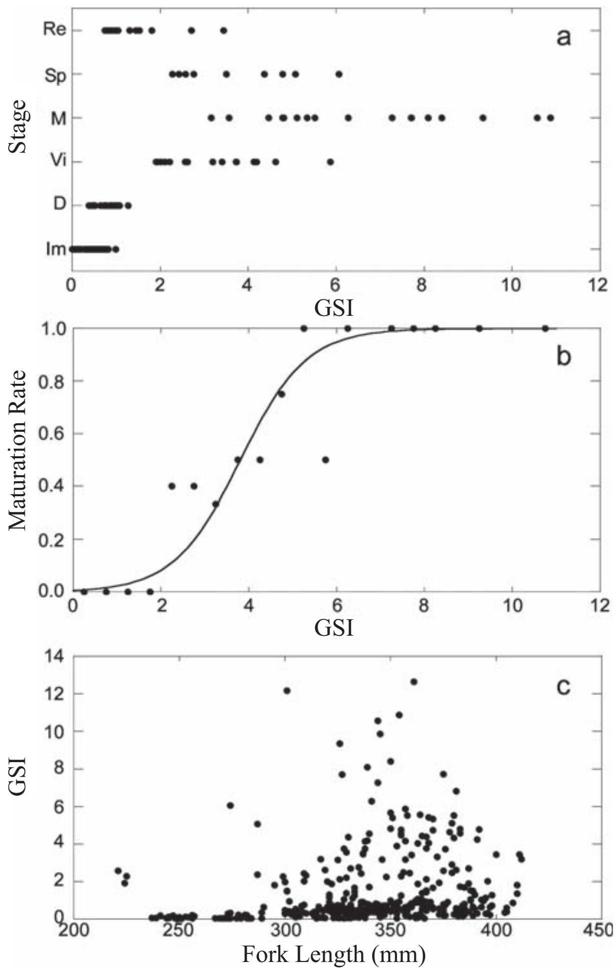

Fig. 8. Relationship between GSI and the most advanced oocytes or maturation rate (a), between fork length and maturation rate (b) and between fork length and GSI (c)

3. Discussion

There are several reports on biological characteristics such as the growth and maturation of *Decapterus* species in the East China Sea[2,3,12,18], and we compared the biological characteristics among *Decapterus* (Table 1). The present study is the first report on the growth and reproductive characteristics of the roughear scad *Decapterus tabl* in the East China Sea. Roughear scad are distributed in tropical and sub-tropical waters worldwide[21,22] including around the Ryukyu archipelago and the southern part of Kyushu[9] (Fig. 1), and are important food sources for human beings[11] as well as bait for tuna long-line fishing[17].

The observation results for the rate of individuals with opaque rings indicated that the opaque rings formed once a year, and the periods of ring formation would mainly be August for the roughear scad (Fig. 2). The periods of ring formation differed from other *Decapterus* species such as round scad, mackerel scad and shortfin scad in the East China Sea (Table 2)[12,18]. Furthermore, the ring formation period also differed slightly from the spawning period in the roughear scad, while the formation periods of other Carangidae species may occur within the spawning periods (Table 2). The opaque rings in jack mackerel[10] formed once a year, but twice a year in horse kingfish (*Kaiwarinus equula*)[6]. The ring on the vertebrae in the genus *Seriola* in

Table 1. Comparison of the biological characteristics among the genus *Decapterus*

Species	FL_∞	k	t_0	First maturation age	Spawning periods	Area	Reference
Decapterus maruadsi	342	0.550	0.580	2	May - August	East China Sea	12
Decapterus macrosoma	346	0.456	0.771	2	May - August	East China Sea	18
Decapterus macrosoma				-	February – June October - December	Southern India	2
Decapterus macrosoma	238	0.750	0.777	-	-	Eastern India	14
Decapterus macarellus	428	0.310	0.821	2	April – July	East China Sea	18
Decapterus akaadsi	599	0.135	2.250	1	May	Eastern Taiwan	3, 4
Decapterus akaadsi	391	0.302	2.326	-	-	Southern Taiwan	3
Decapterus russelli	260	0.500	0.186	-	March – May November - December	Southern India	2, 23
Decapterus russelli	232	0.700	0.163	-	-	Eastern India	14
Decapterus russelli	277	1.237	0.344	-	-	Northern India	23
Decapterus tabl	390	0.560	0.360	2	May – July	East China Sea	Present study

Table 2. Comparison of the biological characteristics among the family Carangidae in the East China Sea

Species	FL_∞	k	t_0	Opaque ring formation period	First maturation age	Spawning periods	GSI_{50}	Reference
Trachurus japonicus	404	0.312	0.750	Winter	1	November-June	-	10, 25
	386	0.356	0.630	Spring				
	325	0.259	1.470	Winter				
Decapterus maruadsi	342	0.550	0.580	June - July	2	May - August	3.85	12
Decapterus macrosoma	346	0.456	0.771	March - June	2	May - August	2.97	18
Decapterus macarellus	428	0.310	0.821	March - June	2	April - July	1.87	18
Decapterus tabl	390	0.560	0.360	June - August	2	May - July	3.80	Present study
Seriola quinqueradiata	1042	0.311	0.988	March - May	2	April - May	5.06	20
Seriola lalandi	1108	0.309	0.588	April - June	2	April - June	-	19
Kaiwarinus equula	273	0.270	0.213	March - April	3	May - October	-	6, 26
	272	0.286	0.111	September - October				

the East China Sea, meanwhile, form once a year[19,20]. These results suggest that the incidence of ring formation on the otolith or vertebrae may indicate significant variations among the family Carangidae.

The von Bertalannffy's growth model of the roughear scad based on the otolith was calculated (Tables 1 and 2, Fig. 3) and we compared the growth models among the genus *Decapterus* (Table 1). The largest species among the genus *Decapterus* is red scad, followed by the mackerel scad in the East China Sea. The growth coefficient (k) of the roughear scad exceeded that of the other species of the *Decapterus* genus in the East China Sea[3,12,18], and the large growth coefficient indicates the potential to grow rapidly. However, the largest growth coefficient species was for the Indian scad in the waters off India[15], and the growth coefficient of Indian scad has significant variations[14,15,23]. The largest species within the family Carangidae in the East China Sea is the golden striped amberjack[19], followed by the amberjack[20]. The growth coefficient of the roughear scad also exceeded that of the other Carangidae species in the East China Sea (Table 2).

The roughear scad individuals developing gonads during the spawning periods (May - July) were over 2 years old (Fig. 4). In the present study, we estimated the age-length relationship of the roughear scad. This relationship enables us to estimate the catch at age based on the growth model and size frequencies. In addition, it will be possible to evaluate whether or not overfishing occurs in the near future.

In the present study, the spawning season for roughear scad was from May to July based on the results of histological observations, while the spawning season for this species in Suruga Bay is from June to October[8]. The sea surface temperature in the present study area in May exceeded that in the area of Suruga Bay based on the database of the Japan Meteorological Agency (http://www.data.kishou.go.jp/kaiyou/db/index.html), while the sea surface temperature during the spawning periods exceeded 20 °C. The spawning seasons for round-, shortfin- and mackerel scad in the East China Sea are from May to August, May to August and April to July, respectively[12,18]. The spawning seasons of shortfin- and Indian scad in the Indian Sea are in spring and autumn[2], while jack mackerel also has a long spawning period, from November to June[10]. The spawning periods for the amberjack and gold striped amberjack run from March to May and April to June, respectively[19,20], while the spawning period of king horsefish is from May to October[26]. The duration of the spawning periods of the genera *Seriola, Decapterus, Kaiwarinus* and *Trachurus* range from 3, 3-4, 5 and 8 months, respectively (Table 2). Fitzhugh[5] reviewed the relationships between age or body size and spawning duration in fin fish, but did not consider the taxonomic relations. The spawning duration in most species rose with increasing body size[5], while the large jack mackerel fish showed a longer spawning duration in the East China Sea[13]. Because the spawning duration would be affected by age or body size, we should monitor the relationship between spawning duration and age (body size) of the roughear scad in future.

The first spawning age of the roughear scad in the East China Sea was 2 years old in the present study (Tables 1 and 2). Most species of the genus *Decapterus* species in the East China Sea firstly spawn at age 2[12,18], but the first spawning age for red scad is 1 year old [4]. The first spawning age of the genus *Seriola* species is also 2 years old[19,20], but jack mackerel is 1 year old and king horsefish is 3 years old, respectively [6,25,26]. The first spawning age of jack mackerel is 1 year old[25], and the species has a long spawning duration (Table 2). We recalculated the value of GSI_{50} for round-, shortfin- and mackerel scad and amberjack. The GSI_{50} value for roughear scad was 3.80, and for the other species of the genus *Decapterus*, it ranged from 1.87 to 3.85 (Table 2). The GSI could be calculated using body weight and gonad weight, so the GSI_{50} values would help determine which are mature or not. The GSI_{50} is considered a criterion for maturation and would thus be useful for comparing the spawning strategy in fish. If the GSI_{50} values in other fish in the East China Sea are calculated, we can understand the reproduction strategies of the species.

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