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FULL PAPER

Size composition and reproductive biology of the ornate jobfish *Pristipomoides argyrogrammicus* (Lutjanidae) off Ishigaki Island, Okinawa

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Abstract The ornate jobfish *Pristipomoides argyrogrammicus* is an important lutjanid species for fisheries in the Okinawan region of Japan. The present study estimated the size composition and reproduction of this species in the waters around Ishigaki Island, Okinawa Prefecture. The length–frequency distribution indicated that males grow larger than females. The fork length (FL; mm)–whole body weight (BW; g) relationship and FL–total length (TL) relationship were as follows: $BW = 1.048 \times 10^{-5}\ FL^{3.121}$ and $TL = 1.101 \times FL + 2.196$, respectively. The main spawning season was estimated as between April and August, since higher gonadosomatic index (GSI) values were found for both sexes, and matured oocytes were observed in females during these months. The developmental stage of ovaries correlated with the GSI of females. Fecundity ranged from 9,530 to 98,260 oocytes in fish of 177.0 to 278.0 mm FL, and the FL–fecundity relationship was as follows: $fecundity = 9.525 \times 10^{-8}\ FL^{4.903}$.

Keywords *Pristipomoides argyrogrammicus* · Body size composition · Length–weight relationship · Spawning season · Fecundity

Introduction

Snappers (Lutjanidae) are one of the important fisheries resources in tropical and subtropical waters (Allen 1985). Some of the lutjanid species (e.g., *Etelis* spp. and *Pristipomoides* spp.) are deep slope reef fishes (>100 m in depth) and important fisheries targets (Kami 1973; Kikkawa 1984; Everson et al. 1989; DeMartini and Lau 1998; Newman and Dunk 2003; Anderson et al. 2009). The ornate jobfish *Pristipomoides argyrogrammicus* is one of the lutjanid species that is distributed in the Indo-West Pacific and occurs over rocky bottoms at depths of between 70 and 300 m (Allen 1985). This species is distinguished by its reddish body with irregular blue markings (Nakabo 2002), and is an important fisheries target in the Indo-West Pacific (Allen 1985; Masuda et al. 1984). It is mainly caught by hook and line. However, little is known regarding its main biological characteristics, such as the size composition and reproduction of the species. The purpose of the study described in the present paper was to investigate the differences between the sexes of *P. argyrogrammicus* off Ishigaki Island, southern Ryukyu Archipelago, in terms of size composition, seasonal changes in gonad development, and fecundity.

Materials and methods

Biological data were collected from specimens purchased from commercial catches made off the coast of the Ishigaki Island, Okinawa, Japan (24°27′N, 124°13′E) between April 2009 and March 2010. Identification as *Pristipomoides argyrogrammicus* was based on the diagnostic characters noted in the "Introduction." All specimens ($n = 219$: 119 males and 100 females) were measured for fork length (FL) and total length (TL) to the nearest 0.5 mm, whole body weight (BW; g), and gonad weight (GW; nearest 0.01 g). Gonads were removed from the specimens and preserved in 20% buffered formalin. FL and BW were plotted and fitted

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with the power function $BW = a\ FL^b$, where a and b are coefficients.

Gonadosomatic index (GSI) was calculated for both sexes using the formula: $GW/(BW - GW) \times 100$. In order to clarify temporal changes in oocyte development, small pieces of the ovaries were placed in 20% buffered formalin for 48 h and then kept in 70% ethanol. After dehydration using a series of ethanol, they were embedded in paraffin (m.p. 56–58°C, paraffin for histology, Merck, Darmstadt, Germany). Embedded tissues were serially sectioned at 6 µm and stained with Mayer's hematoxylin–eosin for microscopy observations. Oocyte development was classified into six stages following Nanami et al. (2010): perinucleolus stage, oil-droplet stage, primary yolk stage, secondary yolk stage, tertiary yolk stage, and mature oocytes. The presence of postovulatory follicles was also recorded. The most developed stage in the oocyte was taken to represent the developmental stage of the examined individual.

The fecundity was estimated for 16 females with mature oocytes. Five small tissue pieces (about 30 mg) were extracted from each ovary examined. Oocytes >0.4 mm in diameter were regarded as mature, and were counted under a Nikon profile projector at 10× magnification. Fecundity was then estimated in accordance with Murua et al. (2003). The FL–fecundity relationship was plotted and fitted with a power function in accordance with Fitzhugh et al. (2009): fecundity $= a\ FL^b$, where a and b are coefficients.

Results

Body size composition. Figure 1 indicates the length–frequency distribution of *Pristipomoides argyrogrammicus*. The body size of males was significantly larger than that of females [159.0–308.0 mm FL, mean ± standard division (SD) = 239.6 ± 29.8 mm FL, $n = 119$ for male; 177.0–278.0 mm FL, mean ± SD = 223.9 ± 21.7 mm FL, $n = 100$ for female] (one-way ANOVA, $df = 1$, $P < 0.001$). The FL–BW relationships were as follows:

Male: $BW = 9.568 \times 10^{-6}\ FL^{3.135}$ ($R^2 = 0.976$)
Female: $BW = 5.537 \times 10^{-6}\ FL^{3.243}$ ($R^2 = 0.969$)
Both sexes combined: $BW = 1.048 \times 10^{-5}\ FL^{3.121}$ ($R^2 = 0.972$)

The FL–TL relationships were as follows:

Male: $TL = 1.101 \times FL + 2.330$ ($R^2 = 0.986$)
Female: $TL = 1.103 \times FL + 1.901$ ($R^2 = 0.992$)
Both sexes combined: $TL = 1.101 \times FL + 2.196$ ($R^2 = 0.989$)

Spawning season, maturation and fecundity. Figure 2 indicates the monthly changes in GSI for both sexes. The GSIs of males were generally higher from April to July (ca. 0.2 on average), whereas it was lower between August and March (<0.2 on average) (Fig. 2), although the GSIs were

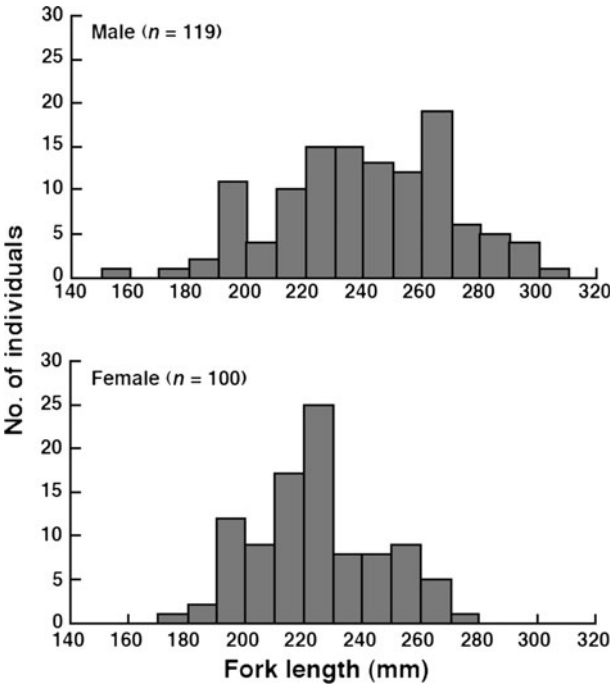

Fig. 1 Size distribution of *Pristipomoides argyrogrammicus*

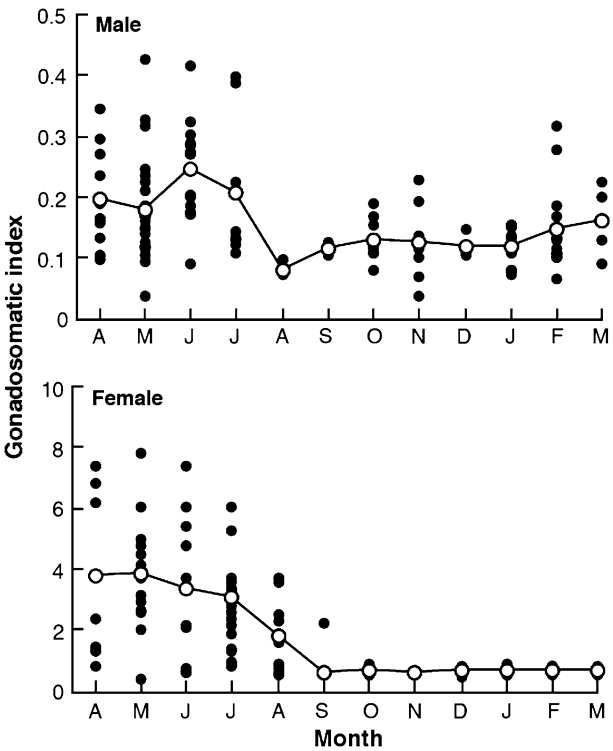

Fig. 2 Monthly changes in gonadosomatic index for *Pristipomoides argyrogrammicus* in males (*above*) and females (*below*). *Black* and *white circles* represent individual and average values, respectively

especially variable in November and February. The GSIs of females were higher between April and August (1.8–3.8 on average) and lower between September and March (0.6–0.7 on average) (Fig. 2). Monthly changes in oocyte development are shown in Fig. 3. Mature oocytes, tertiary yolk stages and postovulatory follicles were observed from April to August (Fig. 3). In September, although mature oocytes were observed for one female, the other 8 individuals had only perinucleolus stage or oil-droplet stage oocytes (Fig. 3). Most ovaries were only at the perinucleolus stage or oil-droplet stage from October to January (Fig. 3). The developmental stages of most ovaries were peri-nucleolus, oil droplet, or primary yolk from February to March (Fig. 3). Secondary and tertiary yolk stages were observed around the mature oocytes, indicating that multiple modes of oocyte development occurred simultaneously in an ovary (Fig. 4).

The relationship between GSI and developmental stage is shown in Fig. 5. Mature oocytes were observed for individuals that had high GSIs (5.2 on average). Secondary and tertiary yolk stages were observed for individuals that had intermediate GSIs (1.8–2.7 on average). In contrast, the GSIs for individuals that exhibited only perinucleolus, oil-droplet and primary yolk stages were less than 1. The GSIs were significantly different among the six developmental stages of oocytes (one-way ANOVA and post-hoc Games–Howell's test, $P < 0.05$). The GSIs of matured oocytes were significantly greater than those of the other five developmental stages (Fig. 5).

Fecundity ranged from 9,530 to 98,260 oocytes in fishes 177.0–278.0 mm in FL ($n = 16$). The FL–fecundity relationship was as follows (Fig. 6):

$$\text{Fecundity} = 9.525 \times 10^{-8}\text{FL}^{4.903} (R^2 = 0.655).$$

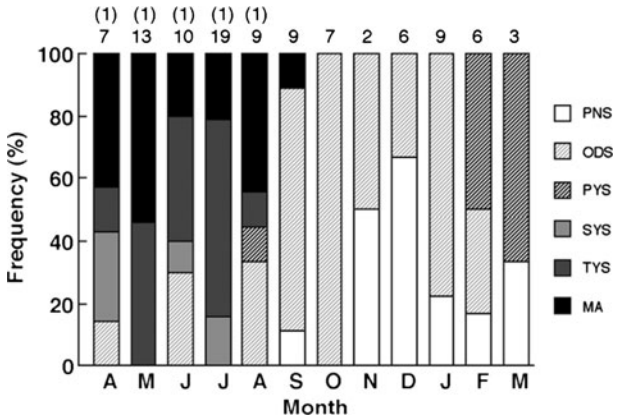

Fig. 3 Seasonal changes in oocyte development for *Pristipomoides argyrogrammicus*. *Numbers above plots* represent sample sizes. *PYS* primary yolk stage, *SYS* secondary yolk stage, *TYS* tertiary yolk stage, *MA* mature oocyte. *Numbers in parentheses* indicate numbers of ovaries with postovulatory follicles

Discussion

Many previous studies have reported the species-specific growth characteristics of coastal lutjanid species (e.g., Newman et al. 1996; Burton 2000; Nanami et al. 2010). Lutjanid species that inhabit deeper rocky bottom areas also show sex differences in their growth (Everson et al. 1989; Newman and Dunk 2003). For the three offshore lutjanid species *Aprion virescens*, *Etelis coruscans* and *Pristipomoides multidens*, females grow larger than males (Everson et al. 1989; Newman and Dunk 2003). In contrast, length–frequency data from the present study indicated that males of *Pristipomoides argyrogrammicus* grow larger than females (Fig. 1).

Although the GSIs of males tended to be higher from April to July and lower from August to March, some individuals had higher GSIs in November and February. In contrast, the GSIs of females from April to August were higher than they were between September and March (Fig. 2), and oocyte maturation was observed during April to August (Figs. 3, 4). This suggests that the main

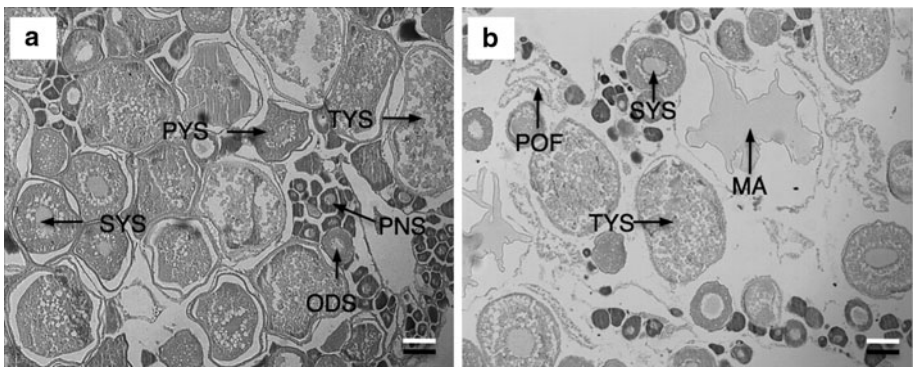

Fig. 4 Histological sections of ovaries for *Pristipomoides argyrogrammicus*. **a** Sample obtained on 17 August 2009 (237.0 mm FL); **b** sample obtained on 1 June 2009 (243.5 mm FL). *PNS* perinucleolus stage, *ODS* oil-droplet stage, *PYS* primary yolk stage, *SYS* secondary yolk stage, *TYS* tertiary yolk stage, *MA* mature oocyte, *POF* postovulatory follicle. *Bar* 100 μm

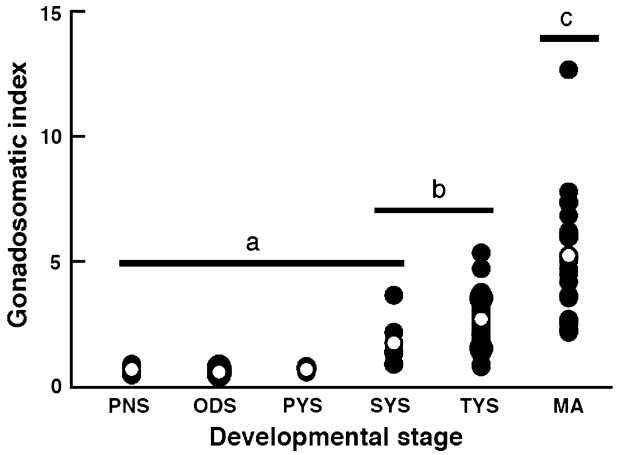

Fig. 5 The relationship between developmental stage of oocytes and gonadosomatic index for *Pristipomoides argyrogrammicus*. *Black* and *white circles* represent individual and average values, respectively. Games–Howell's test was used to test for significant differences between all pairs of six developmental stages. Stages connected by a *horizontal line with the same letter* are not significantly different. *PNS* perinucleolus stage, *ODS* oil-droplet stage, *PYS* primary yolk stage, *SYS* secondary yolk stage, *TYS* tertiary yolk stage, *MA* mature oocyte

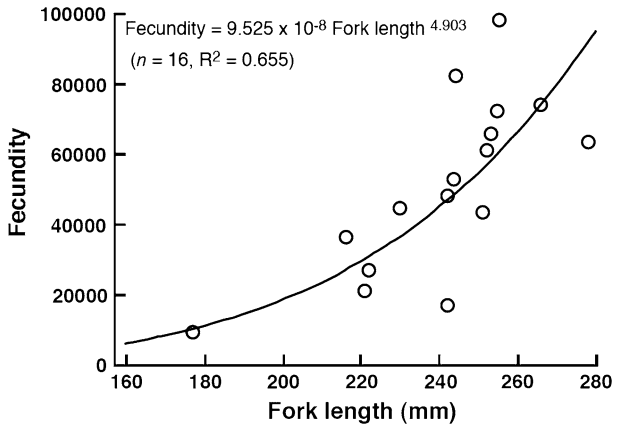

Fig. 6 Relationship between fork length (mm) and fecundity for *Pristipomoides argyrogrammicus*

spawning season of *P. argyrogrammicus* is between April and August (lasting five months). Grimes (1987) showed that there are two patterns in the seasonality of reproduction for lutjanid species. The first pattern is that the reproduction is restricted around the summer season. The second pattern is continuous year-round spawning with peaks in the spring and fall. The results of the present study are consistent with the former case. Since the catch of this species declined from November to March due to bad weather conditions, it was difficult to obtain sufficient samples (A. Nanami, unpublished data). In addition, it was difficult to distinguish between males and females, as the color patterns and/or morphological characteristics of the sexes were similar. Thus, the selective sampling of females was difficult for this species, and the numbers of female samples were small, especially for November and March (Fig. 3). In order to generalize the spawning season of the species, more sampling from November to March is needed in the future.

The size at maturity could not be clarified in the present study, since both the smallest and largest females (177.0 and 278.0 mm FL, respectively) had developed oocytes during the main spawning season. For lutjanid species, size at maturity is about 43–51% of the maximum length (Grimes 1987). If the same relation is applied, it can be hypothesized that the size at maturity for *P. argyrogrammicus* is between ca. 120 and 142 mm in FL, since the maximum FL was 278.0 mm for females in the present study. Since smaller individuals (<150 mm in FL) are rarely caught by fisheries around the present study site, fishery-independent sampling is needed to clarify the size at maturity for this species. Histological observations showed that oocytes at various developmental stages could be found in an individual. This suggests that *P. argyrogrammicus* is a multiple spawner.

It has been reported that the estimated fecundity is variable among species of lutjanids. In species smaller than <300 mm in TL, the average fecundity was ca. 69,450 (ranging between 8,170 and 347,000 in fishes 225–294 mm in TL) (Grimes 1987). This value is approximately consistent with the results of the present study. However, in species attaining larger sizes, such as *Pristipomoides multidens*, *Pristipomoides typus* and *Pristipomoides filamentosus* (356–555 mm in standard length), the fecundity ranged from 490,000 to 2,770,000 (Grimes 1987). These interspecific differences in fecundity may reflect size differences at maturity among species. In the present study, fecundity showed a good fit to a power function of FL for *P. argyrogrammicus*. This suggests that the fecundity dramatically increases with the FL of the fish, and as an individual grows larger, the individual spawns a greater number of eggs. Based on the fitted power function for fecundity, the estimated range of fecundity in *P. argyrogrammicus* for individuals 177.0–278.0 mm in FL is 10,016–91,626. This indicates that if a female's FL increases ca. 1.6-fold (278.0/177.0 = 1.57), the fecundity increases more than ninefold (91,626/10,016 = 9.15).

There is currently no fisheries management of *P. argyrogrammicus*, although this species is an important fisheries target around the Okinawa Islands (Masuda et al. 1984). The protection of one larger sized female would be equivalent to protecting multiple smaller-sized females in terms of reproduction, as mentioned above. This suggests that the protection of larger sized females during the main spawning season (from April to August) is important for effective fisheries management for the species, since the

larger-sized females make a greater contribution to reproduction (Sobel and Dahlgren 2004). Although the catch-and-release approach is generally adopted to protect a particular fish in fisheries management, deep-water fishes that inhabit waters over 100 m deep die with catch and release, due to the decompression and handling involved (Rummer 2007). Thus, prohibiting fishing during the spawning season and/or constructing protected marine areas would be necessary for the effective management for *P. argyrogrammicus*. Although the present study clarified the reproductive activity of this species, other fisheries information, such as age and growth, is still needed.

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