Ichthyol Res (2010) 57:240–244
DOI 10.1007/s10228-010-0160-8

FULL PAPER

Age, growth and reproduction of the humpback red snapper *Lutjanus gibbus* off Ishigaki Island, Okinawa

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Received: 13 November 2009 / Revised: 26 January 2010 / Accepted: 7 March 2010 / Published online: 1 May 2010

Abstract The humpback red snapper *Lutjanus gibbus* (Lutjanidae) is an important species for fisheries in the Kagoshima and Okinawan region of Japan. The present study estimated the age, growth and reproduction of this lutjanid species in the waters around Ishigaki Island, southern part of Okinawa. An opaque zone was formed on the otolith every year, and this formation correlated with their spawning season; these zones were identified as annual rings. Maximum ages of 21 and 24 years were observed for males and females, respectively. The von Bertalanffy growth parameters clarifying the age–fork length relationship were as follows: $L_\infty = 390.5$ mm, $K = 0.210$ year^{-1} and $t_0 = -1.88$ year for males, and $L_\infty = 303.4$, $K = 0.256$ year^{-1} and $t_0 = -3.05$ year for females. The main spawning season was estimated as between May and October, since greater values of gonado-somatic index for females as well as maturation oocytes and/or postovulatory follicles were observed during those six months.

Keywords Snapper · *Lutjanus gibbus* · Age · Growth · Reproduction

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Introduction

Snappers (Lutjanidae) are one of the most important resources for fisheries in tropical and subtropical regions, such as Caribbean and Indo-Pacific waters (Allen 1985). Several previous studies have clarified their spawning, settlement, feeding habits, feeding behavior, home range, age and growth (e.g., Denit and Sponaugle 2004; Kritzer 2004; Heyman et al. 2005; Shimose and Tachihara 2005; Nanami and Yamada 2008a, b, 2009). Some previous studies have examined the age and growth of lutjanid species (e.g., Burton 2000; Patterson et al. 2001; Wilson and Nieland 2001; Grandcourt et al. 2006). The maximum ages for lutjanid species are species specific, and estimates range from 4 to >30 years (Manooch 1987; Newman et al. 2000a, b; Burton 2002; Shimose and Tachihara 2005; Amezcua et al. 2006). The maximum length of females is larger than that of males for some lutjanid species, such as *Lutjanus analis* and *Lutjanus fulviflammus* (Burton 2002; Shimose and Tachihara 2005). In contrast, several other studies have shown that the maximum length of males is larger than that of females in species such as *Lutjanus carponotatus* and *Lutjanus guttatus* (Newman et al. 2000a; Amezcua et al. 2006). Thus, the relationship between age and length appears to be species specific.

Spawning season in lutjanid species has been reported for several study sites (Grimes 1987; Johannes 1978; Kaunda-Arara and Ntiba 1997; Shimose and Tachihara 2005; Fry et al. 2009). Such ecological information is useful for fisheries management, because estimating the spawning season is important for estimating reproductive effort.

The humpback red snapper, *Lutjanus gibbus*, is distributed widely in the western Pacific and eastern Indian Ocean (Allen 1985), and is an important fisheries species in the Okinawan region (Masuda et al. 1984). However, little is

known regarding the age, growth and reproduction of this species. The purpose of the present study was to (1) describe the relationship between age and growth, (2) and describe the seasonal changes in oocyte development for *L. gibbus* off Ishigaki Island, southern part of Okinawa.

Materials and methods

Sample collection and laboratory methods. Biological data were collected from specimens purchased from commercial catches made off the coast of Ishigaki Island, Okinawa, Japan between November 2005 and July 2009. All specimens were caught around Ishigaki Island. All specimens ($n = 626$; 245 males and 381 females) were measured for fork length (FL, mm), whole body weight (g) and gonad (ovary) weight (nearest 0.01 g). Sagittal otoliths were extracted, cleaned in water and dried. Ovaries were removed from the specimens and preserved in 20% buffered formalin.

Age and growth. Sagittal otoliths for all specimens obtained between November 2005 and July 2009 (179–391 mm FL for males and 177–324 mm FL for females) were sectioned transversely into 0.2–0.3 mm thick sections using whetstones (#250, #1000 and #6000). Alumina powder (0.3 μm) and a Buehler polishing cloth were used for final otolith preparations. Sectioned otoliths were observed under the microscope with reflected light (4× to 20× magnifications), and opaque rings were counted. Otolith edges were also observed and judged to be opaque or translucent. As a rule, the numbers of opaque rings of sagittal otoliths were counted twice, and only results that were in agreement were used for the present analysis.

Von Bertalanffy growth curves (von Bertalanffy 1938) were fitted to length-at-age data, applying the least-squares method of the Microsoft Excel Solver routine with the Newton algorithm option. The von Bertalanffy growth equation is as follows: $L_t = L_\infty\{1 - \exp[-K(t - t_0)]\}$, where L_t is the mean FL (mm) at age t, L_∞ is the asymptotic mean FL, K is the growth coefficient, and t_0 is the age at which the mean FL is zero.

FL and whole body weight were plotted and fitted with a power function using the least-squares method and data from samples obtained between April 2007 and April 2009 ($n = 162$ for males and $n = 249$ for females). The relationship was as follows: whole body weight $= a$ FL^b, where a and b are coefficients.

Reproductive activity. In order to confirm reproduction for *Lutjanus gibbus*, samples obtained between May 2008 and April 2009 were used in the analysis. Gonadosomatic index (GSI) for females was calculated using the formula: gonad weight (g)/[whole weight (g) − gonad weight (g)] × 100. Small pieces of the ovaries were placed in 20% buffered formalin for 48 h and then kept in 70% ethanol baths. Embedded pieces of the ovaries were sectioned serially at 5–10 μm and stained with Mayer's hematoxylin–eosin. Oocyte development was classified to six stages. These were peri-nucleolus stage, oil-droplet stage, primary yolk stage, secondary yolk stage, tertiary yolk stage and maturation oocytes. The presence of postovulatory follicles was also recorded.

Results

Age and growth. A total of 626 samples were aged, with body sizes ranging from 179 to 391 mm FL for males ($n = 245$) and 177 to 324 mm FL for females ($n = 381$). Alternate translucent and opaque zones were observed for all otoliths (Fig. 1). For all otoliths, an opaque zone at the edge of the otolith was found predominantly from May to August (Fig. 2), thus indicating that increment formation occurred once a year. Because the season for increment formation was consistent with the spawning season in the present study (see below), the estimated ages were corrected as follows: the individuals obtained between May and August were regarded as exact ages. The ages of individuals obtained between September and December, and between January and April, were corrected as the number of increments +0.33 years and the number of increments +0.67 years, respectively. After the corrections, von Bertalanffy growth formulae were calculated. The derived von Bertalanffy growth formulae were as follows (Fig. 3):

Male: $L_t = 390.5\ \{1 - \exp[-0.210\ (t + 1.88)]\}$ ($R_a^2 = 0.969$)
Female: $L_t = 303.4\ \{1 - \exp[-0.256\ (t + 3.05)]\}$ ($R_a^2 = 0.833$)

The length–weight relationships were as follows:

Male: whole body weight $= 7.31 \times 10^{-6}$ FL$^{3.189}$ ($R_a^2 = 0.985$)
Female: whole body weight $= 1.05 \times 10^{-5}$ FL$^{3.127}$ ($R_a^2 = 0.953$)

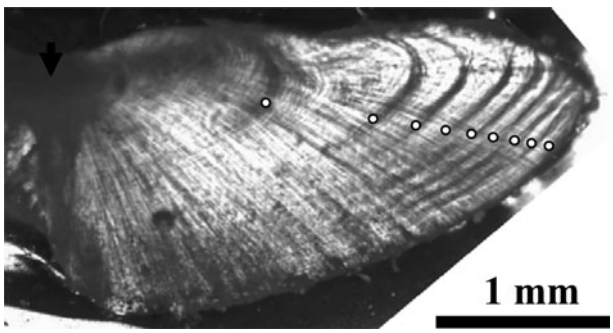

Fig. 1 Transverse section of a sagittal otolith of *Lutjanus gibbus*, showing opaque zones (*white dots*) and core (*white arrow*)

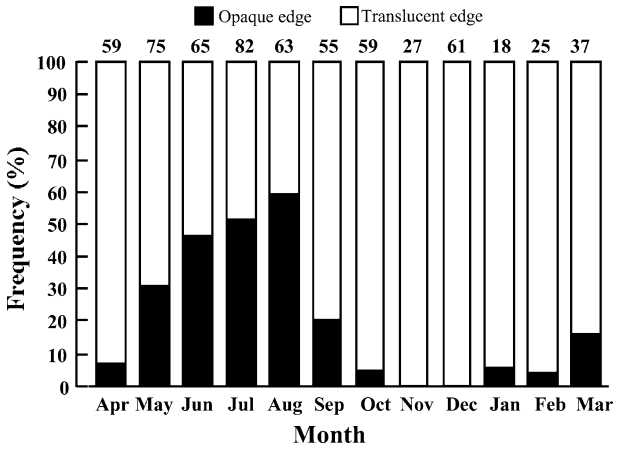

Fig. 2 Monthly changes in the frequencies of different otolith edge conditions for *Lutjanus gibbus*. *Numbers above plots* represent numbers of samples. Data obtained between November 2005 and April 2009 were combined

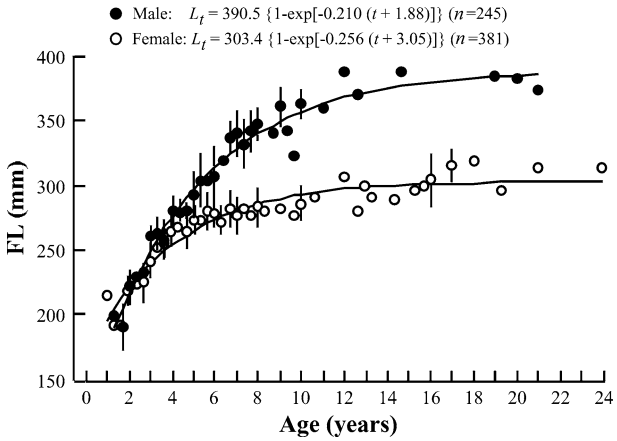

Fig. 3 von Bertalanffy growth curves for males and females of *Lutjanus gibbus*. *Bars* represent standard deviations

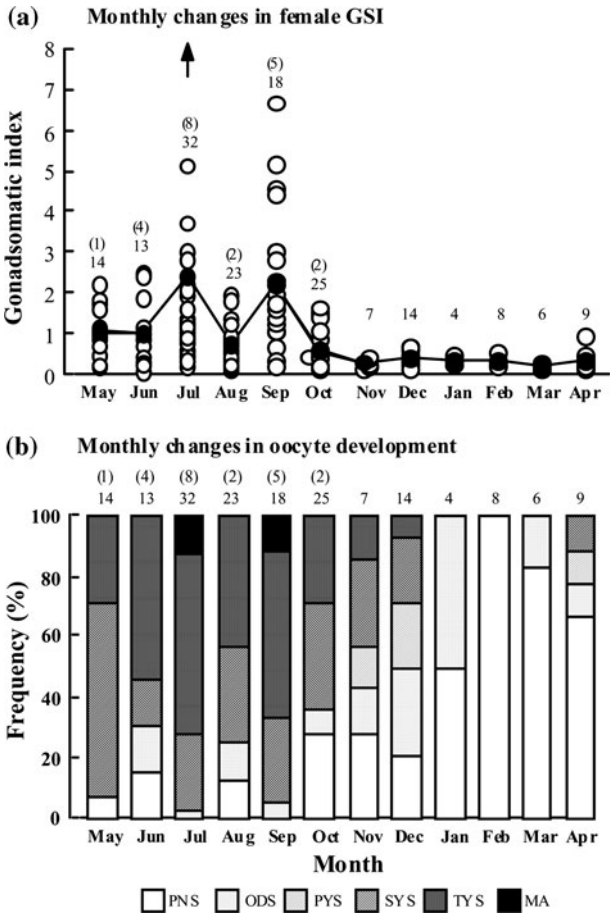

Fig. 4 Monthly changes in gonadosomatic index (GSI) (**a**), and monthly changes in the frequency of the gonadal phase for females (**b**) of *Lutjanus gibbus*. *Numbers above symbols and bars* and *numbers in parentheses* represent numbers of samples and numbers of ovaries with postovulatory follicles, respectively. *White and black circles* represent individual values and average values, respectively. Since the GSI values for three individuals obtained in July were greater than 10 (i.e., 10.51, 12.07 and 15.67), the GSI values for the three individuals are indicated by *an arrow*. *PNS* peri-nucleolus stage, *ODS* oil-droplet stage, *PYS* primary yolk stage, *SYS* secondary yolk stage, *TYS* tertiary yolk stage, *MA* maturation oocytes

Seasonal changes in female GSI and stage composition of oocytes. Figure 4a indicates the monthly changes in female GSI. The GSI for females ranged from 0.05 to 15.67. The GSI was generally higher between May and October, and lower between November and April. Monthly changes in the frequency of the gonadal phase for females are shown in Fig. 4b. Developed oocytes such as those at tertiary yolk stage were observed between May and December, and mature oocytes were observed in July and September (Fig. 4b). Postovulatory follicles were found in the samples obtained between May and October (Figs. 4b, 5c).

Discussion

At Ishigaki, Okinawa, increment formation on *Lutjanus gibbus* otoliths occurred between the months of May and August. These months correspond to the observed spawning season of this species. This result is consistent with that obtained for *L. fulviflammus* on an Okinawan coral reef (Shimose and Tachihara 2005), although some previous studies showed that the increment formed in the colder months for some lutjanid species (Newman et al. 1996). The maximum estimated ages of male and female *L. gibbus* were 21 and 24 years, respectively. Similar results were obtained for several lutjanid species elsewhere, including Okinawa and Australia's Great Barrier Reef, thus indicating that the average maximum age of lutjanids is around 20 (Newman et al. 2000a; Shimose and Tachihara 2005). In contrast, other lutjanid species have been reported to show

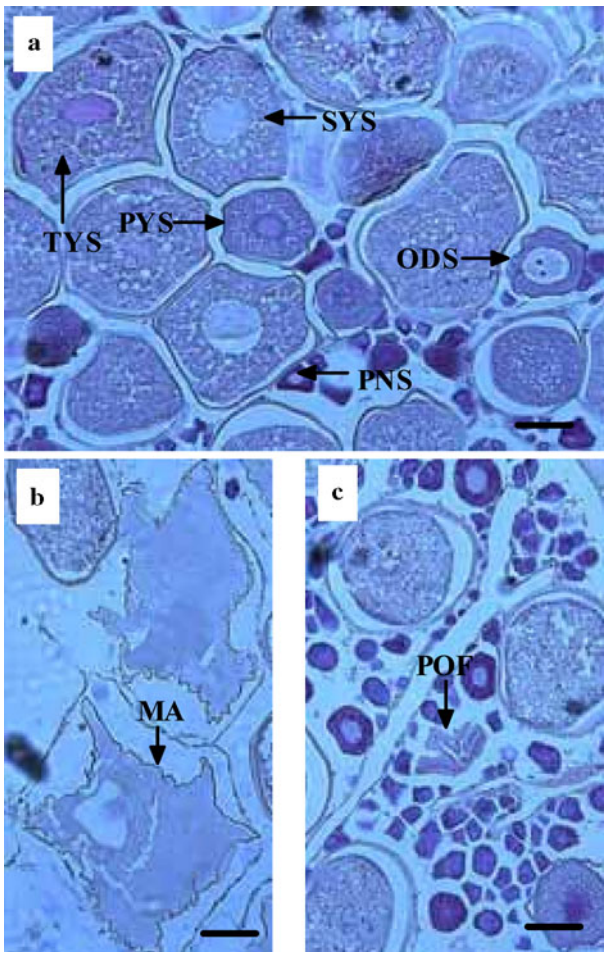

Fig. 5 Histological sections of ovaries for *Lutjanus gibbus*. **a** Five stages (peri-nucleolus stage, oil-droplet stage, primary yolk stage, secondary yolk stage and tertiary yolk stage); **b** maturation oocytes; **c** postovulatory follicles. *PNS* peri-nucleolus stage, *ODS* oil-droplet stage, *PYS* primary yolk stage, *SYS* secondary yolk stage, *TYS* tertiary yolk stage, *MA* maturation oocytes, *POF* postovulatory follicles. *Bar*: 100 μm

longer maximum ages (>30 years) or shorter maximum ages (<15 years) (Newman et al. 2000a, b; Amezcua et al. 2006; Grandcourt et al. 2006). This inconsistency of maximum age among lutjanid species may not be related to latitudinal differences between study sites, since Newman et al. (2000a) have indicated that the maximum ages are 20 and 12 for *L. carponotatus* and *L. vitta*, respectively, on the Great Barrier Reef. Thus, the maximum age of each species may likely be species-specific and not influenced by latitude.

For some lutjanid species, males have been shown to grow larger than females (McPherson and Squire 1992; Newman et al. 1996), and this was true for *L. gibbus* at Ishigaki, Okinawa. In contrast, other previous studies have shown that females grow larger than males (Grimes 1987; Burton 2002; Shimose and Tachihara 2005; Grandcourt et al. 2006). Thus, sex differences in growth exist among species.

The GSI between May and October was higher than that between November and April, and oocyte maturation was observed in July and September. In addition, postovulatory follicles were found between May and October. Thus, it is suggested that the main spawning season of *L. gibbus* is a six-month period between May and October. Since the newly settled juveniles of the species were found six times and clear lunar synchronicity of the settlement was found during the study periods (Nanami, unpublished data), it is suggested that the spawning of the species occurs once per month, and spawning occurs several times per year. Several previous studies have demonstrated that gonadal development and/or spawning occurs over a period of several months (Heyman et al. 2005; Shimose and Tachihara 2005). Grimes (1987) showed that the seasonality of reproduction for lutjanid species has two patterns: (1) a restricted season centered around summer, and (2) more or less continuous year-round spawning with peaks of reproductive activity in the spring and fall. The results of the present study are consistent with the former case. Further data, such as data on total mortality and fishing mortality, is needed for the effective management of this species.

Acknowledgments We express our grateful thanks to S. Sakihara and T. Sakihara for their assistance in collecting samples, M. Mukai for the laboratory work, and the staff of Ishigaki Tropical Station, Seikai National Fisheries Research Institute, for its support during the present study. Constructive comments on the manuscript from K. Yoseda were much appreciated. We also thank the Yaeyama Fishermen's Cooperative Association for permission to collect the samples.

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