Species in the family Lutjanidae (snappers) are important targets of fisheries around the world. Although the checkered snapper *Lutjanus decussatus* is distributed across the Indo-Pacific, little is known about the demographic parameters of this species. Thus, the age, growth, and length–weight relationship of the checkered snapper *L. decussatus* (family Lutjanidae) were investigated in an Okinawan coral reef. Alternate translucent and opaque zones were observed in all sectioned otoliths, with an opaque zone occurring at the edge of the otolith predominantly during the spawning season. The maximum ages of the male and female were 24 and 23 years, respectively. The von Bertalanffy growth parameters for the relationship between age and fork length (FL) were as follows: asymptotic mean FL ($L_\infty$) = 288.3 mm, growth coefficient ($k$) = 0.09 year$^{-1}$, and age when mean FL is 0 ($t_0$) = −12.0 years in males; $L_\infty$ = 316.5 mm, $k$ = 0.08 year$^{-1}$, and $t_0$ = −12.1 year in females. In the case that the growth parameters were re-estimated using a fixed $t_0$ value of 0, $L_\infty$ = 256.1 mm, and $k$ = 0.54 year$^{-1}$ in males; $L_\infty$ = 274.4 mm, and $k$ = 0.45 year$^{-1}$ in females. $L_\infty$ was significantly greater in females than in males, but there were no significant inter-sexual differences in $K$ or $t_0$. The length–weight relationships for males and females were $10^{-3}$ FL$^{1.05}$, respectively. The present study is the first to demonstrate the age, growth, and length–weight relationship of *L. decussatus*, which would be useful biological information for the effective management of this species.

**Keywords** *Lutjanus decussatus*, age, growth, length–weight relationship

### Introduction

Clarifying the relationship between the age and growth of organisms is central to understanding their demographic features (e.g., maximum age, maximum length, and inter-sexual differences in growth) and enables the effective management of various fisheries. In addition, an understanding of the length–weight relationship of organisms is also important for effective fisheries management, as the biomasses of fisheries stocks are estimated from length data. However, the age and growth, and the length–weight relationships of many of the diverse array of marine species around the world remain unknown.

Species in the family Lutjanidae (snappers) are important targets of fisheries around the world, particularly in tropical and sub-tropical waters (Polovina and Ralston
Since the age estimations revealed that age of all samples are greater than or equal to 2 (see Results), the above-mentioned estimated growth parameters might not predict the initial growth of the younger fishes (i.e. age are less than 2). This was probably because the samples were obtained by fishery-dependent method (hook-and-line and/or spears). Thus, the growth parameters were re-estimated using a fixed \( t_0 \) value of 0.

**Length–weight relationship**

The relationship between FL and whole-body weight was described by the following power function: whole...
body weight = aFL^b, where a and b are coefficients. To clarify the length–weight relationship, a generalized linear model (GLM) was fitted to the data using the R statistical computing language (R Core Team 2017). For this analysis, the data were assumed to have a gamma distribution and the log link function was applied.

**Results and Discussion**

Alternate translucent and opaque zones were observed in all otoliths, with an opaque zone occurring at the edge of the otolith predominantly from July to September (Fig. 2), indicating that increment formation takes place once per year. The maximum ages of the males and females were 24 and 23 years, respectively. The derived von Bertalanffy growth formulas were as follows (Fig. 3):

**Males:**
\[ L = 288.3 \left(1 - \exp\left[-0.09(t + 12.0)\right]\right) \]  \( R^2 = 0.907 \)

**Females:**
\[ L = 316.5 \left(1 - \exp\left[-0.08(t + 12.1)\right]\right) \]  \( R^2 = 0.873 \)

\( L_\infty \) was significantly greater in females than in males \((p < 0.05)\), whereas there were no significant differences in \( K \) or \( t_0 \) between the sexes \((p > 0.05)\).

The re-derived von Bertalanffy growth formulas by using a fixed \( t_0 \) \((t_0 = 0)\) were as follows (Fig. 3):

**Males:**
\[ L = 256.1 \left[1 - \exp(0.54t)\right] \]  \( R^2 = 0.867 \)

**Females:**
\[ L = 274.4 \left[1 - \exp(0.45t)\right] \]  \( R^2 = 0.874 \)

The GLM analysis revealed the following length–weight relationships for males and females (Fig. 4):

**Males:**
\[ \text{Whole body weight} = 4.95 \times 10^{-5} \text{FL}^{2.83} \]  \( R^2 = 0.959 \)

**Females:**
\[ \text{Whole body weight} = 1.44 \times 10^{-5} \text{FL}^{3.05} \]  \( R^2 = 0.958 \)

Numerous studies have shown the age and growth of lutjanid species owing to their great importance as fishery targets in tropical and sub-tropical waters (Polovina and Ralston 1987; Piddocke et al. 2015). However, no studies have examined the demographic features of *L. decussatus* in any country to date. Thus, the present study is the first to demonstrate the age, growth, and length–weight relationship of this species.

The increment formation period in the otoliths of *L. decussatus* corresponded with the spawning season, which coincides with other lutjanid species, e.g., *Lutjanus fulviflamma* (Forsskål, 1775) in the southern Arabian Gulf (Grandcourt et al. 2006), *Lutjanus griseus* (Linnaeus, 1758) in western Florida (Allman and Goetz 2009), *Lutjanus campechanus* (Poey, 1860) in eastern Florida (White and Palmer 2004), and *Lutjanus gibbus* (Forsskål, 1775) in Okinawa (Nanami et al. 2010a). In contrast, this phenomenon has not been shown in other species, e.g., *Lutjanus. adetii* (Castelnau, 1873) and *Lutjanus. quinquelineatus* (Bloch, 1790) in the central Great Barrier Reef, Australia (Newman et al. 1996). Thus, it is suggested that the coincidence between otolith increment formation and the spawning season among lutjanid species is species-specific or region-specific.

The male and female *L. decussatus* had maximum ages of 24 and 23 years, respectively, which are similar to other lutjanid species in Okinawa (*L. fulviflammus* and *L. gibbus*: Shimose and Tachihara 2005; Nanami et al. 2010a) and the Great Barrier Reef (*L. adetii*: Newman et al. 1996). In contrast, several lutjanid species in other regions showed shorter or longer maximum ages than those of *L. decussatus*. The maximum ages of *Lutjanus rufolineatus* (Valenciennes, 1830) in American Samoa and *L. fulviflamma* in the Arabian Gulf are 12 and 14, respectively (Grandcourt et al. 2006; Taylor et al. 2018), whereas the maximum ages of *L. quinquelineatus* in the Great Barrier Reef and *Lutjanus fulvus* (Forster, 1801) in Okinawa are 31 and 34, respectively (Newman et al. 1996; Shimose and Nanami 2014). Thus, it appears that the maximum ages differ among lutjanid species.

The female *L. decussatus* had significantly larger FLs than the males, which corresponded with *Lutjanus analis*
Nanami: Age and growth of *Lutjanus decussatus*

In Florida (Burton 2002), *L. fulviflamma* in the Arabian Gulf (Grandcourt et al. 2006), and *L. fulvus* in Okinawa (Shimose and Nanami 2014). In contrast, males grow larger than females in *Lutjanus sabae* (Cuvier, 1816), *L. malabaricus* (Schneider, 1801), and *L. quinquelineatus* in the Great Barrier Reef (McPherson and Squire 1992; Newman et al. 1996), and in *L. gibbus* in Okinawa and American Samoa (Nanami et al. 2010a; Taylor et al. 2018). Thus, sexual differences in growth is also species-specific for lutjanid species.

These sexual differences in growth would affect concrete strategies for the effective management of lutjanid species. In *L. decussatus*, it has been shown that larger females produce greater number of eggs than smaller females (Nanami et al. 2010b). Considering the larger growth of females than males for this species, it is suggested that traditional fishery management tools such as size restriction may not be effective for this species.

**Fig. 3** von Bertalanffy growth curves for male (a) and female (b) *Lutjanus decussatus*. Two estimated growth curves were shown (black lines and dotted lines). Black line: estimated growth curves in which all three parameters (*L*∞, k and *t*0) were estimated. Dotted line: estimated growth curves in which two parameters (*L*∞ and k) were estimated whereas *t*0 was fixed as 0 (see Materials and Methods).

**Fig. 4** Length–weight relationship of *Lutjanus decussatus*
Instead, marine protected areas that enable the protection of individuals across all size classes would be a more effective management tool, as *L. decussatus* has distinct home ranges and relatively high site fidelity (Nanami and Yamada 2008).

The present study also revealed the length–weight relationships for male and female *L. decussatus*, which will be useful for allowing biomass estimations to be made from length data. The demographic features revealed in the present study would be useful for the effective management of this species when they are combined with precise data about size frequency as well as the total annual catch per year. Furthermore, since growth parameters and the length–weight relationship sometimes show regional differences, the demographic features of this species should be extensively studied in a range of areas to gain a more comprehensive understanding of them.

**Compliance**

Since all samples were collected from commercial catches, no legal requirements as well as local regulations were needed.

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