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# Reproductive traits of deep-sea snappers (Lutjanidae): Implication for Okinawan bottomfish fisheries management

Masato Uehara [a,b,*], Akihiko Ebisawa [a,c], Itaru Ohta [a,d]

[a] Okinawa Prefectural Fisheries Research and Extension Center, 1528 Kiyan, Itoman, Okinawa 901-0354, Japan
[b] Motobu substation of Okinawa Prefectural Fisheries Research and Extension Center, 853-1 Ohama, Motobu, Okinawa 905-0212, Japan
[c] Ishigaki Branch Station of Okinawa Prefectural Fisheries Research and Extension Center, 828-2 Kabira, Ishigaki, Okinawa 907-0453, Japan
[d] Fisheries Section, Okinawa Prefectural Government, 1-2-2 Izumizaki, Naha, Okinawa 900-8570, Japan

## HIGHLIGHTS

- We revealed the reproductive profiles of four Okinawan deep-sea snappers: *Etelis coruscans Paracaesio caerulea*, *Pristipomoides filamentosus*, and *Pr. sieboldii*.
- They have long spawning seasons and are iteroparous.
- Their reproductive activity coincided with seasonal sunlight duration changes.
- *E. coruscans* and *Pa. caerulea* were lunar-related spawners.
- *E. coruscans* and *Pa. caerulea* sexual maturity was slower vs. the two *Pristipomoides*.

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## ABSTRACT

We examined the reproductive cycle, sexuality, and length at 50% maturity ($L_{50}$) of the deep-sea snappers *Etelis coruscans*, *Paracaesio caerulea, Pristipomoides filamentosus*, and *Pr. sieboldii* from Okinawan waters based on gonadal histology. The overall sex ratios of *E. coruscans* and *Pr. sieboldii* were significantly female-biased, whereas those of *Pa. caerulea* and *Pr. filamentosus* were not significantly sex-biased. The spawning season was estimated to occur from May to November for *E. coruscans*, from April to September for *Pa. caerulea*, and from March to October for *Pr. filamentosus* and *Pr. sieboldii*. Their initial reproductive activity coincided with an increase in sunlight duration. Of the four species examined, *E. coruscans* and *Pr. filamentosus* indicated significant peaks of spawning around a specific lunar phase. We observed the presence of multiple oocyte maturation stages with postovulatory follicles (POFs) during the spawning season of each species. Transitional gonads were not observed in these four snappers. The $L_{50}$ of the females and males were 67.1 cm fork length (FL) and 37.6 cm FL for *E. coruscans*; 34.8 cm FL and 26.1 cm FL for *Pa. caerulea*; 35.7 cm FL and ≥20.0 cm FL for *Pr. filamentosus*; and 24.6 cm FL and ≥24.0 cm FL for *Pr. sieboldii*, respectively. Thus, the reproductive traits of *E. coruscans, Pa. caerulea, Pr. filamentosus and Pr. sieboldii* are characterized by a long spawning season and iteroparity. The *E. coruscans* and *Pa. caerulea* show relatively slow maturation compared to the two species of *Pristipomoides*. The implications of our results vis-à-vis the conservation and management of Okinawan bottom fisheries are discussed.



## 1. Introduction

The family Lutjanidae (Perciformes), commonly known as snappers, are important commercial target fishes living in shallow water to depths of approx. 550 m of both the Atlantic and Indo-Pacific, and 17 genera with approx. 105 species have been recognized in four subfamilies (Allen, 1985; Anderson, 2003; Anderson and Allen, 2001; Nelson, 2006; Polovina and Ralston, 1987). In Japan's Okinawa, the deep-sea snapper complex provides a regional fishery yielding high-value seafood, and the group comprises approx. 17 species belonging to the six genera *Aphareus*, *Aprion*, *Etelis*, *Paracaesio*, *Pristipomoides*, and *Randallichthys* in the family Lutjanidae (see Sata, 1991). Of these genera, *Etelis coruscans*, *Paracaesio caerulea*, *Pristipomoides filamentosus*, and *Pr. sieboldii* are the dominant species at the Okinawan deep-sea bottomfish fisheries such as vertical longline and trotline, accounting for over 90% of deep-sea bottomfish catches (the catch statistics of Okinawa

* Corresponding author at: Motobu substation of Okinawa Prefectural Fisheries Research and Extension Center, 853-1 Ohama, Motobu, Okinawa, 905-0212, Japan.
*E-mail address:* ueharmst@pref.okinawa.lg.jp (M. Uehara).

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Prefectural Fisheries Research and Extension Center). Their snappers' primary habitat is at the slope and margin of the continental shelf, island shelf, and banks at 100–400-m depths throughout the Ryukyu Archipelago.

Near Japan, the growth and reproductive biology of *E.coruscans* were studied in the Okinawan waters (Ebisawa et al., 2010) and the growth, feeding habits, reproduction, and movement of *Pa. caerulea* were researched in the Izu Islands (Tokyo Fisheries Experimental Station, 1974). In addition to these biological traits, the stock assessment and fisheries information of four commercially important deep-sea snappers, *E. coruscans*, *Pa. caerulea*, *Pr. filamentosus*, and *Pr. sieboldii*, has been well reported in the Okinawan waters (Uehara et al., 2012, 2013, 2015a, b, 2017a, b, c) and the Izu Islands (Tokyo Fisheries Experimental Station, 1974).

In contrast, there is surprisingly many information on the biology and fisheries in other Indo-Pacific regions. Three species of these four deep-sea snappers, *E. coruscans*, *Pr. filamentosus*, and *Pr. siebolldii*, have been well studied on the Hawaiian Archipelago and the Mariana Islands for the determination of the fish' age and growth (Andrews et al., 2011, 2012; DeMartini et al., 1994; Moffitt and Parrish, 1996; Radtke, 1987; Ralston, 1981; Ralston and Miyamoto, 1983; Uchiyama and Tagami, 1984; Williams and Lowe, 1997), reproductive biology (DeMartini, 2016; DeMartini and Lau, 1999; Everson et al., 1989; Kikkawa, 1984; Luers et al., 2017; Ralston, 1981; Uchiyama and Tagami, 1984), habitat (Merritt et al., 2011; Misa et al., 2013; Moffitt and Parrish, 1996), the identification of juveniles (Parrish, 1989), genetic connectivity (Gaither et al., 2011; Loeun et al., 2014), movement (Kobayashi, 2008; Parrish et al., 2015; Weng, 2013), and stock assessment and fisheries management (Brodziak et al., 2011; Friedlander et al., 2014; Grandcourt, 1995; Langi, 1990; Mees, 1993; Mees and Rousseau, 1997; Moore et al., 2013; Polovina, 1987; Ralston, 1981; Sackett et al., 2014; Williams et al., 2012, 2013, 2015; Zeller et al., 2008).

Although these four snappers have been placed on the International Union for the Conservation of Nature Red List in the 'lower extinction' rank (least concern) or 'data deficient' category (Acero, 2010; Russell et al., 2016a, b, c), there is some evidence that over-exploitation has substantially reduced the stock biomass of these snappers throughout the Indo-Pacific regions (Brodziak et al., 2011; Dalzell and Preston, 1992; Polovina, 1987; Uehara et al., 2017a, b; Williams et al., 2012). Especially, in the Hawaiian Islands, the deep-sea snappers and groupers including *E. coruscans*, *Pr. filamentosus*, and *Pr. siebolldii* are known as the "Deep 7" and are managed by marine protected areas and total allowable catch (TAC) regulations (Friedlander et al., 2014; Sackett et al., 2014). The catches of these four snappers in Okinawa has drastically decreased to approx. 25%, i.e., from 1225 metric tons in 1980 to 319 metric tons in 2016 at the central market at Naha, the largest fish auction market in Okinawa Prefecture (Kiyan, 1987; the catch statistics of Okinawa Prefectural Fisheries Research and Extension Center). Given this status, two deep-sea snapper restricted areas (DSRAs) around the Okinawan waters were established in 2005 by the agreement of fishermen for the protection of spawning capable adults and reducing fishing effort. Three DSRAs have been added around the Okinawan waters since 2010, and voluntary local rules concerning the size limit (fork length) for fishing have been introduced by local fishermen. Thus, there are growing concerns about the fisheries management of *E. coruscans*, *Pa. caerulea*, *Pr. filamentosus*, and *Pr. sieboldii*. However, information on biology of the population around Okinawan waters is available only for *E. coruscans* (see Ebisawa et al., 2010); therefore, the clarification of detailed biological traits for *Pa. caerulea*, *Pr. filamentosus*, and *Pr. sieboldii* is urgently needed.

In specific, reproductive traits such as length at maturity and spawning season would be fundamental to understand of the life history and it would be an essential for fisheries management. Lunar-related spawning have also been identified among the many coastal lutjanid fish (D'Alessandro et al., 2010; Davis and West, 1993; Nanami et al., 2010; Randall and Brock, 1960; Reshetnikov and Claro, 1976; Shimose and Nanami, 2014; Strack and Schroeder, 1971; Suzuki and Hioki, 1979), but information is available only for a deep-sea lutjanid fish (*Etelis oculatus*) (D'Alessandro et al., 2010). The elucidation of spawning rhythms (lunar, semi-lunar, and the others) will be as an important step in fishery management strategies.

The specific objectives of the present study were to establish the reproductive traits of *E. coruscans*, *Pa. caerulea*, *Pr. filamentosus*, and *Pr. sieboldii* from Okinawan waters by histological assessment, particularly to determine the spawning season, spawning rhythm, sexuality, and length at maturity of each of these species, and to consider their conservation and management.

## 2. Materials and methods

### 2.1. Study site

The Ryukyu Archipelago is located at the southwestern part of Japan's mainland and extends approx. 1200 km southwest from the southern mainland of Japan to northwestern Taiwan (Fig. 1). The Archipelago defines the boundary between the East China Sea and the Pacific Ocean and consists of three islands: the Satsunan Islands (Tanegashima Island to Yoron Island), the Okinawa Islands (Okinawa Island and adjacent small islands), and the Sakishima Islands (Miyako, Ishigaki, Iriomote, Yonaguni Islands and adjacent small islands).

In Okinawan waters, deep-sea snappers such as *E. coruscans*, *Pa. caerulea*, *Pr. filamentosus*, and *Pr. sieboldii* are widely caught on natural banks around the Okinawa and Sakishima Islands and the continental shelf including the Senkaku Islands throughout the year by vertical longline and by trotline. The fishing grounds for the four species were classified as follow (Fig. 1): middle Ryukyu for the Okinawa Islands; south Ryukyu for the Hozan–Taikyu banks and the Sakishima Islands; and the continental shelf including the Senkaku Islands (Uehara et al., 2012, 2013, 2015a, 2017c). These three major fishing grounds account for >90% of the total catch for the four species in Okinawa Prefecture (Fisheries Statistics Database of the Okinawa Prefectural Fisheries Research and Extension Center).

### 2.2. Collection and preparation of sample

From April 2004 to January 2015, a total of 1829 deep sea snappers was collected from Okinawan waters. Of these, 1331 fish (*E. coruscans*, $n = 444$; *Pa. caerulea*, $n = 269$; *Pr. filamentosus*, $n = 261$; *Pr. sieboldii*, $n = 357$) were obtained at the Tomari fish market and the fish market of Itoman Fishery Cooperative Association. These specimens had been caught by commercial fishermen conducting vertical longline and trotline fishing. We collected the remaining 498 specimens (*E. coruscans*, $n = 374$; *Pa. caerulea*, $n = 20$; *Pr. filamentosus*, $n = 59$; *Pr. sieboldii*, $n = 45$) using trotline aboard the Okinawa Prefectural Government's research vessel *Tonan-maru* (176 ton) from August 2006 to October 2014. The fishing grounds of these fishes were in south Ryukyu for *E. coruscans* and *Pa. caerulea* and in south Ryukyu, middle Ryukyu, and the slope and margin of the continental shelf (including the Senkaku Islands) for *Pr. filamentosus* and *Pr. sieboldii*.

All fresh specimens were transported to the laboratory on ice in a cooler, and their standard length (SL; to the nearest 1 mm), fork length (FL; to the nearest 1 mm), body weight (BW; to the nearest 1 g), and gonad weight (GW; to the nearest 0.01 g) were measured. The gonads were fixed in Bouin' s solution and stored