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Short Communication

Size at maturity of the Pacific bearded brotula (Ophidiidae: *Brotula clarkae*): a commercially exploited species in the Pacific of Costa Rica

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ABSTRACT. The deep-water shrimp fishery is of great commercial importance along the Pacific coast of Latin America. In Costa Rica, shrimp resources have declined considerably over the last decade. Therefore, fisheries have shifted towards teleost species such as the Pacific bearded brotula *Brotula clarkae.* Little is known about the biology and life history of this species, which is becoming increasingly valuable to artisanal and semi-industrial fishers in Costa Rica. A sample of 348 *B. clarkae* was obtained along the Pacific coast of Costa Rica between March 2011 and July 2012 to obtain baseline information of this species. The results revealed that the size at sexual maturity of *B. clarkae* was 71.9 cm T_L, considerably higher than previously reported for South American populations. Since the size at maturity may vary between populations in different geographic locations, detailed information of the reproductive biology of widely distributed species such as *B. clarkae* is critical for developing effective management approaches.

Keywords: *Brotula clarkae***,** size at maturity, reproductive aggregations, latitudinal variation, Eastern Tropical Pacific, Costa Rica.

Talla de madurez sexual del congrio rosado (Ophidiidae: *Brotula clarkae*): una especie de importancia comercial en el Pacífico de Costa Rica

RESUMEN. La pesca de camarón de aguas profundas es de gran importancia comercial en la costa Pacífica de Latinoamérica. En Costa Rica, el recurso camarón ha disminuido considerablemente durante la última década. Como consecuencia, la pesquería ha comenzado a explotar otras especies como, el congrio rosado *Brotula clarkae.* Poco se sabe de la biología de esta especie con valor comercial en las pesquerías artesanales e industriales de Costa Rica. Una muestra de 348 *B. clarkae* fue obtenida a lo largo de la costa Pacífica de Costa Rica entre marzo 2011 y julio 2012 para obtener información base de esta especie. La talla de madurez sexual fue 71.9 cm T_L, siendo considerablemente mayor que la reportada previamente para poblaciones de Sudamérica. Dado que la talla de madurez sexual puede variar entre poblaciones de diferentes áreas geográficas, información acerca de la biología reproductiva de una especie tan ampliamente distribuida es crucial para diseñar estrategias adecuadas de manejo.

Palabras clave: *Brotula clarkae***,** talla de madurez sexual, agregaciones reproductivas, variación latitudinal, Pacífico Tropical Oriental, Costa Rica.

The Pacific bearded brotula, *Brotula clarkae* Hubbs, 1944, is endemic to the Eastern Tropical Pacific and occurs from Palos Verdes, California to Paita, Peru (Lea *et al.*, 2009). The species inhabits soft mud bottoms as adults, and epipelagic waters as juveniles. It can be found at depths between 40 and 650 m (Nielsen

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et al., 1999). Juvenile *B. clarkae* feeds on shrimps and crabs, while the diet of adults is mainly composed of teleosts and stomatopods (Muñoz, 1999; Peña, 2003; Naranjo-Elizondo *et al.*, 2016), echinoderms and mollusks (Chávez-Cevallos & Caballero-Vergara, 2008).

Populations of the commercially exploited deep-water shrimps *Heterocarpus vicarius* (Decapoda: Caridea: Pandalidae) and *Solenocera agassizzii* (Decapoda: Penaeoidea: Solenoceridae) have declined considerably over the past 10 years (Wehrtmann & Nielsen-Muñoz, 2009; Villalobos-Rojas & Wehrtmann, 2011; Wehrtmann *et al*., 2012). Consequently, the fleet has shifted their effort towards shallow-water resources. *Brotula clarkae*, locally known as "congrio rosado", is one of the species that has recently become an important target of the shrimp-trawling fishery in Costa Rica and the Central American region (R. Villalobos, *pers. obs.*).

Despite its increasing commercial importance, both for commercial and artisanal fishers in Costa Rica, basic biological and ecological data on *B. clarkae* is limited (Espinoza & Nielsen, 2006; Naranjo-Elizondo *et al.*, 2016). In fact, the International Union for Conservation of Nature (IUCN) lists the species as data deficient (Lea *et al.*, 2010). Moreover, the few studies available on the species' reproductive biology are restricted to Colombia (Acevedo *et al.*, 2007) and Ecuador (Chávez-Cevallos & Caballero-Vergara, 2008) in South America. The present study estimated the size at first maturity of *B. clarkae* along the Pacific coast of Costa Rica. The size at maturity is a key population parameter and a valuable tool for managing this species both locally and regionally. This information can be used to develop management measures, such as regulations for size restrictions, catch quotas and size selectivity of fishing gear (*i.e.*, to minimize the capture of individuals that have not reached sexual maturity).

Samples of *B. clarkae* were collected between March 2011 and July 2012 as part of an ongoing shrimp fishery-monitoring program conducted along the Pacific continental shelf of Costa Rica (Fig. 1). Specimens were sexed, measured (total length - T_L, cm), and weighed (total weight - T_W, g) (Bussing & López, 1993; Allen & Robertson, 1994). Sex and maturity stage were assessed based on macroscopic observations of the reproductive tract (Brown-Peterson *et al.*, 2011). Males were classified as immature when the testes were thread-like and transparent, smooth and uniformly textured. When mature, testes were large, firm, highly convoluted, and during the spawning season, extruded sperm when compressed. Females were classified as immature when the ovaries were small, clear, and lacking conspicuous blood vessels; mature females had large and pink ovaries with extensive vascularization of the ovary wall. During the spawning season, ovaries had a granular texture and were full of eggs.

The size at first sexual maturity was defined as the size at which 50% of the individuals matured. Size at maturity was estimated by fitting a logistic regression (-a/b) (Conrath, 2005). The proportion of mature individuals in each 2 cm class intervals was fitted using the following equation:

$$Mature = \frac{1}{\sqrt{1 - e^{a + b \times TL}}}$$

where T_L is the total length, a is the intercept and b is the slope (Conrath, 2005). However, due the insufficient number of samples of each sex, size at maturity could not be calculated for males and females separately. Size differences between males and females were examined by plotting the relationship between T_L and T_W. A Student t-test was subsequently applied to corroborate possible differences between slope values of both sexes. If no differences were detected, the size at maturity was estimated for both sexes together.

From the 348 *B. clarkae* collected, 42% of the individuals were males, 40% females, and 18% were undetermined. Size of males ranged from 14.4 to 92.8 cm T_L (mean ± SD; 33.7 ± 17.7), and from 14.5 to 93.0 cm T_L (mean ± SD; 30.9 ± 15.7) for females. Immature individuals (n = 302, 87%) varied in size from 14.4 to 76.3 cm T_L (mean ± SD; 33.3 ± 14.6), and mature individuals from 67.2 to 98.4 cm T_L (mean ± SD; 82.2 ± 7.8). The relationship between T_L and T_W was similar for both males and females (t-test = 0.098, P = 0.922) (Fig. 2a). Size at maturity for *B. clarkae* was estimated at 71.9 cm T_L (68.5-74.5) (Fig. 2b).

Acevedo *et al.* (2007) reported a size at maturity for *B. clarkae* from the Pacific of Colombia of 62.3 cm T_L (60.7-63.8), which is substantially lower than our estimate (71.9 cm T_L). It has been demonstrated that life history traits, such as age and size at maturity, longevity, fecundity, and egg size can change with prolonged periods of exploitation (Rochet, 1998; Law, 2000; Hutchings, 2002). Significant reductions in age and length at maturity have been found in different fish stocks (see reviews by Kuparinen & Merila, 2007; Sharpe & Hendry, 2009). Examples of such changes of life history traits include the Pacific Salmon (*Oncorhynchus* sp.; Ricker, 1981), the North Sea plaice (*Pleuronectes platessa*; Rijinsdorp, 1993), Northwest Atlantic cod (*Gadus morhua*; Hutchings, 2005), and the Scotian shelf haddock (*Melanogrammus aeglefinus*; Neuheimer & Taggart, 2010). In most of these cases, the authors attributed these changes to a genetic response to fishing pressure. *Brotula clarkae* has been exploited for almost 20 years in Colombia (Acevedo *et*

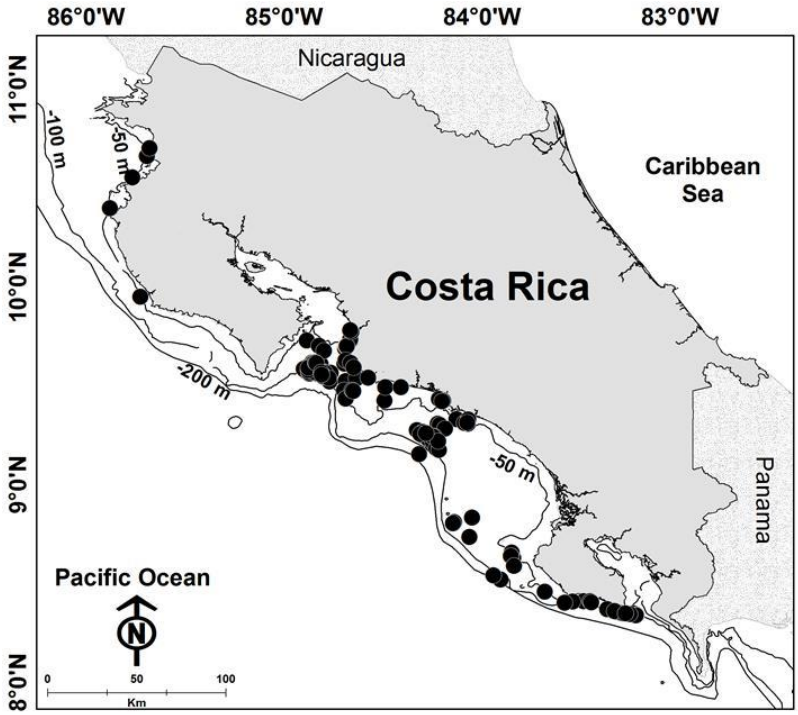

Figure 1. Trawling locations sampled between March 2011 and July 2012 along the Pacific coast of Costa Rica. Depth contours of 50, 200 and 500 m are given.

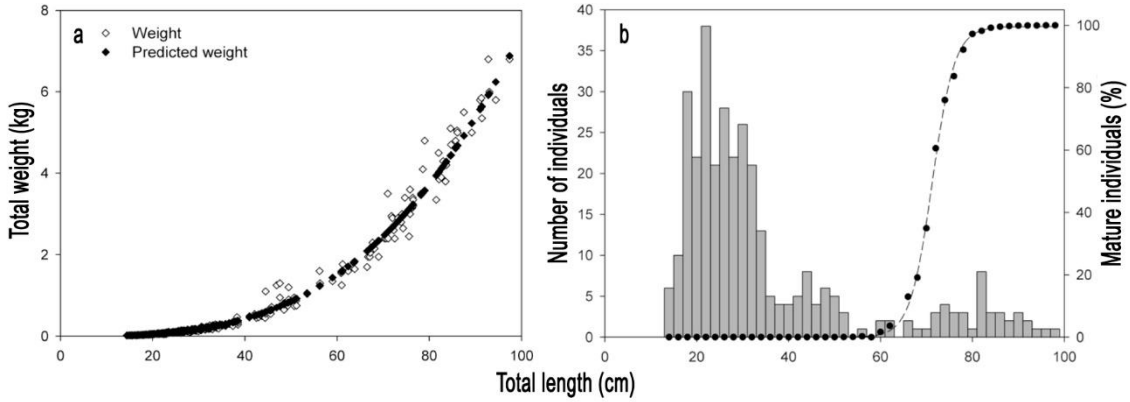

Figure 2. a) Total weight and total length relationship of *Brotula clarkae* (n = 318); b) estimate of size at maturity of *B. clarkae* ($Mature = \frac{1}{\sqrt{1 - e^{26.88 + -0.37 \times TL}}}$) Histograms display the sample size structure (n = 328).

al., 2007), while in Costa Rica this species has only recently become a valuable resource (R. Villalobos, *pers. obs.)*. Therefore, these differences in size at maturity between geographically distinct populations might be interpreted as an indicator of an early exploitation stage of the *B. clarkae* population in Costa Rica.

Age and size at sexual maturity can vary between and within populations because of genotypic and environmental differences between regions (Morgan & Colbourne, 1999; Morgan, 2008). These variations in maturity schedules have been associated with differences in abundance, growth and mortality rates, fishing pressure, and selectivity of fishing gear (Morgan, 2008; Jorgensen *et al.*, 2009). At low population sizes, fish growth rates increase in response to the large abundance of available resources, and therefore mature at younger ages. Likewise, higher

mortality rates can cause a selective pressure towards younger maturation ages (Morgan & Colbourne, 1999). Latitudinal clines in size at maturity have been previously reported in several fish species (Heibo *et al.*, 2005; Lassalle *et al.*, 2008; Chavarie *et al.*, 2010). Therefore, a single report of the size at maturity of such a widely distributed species as *B. clarkae* should not be used to recommend broader management strategies throughout the distribution range of the species.

The vast majority of the specimens obtained in our study were immature individuals of *B. clarkae* (Fig. 1b). Although this species inhabits deep-waters of up to 650 m deep (Nielsen *et al.*, 1999), seasonal reproductive aggregations have been observed to occur in shallow waters, where they are commercially exploited (Clarke *et al.*, 2011). It is likely that the high number of immature individuals captured was during these aggregations, but also due to the non-selectivity of the fishing gear. Jorgensen *et al.* (2009) stated that size selectivity has important evolutionary effects in fisheries as fish that survive pass on their genes to the next generation, then having consequences for the size structure and dynamics of the exploited stocks. For example, trawl-like gears, which are primarily size-selective and remove large fish, tend to select for earlier maturation at smaller size and faster growth (Boukal *et al*., 2008). Gear that only remove fish within a certain size class, such as gillnets, can instead lead to delayed maturation (Boukal *et al*., 2008). This highlights how the regulation of gear selectivity is critical for fisheries management.

Further studies on the reproductive ecology of *B. clarkae* should focus on analyzing spatial and temporal aggregation patterns, as well as identifying essential habitats and spawning seasons. Since *B. clarkae* is currently being targeted by both commercial and artisanal fisheries in the Pacific of Latin America (Puentes *et al.*, 2007; Pro-Ecuador, 2013), including Costa Rica, an adequate knowledge of its distribution and reproductive ecology must be addressed in future studies to achieve sustainable exploitation levels.

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