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Short Communication

Population dynamics of black brotula (*Cherublemma emmelas*) in deep waters of the Gulf of California

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ABSTRACT. First report of the dynamic populations (structure size, growth, size at first maturity, longevity, natural mortality, and recruitment pattern) of black brotula *Cherublemma emmelas* in the Gulf of California. Growth parameters (L_∞, k and t_o) were estimated using the von Bertalanffy model. The ELEFAN II method was used to estimate recruitment pattern and Taylor's equation to estimate longevity. Natural mortality was determined using Pauly's equations and Jensen's. Size at first maturity was obtained by adjusting a logistics model. During four cruises on board the BIP-XI research ship, 2148 specimens were caught at 119-499 m depth in February and May 2005, and June and October 2007. The size structure showed a bimodal distribution with lengths from eight to 32 cm of total length and 15.9 cm average size. The biometric relationship between weight and length showing allometric growth rate ($b \neq 3$) for sex. The fitted growth parameters were L_∞ = 33 cm; k = 0.6 yr^{-1}; t_o = -0.26 year indicated a moderate growth, while longevity was five years of age. Size at first sexual maturity was 18.8 cm, and natural mortality was 0.77 yr^{-1} (by Pauly) and 0.90 (by Jensen). The recruitment pattern showed peaks in June and July.

Keywords: *Cherublemma emmelas*, maturity, growth, mortality, deep-sea, Gulf of California.

At the world level, marine resources in deep waters of the ocean ecosystems have biological and ecological importance. Unfortunately, they are little known, given the high cost of investigations (Acevedo-Cervantes *et al*., 2009; López-Martínez *et al*., 2012). Moreover, fisheries resources in deep waters may be highly vulnerable to fishing (Koslow *et al.,* 2000; FAO, 2010; Zamorano *et al*., 2014), and the lack of knowledge of ecology and demography of deep-sea species may represent a risk for their overexploitation. Thus, further investigations of the population dynamics of species with fishing potential are necessary (Wehrtmann *et al*., 2012).

Cherublemma emmelas (Gilbert, 1890), is a bathydemersal species, found from Baja California to northern Chile (32°N, 16°S), living in depths from 102 to 1145 m (Lea, 1995; Ambrose, 1996; Cárdenas-González & Marolo-Castaño 2011; Aguirre-Villaseñor & Castillo-Velázquez, 2011), and have been reported as the most abundant of the Eastern Pacific Ocean (Zamorano *et al*., 2014).

Knowledge of the species is scarce; nevertheless, it includes aspects of taxonomy, distribution, abundance, and reproduction (Gilbert, 1890; Breder & Rosen, 1966; Lea, 1995; Ambrose, 1996; Castro-Aguirre & Balart, 1996; Nielsen *et al*., 1999; Pequeño, 2000; Acevedo-Cervantes *et al*., 2009; Aguirre-Villaseñor & Castillo-Velázquez, 2011; López-Martínez *et al*., 2012; Zamorano *et al*., 2014). His trophic level of 3.6, showing the average resilience of 1.4 to 4.4 years and vulnerability from low to moderate (Pauly & Christensen 1998). Fundamental aspects of its biology and population dynamics are unknown (Nielsen *et al*., 1999; Cárdenas-González & Marolo-Castaño, 2011), but it has a slightly allometric growth (Froese *et al*., 2013). This study reports population dynamics parameters of the *Cherublemma emmelas* of the Gulf of California to contribute to the knowledge of a little known and abundant fish species from the deep waters of the Eastern Pacific Ocean.

Four research cruises were performed on board of the ship BIP XII (February and May 2005 and June and

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October 2007) catching 2251 organisms of black brotula in depths from 90 to 540 m. The samplings were carried out over the continental slope of the eastern coast of the Gulf of California from Puerto Peñasco, Sonora to Topolobampo, Sinaloa, Mexico (Fig. 1).

For sampling, a bottom trawling net with braided polyethylene mesh was used, with a mesh size of the 38×34 mm, mouth stretched perimeter of 68 m, and head rope of 38 m. The trawls were made by the stern with duration of 60 min to 2.0 knots (5.5 km h^{-1}). Of each trawl, 20 kg of fish were obtained randomly; the sample size was determined by standard criteria (Box *et al*., 2008). Sample organisms were identified in the Fisheries Ecology Laboratory of the Centro de Investigaciones Biológicas del Noroeste, Guaymas, Sonora, México, using the keys of Eschmeyer *et al*. (1983); Fischer *et al*. (1995); Robertson & Allen (2015). Total length (TL) of fishes was measured (±1 mm) with an ichthyometer, and total weight (W) with a digital scale (±0.1 g). Sex and maturity were determined following the morphochromatic maturity scale the five stages; I undefined, II development, III advanced maturity, IV, full maturity and V spawned, proposed by Barreiro-Güemez (1986), which is based on the appearance of eggs and staining of ovaries. The sexual proportion was obtained using a male-female ratio.

Biometric relationship between weight and length was obtained by estimating it with a non-linear system using the least-squares algorithm and using the determination coefficient (R^2) as criterion for setting, adjusting to the potential model $W = a\, LT^b$ where W was the total weight (g) of the organisms; TL the total length (mm); and *a* and *b* are regression constants. The *b* growth coefficient was statistically evaluated with the *t*-test (Zar, 1999). In this case, if the isometry coefficient was $b = 3$, the species showed an isometric and allometric growth if $b \neq 3$ growth (Ricker, 1975). Size structure was obtained by cruise in intervals of 1 cm of TL, and a histogram of frequency was built. The von Bertalanffy (1938) growth model (VBGM) was used to adjust the growth parameters (Beverton & Holt, 1959; Ricker, 1975):

$$TL = TL_{\infty}\ [1- e^{(-k(t-t_0))}]$$

where TL is the total length at age *t* (cm); TL_{∞} is asymptotic total length (cm); *k* is the growth rate (yr^{-1}); and t_0 is the theoretical age (year) when fish would have TL= 0 (King, 2007; Sparre & Venema, 1997).

Growth parameters (TL_{∞} and k) were estimated according to the nonlinear method using the FISAT (FAO-ICLARM Stock assessment Tools) program package (Sparre & Venema, 1997). The seed values for L_{∞} were calculated using the Powell-Wetherall method

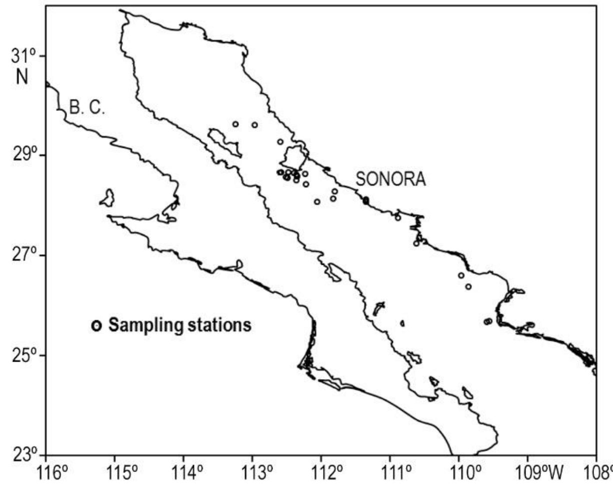

Figure 1. *Cherublemma emmelas*. The study area with trawling sampling stations in the Gulf of California, México.

(Powell, 1979; Wetherall *et al*., 1987); *k* using Shepherd NSLCA method (Shepherd, 1987; Pauly & Arreguín-Sánchez, 1995); and the parameter t_0 with Pauly (1980) empirical equation:

$$t_0 = 1*10^{[-0.3922-(0.2752 \times \log L_{\infty})-(-1.038k \times \log k)}$$

Longevity was estimated by Taylor's equation (1962):

$$T_{max} = 3/k + t_0$$

where *k* is growth coefficient (annual), and t_0 is the hypothetical age at zero.

Natural mortality (M) was calculated by Pauly equation (1980) and Jensen equation (1996). Pauly equation:

$$\log M = -0.0152 - 0.279 \times \log TL_{\infty} + 0.6543 \times \log k + 0.463 \times \log T$$

where T is water temperature (°C), in this case, 10°C was the average temperature registered in this study. Jensen equation (1996):

$$Mj = 1.5 \times k$$

where *k* = instantaneous growth coefficient obtained with VBGM. The Electronic Length Frequency Analysis (ELEFAN II) method was used to estimate the recruitment pattern (Pauly & David, 1981; Pauly, 1987), which projects the samples of frequency length presented in the catches back on the time axis.

The size at first maturity (SFM) was obtained with the accumulative proportion of the mature female at the size. This proportion was fitted to the logistics model (King, 2007):

$$S_L = \left(\frac{1}{1 + \exp(-r \times (X - X_{50}))}\right)$$

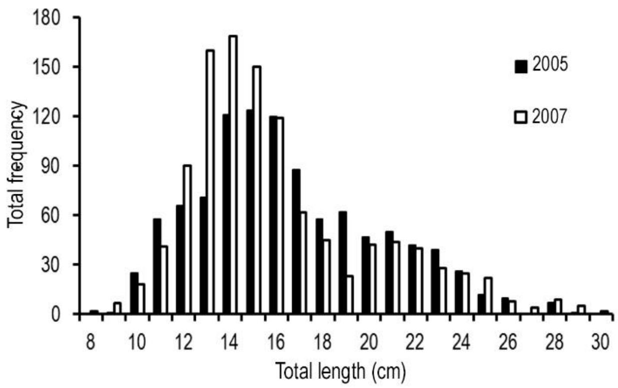

Figure 2. Size frequencies of *Cherublemma emmelas* caught in the Gulf of California (n = 2151).

where: S_L = proportion of mature females; r = slope of the curve; X_{50} = size at first maturity, which indicate to 50% of females are mature. The least squares algorithm was used to obtain the theoretical proportion of mature organisms; Newton's method was used to adjust the parameters (Neter *et al*., 1996).

The 2148 individuals of *C. emmelas* caught recorded sizes from 8-32 cm TL, during this study, with a modal of 14 cm (n = 257) for February of 2005, 16 cm (n = 773) for May of 2005, 15 cm (n = 749) for June of 2007 and with a modal of 14 cm (n = 349) for October 2007. Size structure showed two groups, where the first group with 78% of the individuals was the most abundant (Fig. 2).

Of the total organisms caught (n = 2148), 352 were females (59 individuals in 2005 and 279 in 2007), 35 males (23 in 2005 and 12 in 2007) and 1454 undifferentiated (745 in 2005 and 711 in 2007). The relationship female: male was 10:1. The size range of TL for females was 8-28 cm, and 11-23 cm for males (Fig. 3).

The relationship of length-weight for females was $W = 0.0000002 \times L^{3.1765}$ (R^2 = 0.9137) indicating a positive allometric growth and for males was $W = 0.0002 \times L^{2.2441}$ (R^2 = 0.619) indicating a negative allometric growth. The VBGM parameter values were L_∞ = 33.0 cm, k = 0.6 year and t_o = - 0.2631 year, which described a moderate growth. The model curve showed that in the first year the organisms grew more than 50% of their total size; in their second year, they grew moderately, and after the third year, growth was slower until it stopped (Fig. 4).

The instantaneous rate of natural mortality obtained by Pauly's equation was $M = 0.77$ yr^{-1} (10°C), and the M obtained by Jensen was $Mj = 0.90$ yr^{-1}. The estimate longevity (T_{max}) obtained by Taylor's equation was 4.73 years. The size at first maturity estimated (L_{50}) was 18.8 cm of TL, 178 females with reproductive activity (Fig. 5). *C. emmelas* showed reproductive activity during

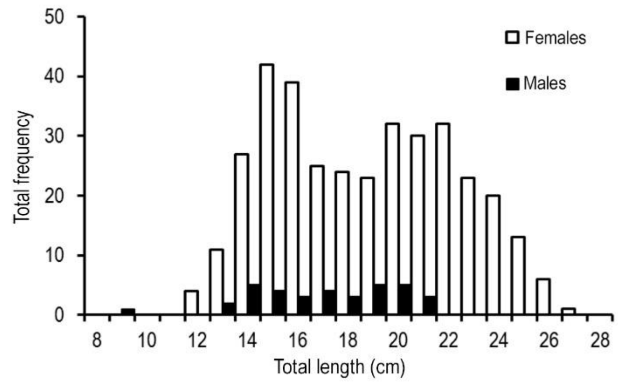

Figure 3. Size frequencies of *Cherublemma emmelas* by sex caught in the Gulf of California.

the study period (Feb, May, Jun, and Oct); 178 females only reached stages III, IV, and V, and immature individuals dominated with 1423 although the average size of males was 18.7 cm and females 18.4 cm.

The annual recruitment pattern showed continuous recruitment (Fig. 6) with one recruitment peak of higher intensity in the months May to September and maximum recruits in June (23%) and July (20%).

The length size of *C. emmelas* in this study was different to that reported by two other studies where the maximum size recorded was 32 cm of TL, more than those of Nielsen *et al.* (1999) and Cárdenas-González & Marolo-Castaño (2011) of 6 and 29 cm of TL, respectively. These discrepancies could be explained because these populations live in different latitudes with different environmental conditions (Froese, 2006). The data observed in this study are within a more extensive range (8 to 32 cm of TL).

This species showed differences in the sex ratio of females versus males, which agrees with Aguirre-Villaseñor & Castillo-Velázquez (2011) who collected seven organisms in the GC, six females, and one male. The high dominance of females may be due to population behaviour of this deep-water species that has a high degree of group segregation (Lea, 1995).

According to Froese (2006), the length-weight relationship between the same species may vary depending on the geographical region, season, size of the population, or differences of annual environmental conditions. In this study, growth type of *C. emmelas* was positively allometric (b = 3.1591 and R^2 = 0.8434); similar results were reported in waters of Central America (Cárdenas-González & Marolo-Castaño, 2011). Also, Froese (2006) reported a value equal to ours (b = 3.16) for this species; the brotulas (*Salilota* *australis)* present allometric growth (Chong-Follert *et al*., 2017). An incorrect determination of growth type according to Carlander (1969) and Froese (2006) is frequently the product of a small number of representative samples. In this study, a large amount of data was analyzed (n = 2142).

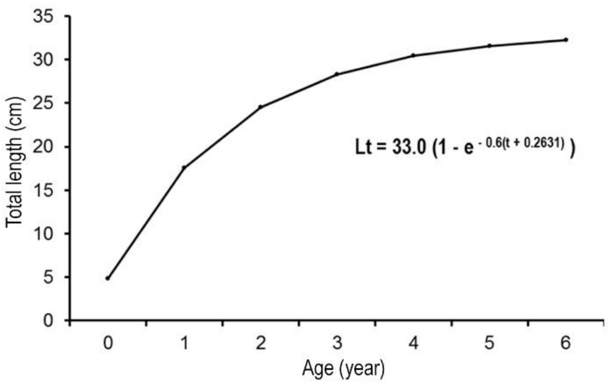

Figure 4. The growth curve for *Cherublemma emmelas* of the von Bertalanffy model.

The results of the analyses of *C. emmelas* growth indicated that the species has a moderate growth. These data could not be compared because no growth studies were found for this species or other species of its genus. However, some species of the Ophidiidae family, for example, with similar size (*Chilara taylori*) showed k = 0.38, less than the species in our study. Our parameters (k and L_∞) are within the range of those reported for this family. Accordingly, FAO (2005) mentioned deep-sea organisms have high longevity, slow growth, late sexual maturity, and low fecundity (*K* strategists) and low resilience (Koslow *et al*., 2000). Some authors have reported that growth parameters differ from one species to another, but they can also vary from a population to another within the same species, and from one place to another (Sparre & Venema, 1997). Other authors have claimed that many deep-sea species grow slowly, to the point that it is difficult to determine their real age, and determination is controversial (FAO, 2010).

The growth parameters (L_∞ = 33 cm and k = 0.6 years) estimated in this study showed moderate growth. However, growth was fast during the first two years of age where the species grew 80% of its total length, but then the growth curve turned asymptote and in the last year almost no growth was observed (Fig. 5). The correct estimation of growth parameters depends on the well-represented population sample size structure by organisms of all sizes (small, medium, and large). According to FAO (2010), the majority of deep-sea fishes have the peculiarity of slow growth and low natural mortality (M). It is generally accepted that M is very high during larval stages and decreases as the age of the fish increases, approaching a constant rhythm (Jennings *et al*., 2001). Natural mortality is a critical parameter in the biology of the species; it is related to their fundamental biological aspects, as reproduction, growth, and longevity (Pauly, 1980; Sparre & Venema, 1997). It is also the most influential parameter for assessing the stock, and the magnitude of M is directly related to population productivity, whose yields can get optimal exploitation rates, management, and points of reference (Brodziak *et al*., 2011).

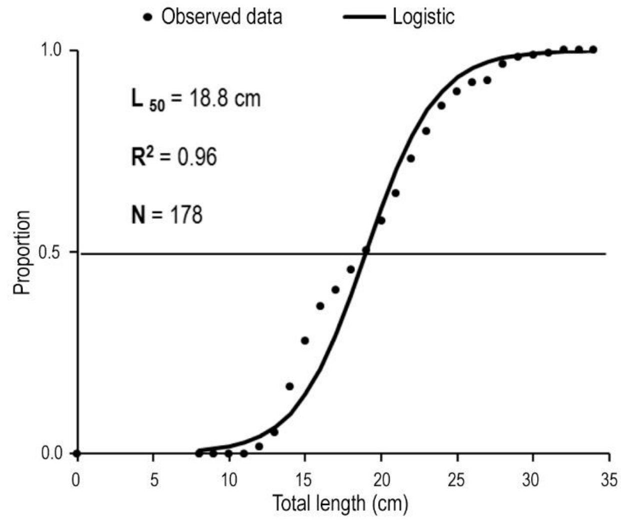

Figure 5. Size at first maturity of *Cherublemma emmelas* in the Gulf of California.

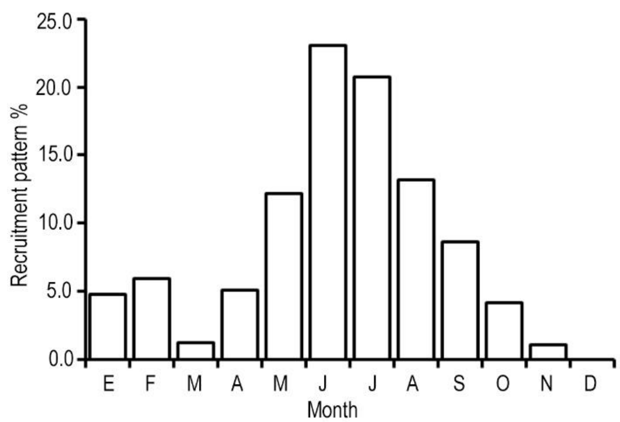

Figure 6. The pattern of annual recruitment of *Cherublemma emmelas* in the Gulf of California.

Given the importance of natural mortality, it is necessary to determine it the most suitable for the species. In this study, two empirical methods recommended for fish (Pauly, 1980; Jensen, 1996) were selected. In our results, compared to that of Jensen, M was lower by Pauly's method (1980). The latter may be the most appropriate for this species, given the moderate growth retrieved in this study. These results could not be compared because of the lack of reports for *C. emmelas*. However, the retrieved value of M agreed with the longevity of this species and with a study by Wiff *et al*. (2011) where M for demersal fish of the Pacific was estimated using five methods, of which the empirical equation of Pauly (1980) turned out to be the best method.

The size first sexual maturity of *C. emmelas* was 18.8 cm of TL, value greater to average size and carving modal of 15.5 cm and 14 cm of TL, respectively, which suggests that it was dominated by young organisms. Moreover, the annual recruitment pattern of *C. emmelas* showed a continuous pattern (Fig. 6) with two pulses, more intense during the summer season where 43% were concentrated in June and July and another pulse in winter (January and February).

According to the results, this species grows slowly (k = 0.6) and could reach a size of 33 cm in TL, the largest reported until now (Fig. 4). This curve was asymptotic coinciding with the longevity estimated, which is closely related to natural mortality that depends on factors such as; predation, diseases, old age and environmental variations (Pauly, 1980; Jones, 1984). Deep-water environment plays an important role given the extreme conditions prevailing there. Variables such as temperature and dissolved oxygen decrease as depth increases. This species was captured at 500 m in depth where a temperature of 7°C and dissolved oxygen of 0.1 mL L^{-1} have been recorded (Acevedo-Cervantes *et al*., 2009).

The results of this work contribute to the knowledge of size structure, growth, size at first maturity, longevity, natural mortality, and recruitment pattern of *C. emmelas* in the Gulf of California and to the understanding of the important role that this species plays in the deep marine water ecosystem. First report of population parameters of this species in the Gulf of California.

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