Growth and mortality rates of *Pseudupeneus grandisquamis* and *Urobatis halleri* bycatch species in the shrimp fishery

Crecimiento y tasas de mortalidad de *Pseudupeneus grandisquamis* y *Urobatis halleri*, especies de fauna acompañante en la pesquería de camarón

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ABSTRACT

Population dynamics of the goatfish *Pseudupeneus grandisquamis* and the round ray *Urobatis halleri* were assessed as dominant shrimp trawl bycatch species in the Gulf of California. Samplings were collected during the 2004-2005 shrimp season onboard 13 shrimp vessels. A total of 3,586 organisms were analyzed (n = 2,463 of *P. grandisquamis* and n = 1,123 of *U. halleri*); size frequencies were obtained by the von Bertalanffy model; growth, natural mortality (*M*), mortality by fishing (*F*), total mortality (*Z*), and exploitation rate (*E*) were determined by Pauly, Jensen, Ricker, and Taylor equations and the catch curve method. Size of *P. grandisquamis* ranged from 20-210 mm in total length (TL); growth parameters (L_∞ 213 mm; $K_{/\text{year}}$ 0.9; $t_{0/\text{year}}$ –0.19) indicated moderate growth, longevity (3.3 years), and high mortality rates ($M_p = 1.73_{/\text{year};}$ $M_j = 1.35_{/\text{year}}$). Size of *U. halleri* ranged from 90-450 mm in TL; growth parameters (L_∞ 472 mm; $K_{/\text{year}}$ 0.27; $t_{0/\text{year}}$ –0.54) indicated slow growth, moderate to high longevity (11.1 years), and moderate mortality rates ($M_p = 0.6$; $M_j = 0.4$ year^{-1}). Exploitation rate was <0.5 for *P. grandisquamis* and 0.8 for *U. halleri*, which was greater than the value suggested for a healthy stock ($E \leq 0.5$). According to the high mortality and exploitation rates estimated, it is conclude that shrimp trawl fishery represents a risk for *U. halleri* but not for *P. grandisquamis*.

Key words: Bycatch, growth, Gulf of California, mortality, trawl.

RESUMEN

Se evaluó la dinámica poblacional de *Pseudupeneus grandisquamis* y *Urobatis halleri*, especies dominantes de la fauna de acompañamiento en la pesquería de arrastre de camarón (FAC) en el Golfo de California. Se efectuaron muestreos de FAC en la temporada de pesca de camarón 2004-2005, a bordo de trece barcos camaroneros. Se analizaron 3,586 organismos (2,463 de *P. grandisquamis* y 1,123 de *U. halleri*) y se obtuvieron sus frecuencias de tallas utilizando el modelo de von Bertalanffy; para determinar el crecimiento, tasa de mortalidad natural (*M*), por pesca (*F*), total (*Z*) y tasa de explotación (*E*), se utilizaron el método de curva de captura y las ecuaciones de Pauly, Jensen, Ricker y Taylor.

El intervalo de tallas de *P. grandisquamis* fue de 20 a 210 mm de longitud total (LT); los parámetros de crecimiento (L_∞ 213mm; $K_{/año}$ 0.9 y $t_{0/año}$ –0.19) indican crecimiento moderado, con longevidad de 3.3 años de edad y tasa de *M* altas (M_p = 1.73$_{/año}$;M_j = 1.35$_{/año}$). El intervalo de tallas de *U. halleri* fue de 90 a 450 mm de LT; los parámetros de crecimiento (L_∞ 472mm; $K_{/año}$ 0.27; $t_{0/año}$ –0.54) indican crecimiento lento, con longevidad de 11.1 años y la M fue moderada (M_p = 0.6$_{/año}$; M_j = 0.4). La tasa de explotación de *U. halleri* fue *E* = 0.8, mayor al valor óptimo para un stock saludable (*E* = 0.5) y para *P. grandisquamis* fue menor al óptimo (*E* = 0.28). De acuerdo a las altas tasas de mortalidad y explotación estimadas, se concluye que la pesca de arrastre de camarón no representa riesgo para *P. grandisquamis*, pero si para *U. halleri.*

Palabras clave: Arrastre, captura incidental, crecimiento, Golfo de California, mortalidad.

INTRODUCTION

Shrimp fisheries, an important activity in the world, is performed in 120 countries where Mexico ranks tenth with 63,621 tons of average annual production (Gillett, 2010). In Mexico shrimp is the most important resource in terms of value, exports, and jobs (SAGARPA-CONAPESCA, 2012). However, one of the main problems of industrial shrimp fisheries is the trawling method employed. This fishing method is very effective for crustaceans, but its low selectivity generates large amounts of bycatch, mainly fish species (Earys, 2007).

The Food and Agriculture Organization of the United Nations (FAO) has estimated 7.3 million metric tons of bycatch produced worldwide each year, where shrimp trawling ranks first with 27%, equivalent to 1.86 million metric tons (Kelleher, 2008). Bycatch is a global problem that must be addressed since the adverse effects of fishing on the population structure of organisms caught as bycatch are still not fully known (Earys, 2007; Kelleher, 2008; Gillett, 2010).

The Gulf of California (a megadiverse region) represents 70% of the total national fishing production where shrimp fishery is one of the most important (Lluch-Cota *et al*., 2007). However, there are more than 250 non-target species including fish, crustaceans, and mollusks. The fish group is the most abundant with more than 70% of the total catch (Rábago-Quiroz *et al*., 2012), among which 15 dominant species represent 55% or more of fish abundance (Tapia, 1998; López-Martínez *et al*., 2010; Rábago-Quiroz *et al*., 2012). The goatfish *Pseudupeneus grandisquamis* (Gill, 1863) and the round ray *Urobatis halleri* (Cooper, 1863) are dominant shrimp trawl bycatch species of the Gulf of California (GC) (López-Martínez *et al*., 2010) that are probably overexploited, but their high capture volumes have not been investigated.

These dominant species are biologically and ecologically important in the benthic-demersal ecosystem and could provide relevant information about ecosystem changes (Pope *et al*., 2000; López-Martínez *et al*., 2010), but have been poorly studied. Therefore, it is necessary to assess them to understand their population dynamics.

P. grandisquamis and *U. halleri* were chosen for our study, besides their minor commercial importance in artisanal fisheries in the GC coast (López-Martínez *et al*., 2010; Rábago-Quiroz *et al*., 2012), to compare two species with different growth rate: a teleost fish with accelerated growth and an elasmobranch with a slow growth.

Pseudupeneus grandisquamis belongs to the Mullidae family; it is a marine demersal species with distribution in the central Pacific coast that inhabits soft sand and mud bottoms (Schneider, 1995). Its growth is allometric according to Lucano-Ramírez *et al*. (2006). However, Aguirre *et al*. (2007) reported an isometric growth for this species. Its size at first maturity was 138 mm, longevity of 6 years (Morales-Nin, 1994; Ramos-Santiago *et al*., 2006), and total length of 300 mm (Eschmeyer *et al*., 1983).

On the other hand*, U. halleri* belongs to the Urolophidae family; it is an elasmobranch distributed in the central Pacific coast on soft sand and mud bottoms. Studies on this species have reported a maximum size of 570 mm; isometric growth (Babel, 1967; Valadez-González *et al*., 2001; Hale & Love, 2008); and low resilience and high vulnerability according to the method proposed by Cheung *et al*. (2005).

The aims of this paper were to analyze size structure, growth parameters, mortality (natural, by fishing, total), and exploitation rates of these two species to generate knowledge of their population dynamics, exploitation level, and the potential impact of shrimp fishery to contribute to management and conservation of shrimp bycatch in the Gulf of California.

MATERIALS AND METHODS

Study area. Industrial shrimp fishery of the Gulf of California is carried out on the continental shelf (9-90 m) where the main operation areas are the coasts of the states of Sonora, Sinaloa, and Nayarit. Our bycatch samples were obtained through a program of observers onboard thirteen vessels of Guaymas, Sonora shrimp fleet during the 2004-2005 shrimp season (September to March). The location of the covered area for these samplings was 21° 13′ 37″ N, 105° 16′ 06″ W and 31° 24′ 35″ N, 114° 22′ 51″ W (Fig.1).

The shrimp vessels in Sonora used two mixed type nets, operating one per band. The mesh size used in the construction of shrimp nets is 5.71 cm in the body, while the permissible minimum

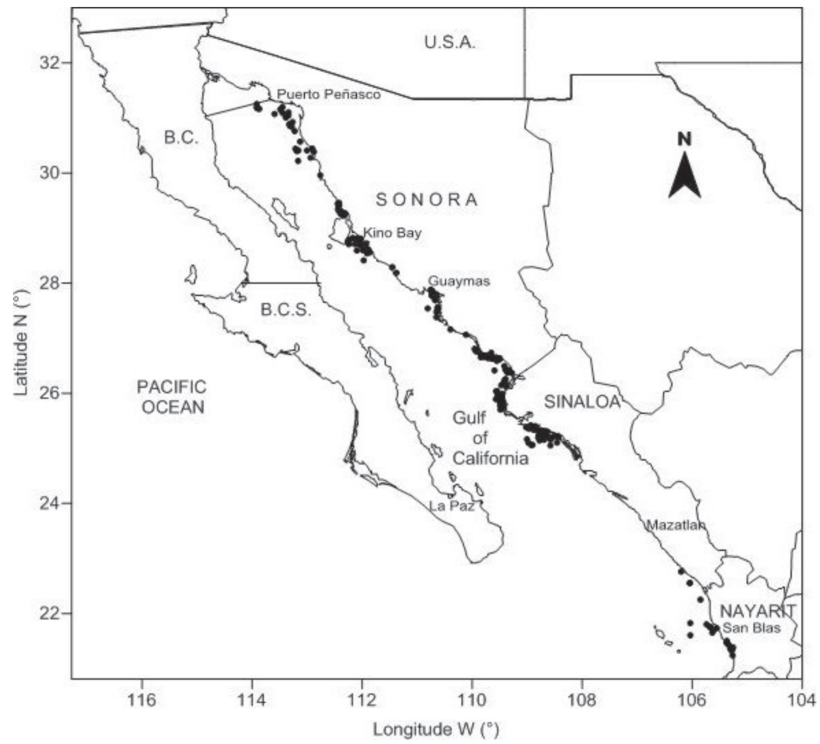

Figure 1. Study area and shrimp fishing zones in the Gulf of California (black points represent sampling stations).

size in the bag is 38.1 mm. During these surveys, trawling lasted for three hours with an average speed of 5.5 km/h. Once the catch of each trawl was on deck, 20 kg of the samples were taken following the method proposed by FAO and confirmed according to standard criteria (Box *et al*., 2008). Samples were labeled with particular data for each trawl and frozen (−20 °C) until processing in the laboratory. Identification and processing of the biological material were performed in the fisheries and ichthyology laboratories of Centro de Investigaciones Biológicas del Noroeste, S.C. (CIBNOR) in La Paz, Baja California Sur and in the Sonora Unit Campus Guaymas.

Pseudupeneus grandisquamis and *U. halleri* were separated from the bycatch, and the species taxonomic identification was performed using keys and descriptions by Jordan and Evermann (1896-1900), Meek and Hildebrand (1923-1928), Miller and Lea (1976), Eschmeyer *et al*. (1983), Fischer *et al*. (1995), and Robertson and Allen (2002).

Measurements of total length (TL; ±1 mm), and total weight (W; ±0.1 g) were taken. These data were used to calculate the total length-weight relationship (TL-W) varying the logarithmic of the equation $W = a\ TL^b$ for each species, where W is the total weight, TL is the total length, *a*-values is the *y*-intercept, and *b* is the slope of the regression line (Downie & Heath, 1981).

When character *b* (coefficient of allometry) is close to 3, it indicates the organism's growth is isometric, which means it should maintain a ratio of 1:3 between size and weight, whereas if it is different to 3, growth is allometric. The hypothesis of allometry was demonstrated through the t-test (Ricker, 1975).

Monthly length frequency distributions (intervals of 5 mm TL) were constructed for each species to obtain growth curves, assuming that the analyzed species followed the kinetics of von Bertalanffy (Pauly, 1987). The model has the following equation: $L_T = L_\infty(1\text{-}e^{-k(t-t_0)})$, where $L_T =$ is the length at age *t*; L_∞ = the asymptotic length; *K* = instantaneous growth rate; and t_0 = the theoretical age at which growth appears to start (Pauly, 1984).

A tentative initial L_∞ value was found by the Powell-Wetherall method (Powell, 1979; Wetherall *et al*., 1987). With this L_∞ value, Shepherd´s method (NSLCA) was used to estimate the *K* value (Shepherd, 1987; Pauly & Arreguín-Sánchez, 1995). New final estimates of *K* and L_∞ were made using the ELEFAN I method, included in the FISAT software (Gayanilo *et al*., 1995). The parameter was obtained by Pauly's empirical equation (Pauly, 1980).

Longevity was estimated as $t\text{max} = 3/K + t_0$ (Taylor, 1962), where *t*max is longevity (year); the other parameters have been described earlier. Instantaneous natural mortality (*M*) for each species was calculated using two methods: (1) Pauly's empirical equation:

$$\ln M = -(0.01529) - 0.279*\ln(L_\infty) + 0.6543*\ln(K) + 0.463*\ln(T),$$

where *T* is the annual mean sea surface temperature (°C) in the species' habitat (22 °C in this case). The other parameters have been described earlier (Pauly, 1980); and (2) Jensen´s equation ($M_j = 1.5*K$), where *K* = instantaneous growth rate (Jensen, 1996).

Total mortality rate (*Z*) was estimated by the linearized length-converted catch curve, $Ln(Ni/Dti) = a + bti$, where Ni is the number of fish in length class *i*; *Dti* is the time needed for the fish to grow through length class *i*; *t* is the relative age where mid-length is reached in class *i*; and *b* is an estimate of *Z* (Gayanilo *et al*., 1995). Fishing mortality (*F*) was calculated by $Z = M+F$ ($F = Z-M$); and the exploitation rate (*E*) was assumed to be $E = F/Z$, where values >0.5 reflect over-exploitation and values <0.5 under-exploitation (Sparre & Venema, 1995).

RESULTS

Samples (373) were collected from September to March 2004-2005 in different areas of the Gulf of California (Fig. 1). Fish from all trawlings were combined, so a total of 3,586 organisms of *P. grandisquamis* (n = 2,463) and *U. halleri* (n = 1,123) were recorded.

Pseudupeneus grandisquamis ranged in sizes from 20 to 220 mm; TL and average size was 130 mm TL (SD = 28.5). Monthly frequency size distribution gave two modal groups located in the ranges of 130-140 and 110-120 mm in TL class marks, respectively (Fig. 2). The combined length-weight relationship of *P. grandisquamis* gave an isometric growth for this species of (a = 0.00005, b = 2.96, $r^2 = 0.93$, $p < 0.05$) (Fig. 3).

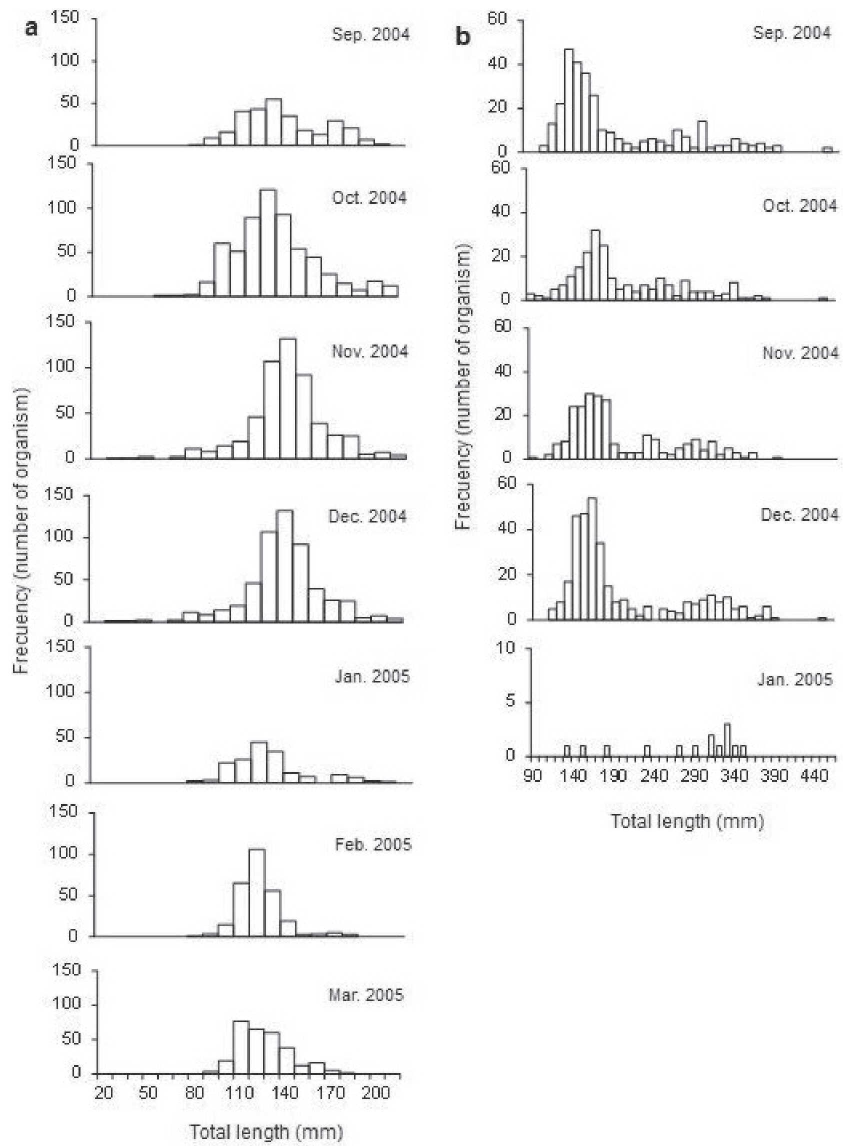

Figure 2. Size structures of (a) *Pseudupeneus grandisquamis* and (b) *Urobatis. halleri* in the Gulf of California during the shrimp fishing season 2004/2005.

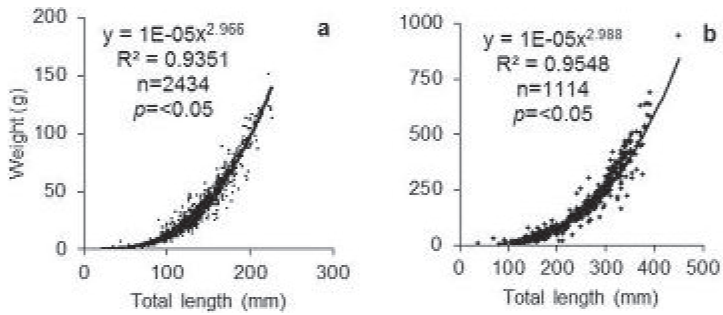

Figure 3. Total length and weight relationship for (a) *Pseudupeneus grandisquamis* and (b) *Urobatis halleri* in the Gulf of California from September 2004 to March 2005.

The growth parameters obtained for this species were L_∞ = 210 mm, K = 0.9 year^{1} and t_0 = –0.1948 year^{-1}, which showed this species had an accelerated growth and longevity of 3.3 years (Fig. 4). The instantaneous natural mortality (M) obtained for *P. grandisquamis* using Pauly's equation was 1.73 year^{-1}, which indicated high natural mortality; whereas with the Jensen equation it was lower, 1.35 year^{-1} (Table 1). Total mortality (Z), mortality by fishing (F), and exploitation (E) rates showed low values using both Pauly's and Jensen's mortality values (Z_p = 1.89, Z_j = 1.89; F_p = 0.16, F_j = 0.54; E_p = 0.08, E_j = 0.29) although F and E showed higher values when using Jensen's equation (Table 1).

Urobatis halleri ranged in sizes from 90 to 460 mm in TL, and average size was 249 mm in TL (SD = 71.2) (Fig. 2). The combined length-weight relationship of the round ray gave an isometric growth for this species (a = 0.00005, b = 2.98, r^2 = 0.95, $p < 0.05$) (Fig. 3).

The growth parameters obtained for *U. halleri* L_∞ = 472 mm, K = 0.27 year^{-1} and t_0 = –0.19 year^{-1} showed slow growth (Fig. 4) and 11.1 years of longevity for this species. The instantaneous natural mortality (M) obtained for *U. halleri* was 0.6 year^{-1} using Pauly's equation, which indicated moderate natural mortality, while Jensen's equation gave lower values (Table 1). Total mortality rate (Z), by fishing (F), and exploitation rate (E) showed high values using both Pauly's and Jensen's mortality values (Table 1). It is important to highlight values of E (0.77 and 0.84, Pauly's and Jensen's, respectively), which are higher than the maximum values acceptable for this parameter.

DISCUSSION

Size frequency distribution can provide information on population dynamics in processes such as growth, mortality and recruitment, and population migration. The recorded sizes of *P. grandisquamis* in our study are similar to those reported by Lucano-Ramírez *et al.* (2006) for the same species (70-230 mm); they obtained organisms with the same type of fishing gear (shrimp trawls) but in different areas (Jalisco and Colima). On the other hand, Aguirre *et al.* (2007) reported larger sizes for this species (78 to 306 mm). Their results might have been different because their samplings were obtained in a lagoon system (Santa Maria La Reforma, Sinaloa) in the southwestern part of the Gulf of California with another fishing gear (modified cast net called *suripera*). In terms of operation principles of the capture system, shrimp trawling is nonselective. In other words, it catches organisms of all sizes, particularly small (100-200 mm), but the larger ones can escape due to slow drift velocity (Balmori-Ramírez *et al.*, 2003). On the other hand, the suripera net is more selective allowing small sizes to escape.

Fish growth is generally isometric, and *P. grandisquamis* showed this growth pattern in our study. Our result is consistent

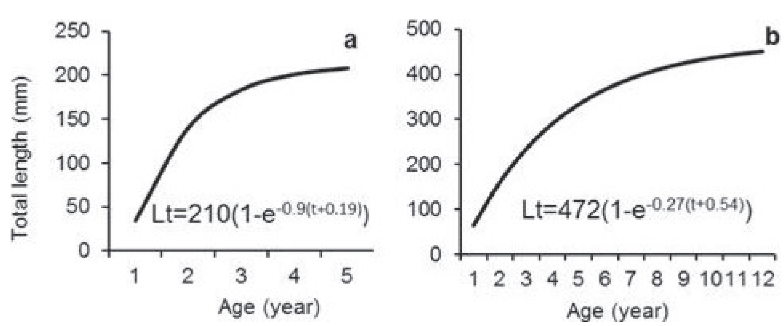

Figure 4. Growth curve of (a) *Pseudupeneus grandisquamis* and (b) *Urobatis halleri* from the Gulf of California in the fishing season 2004/2005.

Table 1. Natural mortality rate (*M*), by Pauly (M_p) by Jensen (M_j), total mortality (*Z*), mortality by fishing (*F*) and exploitation rate (*E*) of *Pseudupeneus grandisquamis* and *Urobatis halleri* of the Gulf of California.

	P. grandisquamis		*U. halleri*	
Parameters	M_p = 1.73	M_j = 1.35	M_p = 0.6	M_j = 0.4
F	0.16	0.54	1.96	2.16
Z	1.89	1.89	2.56	2.56
E	0.08	0.29	0.77	0.84

with that reported by Aguirre *et al.* (2007) for the same species. However, Lucano-Ramírez *et al.* (2006) reported this species growth as allometric. The difference could be due to stomach weight (filling) and maturity stage (gonad sizes) of the organisms at the time of capture (Ricker, 1995).

Growth parameters are important elements in fish biology studies and of other organisms because their determination and incorporation in analytical models for stock assessment allow inferring exploitation level and resource management (Guillory, 2003).

The growth parameters (L_∞, *K* and t_0) estimated for *P. grandisquamis* in our study are in agreement with short longevity (3.3 years) and accelerated growth of these organisms (more than 50% with respect of L_∞ in their first year). Our results differ from those reported by Morales-Nin (1994), where she obtained lower values of L_∞ and higher values of *K* for the same area (Sinaloa and Nayarit). The reason could have been the capture of medium and large sizes and none small size (70-240 mm), which could change *K* estimates, producing an underestimate of the instantaneous growth coefficient and an overestimate of infinite length (López-Martínez *et al.*, 2005). In our study the recorded sizes were 20-210 mm in TL, where those bigger than 210 mm were absent. It could be attributed to the gear used by shrimp trawlers (Balmori-Ramírez *et al.*, 2003).

Natural mortality is one of the most critical parameters in the study of population dynamics, and to date the existing methods are based on empirical equations that have been tested for some groups of organisms, mainly fish (Pauly, 1980). There are no publications about natural mortality rate (*M*) for *P. grandisquamis* or for the Mullidae family; thus, the results of our study are not comparable. Pauly (1980) reported *M* values for other marine species; for example, the mullet (*Mugil cephalus Linnaeus, 1758*) of the Mugilidae family showed values of *M* = 1.70, 1.73, and 1.89 (using temperatures of 27 °C in the equation), similar to those of *P. grandisquamis* when compared to our results with this species.

The *M* value obtained for *P. grandisquamis* agreed with longevity of this species (high values indicate it is a short-life cycle species). Total and fishing mortality rates were low (Table 1) and the exploitation rate (*E* = < 0.5) suggested shrimp trawling in the Gulf of California does not generate an adverse impact in population dynamics of this species.

The recorded sizes of *U. halleri* in our study are lower than those reported by Valadez-González *et al.* (2001) for the same species (120-550 mm in TL), and even though both samples were collected with shrimp trawls, the difference may be due to the area where they were obtained (Jalisco and Colima). The *b* value of the length-weight relationship of *U. halleri* indicated growth was isometric for this species (b = 3). Unfortunately, there are no published references about the length-weight relationship of this species.

The size of the individuals found in our study was over 440 mm and smaller than the maximum size (580 mm) reported by Froese and Pauly (2009) for this species. The absence of larger sizes in the samples could be due to shrimp trawling selectivity or to the population size structure existing in this area (Balmori-Ramírez *et al.*, 2003).

The instantaneous growth coefficient estimated (*K* = 0.27 $year^{-1}$) indicated slow growth for the species; a similar value (0.09 to 0.15) has been reported by Hale & Love (2008); however, it generated higher longevity than that estimated in our study for the species.

Recent age and growth studies of *U. halleri* using vertebrae reported ages over 14 years (Hale & Love, 2008), greater estimates than those made in our study. The difference could be due to the method used, where the formula is dependent on the estimate of *K* (0.27 in this case), which could be underestimated because of the absence of large sizes.

The *M* value obtained for the round ray (0.59 $year^{-1}$) agreed with the species longevity (low values indicate it is a medium to long-life cycle species). The total and fishing mortality rates were high (Table 1), and the exploitation rate (>0.5) indicated its value was greater than that suggested by Gulland in Sparre & Venema (1995) for a healthy stock ($E \leq 0.5$). This result could cause a negative impact on the population dynamics of *U. halleri* species, given their slow growth and longevity.

Both species (*P. grandisquamis* and *U. halleri*) are dominant shrimp bycatch components in the Gulf of California, and trawling impact on them is poorly known.

According to the high mortality and exploitation rates estimated, shrimp trawl fishery represents a risk for *U. halleri* but not for *P. grandisquamis.* Therefore, we suggest reducing the capture of *U. halleri* and continuing with studies to assess the impact of trawling activities on bycatch species mainly on those with slow growth, as elasmobranchs.

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