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Full Length Research Paper

Reproduction of *Diapterus brevirostris* (Percoidei: Gerreidae) in the Mexican Pacific coast

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Abstract

This paper deals with the reproduction of the fish Shortnose Mojarra *Diapterus brevirostris* of the Pacific coast of Mexico. The fish were captured with gill nets and cast nets and are a common low priced product for local consumption. Its study is important to know the reproduction period and ages of first maturity, to help manage the fishery. The fish were obtained from local commercial fishery from April 2010 to July 2012. Sizes, sex and gonad maturity were registered, gonadosomatic index and condition factors were calculated, as well as fecundity by gravimetric method. The female: male ratio was 1.2: 1. Mature organisms occurred all year round. Sexual maturation (L_{50}) of males and females was observed at a mean size of 14.20 cm and 14.25 cm corresponding to one and two years old, in both cases. First maturity length (L_{25}) was 13.53 cm in males and 13.68 cm in females. The allometric relationship with the hepatosomatic index was LW = 0.0001 · $TL^{2.918}$ (r^2 = 0.417). Condition factor indexes of Fulton, Clark and Safran showed a maximum increment during May and June. The gonadosomatic index showed two high value months: September and February. The mean oocytes diameter was 0.27 mm (range 0.15 to 0.35 mm, standard deviation = 0.044). Fecundity ranged from 16,695 to 807,954 oocytes in females between ages 1 and 6 years old, and mean relative fecundity was 1,877 oocytes·g^{-1} (513 to 3,683 oocytes·g^{-1}). *D. brevirostris* has an early sexual maturity, its spawning periods are twice a year and has a high fecundity rate, so it can be fished all year round, if its fishing size is over the first maturity length of 14.00 cm. This study is the base line for the fishery management, where the main regulations need to use information on the first maturity size and reproductive season.

Key words: Fecundity, maturity period, fish reproduction, minimum spawning size, Shortnose Mojarra, *Diapterus brevirostris*

INTRODUCTION

The Shortnose Mojarra *Diapterus brevirostris* (Sauvage, 1879) occurs in the Eastern Pacific from the southern part of the Gulf of California to Peru. Its habitat is near shore on sandy bottoms. Juveniles penetrate brackish of coastal lagoons. The species is mainly carnivorous: it consumes small benthonic invertebrates, fish and small amounts of algae matter (Castro-Aguirre, 1978; Allen and Robertson, 1994; Bussing, 1995; Castro-Aguirre *et al*. (1999).

In Mexican waters, *D. brevirostris* is fished with gill nets and cast nets, and registered in official statistics together with other species of Gerreidae family. In 2011, landings of this resource were 62 thousand tons, the fishery in the Pacific coast contributes with 62% of the total catch, and Colima registered 345 t (1% of the Pacific production according to SAGARPA, 2012). The price at the market is of $30.00 Mexican pesos ($ 2.30 US dollar exchange rate in 2012).

Reproduction studies of the Gerreidae family species have been carried out (García-Cagide *et al*., 1999; Sarre *et al*., 2005; Iqbal *et al.,* 2007; Kanak and Tachihara, 2008;

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Ferrer Montaño, 2009; López-Martínez *et al.*, 2011; Valdez-Zenil, 2013; Espino-Barr *et al*., in press).

The importance of the studies on reproduction lies on the knowledge of population dynamics of a species, and its feedback mechanism, which permits the species continuity in time and space through recruitment of new individuals. If this reproduction mechanism breaks, through the capture of individuals that have not yet reproduced at least once in its lifetime, the population can fall in an extinction danger. Through the information of captured organisms that have reproduced, maximum sustainable yield models and capture predictions can be used. These studies on reproduction also allow establishing banned periods (Gallardo-Cabello *et al*., 2007; Espino-Barr *et al*., 2012).

The objectives of the present study were to know:

1) monthly frequency of the gonadic maturity stages and massive spawning period;
2) monthly values of the gonadosomatic and hepatosomatic index;
3) monthly values of the gastric repletion index;
4) monthly values of the condition factor of Fulton (1902), Clark (1928) and Safran (1992),
5) values of total and relative fecundity;
6) to compare our results to those reported by other authors.

MATERIALS AND METHODS

From April 2010 to July 2012, individuals of *D. brevirostris* were monthly obtained from the commercial captures of the coastal fishery in Manzanillo, Colima, México (19°00' - 19°02'N and 104°10' - 104°21'W) and in Tomatlán, Jalisco, México (19°58' - 20°04'N and 105°26' - 105°32'W). Individuals were captured with gillnets of different sizes (2.5-3.0 inches, 5.5-8.25 cm), which resulted in the capture of a diversity of size lengths and age groups.

Total length (TL, cm) and weight (TW, g) of 1,886 individuals were measured. Of these, 131 were transported to the fish laboratory of the National Fishery Institute, where total length (TL, cm), total (TW, g) and eviscerated weight (EW, g) and sex were recorded macroscopically for each specimen.

Sex and gonad maturation were determined *in visu*, on fresh organisms taken to the laboratory the same day they were caught. The stages of sexual maturity were determined using the key described in Espino-Barr *et al.* (2008), where phase I: Undefined, sexual glands are a fine filament, and females and males cannot be differentiated. Phase II: Immature, the gonads start developing, ovaries are rose translucent and testes resemble a whitish lace. Oocytes cannot be observed. Phase III: Maturing, sexual glands are well differentiated. Ovaries look granular, pink-yellowish color, oocytes small and opaque; testes are ivory white. Phase IV: Mature, sexual glands are well developed, ovaries are rose-orange color, oocytes are big and transparent, and testes are whitish. Phase V: Spawning, ovaries are brilliant orange color; sexual products are ready to be expelled and are pushed out at the slightest pressure, veins are well developed irrigating the entire gonad; testes are white pearly white, sperm emerges at a light pressure. Phase VI: Post-spawn, product has been expelled; sexual glands are flaccid, swelled and brownish-grey. Residual oocytes are reabsorbed.

The first spawning TL for males and females was determined at 50% of the accumulative frequency (L_{50}) of stages IV and V of sexual maturation (Sparre and Venema, 1995), and the minimum TL of first spawning (L_{25}) was also recorded to compare with other authors findings (Rodríguez-Gutiérrez, 1992). The logistic function was described by the equation (Gaertner and Laloe, 1986; Sparre and Venema, 1995):

$$H_P = \frac{1}{1+e^{a+b*Lt}},$$

where: H_P = percentage of females or males sexually mature, a and b are constants; its logarithmic transformation is:

$$\ln 1(1/H_P - 1) = a - b * Lt$$

and the length at which 50% of the population is sexually mature (L_{50}) corresponds to:

$L_{50} = a/b$

The original equation is modified to include L_{50}:

$Y = 1/[1+a(12-TL / L_{50})]$

The gonadosomatic index (GSI) of females and males was calculated according to Rodríguez-Gutiérrez (1992), where gonad weight (GW) is expressed as a function of body weight: $GSI = 100 \cdot GW/TW$.

As a measure of physical fitness of the fishes, we obtained the condition factor

$K = (EW \cdot TL^{-3})*100$ (Clark, 1928),

$K = (TW \cdot TL^{-3})*100$ (Fulton, 1902) and

$a = TW \cdot TL^{-b}$ and $a = EW \cdot TL^{-b}$ (Safran, 1992).

The hepatosomatic index (HSI), was expressed as the percentage of liver weight (LW) with respect to the total weight $HSI = 100 \cdot LW/TW$ (Rodríguez-Gutiérrez, 1992).

Fecundity (F) and relative fecundity were obtained by the gravimetric method using the wet weight of 35 female gonads of *D. brevirostris* in phase V. To estimate total fecundity, two subsamples of 0.1 g were obtained of each individual and put in a modified Gilson fluid (Simpson, 1951) to preserve. All oocytes were counted with the help of a stereoscopic microscope and measured with a micrometric ocular.

The following expression was used in the calculation of fecundity:

$F = n \cdot G_i / g_i$

where F = fecundity of a sample; n = number of oocytes in the subsample; Gi = weight of the gonad (g) and gi = weight of the subsample (g) (Holden and Raitt, 1975).

Table 1: Length (TL, cm), weight (TW, g), liver (LW, g), testis weight (TeW, g), ovary weight (GW, g) and fecundity (number of oocytes) for each age group (years).

Age	TL (cm)	Wt (g)	We (g)	LW (g)	GW (g)	F (eggs)
1	9.97	13.160	12.713	0.082	0.011	16,695
2	14.86	43.175	41.462	0.263	0.190	66,322
3	19.13	91.578	87.613	0.550	1.129	166,759
4	22.87	155.834	148.687	0.926	3.986	325,532
5	26.12	231.450	220.395	1.364	10.188	541,644
6	28.97	315.028	299.516	1.845	21.171	807,954

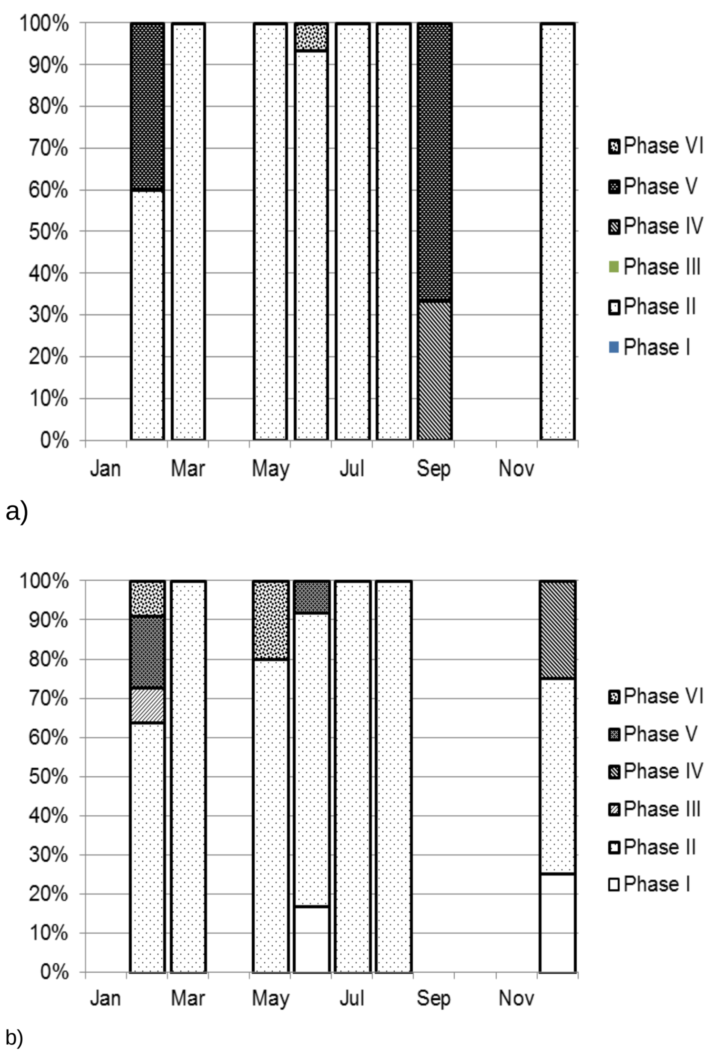


Figure 1: Monthly relation of sexual maturity in a) females and b) males of *Diapterus brevirostris*

The relationship between fecundity and total length and weight was calculated with the formula:

$F = a \cdot x^b$

where F= fecundity, x = individual weight or length, *a* = origin ordinate or initial number of oocytes, *b* = trend or oocyte number changing rate.

The relationships among TL, TW, LW, testis weight (TeW), ovary weight (GW), and fecundity were defined for different ages. Age groups were obtained by sagittal otolith analysis by Gallardo-Cabello *et al.* (2014), where six age groups of *D. brevirostris* were established.

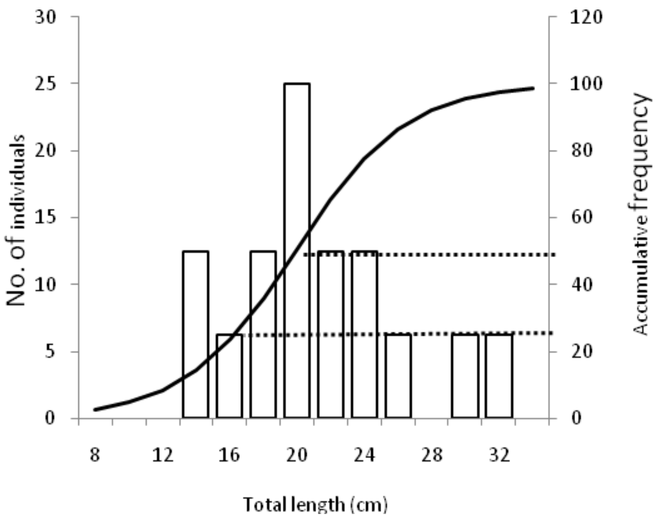
RESULTS

Gonads can be differentiated macroscopically, except for the virgin individuals who have never spawned. Ovaries are cylindrical and when they are mature, oocytes are yellow-orange and easily observed. Testes are elongated and whitish color and smaller than the ovaries. Table 1 shows values of the gonad weight (GW, g) for each age group, as well as the length (TL, cm), and total (TW, g) and eviscerated (EW, g) weight, liver weight (LW, g) and fecundity (number of oocytes).

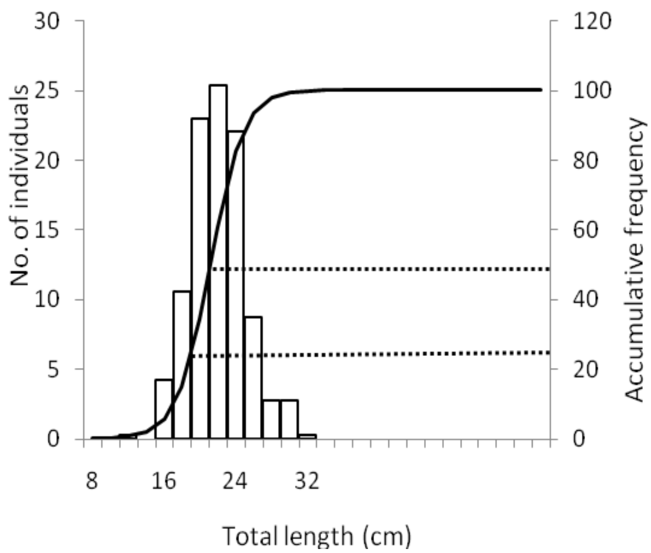
Sample size was of 131 organisms of *Diapterus brevirostris,* of which 67 (51.10%) were females, 53 (40.46%) males, and 11 (8.4%) undetermined. The proportion of female: male was 1.2: 1.

Oocyte diameter was 0.27 mm (±0.044 mm standard deviation: SD), minimum 0.15 mm and maximum 0.35 mm. Fecundity values ranged from 16,695 to 807,954 oocytes in females of 1 to 6 years of age and lengths of 12.06 cm to 30.00 cm, and 23 g to 349.6 g of weight (Table 1). Average value of relative fecundity was of 1,877 oocytes g^{-1} (ranging from 513 to 3,683 oocytes · g^{-1}).

Monthly variations of the relative frequency of gonad maturity phases (Figure 1) show that Phase II or immature females prevails in 60% in February, 100% in March and May, 92% in June, 100 in July, August and December. Males in Phase II were observed 64% in February, 100% in March, 80% in May, 75% in June, 100% in August and 50% in December. Phase III was not observed in females; males were observed in this phase at 10% in February. Phase IV, mature, was observed in females at 33% in September, and in males 25% in December. In females, 40% were observed in Phase V or spawning stage during the month of February and 66% in September; whereas 18% of males were in Phase V during January, 28% in June, and 25% in December.

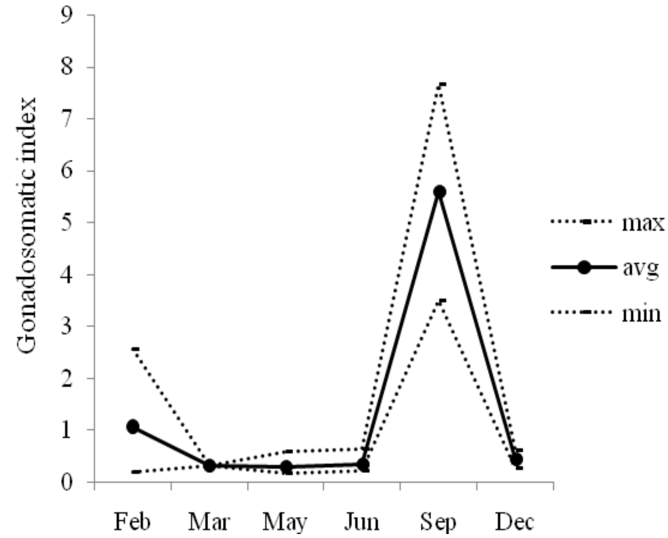


a)

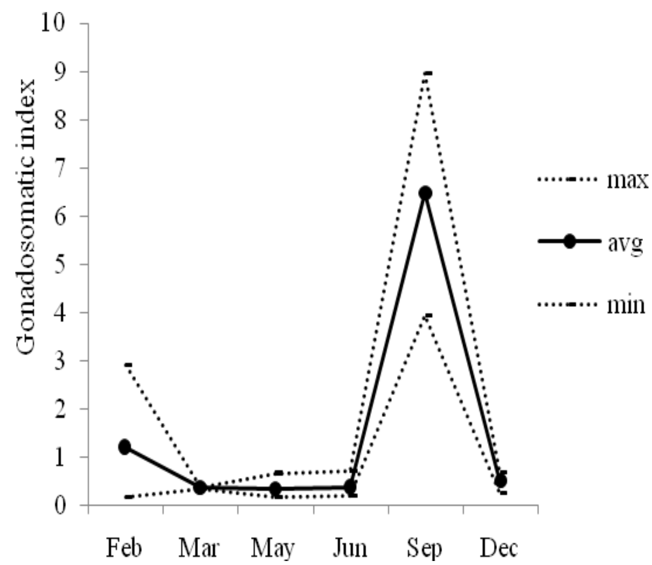


b)

Figure 2: First maturity length (L_{25}) and first reproduction length (L_{50}) of a) females and b) males of *Diapterus brevirostris*.



a)



b)

Figure 3: Monthly variation of the gonadosomatic index (GSI), a) calculated with total weight (g), and b) calculated with eviscerated weight (g).

Phase VI, post-spawning was observed in females 8% in June, and in males 10% in February and 20% in May.

Length of first maturity was L_{25} = 13.53 cm in females and L_{25} = 13.68 cm in males (Figure 2), corresponding to less than two year of age. First reproduction length was L_{50} = 14.25 cm in females and L_{50} = 14.20 cm in males (Figure 2), which is close two years of age. Fifty percent of females in reproductive population were found between 13.53 and 15.60 cm TL, while males were between 13.68 and 16.20 cm TL.

The gonadosomatic index (GSI) reaches its highest values during September for total length as for total and eviscerated weight (Figure 3), and a second spawning period during February. GSI values decrease during the months of March, May, June and December.

The allometric relationship of the hepatosomatic index (HSI) obtained in the present study was LW = 0.0001 · $TL^{2.918}$ (r^2 = 0.417). The allometric index *b* indicates that the liver weight increments in a similar proportion than cubic, in terms of its length, which results in an isometric growth of the fish, incrementing its fatty reserves as it ages. HSI variations are shown in Figure 4: maximum values are observed in May, June and July, lower values in March and August.

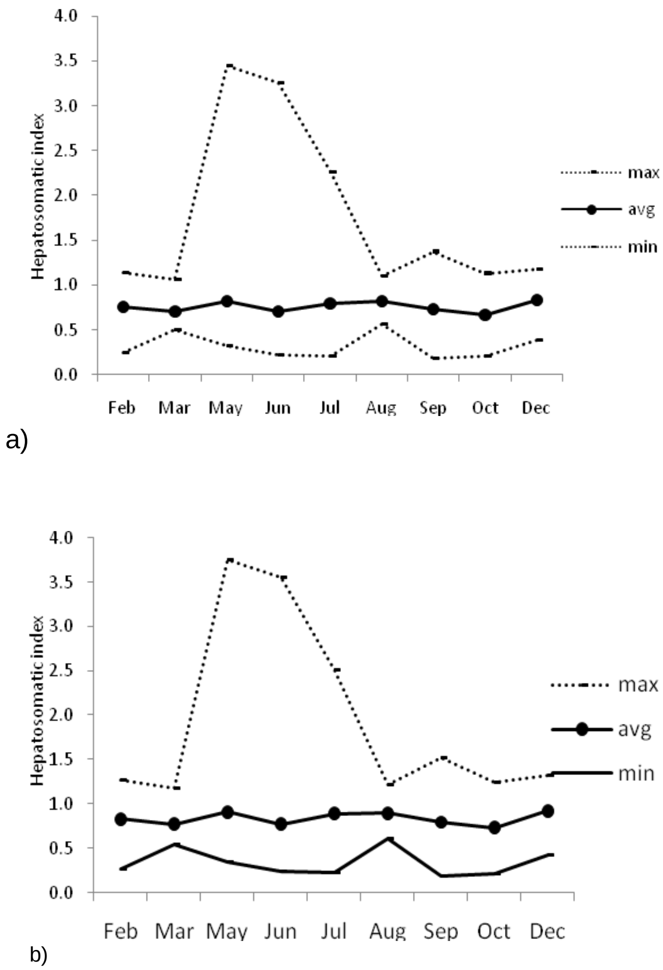


Figure 4: Monthly variation of the hepatosomatic index (HSI), a) calculated with total weight (g), and b) calculated with eviscerated weight (g).

Variations in the gastric repletion index (Figure 5) show higher values during May, July and August, before the spawning season; the lower values are observed during October and February.

Figure 6 shows the values of the condition factor; the higher values are obtained in the months of May and June.

DISCUSSION

Age groups one and two represent the highest values of the length growth rate of *Diapterus brevirostris*, after which it starts to diminish and increase the total weight, gonad weight and the fatty reserve index. So two main periods are considered in its life cycle: a first period of fast growth when most of the energy obtained through alimentation is used to increment its length to avoid depredation and interspecific competence, and a second period, when this energy is used to elaborate the sexual

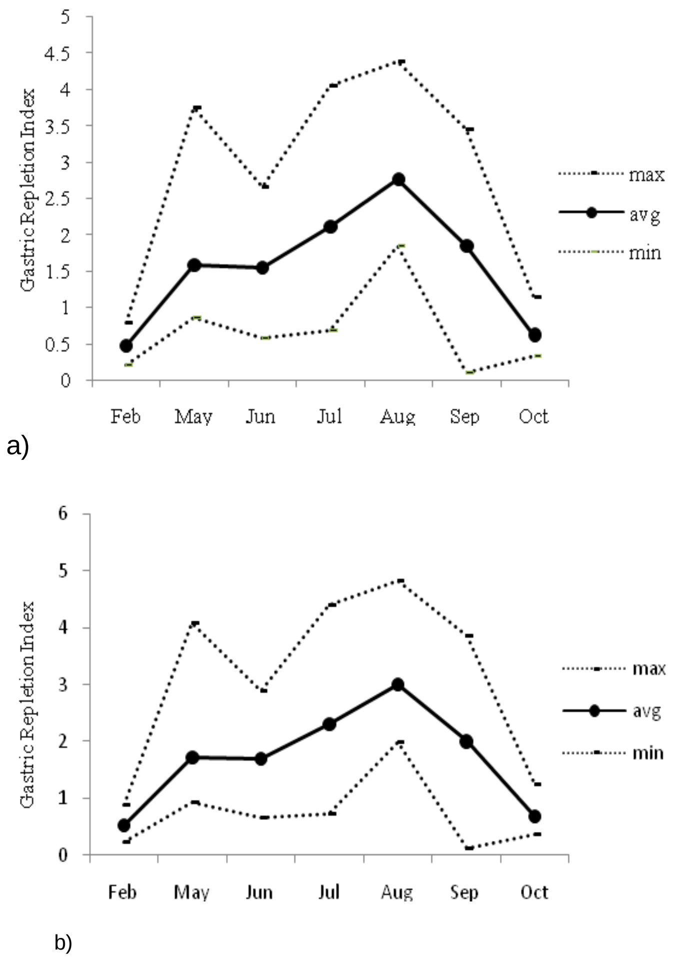


Figure 5: Monthly variation of the gastric repletion index (GRI), a) calculated with total weight (g), and b) calculated with eviscerated weight (g).

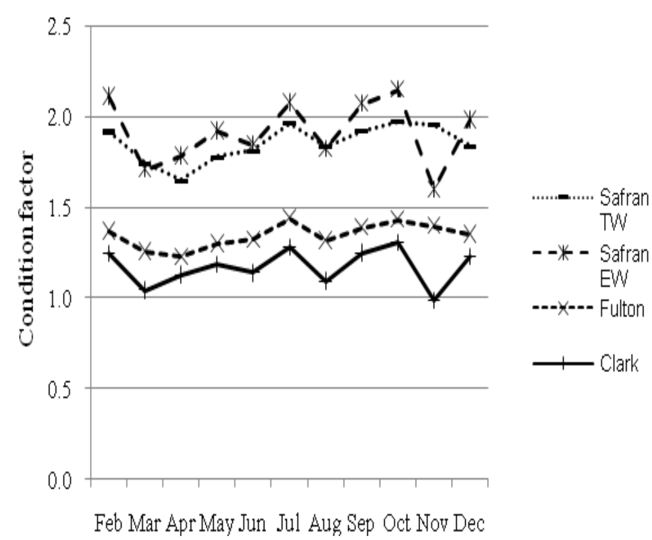


Figure 6: Monthly values of the relative condition factor

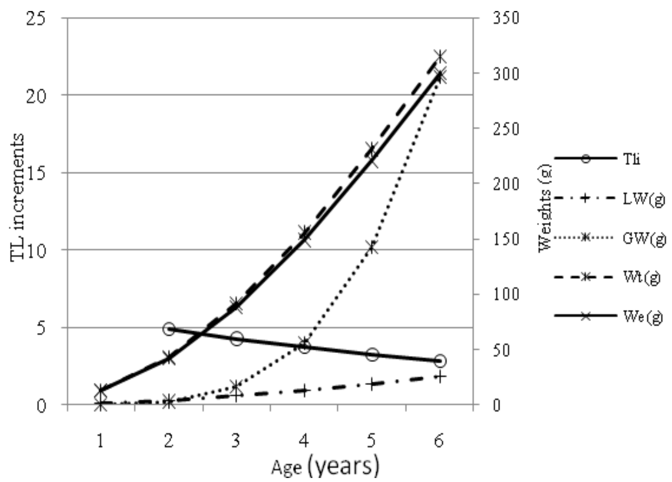


Figure 7: Relationship between age and total length increment (TLi, cm), total weight (TW, g), liver weight (LW, g), gonad weight (GW, g) of *Diapterus brevirostris.*

products (Figure 7) (Espino-Barr *et al*., 2008; Gallardo-Cabello *et al*., 2007).

We found sexual proportion to be 1.2: 1 female: male, opposite to those found for *Gerres cinereus* 1: 1.024 female: male, in Manzanillo, Colima (Espino-Barr *et al*., in press), *Eugerres mexicanus* in the Usumacinta river in Mexico, of 1.2: 1 female: male (Valdez-Zenil *et al*., 2013). Higher values were found for *Eugerres plumieri* in the Maracaibo lake, Venezuela, of 1.77: 1 female: male (Ferrer-Montaño, 2009).

Although the presence of mature organisms of *D. brevirostris* is all year round, massive spawning occurs in September. A second period of massive spawning was observed in February. Table 2 shows spawning periods for different species of the Gerreidae family. Most cases, species spawn during spring and summer. Nevertheless *D. brevirostris* and *Eugerres mexicanus* show massive spawning periods in winter.

According to its first sexual maturity length, the largest values are of *E. mexicanus* of the Usumacinta River: 20.5 cm in females and 17.3 cm in males (Valdez-Zenil *et al.*, 2013), *G. cinereus* in Cuba which matures at 20 cm TL (García-Cagide *et al.,* 1999) and *E. plumieri* of Lake Maracaibo, Venezuela, which matures at 18 cm the females and 17 cm the males (Ferrer-Montaño, 2009). *G. cinereus* in the Mexican Central Pacific presented intermediate values, compared to other species: 16.5 cm females and 15.8 cm males (Espino-Barr *et al.,* in press). *D. brevirostris* is the species that shows smaller sizes of maturity values: 13.53 cm in females and 13.68 cm in males. Lower values were found in *Gerres oyena* from Japan which is a precocious species, that matures at lengths of 8.97 cm (females) and 8.14 cm (males), followed by *Gerres equulus*, also from Japan, with first sexual maturity length values of 14.1 cm in females.

Many authors do not record the value of the first reproductive size. This first maturity size L_{25} in *G. cinereus* was of 20.2 cm in females and 16.4 cm in males, which correspond to age 1 and close to age 2 (Espino-Barr *et al.,* in press). *D. brevirostris* showed values of 14.25 cm in females and 14.20 cm in males, which correspond to ages of 1 and 2 years. Lower values were from *G. oyena* in Japan, of 10.4 cm in females and 9.2 cm in males (Kanak and Tachihara, 2008). Also in Australia, *Paraquula melbournensis* was 11.5 cm in females and 12.1 cm in males (Sarre *et al*., 2005).

The hepatosomatic index obtained in this study was b = 2.918 (r^2 = 0.417), which indicates an isometric growth. As the fish grows older, its fatty reserves increases in the same proportion as in length. Monthly values showed that the liver accelerates its activity of reserving fatty acids during the periods before spawning; therefore its weight increases considerably. The highest activity of fatty acid reserves is in May and June and starts to diminish in August extending till March.

Similar phenomena is observed with *G. cinereus* of the Mexican Central Pacific where most activity of fatty acid reserve takes place during February and lower from the months of June to August on, as the spawning periods occur (Espino-Barr *et al*., in press). Also, this phenomenon is presented in *G. oyena* in the island of Okinawa south Japan, where the hepatosomatic index diminishes during the spawning period of April and May (Kanak and Tachihara, 2008).

The most active feeding seasons are during the periods of time prior to spawning, the feeding is more active during the summer (from May to August), the gastric repletion index decreases during September to February during the spawning months, which is associated to the decreasing photoperiod and food production in the sea.

The condition factor reaches the maximum value during July, October and February with either model: Fulton (1902), Clark (1928) and Safran (1992), and decreases during the spawning seasons, that is, during September.

Similar data were observed for *G. cinereus* in Central Pacific Coast, where the different equations of the condition factor (Fulton, Clark and Safran) gave the same results and its maximum values are reached during February, and decreases during the spawning seasons, that is, during June to September, and November-December, after the massive spawning of October (Espino-Barr *et al*., in press). Fulton's condition factor of *G. equulus* from Japan reached its maximum values during the spawning season from June to September (Iqbal and Suzuki, 2009). The condition factor of *G. oyena* in the Island of Okinawa (south Japan) decreases during the gonadic development (Kanak and Tachihara, 2008).

Table 3 shows values of fecundity in species of three phylogenetic close families (Nelson *et al*., 2004; Nelson, 2006): Haemulidae, Lutjanidae and Gerreidae. Lutjanidae shows the highest fecundity values of the three families, *Lutjanus campechanus* in the coast of Florida reaches fecundity close to 60 million of eggs. Nevertheless, *L. argentiventris* and *L. carponotatus* have fecundity values lower than the

Table 2: Spawning seasons and first maturity (L_{25}) and reproduction (L_{50}) lengths of different species of the Gerreidae family. *

Species	**Country**	**Spawning season**	**L_{25} (cm)**	**L_{50} (cm)**	**Author**
Paraquula melbournensis	Australia	August		11.5 F, 12.1 M	Sarre *et al*. (2005)
Eucinostomus currani	México (Gulf of California)	March-August			López-Martínez *et al*. (2011)
Eugerres mexicanus	México (Usumacinta River)	February	20.5 F, 17.3 M		Valdez-Zenil *et al*. (2013)
Eugerres plumieri	Venezuela (Maracaibo Lake)		18.0 F, 17.0 M		Ferrer-Montaño (2009)
Gerres equulus	Japan	July	14.1 F		Iqbal *et al*. (2007)
G. oyena	Japan	April and May	8.97 F, 8.14 M	10.4 F, 9.2 M	Kanak and Tachihara (2008)
G. cinereus	Cuba	August	20		García-Cagide *et al*. (1999)
G. cinereus	México (Central Pacific)	July and October	16.5 F, 15.8 M	20.2 F, 16.4 M	Espino-Barr *et al*. (in press)
Diapterus brevirostris	México (Central Pacific)		17.9 F, 13.7 M	19,9 F, 14.6 M	This study

* taken from Espino-Barr *et al*. (in press)

Table 3: Fecundity (minimum and maximum) of species of Hamulidae, Lutjanidae and ~~of~~ Gerreidae families*

Author	**Country**	**Species**	**min**	**max**
García-Cagide *et al*. (1994)	Cuba	*Haemulon aurolineatum*	29,000	81,000
	Cuba	*H. album*	800,000	2’200,000
	Cuba	*H. plumierii*	64,000	312,000
	Cuba	*H. sciurus*	25,000	47,000
Cruz-Romero *et al*. (1996)	Manzanillo, México	*Lutjanus argentiventris*	75,900	356,000
		L. guttatus	66,400	2’170,000
Allen (1985)	La Paz, BCS, México	*L. campechanus*	9’300,000	
Collins *et al.* (1996)	Florida, USA, Gulf of México	*L. campechanus*	11,613	59’665,760
Evans *et al*. (2008)	Australia Great Barrier Reef	*L. carponotatus*	7,074	748,957
McPherson *et al.* (1992)	Australia Great Barrier Reef	*L. erythropterus*	5’000,000	7’000,000
		L. malabaricus	5’000,000	7’000,000
		L. sebae	5’000,000	7’000,000
Espino-Barr *et al.*(in press)	Central Mexican Pacific	*Gerres cinereus*	37,784	1’746,510
This study	Central Mexican Pacific	*Diapterus brevirostris*	16,695	807,954

*taken from Espino-Barr *et al*. (in press) members of the Gerreidae family. The Haemulidae family, except *H. album* is the family that shows the lowest values of fecundity of the three families. Generally speaking, the Gerreidae family occupies an intermediate position between the three families. *D. brevirostris* shows lower values of fecundity than *G. cinereus*, but higher than the haemulid species: *H. aurolineatum*, *H. plumieri* and *H. sciurus.*

Recruitment length of *D. brevirostris* to the fishing gear and probably to the area was at 9.1 cm TL and occurred in July, which means that this species spends 10 months as part of the plankton system and other marine strata before becoming part of the adult population. The same happens to *E. plumieri*, it recruits to the adult population during April (Ferrer-Montaño, 2009) and *G. cinereus* at 14 cm during April (Espino-Barr *et al.,* in press).

Some members of the Gerreidae family show migratory movements, from estuaries to open sea, as the case of *G. melanopterus* in the Bay of Guaratuba in Paraná, Brasil, where adults are known to migrate out to sea to spawn during summer and come back to the bay during fall and winter (Chaves and De Castro, 2001). Also, *G. rappi*, *G. acinaces* and *G. filamentosus* were described as going into estuaries when they reached 1.0 cm of standard length and stayed there till they reached sexual maturity: between 7.0 and 11.0 cm, after which females and males leave the estuary before eggs mature (Cyrus and Blaber, 2006). In the case of *D. brevirostris,* these movements are not known, but large and mature specimens are present in the coastal marine artisanal fishery.

Fishing seasons in Mexico have not been established for the fishing of the Gerreidae species, as happens with *E. currani* in the Gulf of California, which is protected during the shrimp fishery ban, because it is captured as bycatch (López-Martínez *et al*., 2011).

Sexual maturity of the species of colder and template climates is reached in more advanced ages and the spawning periods are very specific. In the case of the Gerreidae family, which is formed by tropical species, gonadic maturity occurs at early ages and the spawning period extends throughout the year, although there are massive spawning periods where a mayor part of the population spawns (García-Cagide *et al.*, 1983).

CONCLUSIONS

1. Sex ratio was 1.2 females per male.
2. Average length of sexual maturity (L_{50}) was 14.20 cm in males and 14.26 the females; and average length of first maturity (L_{25}) for males was 13.53 cm in males and 13.68 cm the females.
3. The gonadosomatic index reaches its maximum values in September and February, and the lowest in March, May, June and December. Mature organisms occur throughout the year.
4. The allometric relationship between the liver weight and the fish length is isometric (b= 2.918). Monthly values of the hepatosomatic index are higher in May, June and July, and lower in March and August.
5. The gastric repletion index has its highest values in May, July and August and the lower were observed in October and February.
6. The highest values of the condition factor were observed in May and June.
7. Average oocytes diameter was 0.27 mm (from 0.35 to 0.5 mm). The relative fecundity was of 1,887 oocytes per gram and fecundity oscillated between 16 695 y 807 954 oocytes per female from 1 to 6 years old.

RECOMMENDATIONS

It is important to continue with studies of the reproduction of the Shortnose Mojarra *Diapterus brevirostris*, and to publish them, so there is a base line to compare if significant variations occur in the average size of sexual maturity and average size at first maturity, which may indicate overexploitation of this resource.

These reproduction studies should be complemented with age and growth analysis, fishing gear selectivity, total, natural and fishing mortality, as well as size at first capture, exploitation rates and yield per recruit, in order to establish measures for the management of this resource, as fishing seasons, quotas, bans and fishing gear regulation, which will set a standard for the sustainable exploitation of Gerreidae species in general and particularly the Shortnose Mojarra *Diapterus brevirostris.*

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