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RESEARCH ARTICLE

REPRODUCTION OF BIG EYE SCAD *SELAR CRUMENOPHTHALMUS* (TELEOSTEI: CARANGIDAE) IN THE MEXICAN PACIFIC COAST

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ABSTRACT

Reproduction of *Selar crumenophthalmus* of the Pacific coast, Mexico was studied. Fish were captured with fixed trap-net, gill net, "robador" (hand line with five hooks) and pound net. This species is used exclusively as bait in Colima to catch big pelagic fish with long line and sport fishing of sail fish, marlin and dolphin fish. The proportion of male: female was 1: 0.73. Average length of sexual maturity (L_{50}) was 20.80 cm in males and 20.55 in females; average length of first maturity L_{25} = 20.00 cm for both sexes. The allometric relationship between liver weight and fish length is isometric (b = 2.965). Maximum values were observed in January, July, August, October and November. The gonadosomatic index (GSI) reached its highest values during F ebruary-April, and August-November. The gastric repletion index showed higher values during March, April, July and October, the lower values were observed during February, August and September. Higher values of the condition factor were obtained in February-April, September and October with the indexes of Fulton, Clark and Safran. Oocyte diameter was 0.28 mm (±0.02 mm standard deviation: SD), minimum 0.24 mm and maximum 0.30 mm. Fecundity values ranged from 86,760 to 245,114 oocytes in females of two to six years of age and lengths of 19.04 cm to 24.21 cm, and 68.37 g to 148.49g of weight. Average value of relative fecundity was of 1,667.3 oocytes·g^{-1} (ranging from 70.4 to 4,609.4 oocytes·g^{-1}).

INTRODUCTION

Selar crumenophthalmus (Bloch, 1793) is a coastal pelagic fish distributed in the Indo-Pacific Ocean: from East Africa (Smith-Vaniz, 1984) to Rapa, North and South Japan and the Hawaiian Islands, South to New Caledonia; in the Eastern Pacific: from Mexico to Peru, including the Galapagos Islands (Chirichigno, 1974). Western Atlantic: Nova Scotia, Canada and Bermuda through the Gulf of Mexico and the Caribbean to São Paulo, Brazil (Figueiredo *et al*., 2002). Eastern Atlantic: Cape Verde to southern Angola (Smith-Vaniz *et al*., 1990). Brederand Rosen (1966) established that the big eye scad has an external reproduction, dioic, whose eggs and larvae are scattered in open waters by currents. Studies on its reproduction have been carried out by: Kawamoto (1973), Alves and Lima (1978), Tobías (1987), Honebrink (1990), García-Cagide *et al.* (1994), Clarke and Privitera (1995), Roos *et al.* (2007), and Kamali *et al.* (2015), among others, who describe two reproductive periods in this species and lengths of first reproduction in different places in the world.

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Clarke and Privatera (1995) and Kamali *et al.* (2015) reported fecundity results. Nevertheless few studies analyze the reproduction of this species at a deeper level and report data on the indexes of liver fat reserves and feeding, as are the different states of the gastric repletion and the health state of stocks, through the condition factor analysis. According to this, the objectives of this paper are to determine: the sex ratio, the average length of sexual maturity (L_{50}) and length of first maturity (L_{25}), analysis of the gonadosomatic index, allometric relationship between liver weight and fish length, analysis of the hepatosomatic index, the gastric repletion index and condition factors according to Fulton (1902), Clark (1928) and Safran (1992). Also, the analysis of total fecundity, relative fecundity, and oocytes diameter were analyzed. Comparisons were made with results obtained in the present study and those obtained by other authors of this species and other from the Carangidae family.

MATERIALS AND METHODS

From November 2012 to October 2013, 230 organisms of the bigeye scad *Selar crumenopthalmus* were taken directly from the commercial captures in Manzanillo and Santiago bays in

Manzanillo, Colima, Mexico and taken to the laboratory of the Regional Fishery Research Center (CRIP). Organisms were captured with fixed trap-net, gill net, "robador" (hand line with five hooks) and pound net, to obtain a stratified sample which includes all the age groups and size classes. In the laboratory, data taken from each organism were: total length (TL, cm), total weight (TW, g), eviscerated weight (EW, g), and sex. To compare the relation and morphometric differences between males and females, a one way variance analysis (ANOVA) was carried out (Zar, 1996). 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 Stage I: undefined, sexual glands are a fine filament, and females and males cannot be differentiated. Stage II: Immature, the gonads start developing, ovaries are rose translucent and testes resemble a whitish lace. Oocytes cannot be observed yet. Stage III: Maturing, sexual glands are well differentiated. Ovaries look granular, pink-yellowish color, oocytes can barely be seen; testes are ivory white. Stage IV: Mature, sexual glands are well developed, ovaries are rose-orange color, oocytes are big and transparent, and testes are whitish. Stage 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. Stage 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 by 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/Hp-1)) = a-b · TL, and the length at which 50% of the population is sexually mature corresponds to: L_{50} = a/b. The original equation is modified to include L_{50}: Y = 1/[1+a(1-TL/L_{50})].

The minimum TL of first spawning (L_{25}) was also recorded to compare with other authors findings. The gonadosomatic index (GSI) for females and males was calculated according to Rodríguez-Gutiérrez (1992), where gonad weight (GW) is expressed as a function of body weight: GSI = 100·GW/TW (TW = total weight). As a measure of physical fitness of the fish, we obtained the condition factor $K = (EW \cdot TL^{-3}) \cdot 100$ (Clark, 1928), $K = (TW \cdot TL^{-3}) \cdot 100$ (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·LW/TW (Rodríguez-Gutiérrez, 1992). Fecundity (F) and relative fecundity were obtained by the gravimetric method using the wet weight of 34 phase V female gonads of *S. crumenophthalmus.* 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: $F = n \cdot GW_i/g_i$, where F = fecundity of a sample. *n* = number of oocytes in the subsample, GW_i = weight of the gonad (g) and g_i = weight of the subsample (g) (Holden and Raitt, 1975). 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, where seven age groups of *S. crumenophthalmus* were established by Gallardo-Cabello *et al.* (2016).

RESULTS

Gonads can be differentiated macroscopically, except for the virgin individuals who have never spawned and are too small to see. Fifty individuals were undetermined (Fig. 1), being these more abundant in January, November and December. Ovaries are cylindrical and when they are mature, oocytes are yellow-orange and easily observed. Table 1 shows values of the gonad weight (GW, g) for each age group, as well as the length (TL, cm), total weight (TW, g) and eviscerated weight (EW, g), also liver weight (LW, g) and fecundity (number of oocytes/ organism). Testes are elongated and whitish color and smaller than the ovaries. Table 1 shows that the ovary weight is 3.65 g in individuals of 4 years of age, while testes are 2.19 g in individuals of the same age. Oocyte diameter were 0.28 mm (±0.02 mm standard deviation: SD), minimum 0.24 mm and maximum 0.30 mm. Fecundity values ranged from 86,760 to 245,114 oocytes in females of two to six years of age and lengths of 19.04 cm to 24.21 cm, and 68.37 g to 148.49g of weight (Table 1). Average value of relative fecundity was of 1,667.3 oocytes·g^{-1} (ranging from 70.4 to 4,609.4 oocytes·g^{-1}). Sample size was of 249 organisms of *S. crumenophthalmus,* of which 115 (46.18%) were females, and 84 (33.73%) males, and 50 (20.08%) undetermined. The proportion of female: male was 1: 0.73. Monthly variations of the relative frequency of gonad maturity stages (Fig. 2) show that stage II or immature females are present 6.7% in January and February, 27% in March and 60.0% in May. Males in stage II were observed in 28.6% during February, 71.4% in May, stage III was observed in females at 8.3% during March, 75.0% in May and 8.3% in June and July; males were observed in this stage at 6.67% in February, 13.3% in March, 46.7% in May, 13.3% in June, 6.7% in July, November and December. Stage IV, mature, was observed in females at 7.7 % in March, 46.0 % during May and June; in males, as 16.7% in February, 30.6% in April, 11.1% in May, 5.56% in June, 8.33 in July, 19.4 in August, 8.3% in November. Stage V or spawning stage was observed in females as 1.6% in January, 8.2% in February, 4.9% in March, 11.0% in April, 8.2% in May, 6.6% in June, 15.0% in July, 9.8% in August, 4.9% in September, 23.0% in October and 6.6% in November. Males were in stageV at 11.8% during January, 11.8% in April, 17.6% in May, 5.9% in June, 17.6% in July, 23.5% in September, and 5.9% in October and November. Stage VI, post-spawning was observed in females as 11.0% in February and March, 22.0% in April, 33.0% in May, 11.0% in June and July, males were observed in this stage as 50.0% in May and October.

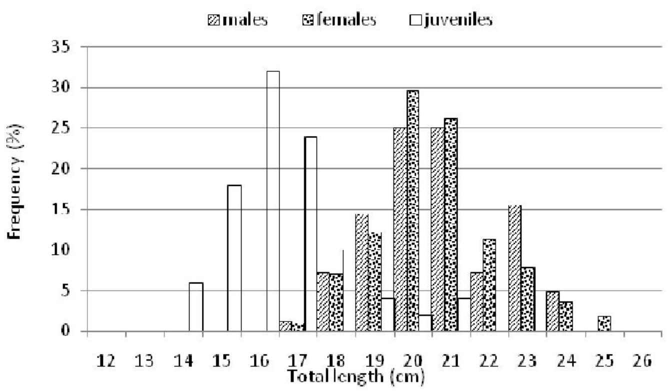
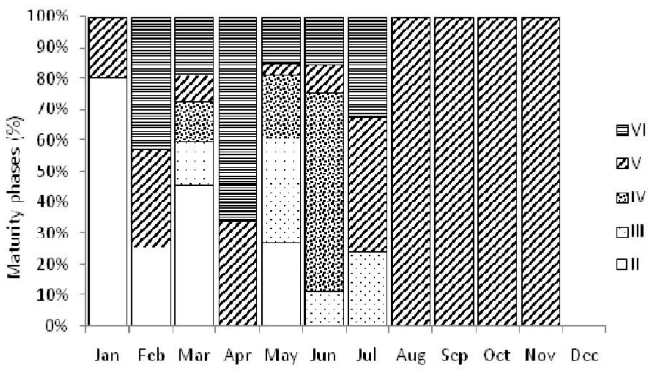
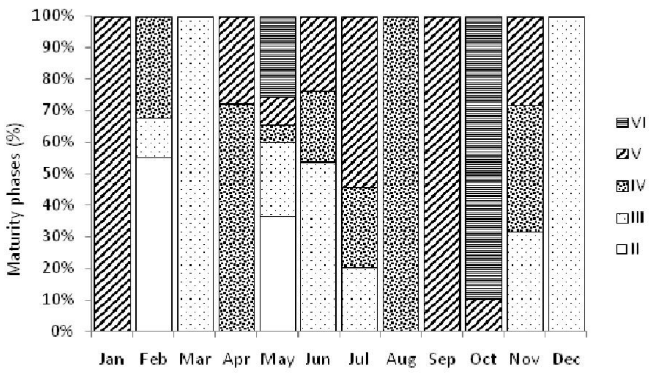


Figure 1. Length distribution of *Selar crumenophthalmus*

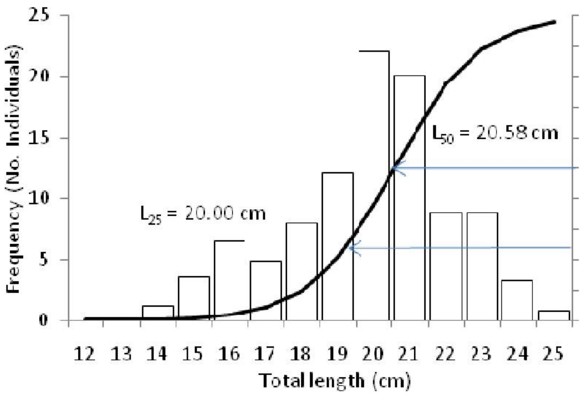


a) Females



b) Males

Figure 2. Monthly relation of sexual maturity in a) females and b) males of *Selar crumenophthalmus*



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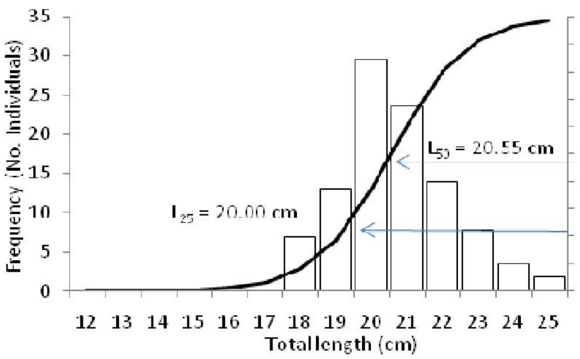

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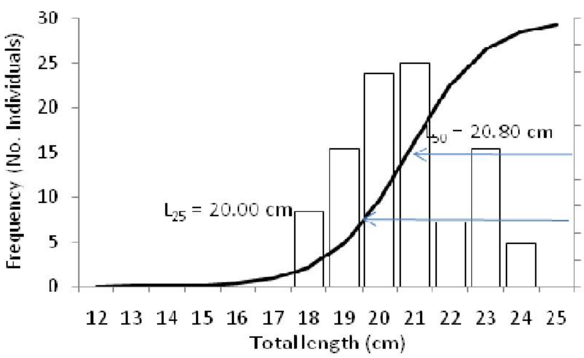
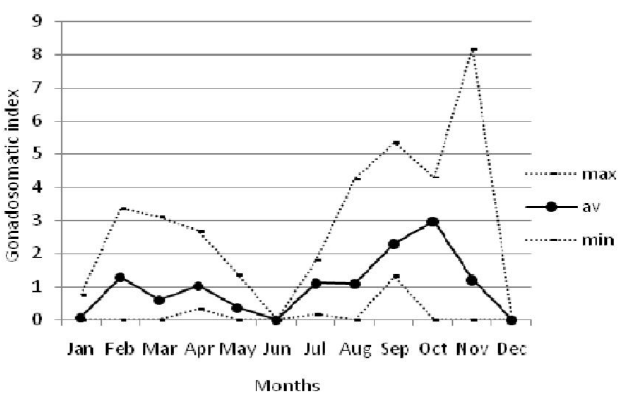
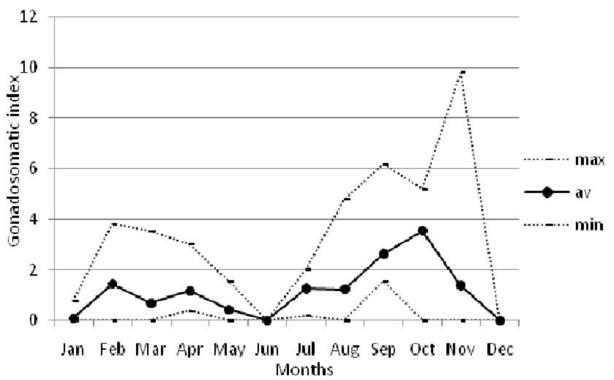


c)

Figure 3. First maturity length (L_{25}) and first reproduction length (L_{50}) of: a) both sexes, b) females and c) males of *Selar crumenophthalmus*



(a)



(b)

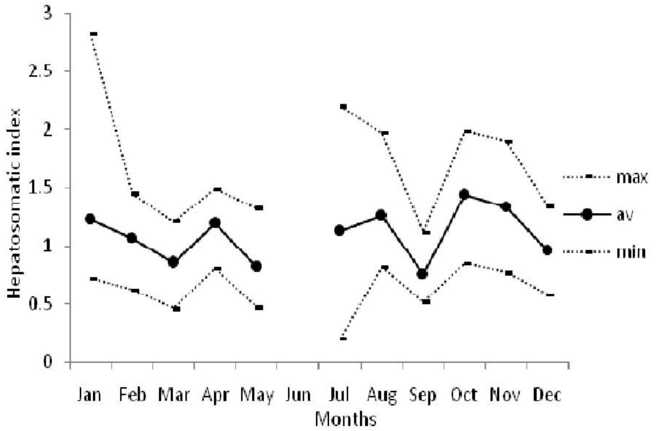
Figure 4. Monthly variation of the gonadosomatic index (GSI), a) calculated with total weight (g), and b) calculated with eviscerated weight (g)

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) of *Selar crumenophthalmus*

age	TL (cm)	Growth index	TW (g)	EW (g)	LW (g)	GW (g)	TeW (g)	F (TL)	F (TW)
0	3.71		0.35	0.34	0.00	0.00	0.00		
1	13.82	10.11	24.29	23.96	0.24	0.05	0.01		
2	19.04	5.22	68.37	67.33	0.62	0.74	0.29	86,760	75,160
3	21.73	2.69	104.81	103.15	0.92	2.19	1.14	153,736	132,597
4	23.12	1.39	128.03	125.96	1.11	3.65	2.19	200,977	172,985
5	23.84	0.72	141.29	138.98	1.21	4.70	3.02	229,335	197,193
6	24.21	0.37	148.49	146.05	1.27	5.33	3.55	245,114	210,653

Table 2. Spawning seasons and first maturity (L_{25}) and reproduction (L_{50}) lengths of *Selar crumenophthalmus* in different countries

Country	Spawning season	L_{25} (cm)	L_{50} (cm)	Author
Hawaii, USA	Apr-Oct		20.00	Clarke andPrivatera (1995)
Ceará, Brasil	May-June			Alves and Lima (1978)
Cuba	March-May			García-Cagide*et al.* (1994)
Hawaii, USA	March-Oct			Honebrink (1990)
Hormuzgan, Iran	Feb-Jun		19.00	Kamali*et al.* (2015)
ReunionIslands	Apr-Nov		21.50	Roos*et al.* (2007)
Virginia Islands	Mar-Sep			Tobías (1987)
Hawaii, USA	Apr-Sep			Kawamoto (1973)
Central MexicanPacific	Feb-Apr, Aug-Nov	20.00	20.58	Thisstudy



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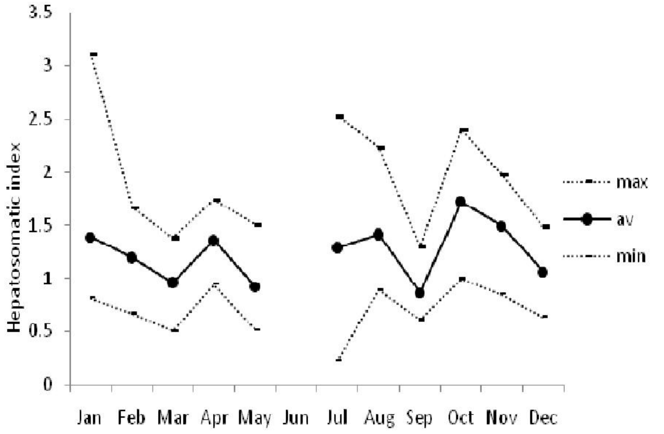
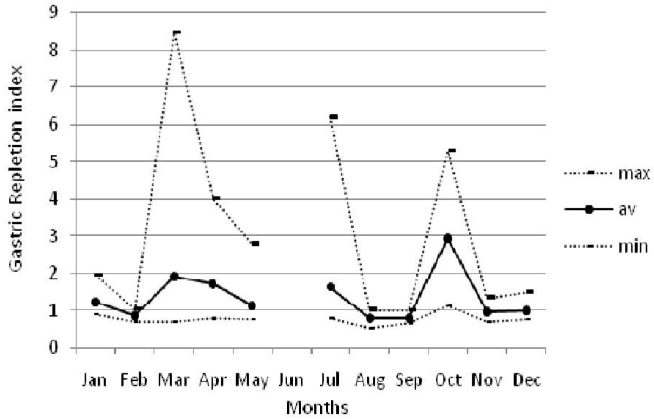


b)

Figure 5. Monthly variation of the hepatosomatic index (HSI), a) calculated with total weight (g), and b) calculated with eviscerated weight (g) of *Selar crumenophthalmus*



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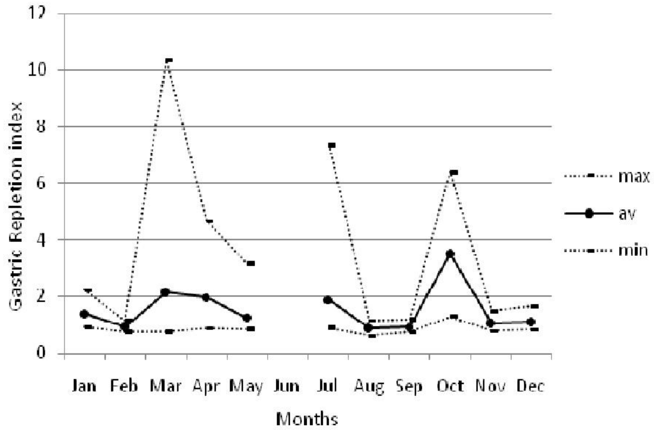

b)

Figure 6. Monthly variation of the gastric repletion index (GRI), a) calculated with total weight (g), and b) calculated with eviscerated weight (g) of *Selar crumenophthalmus*

Table 3. Fecundity (minimum and maximum), and relative fecundity of *Selar crumenophthalmus* and other species of the Carangidae family

Author	Country	Species	Fecundity		Relativefecundity (oocytes/gram)
			min	max	
de Ciechomskiand Cassia (1980)	Mar de Plata, Argentina	*Trachurus picturatus australis*	15,825	82,892	
Breweret *al*. (1994)	Gulf of Carpenteria, Australia	*Caranx bucculentus*	18,000	650,000	
Clarke (1996)	Käne'ohe Bay, Hawaii, US	*Atule mate*	63,000	161,000	741
Karlou-Riga and Econimidis (1997)	Saronikos, Greece	*Trachurus trachurus*			3,280
Dadzie *et al.* (2008)	Kuwaiti	*Parastromateus niger*	71,305	3,895,449	
Shuaib and Ayub (2011)	Karachi, Pakistan	*Alepes djedaba*	8,981	75,075	
Gherramet *al*. (2013)	Olan Bay, Algeria	*Trachurus trachurus*	33,275	56,391	28,595
Alfaro-Martínez *et al*. (2016)	Caribe Colombiano	*Caranx hippos*	291,439	4,380,480	
Clarke and Privatera (1995)	Hawaii, USA	*Selar crumenophthalmus*	92,000	136,000	
Kamali *et al.* (2015)	Hormuzgan, Iran	*Selar crumenophthalmus*		102,841	
Thispaper	Central Mexican Pacific	*Selar crumenophthalmus*	86,760	245,114	1,667

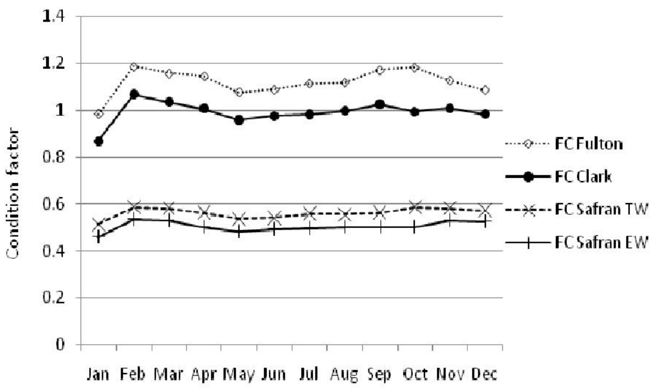

Figure 7. Monthly values of the relative condition factor of *Selar crumenophthalmus*

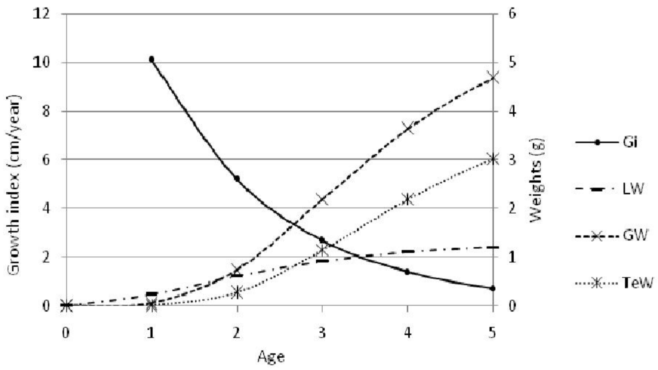

Figure 8. Relationship between age and growth increment (Gi, cm), liver weight (LW, g), gonad weight (GW, g) and testis weight (TeW, g) of *Selar crumenophthalmus*

Length of first maturity was L_{25} = 20.00 cm in females and males. First reproduction length was L_{50} = 20.55 cm in females and L_{50} = 20.80 cm in males (Fig. 3), in both cases corresponding to an age between two and three years. The gonadosomatic index (GSI) reached its highest values during February-April and August-November for total weight as for eviscerated weight (Fig. 4), and a second spawning period during October. GSI values decrease during the months of January, May and July. The allometric relationship of the hepatosomatic index (HSI) obtained in the present study was $LW = 0.0001 \cdot TL^{2.9653}$ ($r^2 = 0.539$). The allometric index *b* indicates that the liver weight increments in lower proportion than cubic, in terms of its length, which results in a negative allometric growth of the fish, nevertheless incrementing its fatty reserves as it ages. HSI variations are shown in Figure 5; maximum values are observed in January, July, August, October and November, lower values in September. Variations in the gastric repletion index (Fig. 6), show higher values during March, April July and October, preceding the spawning season; the lower values are observed during February, August and September. Figure 7 shows the values of the condition factor; the higher values are obtained in the months of February, March, April, September and October for the indexes of Fulton, Clark and Safran.

DISCUSSION

The highest value of the length growth rate of *Selar crumenophthalmus* occurs in group one, 10.11 cm, after which it starts to diminish and the total weight and gonad weight start to rise, likewise the fatty reserve index.

Therefore two fundamental periods were considered in the life cycle of *S. crumenophthalmus*: a first period when most of the energy obtained through food is used to increment in length (to avoid depredation and interspecific competence), a second period, when this energy is oriented to form the sexual products (Table 1, Fig. 8) (Espino-Barr *et al*., 2008; Gallardo-Cabello *et al.,* 2010). The sexual proportion found in this study was of 1 male per 0.73 females. Roos *et al*. (2007) found that in Reunion Island, southwest of the Indic Ocean, the sexual proportion of the big eye scad is of 1 female: 0.58 males. Kamali *et al.* (2015) found in Hormuzgan in the Persian Gulf a sex ratio of 1.05: 1 female: male. In the case of other species of the Carangidae family in México, it was observed that the sex ratio was of 1 female per 0.6 males in *Caranx caninus* and 1 female per 0.7 males in *C. caballus* (Espino-Barr, personal communication). Other members of the Carangidae family presented a sex ratio of 1:1, as *Caranx kalla*, *C. crysos* and *C. bucculentus* (Kagwade, 1968; Pristasand Trent, 1978; Brewer *et al*., 1994). Although the presence of mature organisms of *S. crumenophthalmus* occurs during the year, two massive spawning periods were observed; the first from February to April and the second from August to November. Table 2 shows spawning periods for *S. crumenophthalmus* in different countries of the world. Most of the countries report long periods of the spawning season of this species, as the case of the Hawaiian Island, where the spawning occurs in six months of the year, April to September (Kawamoto, 1973), seven months of the year, from April to October (Clarke and Privatera, 1995), or eight months of the year from March to October as published by Honebrink (1990). In the Virgin Islands, Tobias (1987) reported seven spawning months: from March to September, and in the Reunion Islands, Roos *et al*. (2007) reported eight months from April to November. In

Hormuzgan, Iran, spawning lasts 5 months, from February to June (Kamali *et al*., 2015). Elsewhere, spawning of *S. crumenophthalmus* in Brazil occurs punctually in only two months of the year: May and June (Trinidad-Santos *et al.,* 2015), similar as in Cuba, where it lasts three months: March to May (García-Cagide *et al.,* 1994). The lowest value of the first reproduction size of *S. crumenophthalmus* was 19.00 cm corresponding to Hormuzgan, Iran (Kamali *et al.,* 2015) and the highest value was 21.50 cm in the Reunion Islands (Roos *et al.,* 2007) (Table 2). Median values were obtained in Hawaii Islands, of L_{50}= 20.00 cm (Clarke and Privatera, 1995) and in the present study, of L_{50}=20.58 cm; anyhow, values were similar. The hepatosomatic index obtained in this study was b = 2.965 (r^2 = 0.539), which represents an isometric growth: as the fish grows in length and weight, its liver weight grows in the same proportion (in an average way). 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 January and July and starts to diminish during the spawning period. Similar results were reported by Sylla *et al*. (2009) in another species of the Carangidae family: *Trachinotus teraia* from Ivory Coast; its hepatosomatic index showed two reproduction periods and the fatty acids were reduced during the spawning seasons, which occurred in January-February and August. The highest values of the fatty acid reserves were observed in March and November, proceeding the massive spawning months.

The most active feeding seasons are during the periods of time prior and during spawning, the most active months are March, April, July and October; the gastric repletion index declines significantly after the first and second massive spawning period, that is May and November-December. During winter the gastric repletion index decreases, associated to the decreasing photoperiod and food availability in the sea. Condition factor reaches the maximum values during the February, March, April, September and October with either model: Fulton (1902), Clark (1928) and Safran (1992), and decreases during December and January, after the massive spawning of October. Considering that the reproductive periods of this species can reach seven or eight months, the active feeding periods occur during a long period of time during the year. Sylla *et al.* (2009) reported for *Trachinotus teraia*, off Ivory Coast, that the condition factor values vary in the same manner as the gonadosomatic index, observing higher values during August and January, which coincides with maximum reproductive period when the organisms feed more actively. Table 3 shows values of fecundity in different localities for *Selar crumenophthalmus*. Kamali *et al*. (2015) found in Hormuzganin the Persic Gulf a sex ratio of 1.05:1 female: male. Total and relative fecundity were 102,841 and 581.02, respectively. Massive spawning season occurs between February and June. The relationship between weight and length was $W = 0.032 \cdot L^{2.835}$, which the authors consider isometric growth. Length of first reproduction was L_{50} = 19 cm.

Breder and Rosen (1966) found that the bigeye scad has and external reproduction, is dioic and its eggs and larvae live in open waters and are scattered by currents. Clarke and Privitera (1995) found that the bigeye scad of Hawaii spawns from April to August and October. Its first reproduction length is equal or smaller than 20cm, they spawn at sunset and early evenings. The presence of postovulatory follicles in female show that they spawn every three days, they registered 92,000 batch fecundities.

Conclusions

- The proportion of male: female was 1: 0.73.
- Average length of sexual maturity (L_{50}) was 20.80 cm in males and 20.55 in females; average length of first maturity (L_{25}) was 20.00 cm for both sexes. In all cases corresponding to an age between two and three years.
- The allometric relationship between the liver weight and the fish length is isometric (b = 2.965). Maximum values were observed in January, July, August, October and November, lower values in September.
- The gonadosomatic index (GSI) reached its highest values during February, March, April, August, September, October and November.
- The gastric repletion index showed higher values during March, April, July and October; the lower values were observed during February, August and September.
- For the condition factor, the highest values were obtained in the months of February, March, April, September and October for Fulton, Clark and Safran Indexes.
- Oocyte diameter was 0.28 mm (±0.02 mm standard deviation: SD), minimum 0.24 mm and maximum 0.30 mm.
- Fecundity values ranged from 86 760 to 245 114 oocytes in females of two to six years of age and lengths of 19.04 cm to 24.21 cm, and 68.37 g to 148.49g of weight.
- Average value of relative fecundity was of 1 667.3 oocytes·g=1 (ranging from 70.4 to 4 609.4 oocytes·g^{-1}).

Recommendations

Studies on the reproduction of the bigeye scad *Selar crumenophthalmus* should be enlarged by histological analysis of the gonads, that will allow to continue with the knowledge of the oogenesis and spermatogenesis of this species, which reproduces practically all year, showing asynchronous spawns and pulses of abundant and frequent fecundity that gives it a strong adaptive and evolutionary force.

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