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Reproductive aspects of *Sphyraena ensis* (Perciformes: Sphyraenidae) inhabiting the coast of San Blas Nayarit, southeast Gulf of California

Iram Zavala-Leal,* Deivis Palacios-Salgado, Javier M. J. Ruiz-Velazco, Francisco Valdez-González, Juan Manuel Pacheco-Vega, Jasmín Granados-Amores, And Juan Ramón Flores-Ortega

Posgrado en Ciencias Biológico Agropecuarias, Universidad Autónoma de Nayarit-Escuela Nacional de Ingeniería Pesquera, Km. 12 Carretera Los Cocos, C.P. 63740, San Blas, Nayarit, México (IZL, DPS, JMJRV, FVG, JMPV, JGA, JROF)

**Correspondent: ziram28@hotmail.com*

The Mexican barracuda (*Sphyraena ensis*) represents one of the most important fishing resources on the coast of Nayarit, Mexico. Because of its catch volumes and market prices, this fishery is one of the main economic activities in the region. Despite its relevance, knowledge on reproductive biology of this species in the area is scarce. The purpose of this research is to determine some basic aspects of reproductive biology of the Mexican barracuda. Monthly samplings from February, 2014 to January, 2015 were conducted. Sex ratio and weight-length relationship were determined. The degree of gonadal development was established through qualitative (morpho-chromatic maturity scale) and quantitative (morphophysiological indexes such as GSI, HSI and K) methods. The total sex ratio (1M:1.87F) was different from 1:1 and specimens presented negative allometric growth. The Mexican barracuda population presented constant reproductive activity throughout the year. According to morphophysiological indexes such as GSI and HSI, the period of maximum reproductive activity was observed from April to June.

Key words: length-weight relationships, Mexican barracuda, reproduction, sexual proportion, southeast Gulf of California, *Sphyraena ensis*

Barracudas (*Sphyraenidae*) are neritic pelagic species inhabiting coastal areas in tropical and temperate-warm waters (Nelson et al. 2016). Adults of small species and juveniles of all species of barracuda are gregarious and form schools, while adults of large species are solitary or less gregarious (Sommer 1995). The Mexican barracuda (*Sphyraena ensis* Jordan and Gilbert, 1882) is the most abundant species in the Gulf of California and presents the largest distribution range in the eastern tropical Pacific, from the Gulf of California, Mexico, to the northern portion of Chile (Chirichigno and Cornejo 2001). In the water column, the Mexican barracuda can be found from the surface to 25 m depths

(Robertson and Allen 2008). It is a carnivore species that mainly consumes fish (Blaskovic et al. 2008) and reaches a maximum total length of 137 cm (Robertson and Allen 2008).

The Mexican barracuda represents one of the most important fishery resources on the coast of Nayari, Mexico (Ulloa-Ramírez et al. 2008). Fishing this resource constitutes one of the main economic activities because of its great volume of capture and sales for human consumption, besides being a species of interest for sport fishing activities. It is also a subsistence fishery that satisfies local need for fish protein, since its meat is considered of good quality, especially in the region. However, despite its importance as a fishery resource in the local economy, there is little information on the biological and ecological aspects of this species.

The biological studies of barracudas worldwide have mostly been focused on feeding habits, these include the trophic aspects of *S. viridensis* in the North-eastern Atlantic (Barreiros et al. 2002), *S. barracuda* in Colombia (Hooker et al. 2007), *S. putnamae* in the Persian Gulf (Mohammadizadeh et al. 2010), among others. In Mexico, the length-weight relationship, feeding habits, and gonadal maturation have been estimated for *S. guachancho* in Veracruz (Bedia et al. 2011). While in the Mexican Pacific, a similar study was conducted for the pelican barracuda, *S. idiastes* in which the length-weight relationship, condition factor and trophic level were determined (González-Acosta et al. 2015). Regarding the Mexican barracuda, there are only a few incidental reports of this species in some studies (Bianchi 1991, Madrid et al. 1997, Abitia-Cardenas et al. 2002, Aceves-Medina et al. 2008). Despite the fishing and ecological importance of *S. ensis* in the area, there is a gap of knowledge on its reproductive biology. Therefore, the purpose of this research was to determine some basic aspects of reproductive biology of the Mexican barracuda in order to provide information that supports the regulation of its fishery in the region.

Materials and Methods

Monthly samplings were conducted from February, 2014 to January, 2015 in the coast of San Blas, Nayarit (21° 24' N, 105° 15' W and 21° 33' N, 105° 24' W). Organisms were obtained from coastal commercial fishing, which were captured with line and hook. For each organism, the total length (TL) and weight (W) were recorded. Subsequently, gonads and liver were removed and weighed individually. Sex was determined through direct observation of the gonad. The annual and monthly sex ratio was estimated. To establish whether the sex ratio differed from 1:1, a chi-square test (X^2) was performed (Zar 2010). Length was compared between sexes by non-parametric Kruskal-Wallis test (Zar 2010). The length-weight relationship was determined for the whole sample and separated by sex respectively. Parameters a and b were estimated using the linear regression model ($log\ Wt = log\ a + b\ x\ log\ TL$) on log-transformed data. A log-log plot (Log TL vs Log TW) was used to remove outliers (Froese 2006). To determine the growth rate of barracuda, the obtained slope was compared with the hypothetical value of 3 (isometry) by Student's t-test (Zar 2010).

To establish the degree of gonadal development, qualitative and quantitative methods were used. The qualitative method consisted on establishing a morpho-chromatic scale for females and males of *S. ensis,* based on the morpho-chromatic scale proposed by Agger et al. (1974) and adapted for this species. Subsequently, the reproductive cycle was described considering the monthly frequencies of each stage of gonadal development. The quantitative method consisted of calculating the gonadosomatic index (GSI = weight of the gonad / weight of the fish without gonad * 100), hepatosomatic index (HSI = liver weight / weight of fish without liver * 100) and the relative condition factor (K = $W_{(fish\ weight)} / aL_{T(fish\ length)^b}$) according to Le Cren (1951). Monthly variations of GSI, HSI and K by sex and month were analyzed with non-parametric Kruskal-Wallis analysis of variance. Spearman correlations were estimated between indexes and stages of gonadal development.

Results

A total of 319 barracudas were sampled, 208 of which were females and 111 males. The overall sex ratio (1M:1.87F) was different from 1:1 (X^2=29.50 $_{df = 1}$, P=0.000). Although in most months the sex ratio was higher for females, only in March, September, November, December and January the sexual proportion was significantly different from 1:1. May was the only sampled month in which male ratio (1M:0.24F) was statistically higher than female ratio (Table 1). Size distribution ranged from 32.7 cm to 58.7 cm TL (mean=45.24 cm TL) and weight ranged from 141 g to 836 g (mean=426.73 g) in females, while males presented from 30.6 cm to 53.5 cm TL (Mean=40.76 cm TL) and from 119 g to 638 g (mean=336 g). Comparisons of female/male size indicated that females were larger in total length (H=7.426, $_{df = 1}$, P=0.005) and weight (H=7.419, $_{df = 1}$, P=0.006).

Table 1.— Sexual proportion of the Mexican barracuda, *Sphyraena ensis* from southeast Gulf of California.

Month	Male	Female	Proportion M:F	X^2	P
February	12	23	1:1.9	3.46	0.062
March	4	20	1:5	10.67	0.001*
April	15	7	1:0.47	2.91	0.088
May	17	4	1:0.24	8.05	0.004*
June	7	8	1:1.14	0.07	0.791
July	19	10	1:0.53	2.79	0.094
August	12	17	1:1.42	0.86	0.353
September	5	23	1:4.6	11.57	0.000*
October	12	19	1:1.58	1.58	0.208
November	5	25	1:5	13.33	0.000*
December	2	25	1:12.5	19.59	0.000*
January	1	27	1:27	24.14	0.000*
Total	111	208	1:1.87	29.50	0.000*

* Significant difference (P < 0.05).

The length-weight relationship in the Mexican barracuda, *S. ensis* showed that growth is negatively allometric for the overall sample, presenting a slope value (b=2.796) lower than the hypothetical isometric value (t=1.96, P=0.000). Similarly, negative allometric growth was observed in males (b=2.829, t=1.98, P=0.000) and females (b=2.814, t=1.97, P=0.000) (Table 2).

Table 2. — Length-weight relationship parameters for the Mexican barracuda from the southeast Gulf of California, Mexico. N= sample size, Range= minimum and maximum, a= proportionality coefficients (intercept), aCI95%= confidence limits for a, b= allometry coefficient (slope), bCI95%= confidence limits for b, and r^2= coefficient of determination.

		Total length (cm)	Total weight [g]	Relation parameters						
	N	Range	Range	a	$IC_{95\%}\ a$		b	$IC_{95\%}\ b$		r^2
Females	208	32.7–58.7	141–836	0.0061	0.0042	0.0079	2.9178	2.8397	2.9959	0.9824
Males	111	30.6–53.5	119–638	0.0091	0.0048	0.0135	2.8160	2.6897	2.9422	0.9738
Both sexes	319	30.6–58.7	119–836	0.0073	0.0056	0.0090	2.8732	2.8131	2.9332	0.9829

Gonadal development was characterized at the macroscopic level. For females, five stages of development were established: resting, early developing, late developing, mature and spent (Table 3). In males, four stages of development were established: resting, developing, mature and spent (Table 4). Regarding the reproductive cycle, it was observed that *S. ensis* presents constant reproductive activity throughout the year (Figure 1). Females were found in mature stage in all months, except for November and December. However, in these same months females were found in early and advanced stages of development. Likewise, females were observed in the resting phase throughout the year, except from May to July (Figure 1a). In males, mature organisms were found throughout the year without exception. The resting stage in males was observed during most of the sampling period, except from April to July and in January (Figure 1b). However, in the latter only one male corresponding to the mature stage was found (Table 1 and 2).

Gonadosomatic (GSI) and hepatosomatic (HSI) indexes showed a seasonal variation in both males and females following the same pattern of behavior (Figures 2 and 3). The mean GSI and HSI values were highest from April to June, the highest mean GSI value was observed in May, which was 1.83 and 2.08 for males and females, respectively (Figure 2). The HSI mean value was highest in April and June for females (3.56 and 3.61, respectively) and in April (3.04) for males (Figure 3). The analysis of variance indicated that GSI values were higher in females than males (F=3.752$_{df=1}$, P=0.0489), while HSI did not present significant differences between sexes (F=1.475$_{df=1}$, P=0.2244). The relative condition factor did not show a defined pattern in either sex. In females, the maximum monthly average value was 0.91 and minimum 0.81 (mean=0.88), while males presented a maximum value of 0.96 and minimum 0.87 (mean=0.90).

TABLE 3.— Stages of gonadal development in the ovary of *Sphyraena ensis* according to the morpho-cromatic scale.

Stage	Description
Resting	Thin and elongated ovaries, with translucent red color.
Early developing	Enlarged and flaccid ovaries, with light brown color.
Late developing	Larger and turgid ovaries, with yellowish color. Small oocytes can be observed. Evident external vascularization.
Ripe	Large, turgid and fully filled ovaries, intense yellow. Large oocytes can be easily observed. Very vascularized internally but less evident externally.
Spent	Flaccid and empty ovaries, with reddish brown color.

TABLE 4.— Stages of gonadal development in the testis of *Sphyraena ensis* according to the morpho-cromatic scale.

Stage	Description
Resting	Thin and compact testis, with cream color. May present light red tones.
Developing	Large testis, compact and firm to the touch, with pale cream color and light shades. Vascularization can be easily observed externally.
Ripe	Testicle robust and firm to the touch, with whitish color. The collecting tubule is whiter in the inner part of the lobes, it easily ejects semen when exposed to slight pressure.
Spent	Flaccid and empty testicle, with brown cream color.

The GSI and HSI showed to be good indicators of gonadal development in the Mexican barracuda. According to the correlation analysis, females presented a positive correlation between GSI (R=0.887, P=0.0001) and HSI (R=0.852, P=0.0004) with regard to the late developing stage, whereas these same indexes showed a negative correlation at the resting stage (GSI, R=-0.963, P=0.0000; HSI, R=-0.828, P=0.0008). Males exhibited a positive correlation between GSI and the mature stage (R=0.687, P=0.0112) and negative correlation between GSI and the resting stage (R=0.707, P=0.0019).

DISCUSSION

The lengths found in this study ranged 30.6 cm to 58.7 cm TL. The maximum length found was lower than that reported as record length (137 cm) for *S. ensis* (Robertson and Allen 2008). This could be attributed to the sampling area, since the organisms used for this study were collected near the coast and according to Whitehead et al. (1986), small barracudas are found close to coastal areas, while the largest individuals are found in the open sea. With regard to length by sex, it was observed that females were larger than males. Nikolsky (1963) suggests that females reach greater lengths as a reproductive strategy, for this allows them to produce more eggs. The sex ratio of the Mexican barracuda was 1:1.87 (M:F). Higher proportions of females have been detected in other species of barracuda from different regions: *S. chyrsotaenia* (Rizkalla 1985, Allam et al. 2004), *S. barracuda* (De Sylva

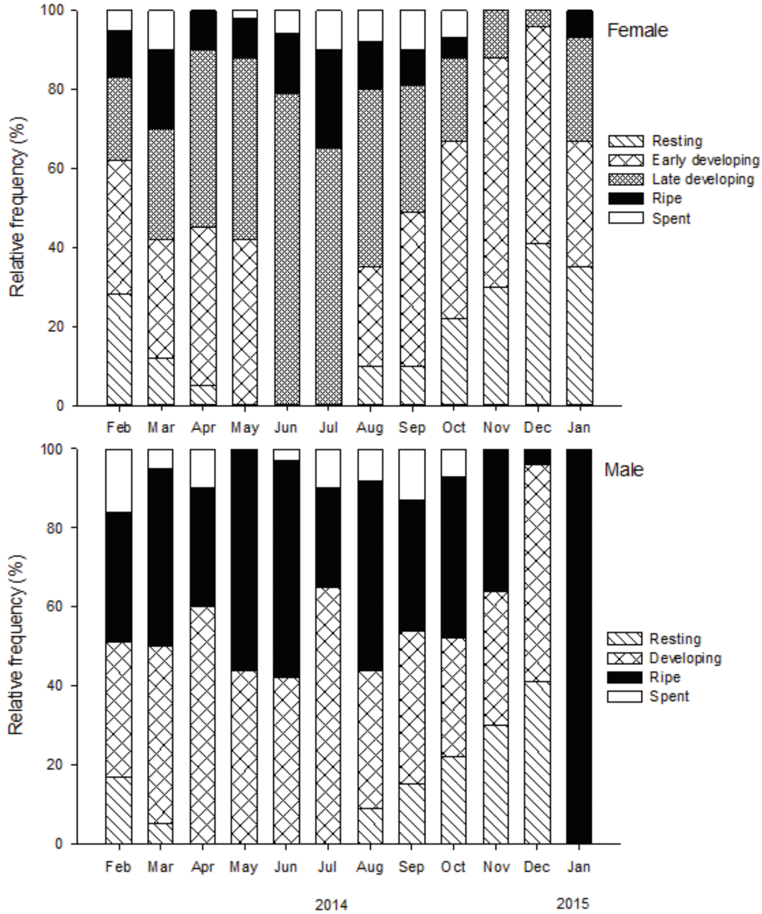

FIGURE 1.— Monthly frequencies of the gonadal developmental stages for females and males of *Sphyraena ensis*.

1963, Kadison et al. 2010), *S. sphyraena* (Allam et al. 2004), *S. guachancho* (Bedia et al. 2011), and *S. idiastes* (González-Acosta et al. 2015). However, in species such as *S. obtusata, S. chrysotaenia*, *S. jello* (Okera 1982), *S. flavicauda* (Allam et al. 2004) the highest ratio has been reported for males. According to Nikolsky (1963), the sex ratio can show variations among populations and may vary during their life cycle due to changes in environmental factors, food availability, mortality, and others, acting differently for each sex. According to length-weight relationship, it was observed that *S. ensis* presents negative allometric growth, which means that individuals grow more in length than weight. Within the family Sphyraenidae, the type of growth is variable among species, for instance, isometric growth has been reported for *S. putnamae* (Mohammadizadeh et al. 2010) and *S. idiastes* (González-

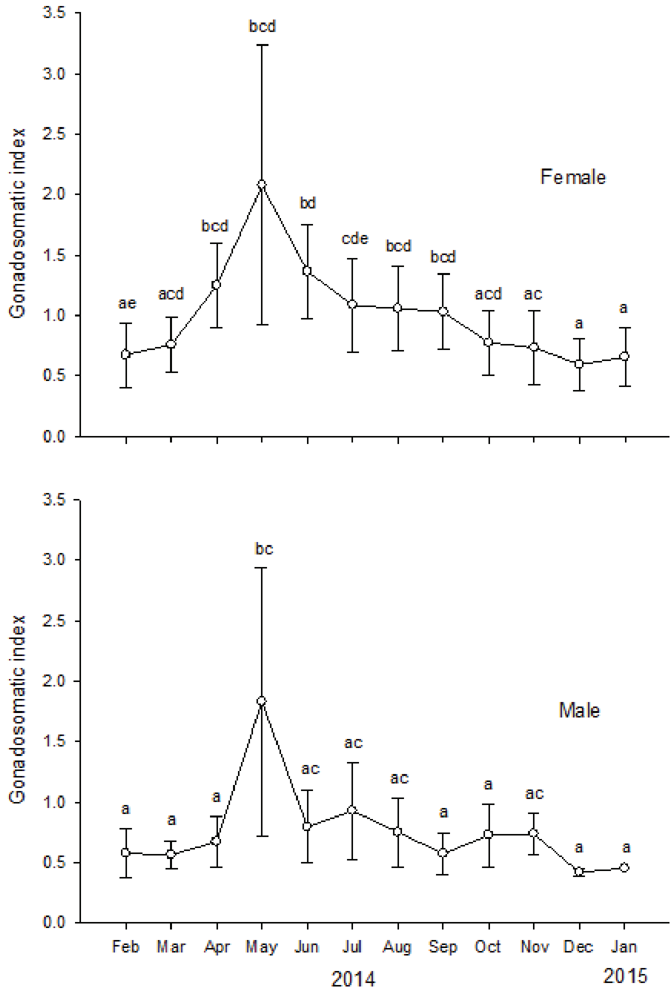

FIGURE 2.— Monthly variation of mean values of the gonadosomatic index for females and males of *S. ensis*. Means that do not share the same superscript are significantly different ($P<0.05$). Bars correspond to standard error.

Acosta et al. 2015). In the Mediterranean Sea, Kalogirou et al. (2012) analyzed the growth rate of *S. viridensis* (b=2.76), *S. sphyraena* (b=2.97), and *S. chrysotaenia* (b=2.85) and found different types of growth even in species of the same region. For *S. guachancho*, different types of growth have been detected according to the sampling season (isometric growth in the rainy season and allometric in windy and dry seasons) (Bedia et al. 2011). Begenal and Tesch (1978) point out that differences in the length-weight relationship can be found with

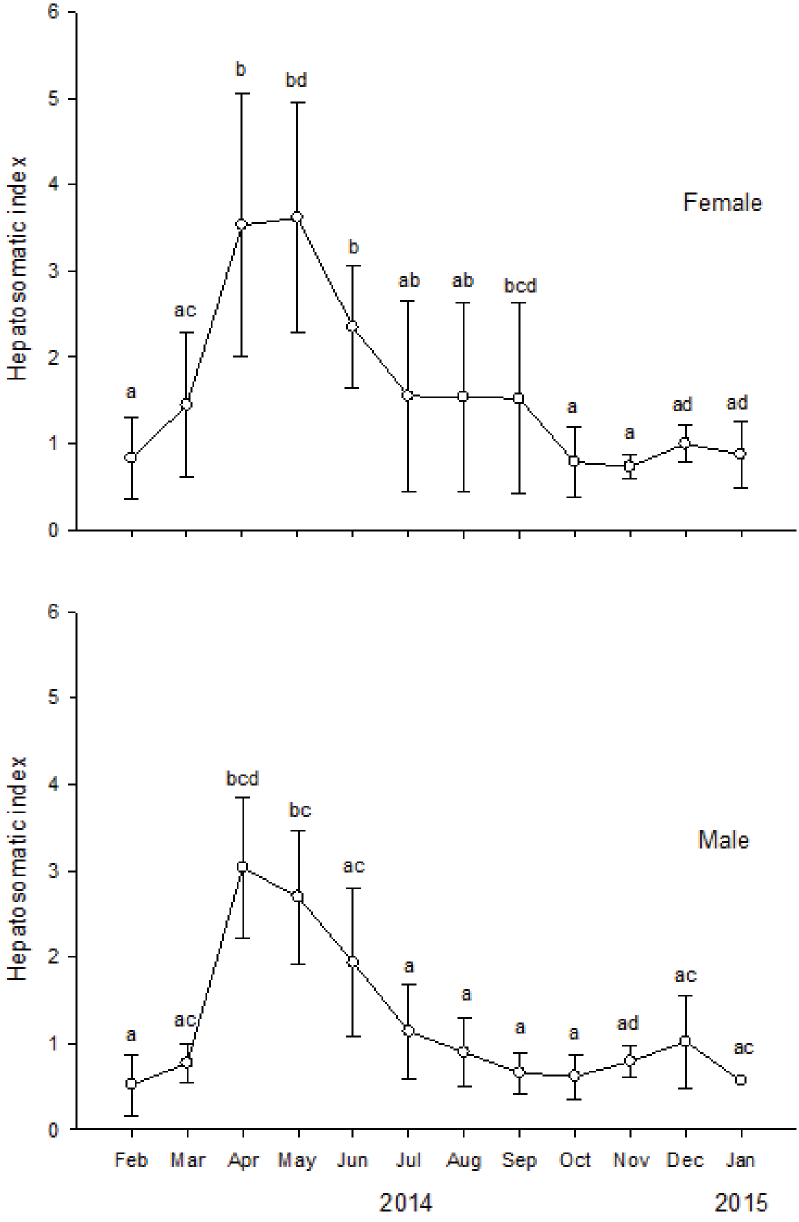

FIGURE 3.— Monthly variation of mean values of the hepatosomatic index for females and males of *S. ensis*. Means that do not share the same superscript are significantly different (P<0.05). Bars correspond to standard error.

regard to sex, sexual maturity, season and even time of the day as a result of stomach filling; therefore, changes in b value can be found in different developmental stages, first sexual maturity and when important environmental changes occur. The reproductive activity of *S. ensis* in the study area remained constant throughout the year. Females in mature stage were observed in all of the sampling months except for November and December; however, the proportion of females at that stage was low and rarely reached 20%. Similarly, mature males were observed during all sampling months. According to the morphophysiological indexes such as GSI and HSI, the period of maximum reproductive activity was observed from April to June. The highest reproductive activity is associated with the highest GSI values, while minimum values are related to resting periods (Htun-Han 1978). In this regard, during April, May, and June there was a high proportion of organisms at developing stages (males), early developing and late developing stages (females), and a low or null proportion of organisms at resting stage. This explains the fact that despite mature organisms being detected throughout the year, the GSI value from April to June was high because it is based on the relationship between gonad weight and total weight of the organisms (Bolger and Connolly 1989). In other barracuda species, a single spawning peak has also been reported: S. barracuda from May to November (De Sylva 1963), S. obtusata from November to December (Okera 1982), S. sphyraena from June to November (George et al. 1998); however, in some cases it is very extended, as occurs with S. guachancho, where the highest reproductive activity is from June to February (Bedia et al. 2011). In S. barracuda a reproductive period (maturity and spawning) was observed from March to November with different peaks in GSI (Kadison et al. 2010).

The GSI and HSI are good indicators of reproductive period. In females, a positive correlation was observed between these indexes and the late developing stage, while a negative correlation was found when compared to the resting stage. Several studies have addressed these indexes together with K value in order to evaluate the reproductive capacity, since vitellogenesis and gametogenesis mobilize energy and body fat (Abascal et al. 2004, Kanak and Tachihara 2008). The GSI and HSI increase as the gonadal development progresses because the liver is the main organ responsible for vitellogenin production, which will furtherly be distributed to the gonads (Henderson and Tocher 1987) for oocyte maturation. In this connection, the energy and body fat obtained from food are temporarily stored in the liver and gonads during the processes of vitellogenesis and gamatogenesis. In males, a positive correlation was observed between GSI and the developing stage, while a negative correlation was found between GSI and the resting stage. These relations could be explained by the progression of gonadal development in males, where the gonads increase their size due to cellular differentiation, even when there is no reserve storage of sexual cells, as occurs in females. Regularly, K is negatively correlated with GSI or degree of maturity (Maddock and Burton 1999), reflecting the transfer of somatic energy to the gonads for gametogenesis support (González and Oyarzún 2002). This correlation was not found in this study. However, K shows a slight tendency to decrease during the month that presented the highest GSI value (May) in both females and males.

In conclusion, the Mexican barracuda population showed the mature stage most of the year in the study area although in a low proportion, the highest reproductive activity according to GSI and HSI was presented from April to June. Therefore, these months of increased reproductive activity can be suggested as a closure period in order to establish a sustainable fishery management plan.

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