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GROWTH AND SEX RATIO OF OCTOPUS *Paroctopus digueti* (PERRIER & ROCHEBRUNE, 1894) IN A WILD POPULATION

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ABSTRACT

In Mexico, studies of octopus *Paroctopus digueti* are scarce, thus the objective of this research is to evaluate some of its biological aspects in Ohuira Bay, Ahome, Sinaloa, Mexico. From autumn 2016 to autumn 2017, a total of 217 organisms of *P. digueti* were collected, from which 166 were females, 31 ovigerous females and 20 males. The lengths of the mantle (ML), tentacles or arms (AL) and total length (TL) were recorded as well as the total weight (TW) of each organism. The software FiSAT II was used to obtain the growth parameters by mediating seasonal size frequencies. Considering both sexes, the average registered mantle length was 40.31±2.5 mm. For the analysis of ML-TL y ML-AL, the data were adjusted to a linear-type model. For the relationship between ML-TL, the minimum determination coefficient was observed during spring $R^2 = 0.335$, and the highest was registered in winter $R^2 = 0.6452$. With regards to the allometry coefficient (*b*), it was different among the 4 climatic seasons. The theoretical ML growth curve showed both sexes of $ML_\infty = 73.50$ mm, K = 1.30 $year^{-1}$ and $t_0 = 0.10$. The estimated values from the growth equation revealed faster growth ($ML_\infty = 63$ mm) within the 1.2 years of their lives, reaching a maximum length at 2.5 years of age. The total weight growth curve of *P. digueti* octopus was formed by an exponential first stage up to six months and the second logarithmic stage from seven months to approximately 1.8 years. In the summer there were slightly lower coefficients and percentages of instantaneous growth coefficients (IGC) for the lengths and total weight of octopus *P. digueti*. The highest Fulton's condition index (k) was recorded in winter. The sex ratio was significant in a proportion of 9.85 F:1 M.

Keywords:
Paroctopus digueti
Population
Growth
Ohuira Bay
Mexico

How to Cite

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INTRODUCTION

Octopods are a major resource in worldwide fisheries, representing 5.6% of the proportion in value and 4.0% within the main groups of species in production and marketing (FAO, 2016). According to its volume, the octopus fishery in Mexico is in ninth place within the fishery production; nevertheless, concerning its value, it occupies the fourth place. In the Mexican Pacific coasts, Baja California Sur holds 1.98% (545 Ton) of the national fishery, including every octopus species subject to capture in the area (27541 Ton). The state of Sinaloa, including zone I, contributes 1.2% (331 Ton) of the national octopus production. On the Mexican Pacific coastline, catches mainly consist of *Octopus hubbsorum*, followed by *Octopus macrocopus* and *Octopus bimaculatus*, with records from 1970 until now (CNP, 2012).

Octopus *Paroctopus digueti* is distributed in Mexico, the Gulf of California and the Pacific coastline, particularly by the middle portion of the southern zone of the Baja California Peninsula. The most distinctive morphological characteristics that *P. digueti* shows is a long and pointy igula (intromittent organ), a small body with a rounded mantle, a small body and arms that measure around 2 and 2.5 times the body length, as well as bigger sizes in males (Voight, 1990). *P. digueti* is a benthic species that inhabits sandy, muddy and rocky banks of the intertidal shore (FAO, 1995). It has a short life span, a high growth rate, a direct development and it easily adapts to life in captivity (DeRusha et al., 1987; Jereb et al.,2016). In the Mexican Pacific, studies on the growth of this species are scarce (Voight, 1990), so it is necessary to update or provide recent information on all aspects of biology (Dominguez-Contreras et al., 2018; Diarte-Plata et al., 2019). The lack of these basic scientific elements has held back the establishment of management measures to regulate its sustainable use. The purpose of the present study is to provide information on the growth and sex ratio of octopus *P. digueti* in Ohuira Bay, Ahome, Sinaloa, Mexico.

MATERIAL AND METHODS

Study area

Ohuira Bay (25.32°, -25.36° N; -108.51°, -109.03° W) communicates with the Port of Topolobampo, in Ahome, Sinaloa, Mexico by a 700 m wide channel. Ohuira Bay has an area of 125 km^2 (9900 has), its origin comes from the basin of an ancient canal from the Fuerte river which extended through Topolobampo Bay, flowing into this port. It is an area of shallows that during the rainy season presents a deep zone with a variable location due to the tides and sediment dragging, and has a bifurcation that connects it with Navachiste Bay in the municipality of Guasave, Sinaloa, Mexico. Dry weather predominates and the hottest season takes place from July to October, whereas the coldest prevails from November to February. The annual average relative humidity is 84.5% and the annual average atmospheric pressure is equivalent to 1022.90 mb (at sea level) (Cifuentes-Lemus and Gaxiola-López, 2003; Cárdenas-Gámez, 2006; Zavala-Norzagaray, 2011) (Fig. 1).

Capture of organisms

Seasonal samplings were made from Autumn 2016 to Autumn 2017. Octopuses were collected with and without shelters by diving with a snorkel to a depth of 4 m in Ohuira Bay. The organisms were placed individually inside labelled plastic bags; each label contained the information from each individual (González et al., 2015; Bañón-Otero et al., 2018; Duarte et al., 2018; Diarte-Plata et al., 2019).

Biometric data

The mantle length was measured for each octopus (ML), as well as the arms (AL) and total length (TL) by using a digital vernier caliper with 0.05 mm of precision (Mitutoyo® 500-197, 965 Corporate Boulevard Aurora, Illinois 6050, USA). The total weight (TW) was registered with a digital scale (Ohaus®, Scout Pro SP 200 Balance, Pine Brook, NJ 07058, E. U. A.) (Diarte-Plata et al., 2019).

Size structure

Frequency size histograms were created per climate season by considering the mantle length (ML), the length of the arms (AL), total length (TL) and total weight (TW) for *P. digueti* (Jackson, 2004; Ortiz-Arellano, 2005; Diarte-Plata et al., 2019).

Morphometrics

In order to determine the relationship among ML, AL and TL, the data were adjusted into a linear type model by applying the following equations (Ortiz-Arellano, 2005; Diarte-Plata et al., 2013) (Equations 1 and 2):

$$ML=a+bTL \qquad \text{(Eq. 1)}$$

$$AL=a+bTL \qquad \text{(Eq. 2)}$$

where ML = Length of the mantle (mm), AL = Length of the arms, TL = Total Length (mm), *a* = y-intercept, *b* = slope.

Regarding the relationship TW-ML, TW-AL and TW-TL of *P. digueti*, the values were adjusted to potential type models by using the following equations (Equations 3, 4 and 5):

$$TW=aML^b \qquad \text{(Eq. 3)}$$

$$TW=aAL^b \qquad \text{(Eq. 4)}$$

$$TW=aTL^b \qquad \text{(Eq. 5)}$$

where TW = Total weight of the organism (g), ML = Mantle length (mm), AL = Arm length, TL = Total length of the pygmy octopus (mm), the *a* factor is the condition factor or level of individual robustness, and *b* is an allometric factor, meaning the relative growth coefficient in weight in accordance with the length (Pauly, 1983; Safran, 1992; Salgado-Ugarte et al., 2005).

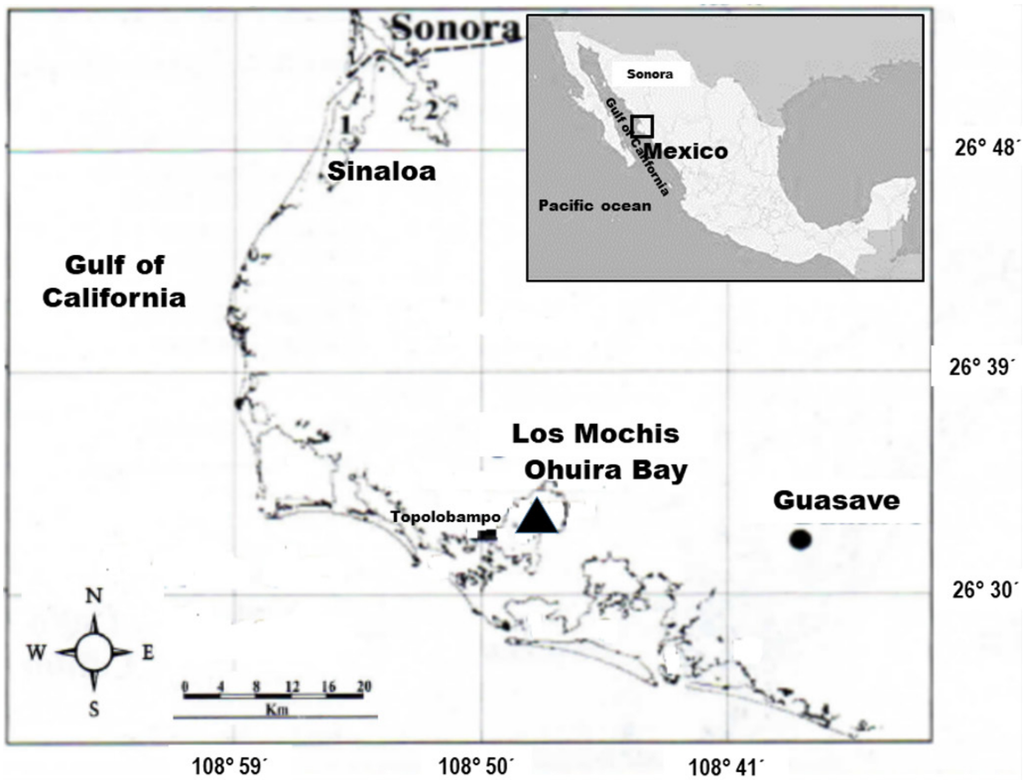

Fig 1. Sampling area in Ohuira Bay, Ahome, Sinaloa, Mexico

Mantle length growth

The ML data were used for the growth model and grouped in frequency histograms, and were analyzed by the modal progression method with the software FISAT II (FAO-ICLARM Stock Assessment Tools II, Roma, Italia) (Sparre and Venema, 1997). To determine the age, the L_∞ and K parameters were determined, as well as their dispersion from the traditional von Bertalanffy individual growth model through non-linear approximations by the use of the method of least squares from the data of length to the resulting age of the modal progression (Sparre and Venema, 1997; Escamilla-Montes, 1998). Once the values for each variable from the growth equation were obtained, they were projected through time, starting with the sizes from the smallest juveniles as the origin value. With the exception of the theoretical age of birth (t_0), the value proposed by other authors was used (Garcia-Flores, 2017), which allowed the calculation of the absolute age of the species under study (Guerra, 1979; Hanlon and Forsythe, 1985; DeRusha et al., 1987) (Equation 6).

$$ML=ML_\infty\ (1-e^{-K(t-t_0)}) \qquad \text{Eq. (6)}$$

where, ML = Mantle length (mm), ML_∞ = Average asymptotic mantle length, K = Coefficient of growth, t = Age of organism, t_0= Theoretical age in which mantle length is zero.

Total weight growth

Growth curves for total weight were estimated considering both sexes. The highest values of the ratio between the length of the total mantle-weight represented by a potential model were used. Total weight growth in the first stage was adjusted to an exponential model and in the second stage to a logistics model (Opresko and Thomas, 1975; Guerra, 1979; Hanlon and Forsythe, 1985; DeRusha et al., 1987; Tian et al., 1993; Sánchez et al., 1998; Urban, 2002; Hernandez-Llamas and Ratkowsky, 2004) (Equations 7 and 8).

$$TW=ae^{kt} \text{ (Exponential model)} \qquad \text{Eq. (7)}$$

$$TW=TW_\infty/(1+e^{-k(t-t_i)}) \text{ (Logistic model)} \qquad \text{Eq. (8)}$$

where TW= Total weight of the organism (g), TW_∞ = Asymptotic weight (TW_∞>0), a = is the condition factor or level of individual robustness (a>0), t = age (yr), t_i = Age at the inflexion point, k = Growth constant (yr^{-1}).

Munro index

The variations of ML and TW growth efficiency was determined following the Phi Prima equation from Munro (Ø) (Pauly and Munro, 1984) (Equations 9 and 10):

$$Ø´ML=Log10\ (k)+2*Log10\ (ML_\infty) \qquad \text{Eq. (9)}$$

$$Ø´TW=Log10\ (k)+2*Log10\ (TW_\infty) \qquad \text{Eq. (10)}$$

where $\acute{Ø}'$= Efficiency of growth (Phi Prima from Munro), ML_∞ = Average asymptotic mantle length, TW_∞ = Average asymptotic total weight, K = Coefficient of growth.

Instantaneous growth coefficient

Growth rates for ML and TW were calculated using the instantaneous coefficient of growth "g" calculated from equation 11 (DeRusha et al., 1987).

$$g=lnY2-lnY1/t2-t1 \qquad \text{Eq. (11)}$$

where Y1 and Y2 are lengths or weight at times t1 and t2. Multiplying "g" by 100 gives the instantaneous relative growth rate as a percent increase in body size per day. Multiplying "*g*" by mean lengths or weights over the given time interval gives a growth rate as $mm.day^{-1}$ or $g.day^{-1}$.

Fulton's condition index (K)

This coefficient has been widely used as an indirect growth index, taking into account variables like TL and TW (Leyton et al., 2015). To calculate it the following equation 12 was used:

$$K=100*(TW/TL^3) \qquad \text{(Eq. 12)}$$

where TL = Total length of the organism (mm), TW = Total weight of the organism (g).

Sex ratio

In females (F), sex was determined according to the shape and composition of the ovary and both oviducts. In males (M), it was determined according to the testicle, the spermatophoric complex and the presence of calamus in mature males, a modification found in the final part of the third or fourth pair of arms, also known as the hectocotylus. The sex ratio (F: M) was calculated dividing the number of females (F) by the number of males (M) (Rodríguez-Garcia, 2010; Garcia-Flores, 2017; Diarte-Plata et al., 2019) (Equation 13):

$$\chi^2=\sum i(Oi-Ei)^2/Ei \qquad \text{(Eq. 13)}$$

where ∑i = Summation, Oi = Relationship observed, Ei = Expected relationship.

Statistical analyses

Significant differences among the sizes of ML, AL, TL and TW between climatic seasons were analyzed by a one-way ANOVA, with their corresponding post-hoc Tukey test applied. Regarding the relations between TW-ML, TW-AL and TW-TL in the potential regressions, *t* tests were applied to *b* values in order to determine the significance in connection to the isometry (*b* = 3). To calculate the significance of the growth efficiency, the Munro index variation coefficient ($CV\acute{Ø}'$) was used, which is equivalent to the arithmetic average and the standard deviation of the Phi Prima ratio ($\acute{Ø}'$) (Pauly and Munro, 1984; Sparre and Venema, 1997; Zar, 2010). The significances of sex ratios (H_0: 1H= 1M) were valued by Ji-square tests (χ^2). A level of significance of α=0.05 was used. Statistical packages of Excel® and Statistica® 7.0 were used (Chen et al., 1992; Salgado-Ugarte et al., 2005; Zar, 2010).

RESULTS

Size structure

The size-frequency distribution of 217 organisms of *P. digueti* was analyzed, from which 166 were females, 31 ovigerous females and 20 males. Considering both sexes, the ML had a variation of 22 to 59 mm, with an average of 40.31±2.5 mm (mode of 45 mm). The AL varied from 54 to 181 mm, with an average of 115.21±7.05 mm (mode of 105 mm) (Fig. 2). The size interval TL ranged from 85 to 217 mm, with an average of 171.38±28.94 mm, with a bi-mode of 160 and 180 mm. The TW varied from 11.5 and 65.9 g with an average of 30.20±10.76 g, and a bi-mode of 25 and 30 g (Fig. 3). In the case of females (F), the ML was 41.37±6.72 mm (22-59 mm, interval), the AL was 115.33±17.18 mm (136-156 mm, interval), the average TL was 170.59±31.48 mm (57-295 mm, interval), and an average TW was 30.60±0.82 g (11.5-65.9 g, interval). In the case of males (M), the average size ML was 39.87±5.99 mm (30-49 mm, interval), the AL was 117.22±19.44 mm (80-146 mm, interval), the TL was 165.80±27.03 mm (119-217 mm, interval), and a TW was 26.35±9.65 g (15.3-52 g, interval).

The sizes regarding ML ($F_{(3, 0.05)}$ = 22.31; *P* = 0.0000001), AL ($F_{(3, 0.05)}$ = 15.36; *P* = 0.0000001), TL ($F_{(3, 0.05)}$ = 29.90; *P* = 0.0001) and TW ($F_{(3, 0.05)}$ = 38.72; *P* = 0.001), considering both sexes, presented significant differences between climatic seasons. The ML was different in comparison between spring-summer season (*P* = 0.0000008), fall-winter (*P* = 0.00004), and winter-spring (P=0.00008). AL showed a significant difference between spring-fall (*P* = 0.0327), spring-summer (*P* = 0.00008) and winter-summer (*P* = 0.000059). TL was different in fall concerning spring (*P* = 0.0044) and summer (*P* = 0.0022). TW was different during spring with respect to summer (*P* = 0.000766) and winter (*P* = 0.000008) (Table 1).

Morphometrics

For the analysis of ML-TL y ML-AL, the data were adjusted to a linear type model (Fig. 4). For the relationship between ML-TL, the minimum determination coefficient was observed during spring (R^2 = 0.335), and the highest was registered in winter (R^2 = 0.6452). Whereas for the relationship between ML-AL, the lowest value was recorded in summer (R^2=0.2028), and the highest in winter (R^2= 0.3913). In both linear regressions, summer presented the lowest relationship, whereas winter showed the highest significant relationship. In order to get the values of the relationship between TW-TL, the data were adjusted to a potential type model (Fig. 5), where the lowest determination coefficient was R^2= 0.2093 in spring and the highest R^2= 0.6237 occurred during summer. With regards to the allometry coefficient (b), it was different among the 4 climatic seasons (autumn: t = 0.093, winter t = 0.045, spring: t = 0.010 and summer t = 0.178; $t_{critical}$ = 6.12, *P*< 0.05) (Fig. 5).

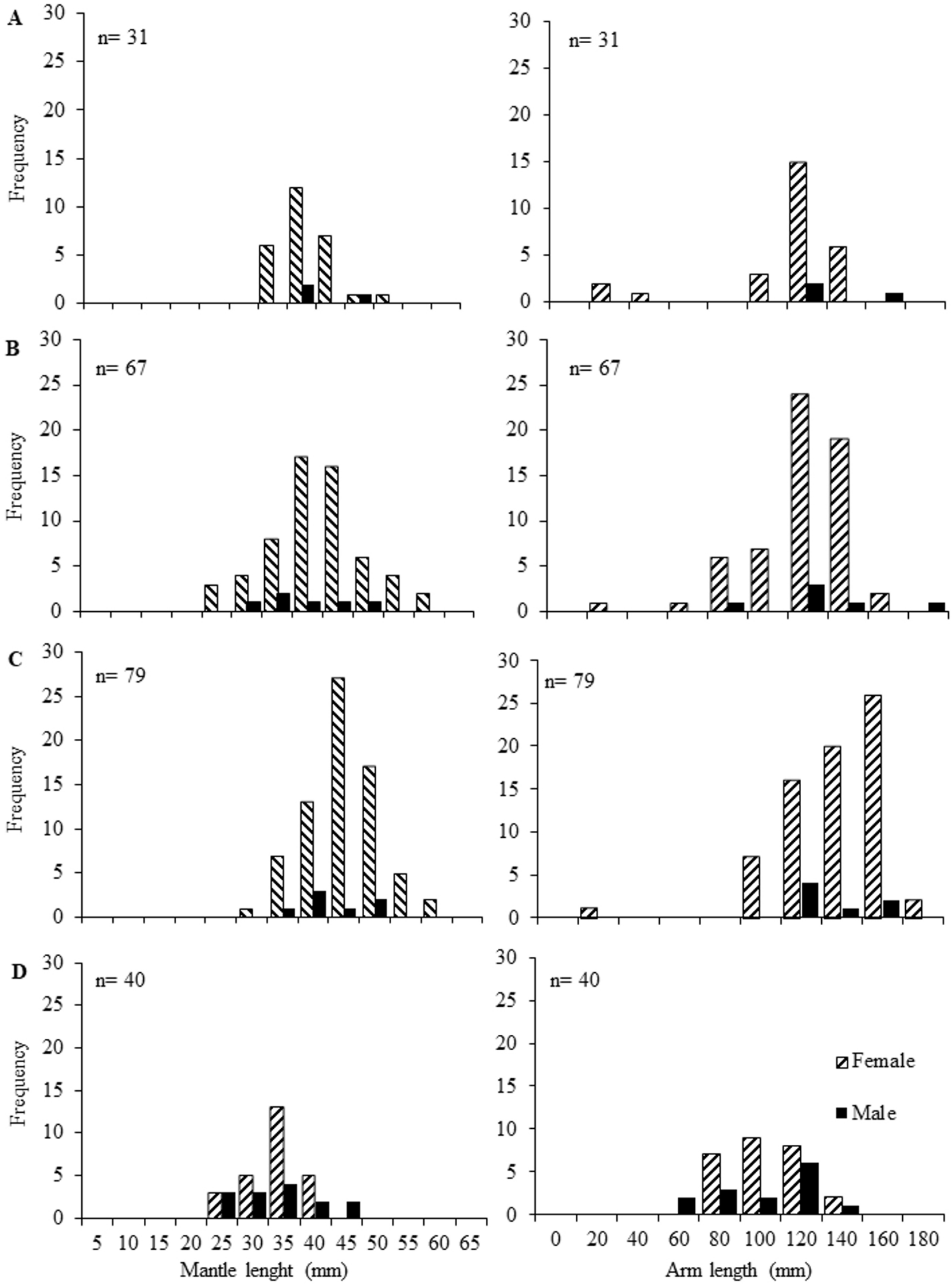

Fig 2. Size structure in mantle length and arm length of *Paroctopus digueti*. Females (F), Males (M) by climatic seasons: (**A**) autumn, (**B**) winter, (**C**) spring and (**D**) summer in Ohuira Bay, Ahome, Sinaloa, Mexico

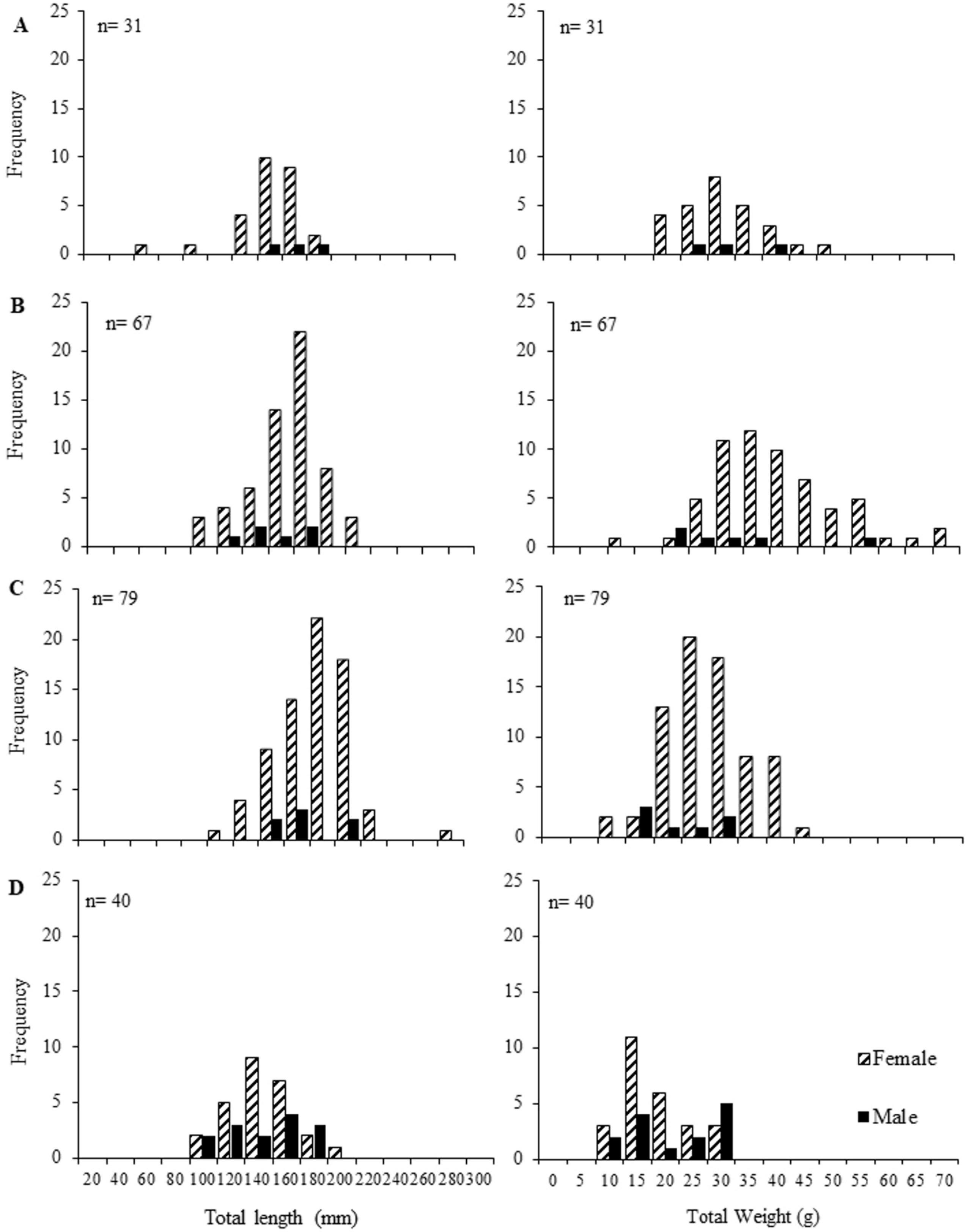

Fig 3. Size structure in total length and total weight of *Paroctopus digueti*. Females (F), Males (M) by climatic seasons: (**A**) autumn, (**B**) winter, (**C**) spring and (**D**) summer in Ohuira Bay, Ahome, Sinaloa, Mexico

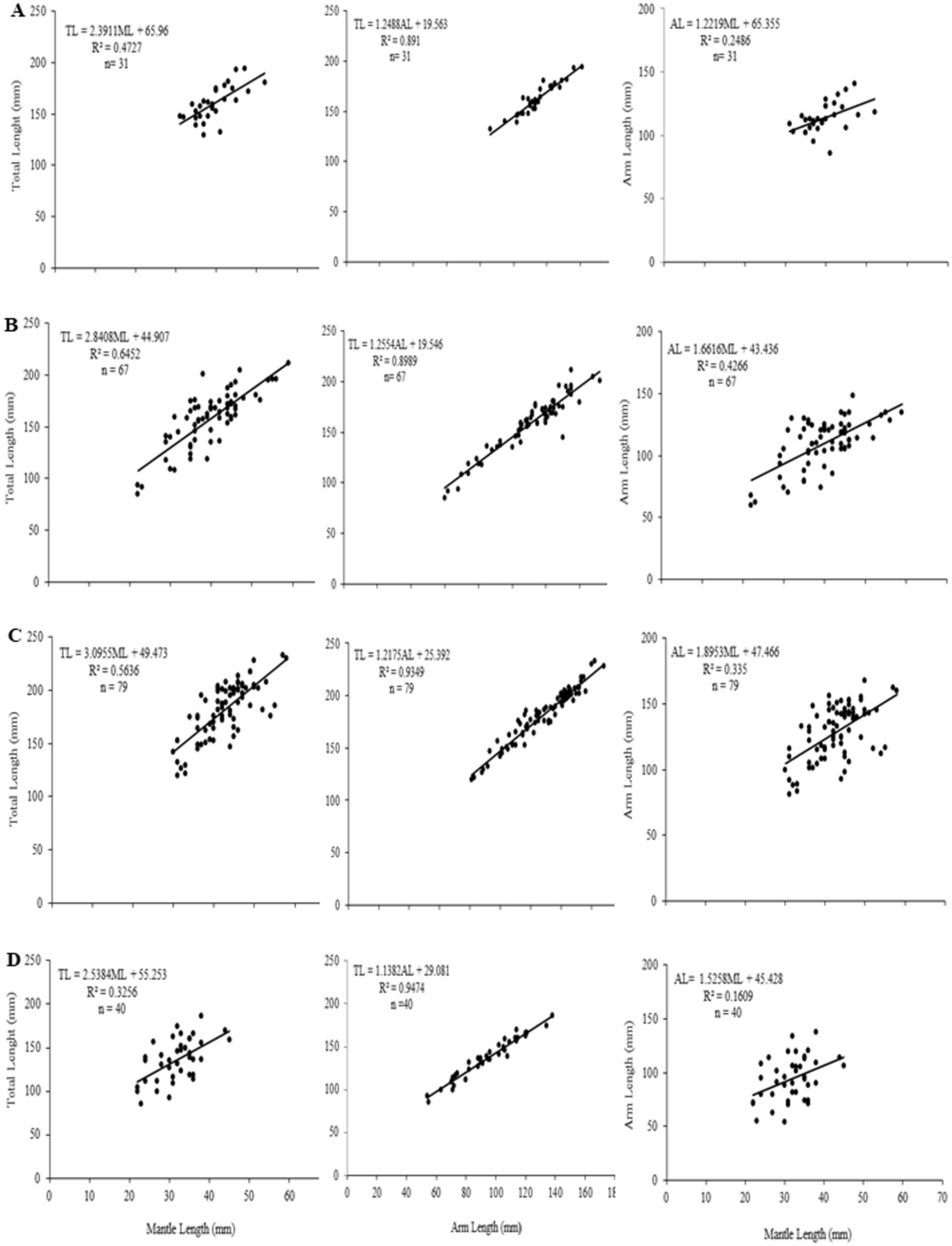

Fig 4. Morphometric relationships between length mantle-total length (ML-TL) and the length arms-total length (AL-TL), length mantle-arm length (ML.AL) of *P. digueti* by climatic seasons: (**A**) autumn, (**B**) winter, (**C**) spring and (**D**) summer in Ohuira Bay, Sinaloa, Mexico

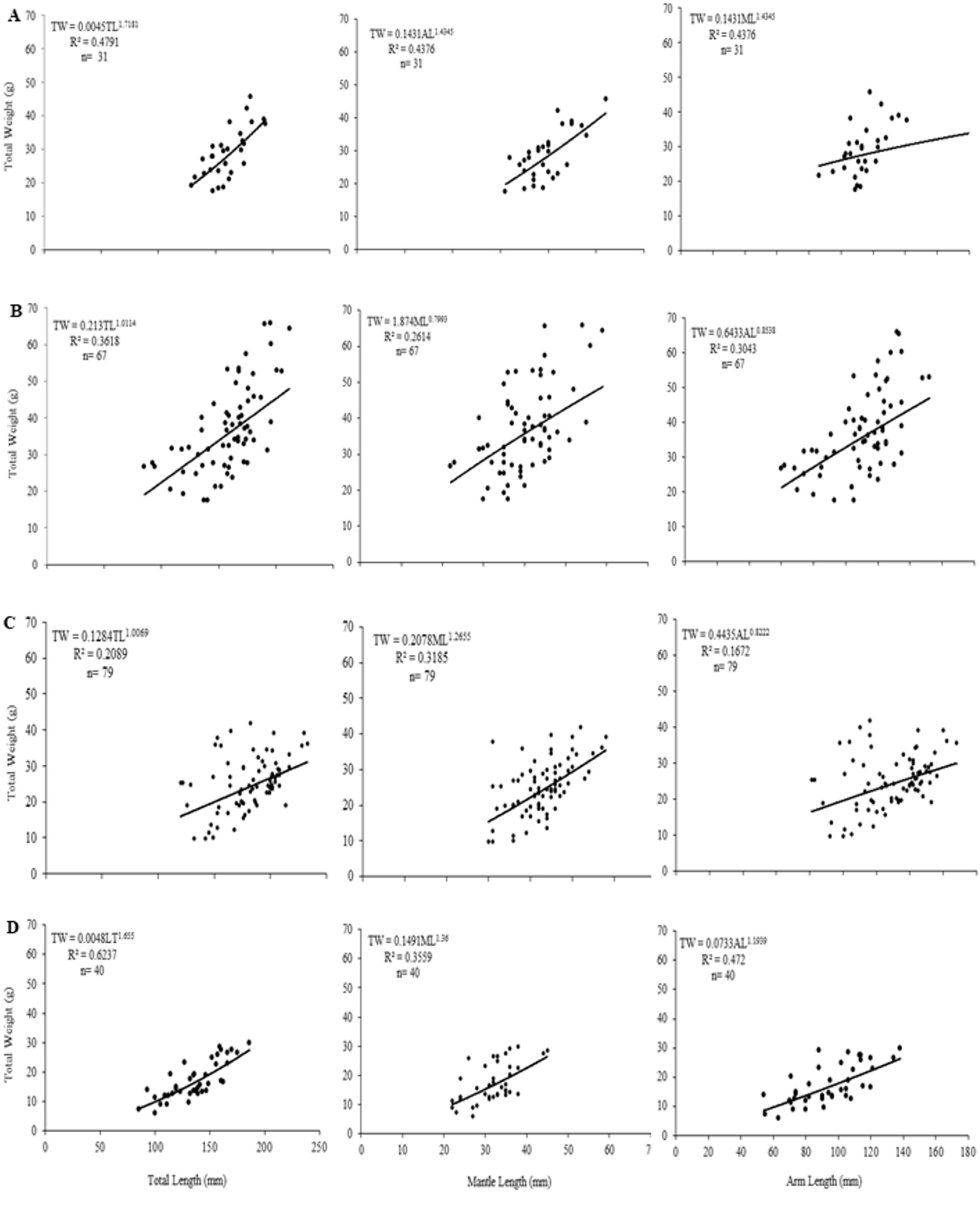

Fig 5. Potential regression between TL-TW, ML-TW and AL-TW of *P. digueti* by climatic seasons: (**A**) autumn, (**B**) winter, (**C**) spring and (**D**) summer in Ohuira Bay, Sinaloa, Mexico

Table 1. Significance in the size structures by seasons of octopus *Paroctopus* digueti in Ohuira Bay, Ahome, Sinaloa, Mexico

Measurement	Season	Mean ± SD.
ML	Autum	39.57 ± 0.00 [b]
	Winter	39.86 ± 0.00 [b]
	Spring	43.27 ± 0.00 [a]
	Summer	31.85 ± 0.00 [c]
AL	Autum	109.90 ± 0.00 [b]
	Winter	116.10 ± 0.00 [bc]
	Spring	126.09 ± 0.00 [c]
	Summer	93.13 ± 0.00 [a]
TL	Autum	160.57 ± 0.00 [a]
	Winter	157.71 ± 0.00 [a]
	Spring	183.18 ± 0.00 [c]
	Summer	136.67 ± 0.00 [b]
TW	Autum	28.61 ± 0.00 [b]
	Winter	36.03 ± 0.00 [c]
	Spring	25.08 ± 0.00 [b]
	Summer	17.30 ± 0.00 [a]

ML: Mantle length (mm); AL: Arm's length (mm); TL: Total length (mm); TW: Total weight (g). The different letters show significant differences as homogenous groups (P <0.05)

Mantle growth

Figure 6 shows the theoretical growth curve according to the estimated growth parameters from the von Bertalanffy equation at different ages. It shows both sexes, their values together ML_∞= 73.50 mm, K = 1.30 year^{-1} and t_0= 0.10. The estimated values from the growth equation revealed they grow faster (ML_∞= 63 mm) within the 1.2 years of their lives, reaching a maximum length at 2.5 years of age for both sexes.

Total weight growth

Weight growth curve indicated that from the first seven months to the first year of age, females and males reach a weight of 55.0 g, obtaining a weight of 66.0 g during the 10 months of age, whereas maximum weight of 90.0 g, reaching their maximum weight at 1.8 years of age. The total weight growth parameters were TW_∞ = 65.9 g, K = -1.42 and t_0 = 0.1005. The total weight growth of *P. digueti* octopus was formed by the first exponential stage up to six months and the second logarithmic stage from seven months to approximately 1.8 years (Fig. 7).

Instantaneous growth coefficient

The instantaneous growth coefficients (IGC) and the percentages of the IGC are shown in Table 2. It can be seen that for summer there were slightly lower coefficients and percentages for the lengths and total weight of octopus *P. digueti.*

Munro index (Ø´)

The performance estimate of the mantle length and total weight growth parameters in both sexes using the Munro index (Ø´) was 3.69 and 3.90 respectively, while the Munro index variation coefficient (C.V. Ø´) was 8% for ML and 7% for TW. No significant differences were found between the mantle length and total weight growth of *P. digueti* in Ohuira Bay compared to the growth reported in other study sites (Table 3).

Fulton's condition index (K)

For *P. digueti* Fulton's condition index (K) reached its highest in winter with 0.000009107 and its minimum during spring (0.00000408) (Fig. 8).

Sex ratio

The sex ratio for octopus *P. digueti* shows that females are more frequently seen during all climatic seasons in a proportion of 9.85 F: 1 M (Female: Male; $\chi^2_{calculated} = 31.44$; $\chi^2_{critical\ (3,\ 0.05)} = 0.352$; $P<0.05$).

During winter ($\chi^2_{calculated} = 5.35$; $\chi^2_{critical\ (3,\ 0.05)} = 0.352$; $P<0.05$) and spring ($\chi^2_{calculated} = 8.49$; $\chi^2_{critical\ (3,\ 0.05)} = 0.352$; $P<0.05$) the highest number of females were caught (Fig. 9).

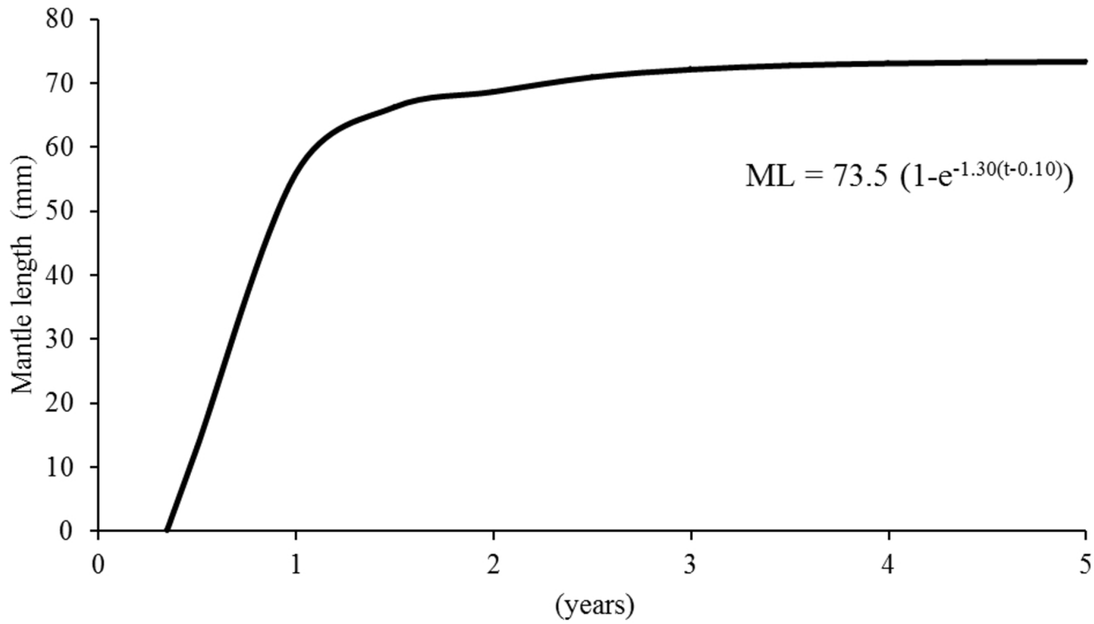

Fig 6. Mantle length growth curve von Bertalanffy model of both sexes of octopus *P. digueti* in Ohuira Bay, Ahome Sinaloa, Mexico

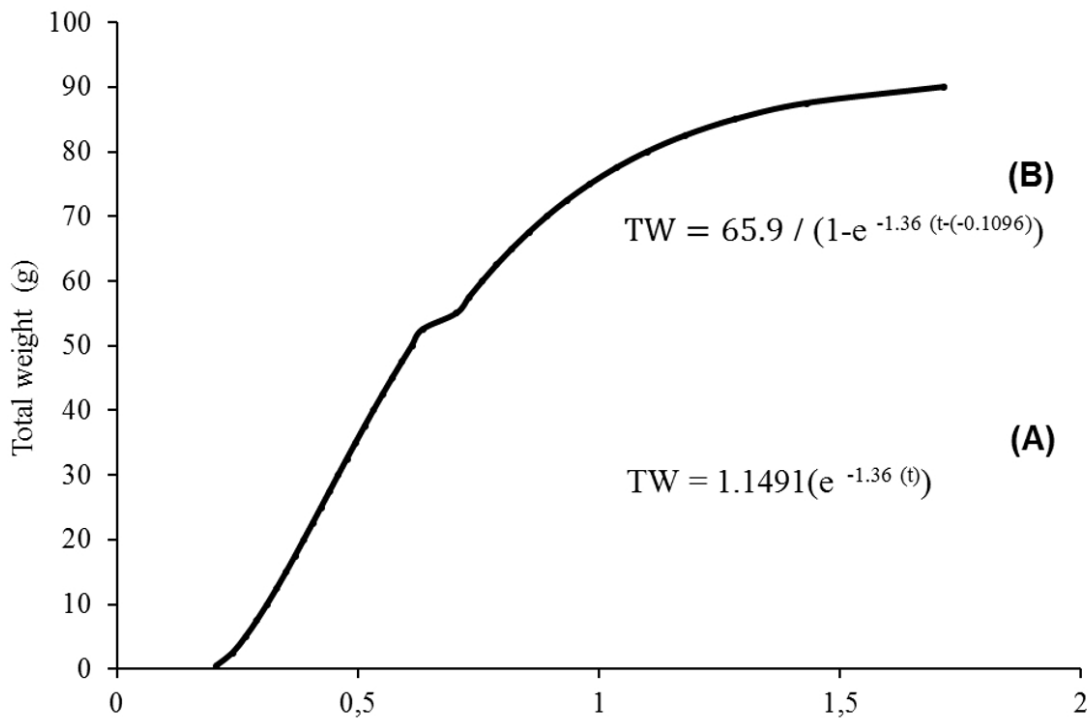

Fig 7. Total weight growth curve of both sexes of octopus *P. digueti* in Ohuira Bay, Ahome Sinaloa, Mexico. (**A**) Growth of the total weight expressed in the first stage of life by an exponential model. (**B**) Growth in total weight expressed in the second stage of life by a logistic model

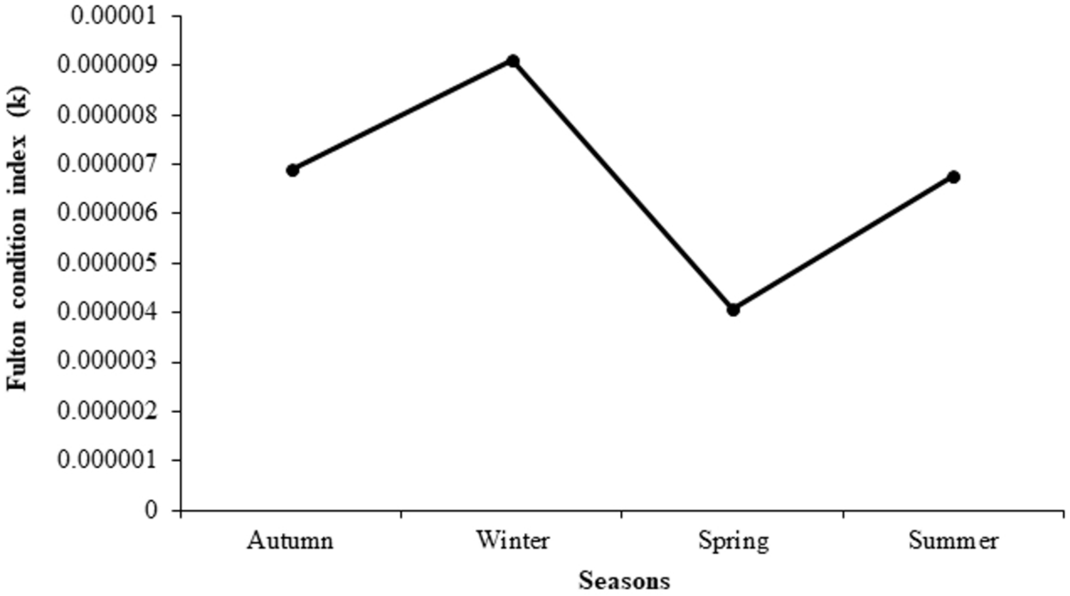

Fig 8. Fulton condition index (K) of total length (LT) versus total weight (TW) of *P. digueti* by climatic seasons in Ohuira Bay, Sinaloa, Mexico

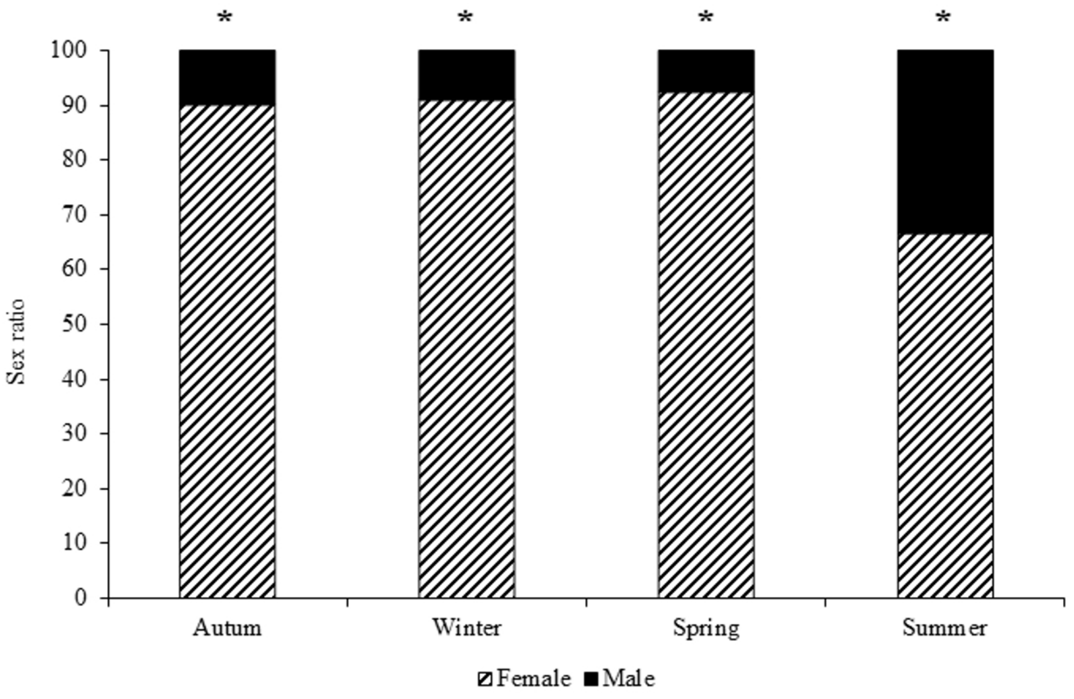

Fig 9. Sex-ratio of *P. digueti* by climatic seasons in Ohuira Bay, Sinaloa, Mexico. Asterisks above the columns indicate significant differences between the proportions of males and females ($p < 0.05$)

Table 2. Instantaneous growth coefficients (IGC) and percentages IGC of mantle length (ML), arm length (AL), total length (TL) and total weight (TW) of octopus *Paroctopus digueti* in Ohuira Bay, Ahome, Sinaloa, Mexico

Season	Mantle length (mm day^{-1})	Arm length (mm day^{-1})	Total length (mm day^{-1})	Total weight (g day^{-1})	IGC-ML %	IGC-AL %	IGC-TL %	IGC-TW %	n
Autum	0.0409	0.0522	0.0564	0.0373	4.09	5.22	5.64	3.73	31
Winter	0.0410	0.0528	0.0577	0.0398	4.10	5.28	5.77	3.98	67
Spring	0.0419	0.0537	0.0579	0.0358	4.19	5.37	5.79	3.58	79
Summer	0.0398	0.0504	0.0546	0.0317	3.98	5.04	5.46	3.17	40

Table 3. Comparison of the growth efficiency (Ø) of the mantle length and total weight of octopus *P. digueti* in different coastal lagoons of Mexico

Sex	ML_∞ (mm)	TW_∞(g)	K-ML (year)	K-TW (year)	Ø ML	Ø TW	Source	Location
Combined	73.50	65.9	1.30	1.4245	3.85	3.79	This research	Ohuira, Ahome, Sinaloa
Combined	60	70	1.18	2.08	3.62	4.01	Hanlon and Forsythe (1985)	Baja California Norte and Sur, Gulf of California
Combined	74.0	68.70	1.19	3.13	3.81	4.17	DeRusha et al. (1987)	Puerto Peñasco, Sonora
Male	38.7	30.68	1.07	2.82	3.20	3.42	DeRusha et al. (1987)	Puerto Peñasco, Sonora
Female	57.62	68.7	1.26	3.28	3.62	3.81	DeRusha et al. (1987)	Puerto Peñasco, Sonora
Combined	60.0	70.0	1.18	2.08	4.05	4.19	Voight (1990)	Choya Bay, Sonora
Average K and Ø ML	---	---	1.20	---	3.69	---		
Average K and Ø TW	---	---	---	2.47	---	3.90		
S.D. Ø ML	---	---	---	---	0.29	---		
S.D. Ø TW	---	---	---	---	---	0.29		
C.V. Ø ML(%)	---	---	---	---	8.0	---	NS	
C.V. Ø TW(%)	---	---	---	---	---	7.0	NS	

Combined: Male + Female, ML: Mantle length, TW: Total weight, ML_∞:Asymptotic mantle length, TW_∞: Asymptotic total weight, K: Growth constant, Ø ML: Munro index of mantle length, Ø TW: Munro index of total weight, S.D.: Standard deviation, C.V.: Coefficient of variation, NS: No significant

DISCUSSION

Size structure

For the proper management of a resource that is under exploitation, there should be understanding about the population processes that determine the addition and removal of individuals over time and one of the basic principles is growth (from an individual or population), which is an important tool in ecology studies. Data about size give an estimate of the rate of growth and how it changes according to mass, age and condition (somatic and reproductive) (Boyle and Rodhouse, 2005).

For that matter, the knowledge about size structure and growth in organisms is relevant because it gives information about the local dynamic of the studied population. This will allow the establishment of capture sizes that will guarantee that the fishery will be acting on post-reproductive adults, enabling the younger individuals to reach reproductive age and therefore integrate into the exploited stock (Boyle and Rodhouse, 2005; Hernández-Moreno and Arreola-Lizárraga, 2007).

The average mantle length (ML) found in the present study (40.31±2.5 mm) was less than reported by FAO (1995), where the highest ML recorded for *P. digueti* was 60 mm. While comparing this size with octopus *O. bimaculoides*, it was lower, since it is reported by Ibarra-García (2012) that it can reach 65 to 130 mm of ML in organisms collected in Bahía Magdalena, Baja California Sur (BCS), Mexico. Moreover, this author analyzed the size-frequency structure of octopus *O. bimaculoides* and found an interval that ranged from 65 up to 130 mm in ML, and from 98 to 1360 g for TW, being higher than the weight recorded for *P. digueti* in Ohuira Bay, Sinaloa. It is known that the adequacy of the measurements in accordance with ML, as a measure of size through a significant relationship with weight, is strongly correlated with size. There is also information available for octopus *O. bimaculatus* with regards to the analysis of frequencies of the TL which reveals that it is not highly recommended (direct method) to estimate growth because octopuses are organisms with soft bodies (López-Rocha et al., 2012).

Morphometrics

The weight-length relationship is one of the indicators about the type of growth the organisms have and it is determined by the allometry coefficient *b*. It indicates if the growth is isometric, when the value is three, which indicates that all the parts of the organism grow proportionally. If the *b* value differs from three, there will be an allometric growth, which means that all the different parts of the organism grow disproportionately (Forsythe and van Heukelem, 1987; Arreguín-Sánchez, 2000). In the present study, *P. digueti* showed a negative allometric growth ($b < 3$) in every season of the year, which indicates that octopuses from this species tend to grow more in length than in TW. This can occur due to the decrease in the growth rate in size or weight over time, which is not constant because they are defined by the reproductive season and environmental factors (Díaz-Álvarez, 2011). This type of growth is the most common in cephalopods, which is related to the differential growth between the arms and the mantle (Boyle and Rodhouse, 2005). This type of growth was reported in other studies of cephalopod from Baja California Sur (Domínguez-Contreras, 2011), Jalisco (López-Uriarte et al., 2005; López-Uriarte and Rios-Jara, 2009) and Oaxaca (Alejo-Plata et al., 2009).

Growth

According to Sparre and Venema (1997), the growth parameters in fish and aquatic organisms differ among species. In those water bodies with a subtropical climate regime, moreover a temperate one, growth will not remain constant throughout the year. It has been discussed that in warmer seasons, where food availability is higher, growth tends to be faster than when temperatures are lower. In addition, these parameters can be different from one population to another. Within the same species, different values can be observed during the life cycle. Subsequent cohorts can grow differently depending on the environmental conditions and the growing parameters usually vary based on the sex and reproductive conditions. Specially crustaceans are more affected by this due to the shedding processes (Mangold, 1987; Sparre and Venema, 1997; Chang et al., 2012).

The pattern of growth curves allows us to estimate the size that organisms will achieve until they reach a maximum asymptotic size in a given time (Guerra,1979; Sánchez et al., 1998; Hernandez-Llamas and Ratkowsky, 2004). The estimated growth parameters for this study showed that the relative age in which organisms of the species *P. digueti* attain their maximum mantle growth is between 1.5 and 2 years of age for both sexes. The former being similar to what was reported for the Guaymas, Puerto Peñasco and Choya Bay, Sonora where octopus of this species attain their biggest size at 2.5 years of age for both sexes (Hanlon and Forsythe, 1985; DeRusha et al., 1987; Voight, 1990) (Figs. 6 and 7, Table 3). In this study, there were no differences (CVØ´= 8.0%) between the calculated mantle and total weight growth parameters using the Ø´ Munro index recorded for the same species (*P. digueti*) in different places, where the values are found within the known intervals (Table 3). However, despite this a generalization cannot be established about growth, and the differences observed are related to the environmental characteristic of each site (Urban, 2002; Hernandez-Llamas and Ratkowsky, 2004). Mangold and Boletzky (1973) observed that organisms belonging to the same cohort may have variability in size at the end of the first year of life, which is due to different causes (Urban, 2002). Guerra (1979) reported that the growth for octopus *Octopus vulgaris* during the early bentonic stages is rapid, about three months after hatching, octopuses reach weights between 11 and 69 g, with an average of 39 g. The larvae observed by this author in the laboratory, after their fixation to the bottom, reached 50 mm in the length of the mantle at 90 days, and at five or six months after hatching the octopuses were between 50 and 60 mm ML. Also, for *P. digueti* in the present study similarity was found with DeRusha et al. (1987) and Voight (1990) with respect to the type of growth in total weight with an exponential phase for the first months of age, and logarithmic for the second stage of growth in total weight, which was observed in Figure 7. Semmens et al. (2011), with a multilevel approach to examine cephalopod growth by using the octopus *Octopus pallidus* as a model, developed a controlled experiment where an exponential growth was observed for this species. These authors also indicated a faster growth in younger octopuses that suggested that *O. pallidus* exhibited a two-phase double exponential pattern. Another study from the Gulf of Mexico performed by Velázquez-Abunader et al. (2015) evaluated the inter-cohort growth for three tropical resources, octopus *Octopus maya* being one of the resources. In this study, the authors mention that growth parameters are an important compound to evaluate the stock of aquatic exploited species. They also consider that it is difficult to apply direct methods to estimate growth and analyze differences between populations and even between males and females, particularly in tropical areas, by using simple methods to compare individual growth curves from size-frequency distribution in females and males by modal progression analyses. In this case, it was seen to be useful in order to highlight the differences between sex growth from a specific cohort, bringing out a possible potential effect of extrinsic and intrinsic factors in the organism's development as seen in the cohort size distribution.

Instantaneous growth coefficient

According to the results of the percentages of the IGC for the ML, AL and TL, maximum values in spring were 4.19, 5.37, and 5.79%, respectively. The lowest values were for the TW with an interval of 3.17 to 3.98%; in winter the maximum value and in the summer the minimum (Table 2). These percentages of IGC are higher than the trend reported by DeRusha et al. (1987) for the ML and TL of *P. digueti* under laboratory conditions. Likewise, Hanlon and Forsythe (1985) for the same species reported a daily TW growth of 4%, similarly to what was recorded in the present study. If the IGC of *P. digueti* is compared with another species of octopus such as *Octopus mimus*, Cortez et al. (1999) found that in the summer the highest percentages were presented in both TW and TL for females and males in northern Chile (Iquique).

Fulton's condition index (K)

Octopus growth expressed in lengths (ML, AL, TL) and total weight (TW) may occur by one or a combination of two processes: hyperplasia (generation of new muscle fibers) and hypertrophy (increase in the size of those fibers already in existence) (Hoyle, 2002; Moltschaniwskyj, 2004; Semmens et al., 2004). Fulton's condition index (K) has been widely used as an indirect growth index, assuming a better physiological state in those organisms with higher values; it estimates the influence of external (environmental) and internal (physiological) factors, along with the length or size in relation to the total weight. In this current study, the condition index (K) was higher during winter than in the rest of the climatic seasons, where a recovery in the condition of octopus *P. digueti* was seen during autumn, decreasing in spring and increasing during the summer. In general, these variations could be caused by many factors such as reproductive activity, dietary changes and environmental factors (Ramirez and De la Cruz, 2015; Ruiz-Barreiro et al., 2019). The trend observed in the present study for the K index may be caused by the incidence of ovigerous females found in shelters. A reproductive aspect that has been reported can influence octopus growth (O´Dor and Wells, 1987; Semmens et al., 2004).

Sex ratio

For this current study, the sex ratio for *P. digueti* (9.85 F: 1 M) was biased towards females, which could be related to behavioral differences between sexes, especially between mature individuals. As females become impregnated, they move less, consume less prey and remain closer to a shelter that can be used to incubate eggs. On the other hand, males can move faster with the imminent senescence to look for sexually receptive females. As time goes by and they become older, the cost of turning into prey is less than the one of not mating (Wodinsky, 1972; DeRusha et al., 1987). According to these current findings, the number of females in relation to males was higher for pygmy octopus *P. digueti* in Ohuira Bay, Ahome, Sinaloa compared to the sex ratios recorded in Bahía Magdalena for the species *O. bimaculoides* (0.48 F: 1M) and *O. hubbsorum* (0.33 F: 1 M) (Dominguez-Contreras, 2011), and in Bahía Sebastián Vizcaíno, Baja California Sur, Mexico for *O. bimaculatus* (1F:1M) (Rodríguez-García, 2010). For this study, the capture (diving with snorkel) of those octopuses found in shelters matched the periods in which most of the females were hatching their eggs, as seen in *O. doflebli* where divers significantly capture females more frequently than males (Hartwick et al., 1984). In other studies, the predominance of males over females was observed, as in the case of *Octopus mimus* explained as female post-spawning mortality (Pliego-Cárdenas et al., 2011), or because spawning females retreat to their dens or migrate to deeper waters (Olivares et al., 1996; Ishiyama et al., 1999).

CONCLUSIONS

The sizes with respect to ML, AL, TL and TW considering both sexes, presented significant differences between the climatic seasons. However, no significant differences (Munro Index) were found between the parameters for growth in ML and the total weight of *P. digueti* octopus with the parameters reported in other lagoon systems. The highest determination index (linear type model) was recorded for the relationship between ML-TL (winter). The Fulton condition index (K) reached its highest level in winter. More females were captured than males.

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SAŽETAK

RAST I OMJER SPOLOVA HOBOTNICE *Paroctopus digueti* (PERRIER & ROCHEBRUNE, 1894) U SLOBODNO-ŽIVUĆIM POPULACIJAMA

Istraživanja hobotnice *Paroctopus digueti* u Meksiku su rijetka te je stoga cilj ovog istraživanja procijeniti neke od bioloških karakteristika navedene vrste u zaljevu Ohuira, Ahome, Sinaloa, u Meksiku. Tijekom jeseni 2016. do jeseni 2017. g. uzorkovano je 217 hobotnica *P. digueti* od kojih su 166 bile ženke, 31 ovigerne ženke i 20 mužjaka. Svakoj hobotnici je zabilježena dužina plašta (ML) i krakova (AL), ukupna dužina (TL) i ukupna masa (TW), a korišten je FiSAT II program za dobivanje parametara rasta posredstvom frekvencija sezonskih veličina. S obzirom na oba spola, prosječna dužina plašta bila je 40,31 ± 2,5 mm. Za analizu odnosa ML-TL i ML-AL, podaci su prilagođeni modelu linearnog tipa. Za odnos između ML-TL, najmanji je koeficijent determinacije zabilježen tijekom proljeća R^2 = 0,34, a najviši je zabilježen zimi R^2 = 0,65. Što se tiče koeficijenta alometrije (b), bio je različit u četiri klimatske sezone. Teorijska krivulja rasta ML pokazala je oba spola ML_∞ = 73,50 mm, K = 1,30 godina^{-1} i t_0 = 0,10. Procijenjene vrijednosti iz jednadžbe rasta pokazale su brži rast (ML_∞ = 63 mm) unutar 1,2 godine njihova života, dostižući maksimalnu duljinu u dobi od 2,5 godine. Krivulja rasta ukupne mase hobotnice *P. digueti* formirana je eksponencijalnim rastom u prvom stadiju do šest mjeseci, te u drugom, logaritamskom stadiju od sedam mjeseci do približno 1,8 godina. Ljeti su zabilježeni nešto niži koeficijenti i postoci trenutačnog koeficijenata rasta (IGC) za duljine i ukupnu masu hobotnice. Najviši Fultonov indeks kondicije (K) zabilježen je zimi. Omjer spola bio je značajno na strani ženki 9,85 F: 1 M.

Ključne riječi: *Paroctopus digueti*, stanovništvo, rast, Ohuira zaljev, Meksiko

REFERENCES

Alejo-Plata, M.C., Gómez-Márquez, J.L., Ramos-Carrillo, S., Herrera-Galindo, J.E. (2009): Reproducción, dieta y pesquería del pulpo *Octopus (Octopus) hubbsorum* (Mollusca: Cephalopoda) en la costa de Oaxaca, México. Revista de Biología Tropical, 57, (1-2), 63-78.

Arreguín-Sánchez, F. (2000): Octopus–red grouper interaction in the exploited ecosystem of the northern continental shelf of Yucatan, Mexico. Ecological Modelling, 129, 119–129.

Bañón, R., Otero, J., Campelos-Álvarez, J.M., Garazo, A., Alonso-Fernández, A. (2018): The traditional small-small *Octopus* trap Fishery off the Galician Coast (Northeastern Atlantic): Historial notes and Current Fishery dynamic. Fisheries Research, 206, 115-128.

Boyle, P., Rodhouse, P. (2005): Cephalopods: Ecology and Fisheries. 1st edition.UK. Blackwell Science Ltd.

Cárdenas-Gámez, S. (2006): Modelación hidrodinámica de la laguna costera El Colorado, Ahome, Sinaloa. (Master's Thesis). Instituto Politécnico Nacional-CIIDIR Sinaloa. Guasave, Sinaloa, México. 120 p.

Chang, Y.J., Chi, L.S., Chen, Y., Yeh, S.Z. (2012): Modelling the growth of crustacean species. Reviews in Fish Biology and Fisheries, 22, 157-187.

Chen, Y., Jackson, D.A., Hervey, H.H. (1992): A comparison of von Bertalanffy and polynomial functions in modeling fish growth data. Journal of Fisheries and Aquatic Science, 49, 1228-1235.

Cifuentes-Lemus, J.L., Gaxiola-López, J. (2003): Atlas de los Ecosistemas de Sinaloa. 1st Edición. Culiacán, Sinaloa, México. El Colegio de Sinaloa Editorial.

CNP (Carta Nacional Pesquera) (2012): Pesquería de Pulpo. Cata Nacional Pesquera. Diario Oficial de la Federación. México.

Cortez, T., Gonzalez, A.E., Guerra, A. (1999): Growth of *Octopus mimus* (Cephalopoda: Octopodidae) in wild populations. Fisheries Research, 42, 31-39.

DeRusha, R.H., Forysthe, J.W., Hanlon, R.T. (1987): Laboratory growth, reproduction and life span of the Pacific Pygmy Octopus *Octopus digueti*. Pacific Science, 41, 1-4.

Diarte-Plata, G., Escamilla-Montes, R., De la Cruz-Agüero, G., Granados-Alcantar, S., Álvarez-Ruíz, P. (2013): Crecimiento y supervivencia del mejillón *Mytella strigata* (Bivalvia: Mytilidae) en cultivo suspendido en la laguna Macapule, Sinaloa, México. Hidrobiológica, 23, 3, 374-385.

Diarte-Plata, G., Escamilla-Montes, R., Granados-Alcantar, S., Pineda-Mendoza, N.Y., Sainz-Aboyte, V., Luna-González, A. (2019): Biología poblacional del pulpo pigmeo *Paroctopus digueti* (Perrier & Rochebrune, 1894): Caso de estudio en el norte de Sinaloa, México. *In*: Estudios recientes sobre economía ambiental y agrícola en México. Editorial Formas e Imágenes S. A. de C. V. La Paz, Baja California Sur, México. ISBN UABCS: 978-607-8654-15-4. UABCS-UAChapingo.

Díaz-Álvarez, A.G. (2011): Edad y crecimiento de pulpo *Octopus vulgaris* (Cuvier, 1797) en el Parque Nacional Sistema Arrecifal Veracruzano. (Master`s Thesis). Universidad Veracruzana. Boca del Rìo, Veracruz. México.

Domínguez-Contreras, J.F. (2011): Reproducción del pulpo *Octopus hubbsorum* (Berry, 1953) en Bahía Magdalena, Baja California Sur. (Master`sThesis). Universidad Nacional Autónoma de México, Ciudad de México, México.

Domínguez-Contreras, J.F., Munguía-Vega, A., Ceballos-Vázquez, B.P., Arellano-Martínez, M., García-Rodríguez, F.J., Culver, M., Reyes-Bonilla, H. (2018): Life histories predict genetic diversity and population structure within three species of *Octopus* targeted by small-scale fisheries in Northwest Mexico. Peer J, 6, 1-25.

Duarte, J.A., Hernández-Flores, A., Salas, S., Seijo, J.C. (2018): Is it sustainable fishing for *Octopus maya* (Voss & Solis, 1966) during the breeding season using a bait-based fishing technique. Fisheries Research, 199, 119-126.

Escamilla-Montes, R. (1998): Aspectos de la biología de las jaibas del género *Callinectes* en el Estero El Conchalito, Ensenada de La Paz, B. C. S. (Master`s Thesis). CICIMAR IPN, La Paz, Baja California Sur, México, pp. 107.

FAO (1995): *Octopus digueti* (Perrier & Rochebrune, 1894), *In*: Pacifico Centro-Oriental-Volumen I: Guía FAO para la identificación de especies para los fines de la pesca. Roma, Italia. FAO.

FAO (2016): El estado mundial de la pesca y la acuicultura-Contribución a la seguridad alimentaria y la nutrición para todos. Roma, Italia. FAO.

Forsythe, J.W., van Heukelem, W.F. (1987): Growth. in: Cephalopod Life Cycles Vol. 2, P. R Boyle London. Academic Press.

García-Flores, M. (2017): Ontogenia inicial y fecundidad del pulpo pigmeo del pacifico *Paroctopus digueti* (Perrier & Rochebrune, 1894). (Master`sThesis). Instituto Politécnico Nacional-CICIMAR. La Paz, Baja California Sur, México.

González, L.W., Eslava, N., Guevara, F., Troccoli, L. (2015): Biología y pesquería del pulpo *Octopus vulgaris* (Octopoda: Octopodidae) en las costas del estado Nueva Esparta, Venezuela. Revista de Biología Tropical, 63, 2, 427-442.

Guerra, A. (1979): Fitting a Von Bertalanffy expression to *Octopus vulgaris* growth. Investigación Pesquera, 43, 319-327.

Hanlon, R.T., Forsythe, J.W. (1985): Advances in the laboratory culture of octopuses for biomedical research. Laboratory Animal Science, 35, 33-40.

Hartwick, E.B., Ambrose, R.F., Robinson, S.M.C. (1984): Dynamics of shallow-water populations of *Octopus dofleini*. Marine Biology, 82, 65-72.

Hernandez-Llamas, A., Ratkowsky, D.A. (2004): Growth of fishes, crustaceans and molluscs: estimation of the von Bertalanffy, Logistic, Gompertz and Richards curves and a new growth model. Marine Ecology Progress Series, 282, 237-244.

Hernández-Moreno, L., Arreola-Lizárraga, J.A. (2007): Estructura de tallas y crecimiento de los cangrejos *Callinectes arcuatus* y *C. bellicosus* (Decapoda: Portunidae) en la laguna costera Las Guásimas, México. Revista de Biología Tropical, 55, 1, 225-233.

Hoyle, K. (2002): Growth and life history of *Octopus pallidus*: Effects of seasonal temperature change. BSc (Hons) Thesis. University of Tasmania: Hobart, Australia.

Ibarra-García, L.E. (2012): Análisis de edad y crecimiento de *Octopus hubbsorum* (Berry, 1953) y *Octopus bimaculoides* (Pickford & McConnaughey, 1949) con lecturas de anillos de crecimiento en los estiletes. (Master`s Thesis). Centro de Investigaciones Biológicas del Noroeste. La Paz, Baja California Sur, México.

Ishiyama, V., Shiga, B., Talledo, C. (1999): Reproductive biology of the octopus *Octopus mimus* (Mollusca: Cephalopoda) from the Matarani region, Arequipa, Peru. Revista Peruana de Biología, 6, 110–122.

Jackson, G. (2004): Cephalopod Growth: historical context and future directions. Marine and Freshwater Research, 55, 327-329.

Jereb, P., Roper, C.F.E., Norman, M.D., Finn, J.K. (2016): Cephalopods of the world: an annotated and illustrated catalogue of cephalopods species known to date. Volume 3: Octopods and Vampire Squids. Rome, Italy. FAO.

Leyton, S.A., Muñoz, E., Gordillo, M., Sánchez, G.C., Muñoz, L.A., Soto, A. (2015): Estimation of Fulton's condition factor (*k*) and the length-weight relationship of three fish species present in a sector subjected to environmental stress factors in high Cauca river basin. Revista de la Asociación Colombiana de Ciencias Biológicas, 27, 24-31.

López-Rocha, J.A., Arellano-Martínez, M., Ceballos-Vázquez, B.P., Velázquez-Abunader, I., Castellanos-Martínez, S., Torreblanca-Ramírez, E. (2012): Use of length–frequency analysis for growth estimation of the California two-spotted octopus *Octopus bimaculatus* (Verril 1883) of the Gulf of California. Journal Shellfish Research, 31, 4, 1173-1181.

López-Uriarte, E., Rios-Jara, E. (2009): Reproductive biology of *Octopus hubbsorum* (Mollusca: Cephalopoda) along the central Mexican Pacific coast. Bulletin of Marine Science, 77, 171-180.

López-Uriarte, E., Rios-Jara, E., Pérez-Peña, M. (2005): Range extension for *Octopus hubbsorum* (Cephalopoda: Octopodidae) in the Mexican Pacific. Bulletin of Marine Science, 77, 171–180.

Mangold, K. (1987): Reproduction, in Cephalopod Life Cycles Vol. 2. P.R. Boyle. London. Academic Press. pp. 157-200.

Mangold, K., Boletzky S.V. (1973): New data on reproductive biology and growth of *Octopus vulgaris*. Marine Biology, 19, 7-12.

Moltschaniwskyj, N.A. (2004): Understanding the process of growth in cephalopods. Marine and Freshwater Research, 55, 379-386.

O´Dor, R.K., Wells, M.J. (1987): Energy and nutrient flow, in: Cephalopod life cycles Vol II: Comparative reviews. (Ed. PR Boyle) pp. 109-134. Academic press: London, UK.

Olivares, A., Zúñiga, O., Castro, G., Segura, C., Sánchez, J. (1996): Biological basis for management of *Octopus mimus*: reproduction and growth. Estudios Oceanologicos, 15, 61–74.

Opresko, L., Thomas, R. (1975): Observations on *Octopus joubini*: Some aspects of reproductive biology and growth. Marine Biology, 31, 51-61.

Ortiz-Arellano, M.A. (2005): Sistemática y ecología de la malacofauna de la zona intermareal de las islas de la bahía de Navachiste, Sinaloa, México. (Master`sThesis). Instituto Politécnico Nacional- CIIDIR Sinaloa, Guasave, Sinaloa, México.

Pauly, D. (1983): Algunos métodos simples para la evaluación de recursos pesqueros tropicales. Organización de las Naciones Unidas para la Agricultura y la Alimentación (FAO), Rome, Italia. Documento Técnico de Pesca. 234.

Pauly, D., Munro, J.L. (1984): Once more on the comparison of growth in fish and invertebrates. Fishbyte, 2, 1, 21.

Pliego-Cárdenas, R., García-Domínguez, F.A., Ceballos-Vázquez, B.P., Villalejo-Fuerte, M., Arellano-Martínez, M. (2011): Reproductive aspects of *Octopus hubbsorum* (Cephalopoda: Octopodidae) from Espiritu Santo Island, Southern Gulf of California, Mexico. Ciencias Marinas, 37, 23–32.

Ramírez, P., De la Cruz, J. (2015): Islas Lobos de afuera: evaluación de pulpo *Octopus mimus* Gould, 1852 y percebes *Pollicipes elegans* (Lesson, 1831), Lambayeque 2010. Informe del Instituto del Mar del Perú, 42, 3, 271-281.

Rodríguez-García, O.U. (2010): Biología reproductiva del pulpo *Octopus bimaculatus* (Verril, 1883) en Bahía Sebastián Vizcaíno, Baja California Sur, México. (Master`sThesis). Centro de Investigaciones Biológicas del Noroeste. La Paz, Baja California Sur, México.

Ruiz-Barreiro, T.M., Arreguín-Sánchez, F., González-Baheza, A., Hernández-Padilla, J.C. (2019): Effects of environmental variability on the abundance of commercial marine species in the northern Gulf of California. Scientia Marina, 83, 195 - 205.

Safran, P. (1992): Theoretical analysis of the weight-length relationship in fish juveniles. Marine Biology, 112, 545-551.

Salgado-Ugarte, I.H., Gómez-Márquez, J.L., Peña-Mendoza, B. (2005): Métodos actualizados para análisis de datos biológicos-pesqueros. Universidad Nacional Autónoma de México. Ciudad de México, México. Laboratorio de Multimedia de la Facultad de Estudios Superiores Zaragoza UNAM México Editorial.

Sánchez, F.J., Iglesias, J., Moxica, C., Otero, J.J. (1998): Growth of octopus (*Octopus vulgaris*) males and females under culture conditions. ICES CM1998/M:47.

Semmens, J.M., Pecl, G.T., Villanueva, R., Jouffre, D., Sobrino, I., Wood, J.B., Rigby, P.R. (2004): Understanding octopus growth: patterns, variability and physiology. Marine and Freshwater Research, 55, 367-377.

Semmens, J., Doubleday, Z., Hoyle, K., Peci, G. (2011): A multinivel approach to examining cephalopod growth using *Octopus pallidus* as a model. Journal of Experimental Biology, 214, 2799-2807.

Sparre, P., Venema, S.C. (1997): Introducción a la evaluación de recursos pesqueros tropicales. Parte 1: Manual. FAO Documento Técnico de Pesca 306/1. Roma, Italia.

Tian, X., Leung, P.S., Hochman, E. (1993): Shrimp Growth Functions and Their Economic Implications. Aquaculture Engineering, 12, 81-96.

Urban, H.J. (2002): Modeling growth of different developmental stages in bivalves. Marine Ecology Progress Series, 238, 109-114.

Velázquez-Abunader, I., Gómez-Muñoz, V.M., Salas, S., Ruíz-Velazco, J.M. (2015): Inter-cohort Growth for three tropical Resources: tilapia, octopus and lobster. Revista of Biología Tropical, 63, 3, 617-627.

Voight, J.R. (1990): Population Biology of *Octopus digueti* and the morphology of American Tropical Octopods. (Doctoral Thesis). University of Arizona. United States of America.

Wodinsky, J. (1972): Breeding season of *Octopus vulgaris*. Marine Biology. 16, 59-63.

Zar, J.H. (2010): Biostatistical analysis. 662 pp. New Jersey. United States of America. Prentice Hall.

Zavala-Norzagaray, A. A. (2011): Ficha informativa de los humedales RAMSAR (FIR)-Versión 2009-2012. Lagunas de Santa María-Topolobampo-Ohuira. Secretaria del Medio Ambiente y Recursos Naturales. Comisión Nacional de Áreas Naturales Protegidas. Ciudad de México. México.

