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Reproductive aspects of *Octopus vulgaris*, Cuvier 1797 (Cephalopoda: Octopodidae), caught in Mauritanian waters by the industrial Spanish fleet (NW Africa)

Alba Jurado-Ruzafa, Verónica Duque & M. Nazaret Carrasco

Instituto Español de Oceanografía (Centro Oceanográfico de Canarias)
Vía Espaldón, Dársena Pesquera, Parcela 9
38180 - Santa Cruz de Tenerife (Spain)
alba.jurado@ca.ieo.es

Jurado-Ruzafa, A., V. Duque & M.N. Carrasco. Aspectos reproductivos de *Octopus vulgaris*, Cuvier 1797 (Cephalopoda: Octopodidae) capturado en aguas de Mauritania (NO de África) por la flota industrial española. *Vieraea* 42: 149-164.

RESUMEN: Entre enero de 2010 y septiembre de 2011, se analizaron 4044 pulpos *Octopus vulgaris* (2554 machos y1490 hembras) capturados en Mauritania y se abordaron algunos aspectos de su biología a partir de los datos que se pueden obtener de las capturas comerciales. Se obtuvo la relación entre la Longitud Dorsal del Manto (LDM) y el Peso del Cuerpo (PC) ($PC=0{,}36 \cdot LDM^{3{,}05}$; $R^2=0{,}86$). La proporción de machos fue superior a la de hembras en el cómputo general (1,71:1) y en casi todos los meses del periodo. Se identificaron dos periodos de puesta para las hembras, en invierno-primavera y en otoño, coincidiendo con los periodos de paro biológico y con el reclutamiento. Los tamaños de madurez se obtuvieron para ambos sexos. La LDM_{50} fue 6,0 cm para machos (PC_{50}=59,4 g) y 16,8 cm para hembras (PC_{50}=2103,1 g).

Palabras clave: *Octopus vulgaris*, relaciones talla-peso, reproducción, tamaño de madurez, Mauritania, Atlántico Centro-oriental.

ABSTRACT: From January 2010 to September 2011, a total of 4044 *Octopus vulgaris* (2554 males and 1490 females) caught in Mauritanian waters were analyzed, and some biological aspects were addressed based on data from commercial catches. Dorsal Mantle Length (DML) – Body Weight (BW) relationship was obtained ($BW=0.36 \cdot DML^{3.05}$; $R^2=0.86$). Males outnumbered females in the overall sex ratio (1.71:1) and in almost all months of the period. Two spawning peaks were identified in winter-spring and autumn among females, overlapping the shutdown periods (when the recruitment seasons occur). Sizes at maturity were obtained for both sexes. The

DML_{50} was 6.0 cm for males (BW_{50}=59.4 g) and 16.8 cm for females (BW_{50}=2103.1 g).

Keywords: *Octopus vulgaris*, length-weight relationships, reproduction, size at maturity, Mauritania, Central-East Atlantic.

INTRODUCTION

The common octopus *Octopus vulgaris* Cuvier, 1797 is a benthic cephalopod distributed across rocky, sandy and muddy bottoms, from the coastal waters to the edge of the continental shelf (Mangold, 1983). It inhabits in the Mediterranean, eastern and western Atlantic and north-western Pacific (Warnke *et al.*, 2004). The big fishing grounds in NW Africa support the greatest fishery of *O. vulgaris* (both by artisanal and industrial fleets), which is the most fished octopus species in the world (Bonfil *et al.*, 1998). This is a very productive area under the influence of a major upwelling, the Canary Current System, and the octopus populations —very environmental dependent— present large fluctuations from year to year (Demarcq & Faure, 2000; Faure *et al.*, 2000; Balguerías *et al.*, 2002; Polanco *et al.*, 2011).

There are several contributions about aspects related to the reproductive biology of populations of the common octopus from areas adjacent to Mauritania in the Atlantic Ocean

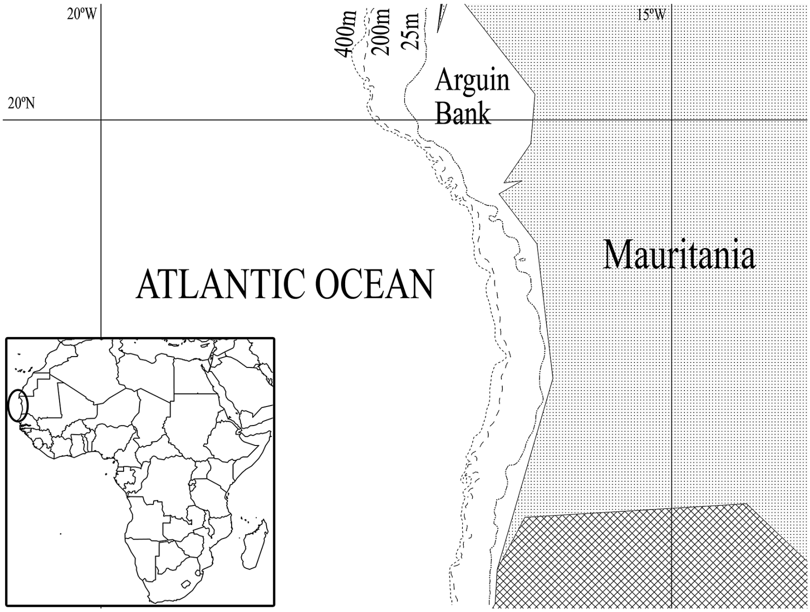

Figure 1. Fishing area of the cephalopod-targeted Spanish fleet off Mauritania, excluded the influenced zone by the Arguin Bank (Council Regulation (EC) No 1801/2006 of 30 November 2006). Isobaths of 25, 200 and 400 m of depth are shown.

(Hernández-López, 2000) and from the NW African coast (Hatanaka, 1979; Fernández-Núñez *et al*., 1996), Morocco (Idrissi *et al*., 2006; Faraj & Bez, 2007) and Senegal (Caverivière, 2002). Although a few studies on this subject have been carried out on Mauritanian *O. vulgaris* (Dia, 1988; Dia & Goutschine, 1990; Inejih, 2000; Faure, 2002; Perales-Raya *et al.*, 2014), recent data of the species are not available, which are crucial for correct management especially in such variable populations (Pierce & Guerra, 1994).

Between 2010 and 2011, a collaborative project was carried out by the Instituto Español de Oceanografía through its Centro Oceanográfico de Canarias (IEO-COC) and the shipowners association ANACEF of Spanish freezing trawlers, operating in Mauritanian waters (Fig. 1). Among the goals of this collaboration, analyzing and collecting biological parameters of this population were included. Therefore, we aim to provide updated biological information of *O. vulgaris* population from Mauritanian waters.

MATERIALS AND METHODS

From January 2010 to September 2011 (excluding the biological shutdowns in May-June and October-November), eighteen freezer trawlers targeted to cephalopods kept a weekly sample consisting of selected octopuses of varied commercial sizes (> 500 g) and non-commercial sizes (< 500 g). Every specimen was labeled individually with the catch date, and conserved frozen. A total of 4044 defrosted octopuses were analyzed from 94 fishing trips (Table I).

Table I. Summary of number of *O. vulgaris* sampled from January 2010 to September 2011, by weight groups.

Weight range (kg)		<0.5	0.5-1.5	1.5-2.5	2.5-3.5	3.5-4.5	>4.5	Total
2010	January	1	12	7		1		21
	February	11	25	15	7	4	3	65
	March	53	166	107	67	39	21	453
	April	55	150	98	54	27	20	404
	July	84	205	95	65	34	14	497
	August	88	203	111	54	36	24	516
	September	70	177	96	56	27	11	437
	December	45	143	80	36	13	1	318
2011	January	46	135	78	25	13	3	300
	February	58	118	73	36	22	7	314
	March	52	121	68	47	19	15	322
	April	43	92	55	35	16	9	250
	July	19	23	8	6	1	2	59
	August	14	24	12	5	2	2	59
	September	11	11	4	1		2	29
Total		650	1605	907	494	254	134	4040

Biological sampling

Every *O. vulgaris* was measured for the Dorsal Mantle length (DML) to the lowest mm, and weight for the total Body Weight (BW) to the lowest 0.1 g. Sex and maturity stages (SMS) were assigned by macroscopic observation, based on a 5 stages scale (modified from Dia & Goutschine (1990) and Inejih (2000)): I-immature, II-maturing; III-mature; IV-spawning and V-post-spawning/spent. Gonads-accessory glands weight (GonW: testis and spermatophoric sac-penis for males, and ovary and oviductal glands for females) and Eviscerated Weight (EW) were also obtained to the lowest 0.1 g.

Length-weight relationships

DML-BW relationships were calculated for the total sample, for males and females, fitting the data to the potential model: $BW = a \cdot DML^{b}$. Analysis of covariance (ANCOVA) was used to test the homogeneity of slopes across sexes, with GraphPad Prism® 4. As commercial landings are expressed in EW, lineal relationship between BW-EW was obtained for males and females combined.

Sex ratio

Sex ratios (males:females) were calculated monthly and by groups of size (DML_i) to the lowest cm. Significant deviations from the 1:1 sex ratio were tested with the Chi-square (χ^2) test.

Spawning season

It is accepted that high values of the reproductive indices can be associated with maturity (Bakhayokho, 1983). Therefore, the reproductive cycle was defined by a combination of the monthly frequencies of maturity stages (I-V) and the variations in the monthly average of the Gonadosomatic Index ($GSI = 100 \cdot GonW/(BW - GonW)$) (Guerra, 1975), both for males and females. On the other hand, the mean values of GSI were calculated for males and females at each SMS, and compared within each sex using the Kruskal-Wallis test ($\chi^2_{\text{Kruskal-Wallis}}$).

Size at maturity

The DML at maturity (DML_{50}) is the size at which the proportion of mature individuals (p_i) is 50%. Octopuses in stages IV or V were considered mature. Grouped data by DML_i were fitted to the logistic model, for males and females: $p_i = 1/[1 + \exp(-(\alpha + \beta \cdot DML_i))]$. The same criterion was followed in the case of BW at maturity (BW_{50}), where individuals where grouped in 100 g BW classes (BW_i): $p_i = 1/[1 + \exp(-(\delta + \varepsilon \cdot BW_i))]$. All the individuals caught round the year were considered, because of the lack of octopuses during the spawning seasons (Fernández-Núñez *et al.*, 1996).

RESULTS

Length-weight relationships

The DML_i distribution of the analyzed octopuses between January 2010 and September 2011 is shown in Figure 2. Data from length-weight sampling are summarized in Table II. DML_i ranged from 5 to 25 cm for pooled sexes. More than 75% of sampled individuals corresponded to DML from 10 to 18 cm. Noticeable differences were found between sexes related to BW, due to males reaching greater weights.

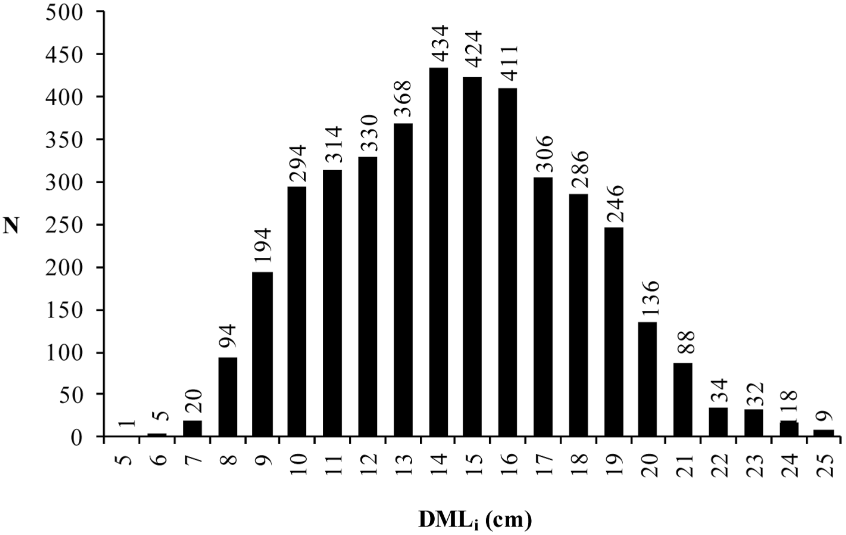

Figure 2. Length frequency distribution (DML_i, Dorsal Mantel Length classes) of the Mauritanian *O. vulgaris* analyzed from January 2010 to September 2011. Number of individuals (N) is indicated above each column.

Table II. Summary of the data obtained during the biological sampling for DML (Dorsal Mantel Length) and BW (Body Weight) measurements. N: number of individuals; Min.: minimum; Max.: maximum; sd: standard deviation.

	N		Min.	Max.	Mean	sd
Total	4044	DML	5.7	25.7	14.9	3.5
		BW	128.6	8086.8	1667.8	1234.9
Males	2554	DML	5.7	25.7	15.5	3.5
		BW	128.6	8086.8	1977.4	1351.9
Females	1490	DML	6.3	24.0	13.8	3.2
		BW	129.2	4338.8	1137.0	748.9

DML-BW relationships obtained for males, females and sexes pooled are presented at Figure 3. It shows that at big DML, weight in males is manifestly higher than weight in females. By an ANCOVA test, extremely significant differences were found between slopes in DML-BW relationships for males and females (F = 62.6; $p<0.0001$). The conversion relationship between BW and EW is shown at Figure 4. A selection of the length-weight relationships from other studies in the area are presented in Table III.

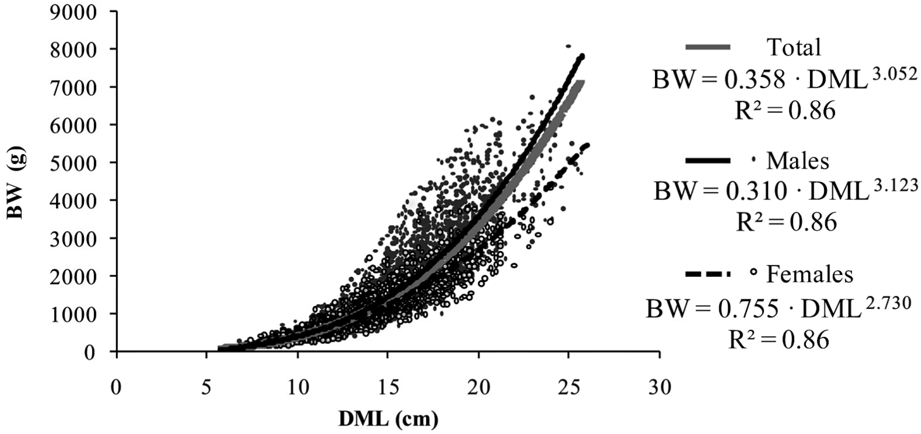

Figure 3. Dorsal Mantle Length (DML) - Body Weight (BW) relationship obtained for *O. vulgaris* caught in Mauritanian waters.

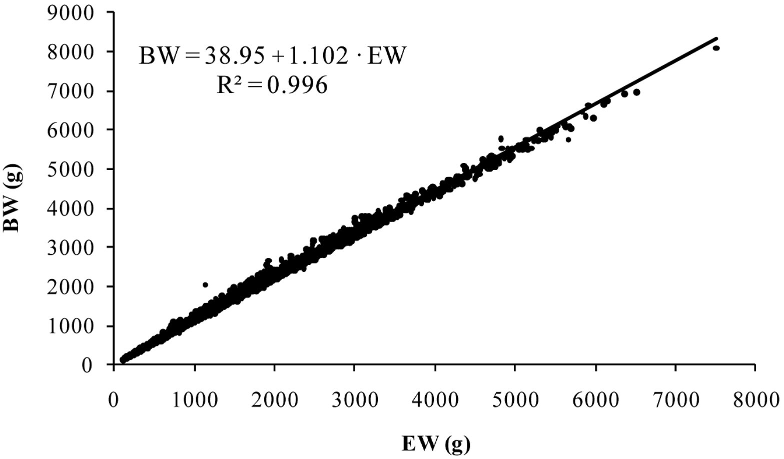

Figure 4. Body Weight (BW) - Eviscerated Weight (EW) relationship obtained for O. vulgaris caught in Mauritanian waters.

Table III. Length-weight relationships obtained for *O. vulgaris* from close areas. DML: Dorsal Mantle Length; VML: Ventral Mantle Length; N: number of individuals.

Area and Reference	Length considered	N	*a*	*b*	R²	Sex
South Morocco (Idrissi *et al.*, 2006)	DML	1407	0.0088	2.792	0.81	Males
		1665	0.0086	2.794	0.84	Females
		3072	0.0087	2.79	0.92	Pooled
NW Africa (Fernández-Núñez et al., 1996)	VML	275	1.17	2.91	r= 0.97	Males
		227	1.34	2.85	r= 0.97	Females
		502	1.24	2.89	r= 0.97	Pooled
Mauritania (Dia, 1988)	DML	241	–0.117	2.84	0.83	Males
		187	1.54	2.12	0.76	Females
		428	0.609	2.53	0.80	Pooled
Senegal (Fall & Ndiaye, 2002)	DML	841	0.4378	2.888	0.88	Pooled
Canary Islands (Hernández-García et al., 2002)	VML	481	0.0007	3.112	r= 0.86	Males
		247	0.0007	3.098	r= 0.77	Females
		760	0.0007	3.096	r= 0.95	Pooled

Sex ratio

The overall sex ratio of males (N=2554) to females (N=1490) was 1.71:1, resulting in a significant higher proportion of males ($\chi^2=279.94$; $p<0.001$). When studying the monthly evolution of the proportions between males and females (Fig. 5), except in April 2011, the same pattern was obtained in almost all months (not in the extremes of the period: January 2010 and July, August and September 2011, in which samples were small and they were not

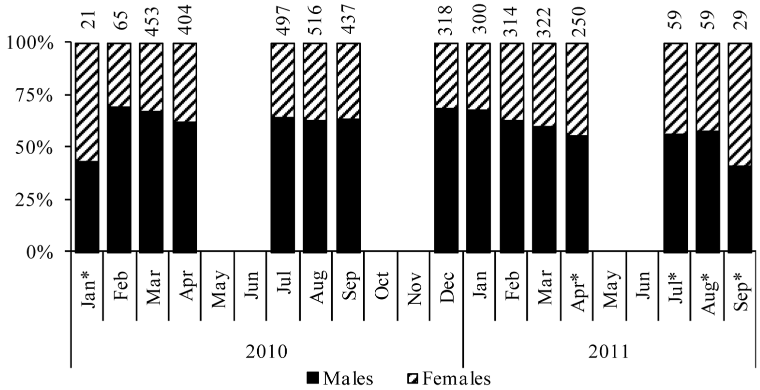

Figure 5. Mauritanian *O. vulgaris*: sex ratio by month. Number of individuals is indicated above each column. (*) Sex ratio 1:1 may be assumed with $p>0.05$.

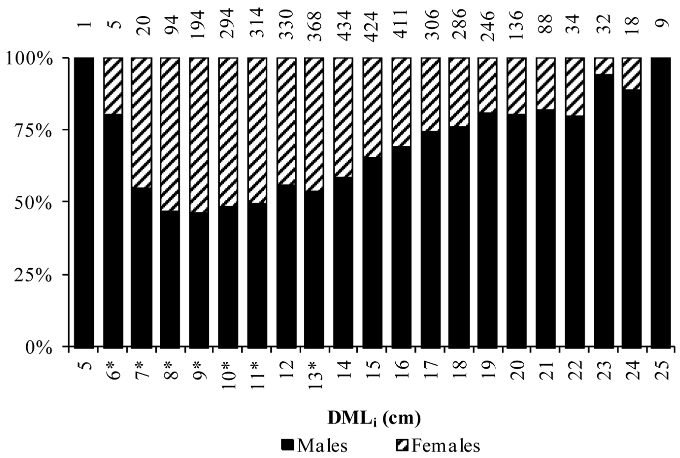

Figure 6. Mauritanian *O. vulgaris*: sex ratio by DML classes, grouped to lower 1 cm. Number of individuals is indicated above each column. (*) Sex ratio 1:1 may be assumed with p>0.05.

taken into account). Sex ratios by groups of size class (DML$_i$) are presented in Figure 6. Males outnumbered females in the bigger classes, and some groups among the smaller showed the same proportion between sexes.

Spawning season

Maturity stages assigned to males ranged from mature to spent (immature or maturing were not found), and mature males were present all year round (Fig. 7a). On the other hand, females in maturity stages from I to IV were found throughout the year, although it is noticeable that spawning and spent females increase before the shutdown months (Fig. 7b). In both sexes, spent individuals were found in December-January and July, following the biological shutdowns.

Although samples from the main spawning months were not available, two issues could be observed from the monthly evolution of IGS (Fig. 8): 1) no noticeable trends could be observed in males, in which GSI remained stable with small sd values; 2) females pre-

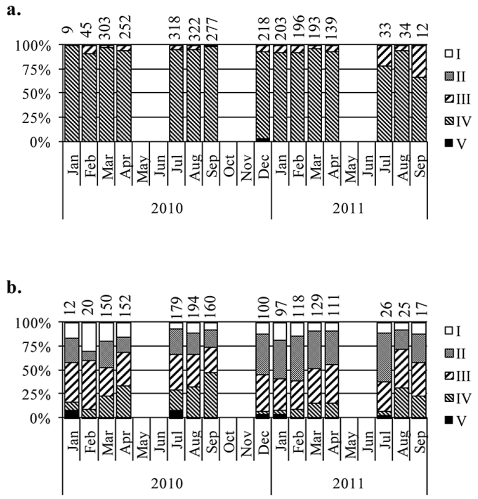

Figure 7. Mauritanian *O. vulgaris*: monthly frequency (%) of the Sexual Maturity Stages for males (a.) and females (b.). I: immature; II: maturing; III: mature; IV: spawning; V: post-spawning. Number of individuals is indicated above each column.

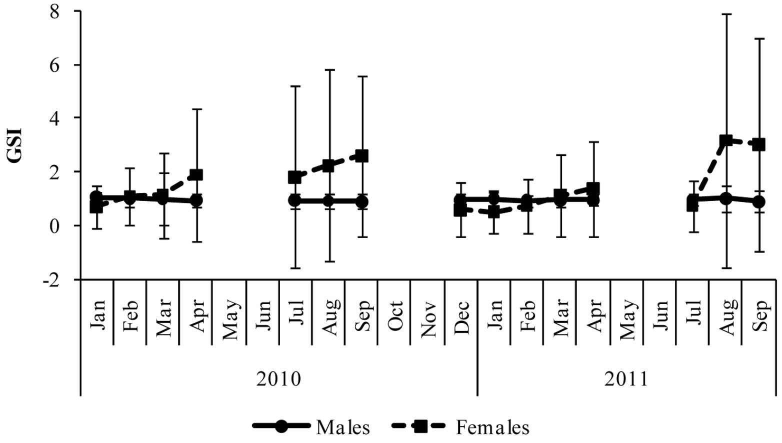

Figure 8. Monthly evolution of Gonadosomatic Index (GSI ± standard deviation), for males and females of *O. vulgaris* from Mauritania.

sented upward trends in the previous months to shutdowns, with the highest sd values associated.

The development of GSI by SMS (Fig. 9b) showed an abrupt increase for females from mature to spawning stage (with the maximum standard deviation) and a similar decrease to spent stage. This trend did not occur in males (Fig. 9a), in which the maximum GSI mean value corresponded to the post-spawning group. Significant differences occurred within maturity stages both for males ($\chi^2_{\text{Kruskal-Wallis}} = 10.32$, $p<0.01$) and females ($\chi^2_{\text{Kruskal-Wallis}} = 1081.4$, $p<0.001$).

Size at maturity

The sizes and weights of the smallest mature specimens were 5.7 cm and 128.6 g for males, and 8.2 cm and 240.4 g for females. The DML_{50} was 6.0 cm for males and 16.8 for females (Fig. 10.a.), while BW_{50} was 59.4 g

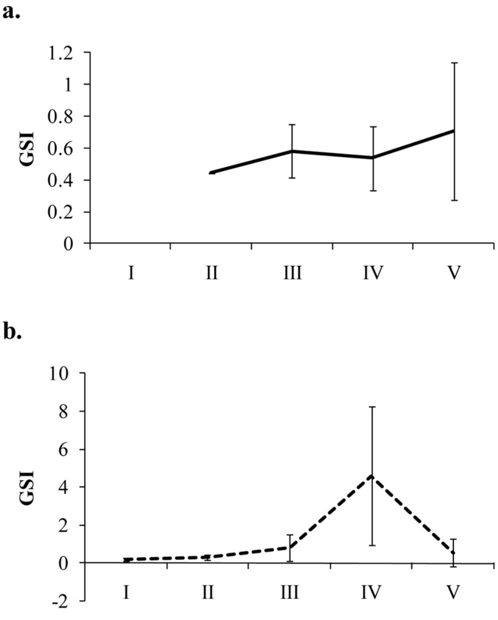

Figure 9. Mauritanian *O. vulgaris*: mean value of gonadosomatic index (GSI ± sd) in males (a.) and females (b.) by Sexual Maturity Stage. I-immature, II-maturing; III-mature; IV-spawning and V-post-spawning/spent.

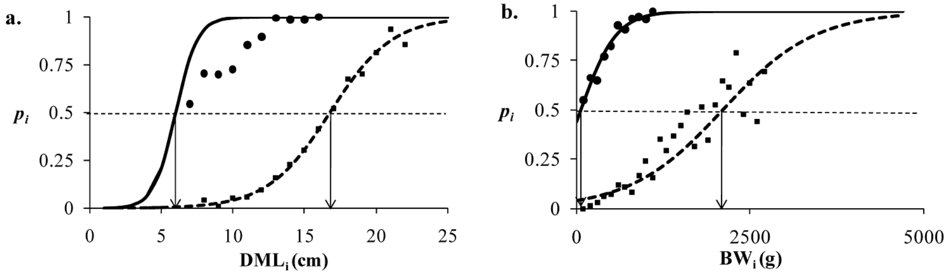

Figure 10. *O. vulgaris* from Mauritania: Maturity ogives corresponding to Dorsal Mantle Length (DML) (a.) and Body Weight (BW) (b.), for males and females. Arrows indicate sizes at maturity.

Table IV. Estimated parameters of the maturity ogives, both for Dorsal Mantle Length (DML) and Body Weight (BW). N: number of individuals; DML_{50} and BW_{50}: sizes at maturity.

	N	DML Maturity ogive				BW Maturity ogive			
		α	β	R^2	DML_{50} (cm)	δ	ε	R^2	BW_{50} (g)
Males	2565	7.94	-1.3	0.79	6.0	0.23	-0.0039	0.93	59.4
Females	1496	7.71	-0.5	0.95	16.8	3.16	-0.0015	0.86	2103.1

and 2103.1 g for males and females, respectively (Fig. 10.b.). Estimated parameters of the logistic model (for DML and BW) are shown in Table IV.

Because males become sexually active at a small size, only the mean DML-monthly evolution for females was studied. DML of the total sample was compared with the DML of all the females analyzed and the mature ones (Fig. 11). Upward trends are visible before the spring shutdown periods in the DML for mature females.

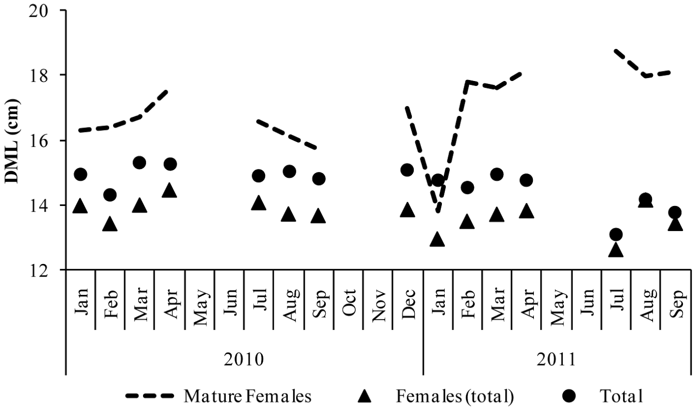

Figure 11. Monthly evolution of the Dorsal Mantle Length (DML) mean for mature and total females and for the total of the analyzed *O. vulgaris*.

DISCUSSION

As Fernández-Núñez *et al.* (1996) exposed, constraints inherent to the data source have to be taken into account in studies based on industrial fisheries. Although sampling was extensive and varied, it has to be considered that the smaller individuals were not likely to be caught by the nets because of the technical characteristics/limitations. In addition, the biggest individuals are scarce and spend more time in their lairs, owing to the reproductive behaviour of this species, especially females (Anderson *et al*., 2002).

Length-weight relationships showed that males increase in weight faster than females ($b_{males}>b_{females}$), as occurs in most close populations. Noticeable differences have been found among the estimated relationship parameters from adjacent areas (a revision is presented in Table III). Several issues have to be taken into account: 1) the high individual variability in this species leads to octopuses belonging to the same cohort reaching significantly different weights with one year of life (Mangold-Wirz & Boletzky, 1973; Domain *et al*., 2000); 2) two mixed cohorts are being assessed and differences between their growth rates (and between sexes) cannot be considered separately without an ageing study; 3) the present study was carried out with defrosted specimens and some differences may occur in these relationships.

Table V. Length at maturity (L_{50}) and Body Weight at maturity (BW_{50}) obtained for *O. vulgaris* from adjacent areas of the African coast. DML/VML: Dorsal/Ventral Mantle Length.

Area and Reference	Length considered	L_{50} (cm)	BW_{50} (g)	Sex
Gulf of Cádiz (Spain) Silva *et al.* (2002)	DML	10.4	671	Males
		17.6	2023	Females
South Morocco Idrissi *et al*. (2006)	DML	12.1		Males
		14.3		Females
NW Africa Fernández-Núñez *et al*. (1996)	DML	14.5	1255	Males
		16.3	1792	Females
Cape Barbas to Cape Blanc Bravo de Laguna (1988)	DML	8	260	Males
		12-13	1100	Females
Mauritania $^{A.}$ Dia (1988) $^{B.}$ Inejih (2000) $^{C.}$ Present study	^{A} DML	12.2		Males
		13.5		Females
	^{B} DML		580-714	Males-spring
			814-768	Males-autumn
			1329-1337	Females-spring
			729-715	Females-autumn
	^{C} DML	6	59.4	Males
		16.8	2103.1	Females
Canary Islands Hernández-García *et al.* (2002)	VML	10.5	1125-1250	Males
		11.3	1200-1300	Females

The sex ratio was biased towards males in almost all of the analyzed cases. As Caverivière (2002) in Senegal, and Dia (1988) in Mauritania, we could conclude that only in the small sizes, non-significant deviations of the 1:1 may be assumed. The observed bias in the sex ratio could be explained by a combination of different factors such as migration, feeding, breeding and post-spawning mortality (Oosthuizen & Smale, 2003; Otero *et al.*, 2007). Besides, most studies reported that the maximum sizes were reached by males, which usually have a slightly higher longevity than females (Domain *et al.*, 2000; Perales-Raya *et al.*, 2014).

Although the presence of spent individuals in the sample seems incidental, they are really valuable specimens due to its scarcity in the wild (Domain *et al.*, 2000; Anderson *et al.*, 2002). Besides, they were caught in the months after the shutdowns, what confirms that the shutdowns period coincide with the spawning period.

It has been discussed that, depending on the area, one or two spawning peaks occur during the year (winter-spring and autumn). Several studies have found the occurrence of two spawning peaks off the Northwest African coast (Idrissi *et al.* (2006) in Morocco; Fernández-Núñez *et al.* (1996) in the Saharan Bank; Hatanaka (1979) in Cape Blanc; Dia (1988), Inejih (2000) and Perales-Raya *et al.* (2014) in Mauritania; Caverivière (2002) in Senegal; etc). The reasons for this occurrence have been discussed by Jouffre *et al.* (2000) and Otero *et al*. (2007), and they concluded that oceanographic parameters (mainly the temperature) but also food availability, determine the life cycle duration and the occurrence of at least two cohorts per year (with all the intermediate situations) produced in two main spawning seasons. The relative importance between these events depends on the area, the autumn-spawning peak being more important to the South, and the winter-spring peak to the North (Inejih, 2000).

In both years, DML mean values of mature females were smaller before the autumn spawning period than before the winter-spring one, mainly in the central events of the studied period (in which more individuals were sampled). This is in disagreement with the more favorable conditions happening in summer, when the upwelling stops, water temperature increases and the growth rate should be accelerated, as has been described for many cephalopod species (Mangold, 1983; Rocha & Guerra, 1999; Wood & O'Dor, 2000; Jackson & Moltschaniwskyj, 2001a; Jackson & Moltschaniwskyj, 2001b). However, Inejih (2000) estimated sizes at maturity for both cohorts separately, and the autumn spawners were significantly smaller. As reported by Balguerías *et al.* (2002), this could be linked to the more favorable environmental conditions, which could accelerate the maturation process and smaller females would achieve maturation faster than the winter-spring spawners (Perales-Raya, 2001). In addition, this decrease in the DML before autumn could be explained by the recruitment produced in this season (Fernández-Núñez *et al.*, 1996; Faure *et al.*, 2000; Jouffre *et al.*, 2000), whose octopuses belong to the previous winter-spring spawning period. On the other hand, minimum DML values were obtained in winter months, which could correspond to the secondary recruitment period, occurring from January to April. But it has to be considered the hypothesis of spawners concentration towards inshore waters (upper than 20 m depth), which could produce seasonal oscillations on the octopuses abundance and length composition by depth (Inejih & Jouffre, 1997). Then, the spawners (and bigger individuals) would be less available for the industrial fishery during the spawning months.

Mean GSI values by SMS agree reasonably well with the subjectively-assigned maturity stages in the case of females. As might be expected by the macroscopic aspect of the gonads and their accessorial glands, the mean GSI by SMS indicated different trends for each sex. The maturity-related indices analyzed showed upward trends in females before shutdowns, mainly before the autumn spawning peak, which was described as stronger by Jouffre *et al*. (2000). It would be related to the food availability in the planktonic phase of this cohort, and the more favorable temperature in summer months (Faure *et al.*, 2000). No data were available from the desirable spawning-peaking months, which are coincident with the spawning seasons established in Cape Blanc by Hatanaka (1979). In addition, it seems to be more adequate to relate the biological shutdowns to the recruitment periods, established in June and September-November by Jouffre *et al*. (2000) for the same area.

Sizes at maturity were calculated using individuals caught round the year, what could overestimate these parameters (Fernández-Núñez *et al.*, 1996). Moreover, differences between studies (Table V) could be explained by the maturity scales used (Fernández-Núñez *et al.*, 1996), but also by the fact that two cohorts are being considered as a unique population, and important growth variations occur between them (see Inejih (2000) in Table V). Although genetic divergences have not been found in the Mauritanian octopus population (Murphy *et al.*, 2002), Inejih (2000) described geographical differences in its maturation process between the north and south areas, maybe influenced by the upwelling system (Balguerías *et al.*, 2002; Martínez-Marrero *et al.*, 2008).

As discussed Lourenço *et al.* (2012), the sampling strategies, the proportion of samples corresponding to peak reproduction seasons, gears with which octopuses were collected, etc., likely influence strongly the results. In this context, sampling programs from commercial fisheries have to assume two limits: the seasonal variation of octopus abundance at the time of capture (i.e. because reproductive behaviour or sex-related migratory patterns) (Rocha & Guerra, 1999) and the legal minimum size that biases the composition of catches. In this sense, octopuses under the minimum legal size analysed (provided just for the present study) allowed to detect when juveniles incorporate into the fishery.

The presented results contribute to the knowledge of the biological cycle of *O. vulgaris* in the region. New research trends have been developed around this important fishery: relationships between oceanographic variations and concentration-retention of biomass and/or growth rates; tagging studies (to monitor migratory and growth patterns); ecological assemblages, etc. Multidisciplinary approaches are necessary to improve its assessment and management. Therefore, further joint efforts among the sectors involved will help to achieve a better understanding about how these 1-year-lifespan populations react to fishing pressure and to environmental fluctuations.

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