Study of reproduction of the common octopus *Octopus vulgaris* in the South Atlantic area of Morocco (1998-2010)

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Abstract. Aboard the "Charif Al Idrissi Vessel", the study on the octopus (*Octopus vulgaris*) breeding period was conducted for 41 surveys (from 1998 to 2010) in the South Atlantic Ocean of Morocco, between Cape Boujdour (26°10' N) and Cape Blanc (20°50' N). The area was divided into two zones: zone A (Cape Boujdour-Cintra bay) and zone B (Cintra bay-Cape Blanc). According to the statistical analysis, it has been confirmed that in the zone A, the mature females migrate from the coast to the large during the spring season, while those in zone B remain concentrated above 50 meters deep with a gradient crossing to the open sea. The results revealed the existence of two seasonal breeding peaks: in spring (April to May) and autumn (September to October). The peak of spawning varied between the two areas. While, the main peak in zone A is on spring and for zone B it is on autumn and vice versa for the secondary peak. However, mature females in zone B have a lower sexual maturity size than zone A during both seasons. Similarly, sex ratio rates are related to seasonality.
Key Words: migration, *Octopus vulgaris*, South Atlantic, spawning, surveys.

Introduction. Because of the crises that occurred in Japan in 1950, cephalopod fishing practice was developed in Morocco since the sixties. Searching for other areas around the world where these invertebrate species live together became attractive especially with the increased international market demand. Cephalopods export has grown rapidly in Morocco to reach almost 46 000 tons by 2020 (DPM 2020). The main target species is the octopus. However, operators are often faced with the instability sometimes drastic of these resources abundance from one year to another. In 2003, the case of economic collapse of the octopus fishing industry witness it (Faraj et al 2006). This is all more worrying when yields and production are dropping which contributed to compromising the levels of economic and biological sustainability of the fishery. Indeed, the brutality of the stock collapse, the non-regulation of fisheries and the ignorance of some factors of the dynamics of the stocks are the main cause of the failure of the stock management (Faure et al 2000).

From a biological point of view, the octopus cycle of reproduction shows a very important seasonal periodicity and therefore a very significant irregularity in spawning periods (Mangold 1963; Guerra 1975; Inejih 2000).

The purpose of this work is to study the reproductive phase part of the common octopus (*Octopus vulgaris*) life cycle. The octopus life cycle has been the focus of many studies (i.e Boumaaz et al 1997; Idrissi et al 2006) which have reiterated the delicacy of this subject concerning a very mutant resource with a very limited lifespan. A collection of the main features characterizing the common octopus was integrated in this part. To meet this objective, this study focuses on the data analysis gathered during the prospection campaigns carried out by the vessel of research from the National Institute of Fisheries Research (INRH) of stock assessment cephalopods, mainly that of octopus along the continental shelf of the South Atlantic zone of Morocco. Land use results were used to supplement this campaign data including data from the sampling of small-scale fishing landings.

Material and Method. All of the data processed was collected during bottom trawl survey campaigns, which are part of the cephalopod stock status-monitoring program, particularly that related to the octopus. These prospecting surveys were carried out at different seasons on board of the research vessel "Charif Al Idrissi", in the study area between Boujdor Cap (26°10' N) and Blanc Cap (20°50' N), for the periods from 1998 to 2010 (Figure 1).

The aim of the adopted sampling strategy was to provide a better coverage of the continental shelf and to use a sampling network more suitable to geostatistical techniques (Conan et al 1988). It is a regular square mesh grid with trawling lines randomly and individually positioned according to a uniform law and which do not overlap (Matheron 1965). This sampling section is constituted by its regular cutting of the identical strata. Each contains a single observation point outside of consideration homogeneity of the regionalized variable. During the 41 scientific cruises (3438 trawling stations), the methodology consisted of a stratified geostatistical random sampling, where the total area of the study area is subdivided into a 10 mile square and the stations are made randomly in each square. Trawl lines are standardized at 30 minutes with trolling speed average of 3 knots. The different biological parameters such as the weight, mantle length, sex and maturity stages were taken, followed and measured on board.

The study area is subdivided into two separate areas, with reference to the assumptions made by Hatanaka (1979) and Murphy et al (2002) on the existence of two octopus populations in the said area on one hand and the narrowing of the continental shelf thus the sandy-muddy nature of the bottom on the other hand.

These two areas are:

- zone A between latitudes 26°10' N - 22°43' N;
- zone B between latitudes 22°43' N - 20°50' N.

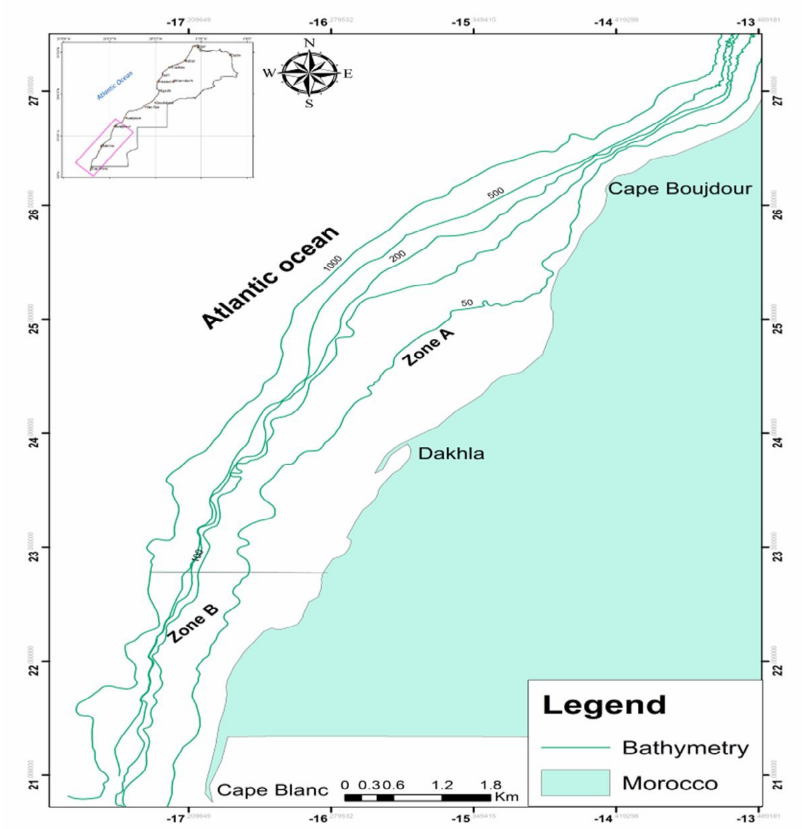

Figure 1. Sampling area of *Octopus vulgaris*.

Then, the two zones A and B were divided into four strata of depth (00-30 m, 31-50 m, 51-75 m and more than 75 m), in order to follow the evolution of the distribution at different depth.

All of the treatments were carried out on a batch of approximately 52,126 individuals (26,565 males and 25,561 females). In addition, the data collected were processed monthly over a year average and standardized as a percentage.

The study of reproduction is based on the analysis of the sexual maturity of *Octopus* females. The scale used was a macroscopic (three-stage) scale used by Hatanaka (1979) and Idelhaj (1984).

The maturity or reproduction index (IRProd) is defined as the ratio of number of females in stage of maturity 3 (mature female) over the total females observed:

$$IRProd = \sum (\text{mature females}) / \text{total females}$$

The study of the evolution of this index during the different seasons of the year allows illustrating the period of the eggs laying.

The sex ratio is defined as the proportion of each sex, determined by macroscopic observation of gonads in a given population. The principal hypothesis supposes that there is equal sex ratio. This was evaluated with a chi-square test.

The mantle length at which 50% of specimens attains maturity (stage 3 is retained as the point at which the fish is considered mature) was deduced using theoretical maturity curve which corresponds to the regression between P parameter depending on the fish size ($P = 1 / (1 + e^{-(a + b \times L)})$ (Pope et al 1983); where P is a mature proportion by class size, L is the mantle length, a is an intercept and b is a slope). The linearization of this formula by introducing the natural logarithm gives: $-\ln((1 – P) / P) = a + b \times TL$. The regression between $\ln (P / 1 - P)$ and mantle length (ML) makes finding the parameters a and b. So: $L_{50} = -a / b$.

Furthermore, an analysis by the generalized linear model (GLM) model of the distributions of mature females by depth stratum was carried out during the two seasons (spring - autumn). The over-dispersion, the nature of the dependent variable, counting variable, and the negative binomial distribution were assumed for model errors.

Analysis of variance (ANOVA) was applied to test the differences between areas and depth stratum using Tukey test ($p \leq 0.05$) using R software.

Results

Reproduction. The spatial distribution of mature females was analyzed by season and by strata of depth. During the spring and autumn seasons (Figures 2 and 3), the mature females ready for egg-laying (laying females) occupy the entire continental shelf of the two zones A and B.

In spring, the females laying eggs in zone A tend to disperse throughout the entire continental shelf, with a significant proportion at the level of strata below 75 meters deep.

In zone B, the proportion of females laying eggs remains concentrated in the strata deeper than 50 meters with an increasing gradient towards the open sea. The coastal strip (0-30 m deep) is not covered due to its geomorphology (rocky area not trawlable) because we do not have information on the rate of females laying eggs at this strip.

The results indicate a highly significant relationship between the rate of females in egg-laying, area and depth. This is related to the nature of spatial occupation of laying females and geomorphological disparities between the two areas which would induce a different spatial behavior of the laying females between the two zones (Table 1).

In autumn, mature females in zone A show a dominance at the level of strata less than 50 meters deep. Unlike zone B which shows the dominance of mature females beyond 50 meters deep (Figure 3).

The results in Table 2 indicate a highly significant relationship between the rate of females laying eggs, the area and the depth. The depth-zone interaction does not affect the distribution of laying females. This same result is obtained for the spring season, except for the depth-zone interaction factor which impact the distribution of laying females in spring and absent in autumn.

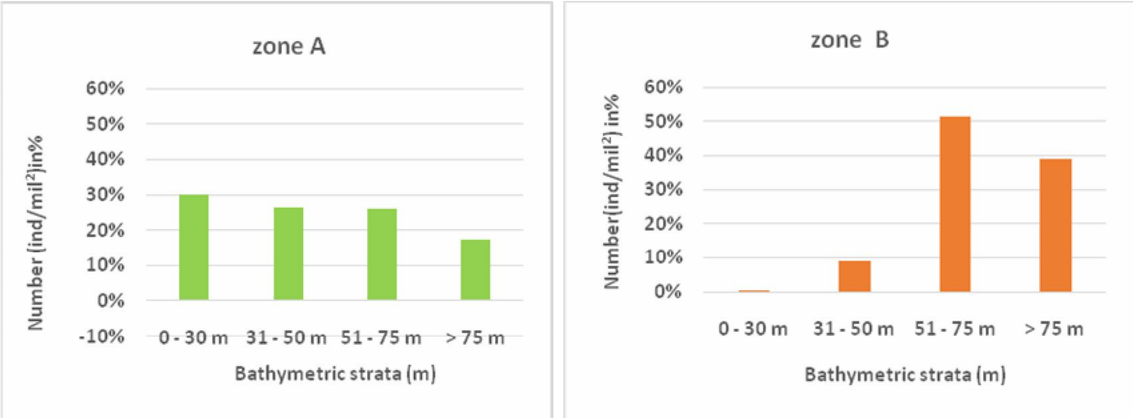

Figure 2. Distribution of females laying octopus by depth stratum zones A and B (spring).

Table 1
Results of the ANOVA test relating to the rate of females laying eggs by area and by deep stratum during the spring season

Variables	*Resid. Df*	*Resid. Dev*	*Δ deviance*	*% deviance*	*p-value*
Null	536	644.73			
Strata	533	574.04	70.69	10.96	3.040e-15***
Zone	532	553.31	20.73	3.21	5.263e-06***
Strata:zone	529	531.04	22.27	3.45	5.769e-05***

Note: ***highly significant ($p < 0.05$).

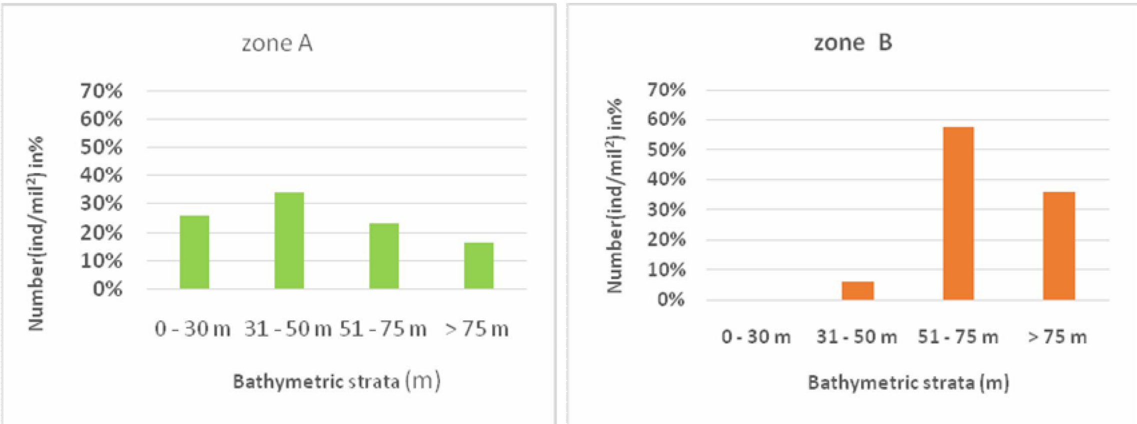

Figure 3. Distribution of females laying octopus by depth stratum zones A and B (autumn).

Table 2
Results of the ANOVA test relating to the rates of female bridges by area and by depth stratum during the fall season

Variables	*Resid. Df*	*Resid. Dev*	*Δ deviance*	*% deviance*	*p-value*
Null	732	798.78			
Strata	729	749.13	69.53	8.70	9.486e-11***
Zone	728	729.25	19.88	2.48	9.486e-11***
Strata:zone	726	728.81	0.44	0.05	0.8015

Note: ***highly significant ($p < 0.05$).

The bridge index from scientific surveys*.* In the two zones A and B, the proportions of mature females is variable in time. The absence of a zero value indicates that the spawning is spread over the whole year.

The analysis of the evolution of the octopus spawning index in zone A shows that the spawning activity is dynamic. It is more intense during spring than in autumn. At

2009, an intense egg-laying was noticed at the month of October mainly due to the global warming which probably favored an important secondary spawning (Figure 4) (cf. temperature evolution below).

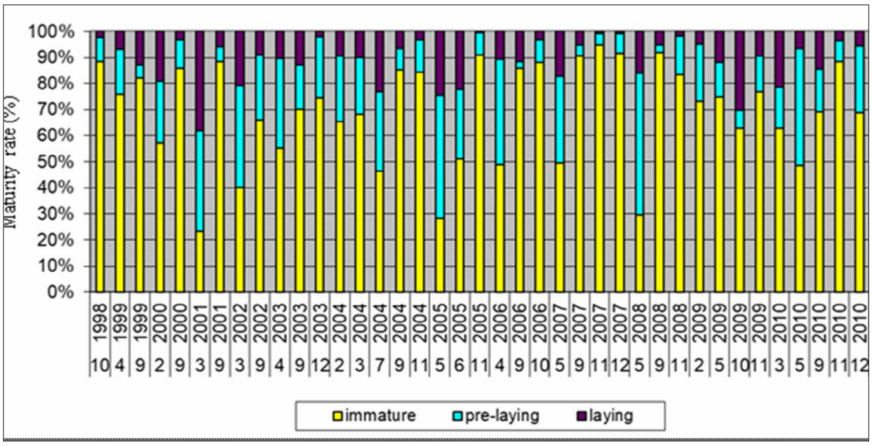

Figure 4. Monthly evolution of the sexual maturity rate of octopus females zone A.

The seasonal interannual evolution of the sea surface temperature shows that the average temperature in autumn is higher than in spring (Figure 5).

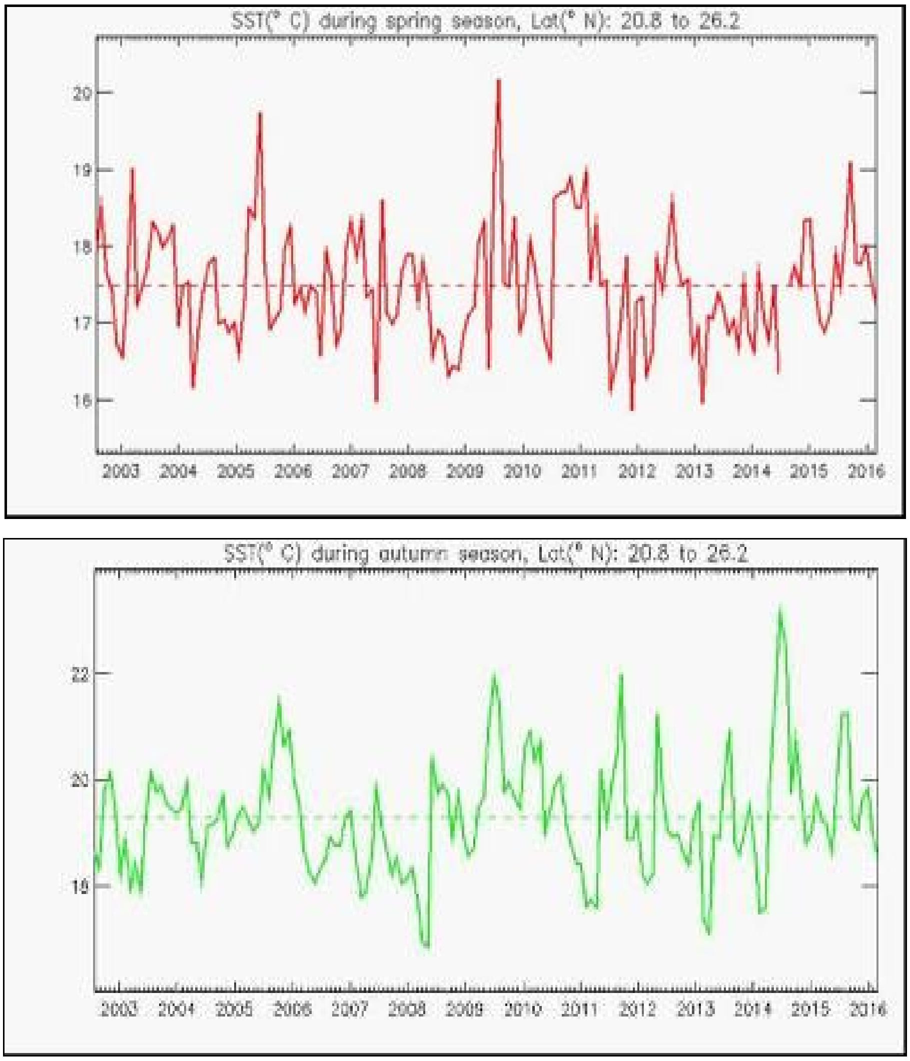

Figure 5. The interannual evolution of the sea surface temperature during spring (above) and autumn (below) in the period between 2003-2016.

In zone B, the egg-laying index during the autumn is more intense than that of the spring. However, the year 2004 was marked by an intense spawning observed in summer. This was probably due to the fishing suspension which lasted 8 months (September 2003 to mid-May 2004) (Figure 6).

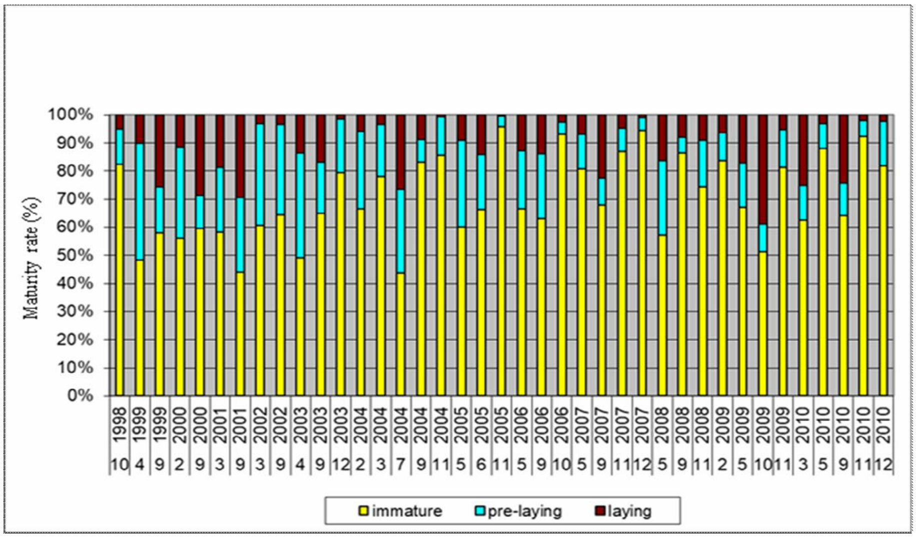

Figure 6. Monthly evolution of the sexual maturity rate of octopus females in zone B.

In order to illustrate the diagram of the octopus laying in each study area, a monthly reproduction index was calculated over an average year. The figure 7 shows the evolution of the octopus monthly reproduction index in zone A. The months of March to May and from September to October show distinct peaks of reproduction. The spring season shows the main peak of the reproductive index, while the autumn season shows a secondary reproductive index (Figure 7).

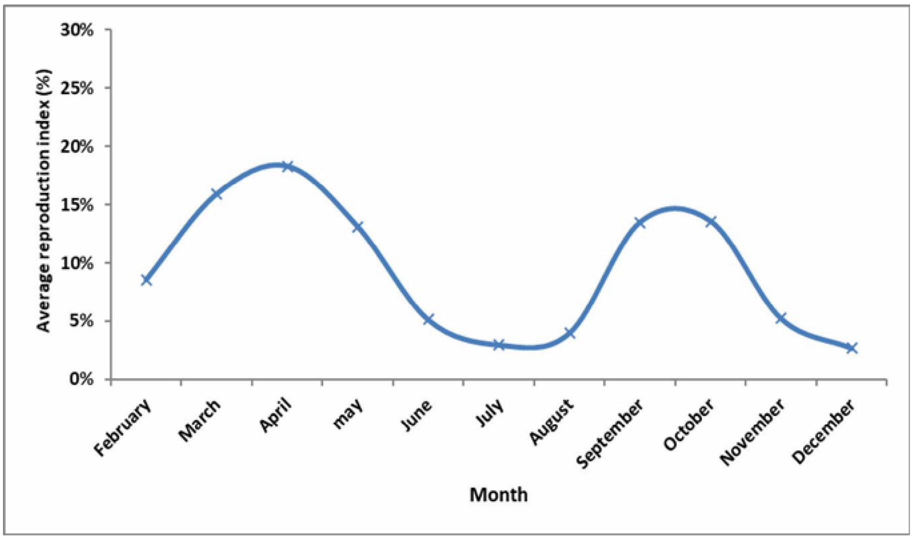

Figure 7. Monthly evolution of the average reproduction index of octopus in zone A.

In zone B, the monthly reproduction index (Figure 8) shows activity spread over the whole year with a lower rate in winter. The main peak of egg-laying is recorded during the autumn season and the secondary peak during spring.

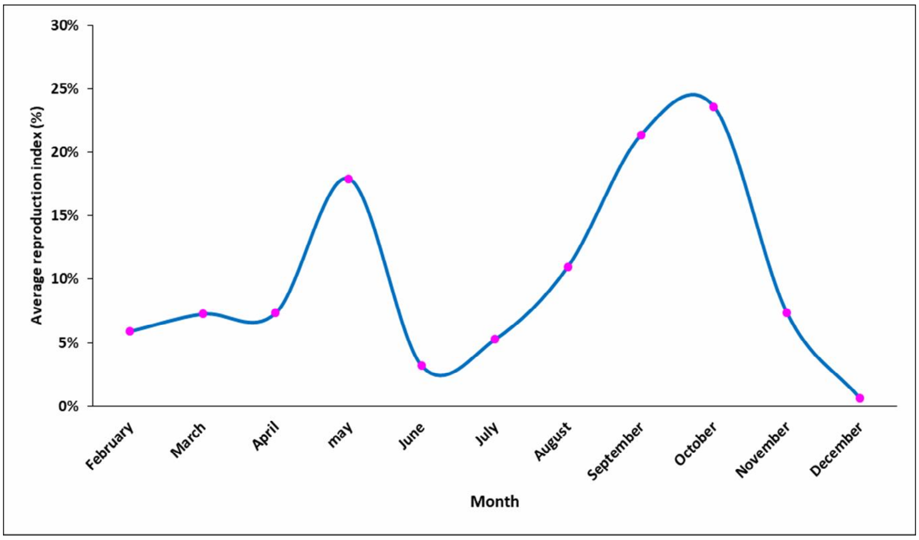

Figure 8. Monthly evolution of the average reproduction index of octopus in zone B.

The comparison of the average reproduction index shows that during the spring season, the egg-laying of octopus in the zones B is delayed compared to zone A (Figure 9). It is more spread out in zone A. In autumn, zone B presents a greater spawning peak, that coincides with that of zone A.

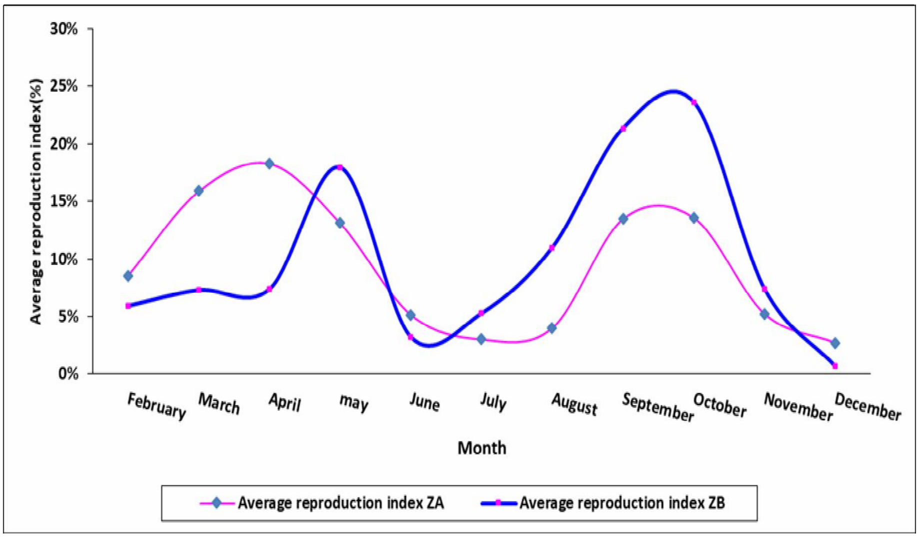

Figure 9. Monthly comparison of the average reproduction index of octopus zones A and B.

The octopus sexual maturity index through the landings of the artisanal fishery. For further information on the octopus laying phase in the study area, biological octopus sampling operations from landings in the artisanal segment were used. Knowing that the area of artisanal fishing that targets octopus extends between the parallels 24° N to 22° 30' N), that is to say at zone A level only.

Analysis of the biological sampling of landed octopus shows that the highest sexual maturity rate (Figure 10) is encountered during the period from May to July. Period which coincides with the main period of the spring trawling campaigns in zone A with an extension until July.

It should be noted that the months September and October correspond to periods of biological octopus rest and therefore not covered by sampling on the ground.

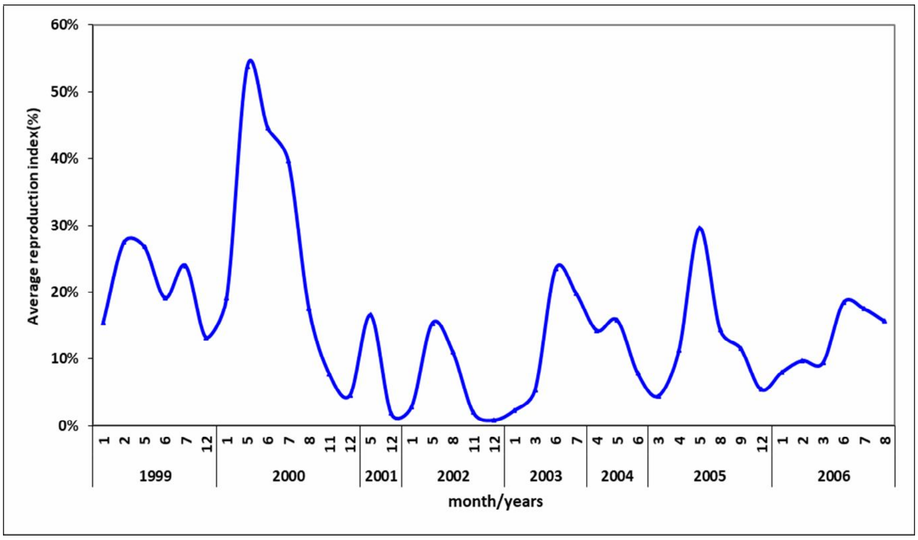

Figure 10. Monthly evolution of the reproduction index of the octopus landed by artisanal fishing in Dakhla.

Direct monitoring (trawling campaigns) and indirect monitoring (shore-based biological sampling) in zone A records the appearance of females laying eggs during the spring season. However, the peak detected during the month of April by the series of cruises at sea is detected with a swing of one month by indirect monitoring. This is due to the fishing gear which is the jig, used by the artisanal fishery during the spring season, which hardly catches the laying females which are sheltered and whose trophic activity is almost zero.

On the other hand, in summer, this artisanal segment uses the (pot or octopus), which is a favorable device to shelter the laying females. This shows that the landing are composed of mature females during the months of June and July. Therefore, the monitoring of the octopus spawning index through indirect monitoring shows an extension of the spawning period over time until the period June - July in zone A.

The size of the first sexual maturity of the octopus across the countryside. The size of the first sexual maturity (L50 %) makes it possible to define the size at which half of the population (50%) is mature. The sizes of first sexual maturity, of males and females of octopus, were grouped by period going from 1999 to 2004, from 2005 to 2010 (choice of the period is based on the management mode of the octopus fishery), the sizes are calculated by the method of proportions regression in zones A and B. The results are presented in Table 3.

Table 3

The size of the first sexual maturity of the octopus

Seasons	*Period*	*Zone A*				*Zone B*			
		Female (cm)	R^2	*Male (cm)*	R^2	*Female (cm)*	R^2	*Male (cm)*	R^2
Spring	1999-2004	13.98	0.94	7.34	0.98	11.96	0.81	6.48	0.90
	2005-2010	13.79	0.94	7.88	0.99	11.26	0.95	6.64	0.99
Autumn	1999-2004	13.14	0.98	7.06	0.92	10.07	0.98	6.02	0.95
	2005-2010	12.56	0.98	6.27	0.96	10.09	0.98	6.07	0.95

The table above indicates that the individuals of zone B are characterized by inferior sexual maturity sizes compared to those in area A. Similarly, the octopus males have power of sexual maturity more important than that of females. Hence, they show a maturity ahead of those of females, and this, in the two zones. In addition, the size of maturity in the autumn season is lower than that in the spring (Figures 11-14).

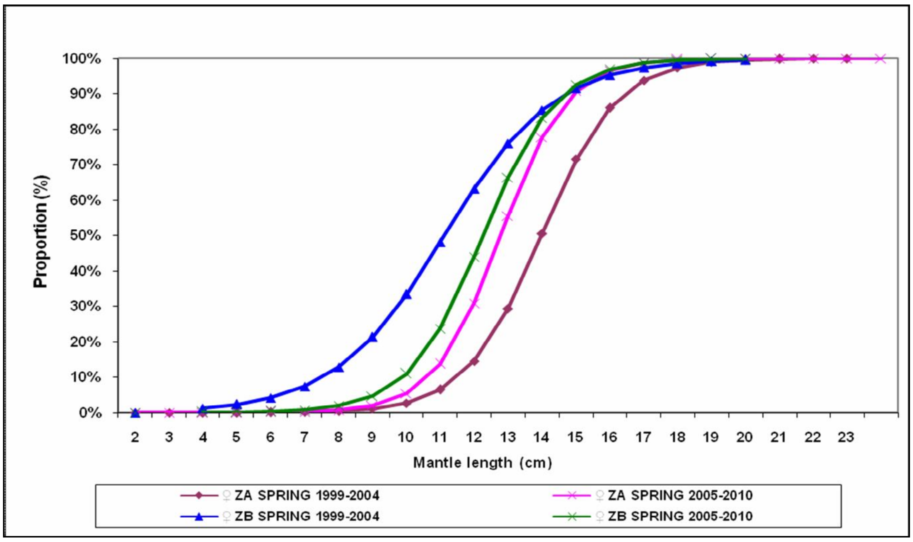

Figure 11. Size of octopus female's first sexual maturity spring season.

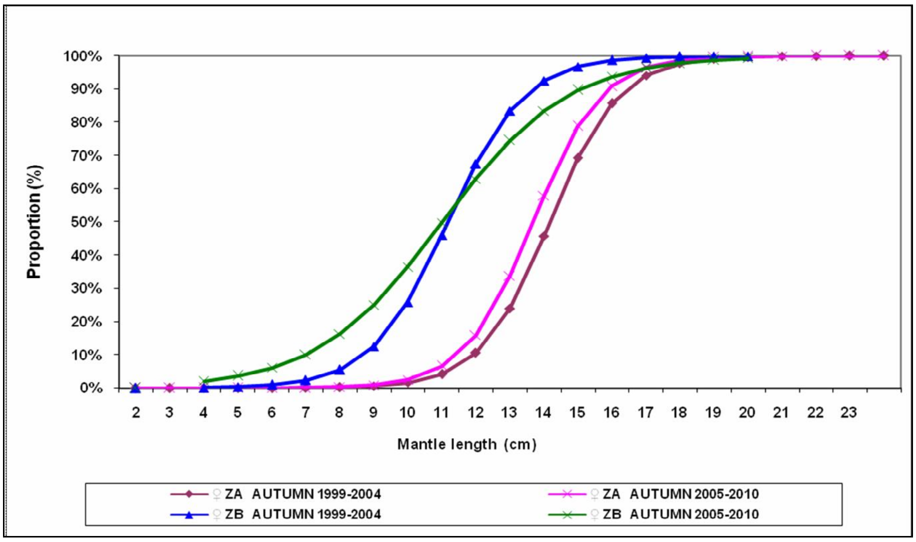

Figure 12. Size of octopus female's first sexual maturity autumn season.

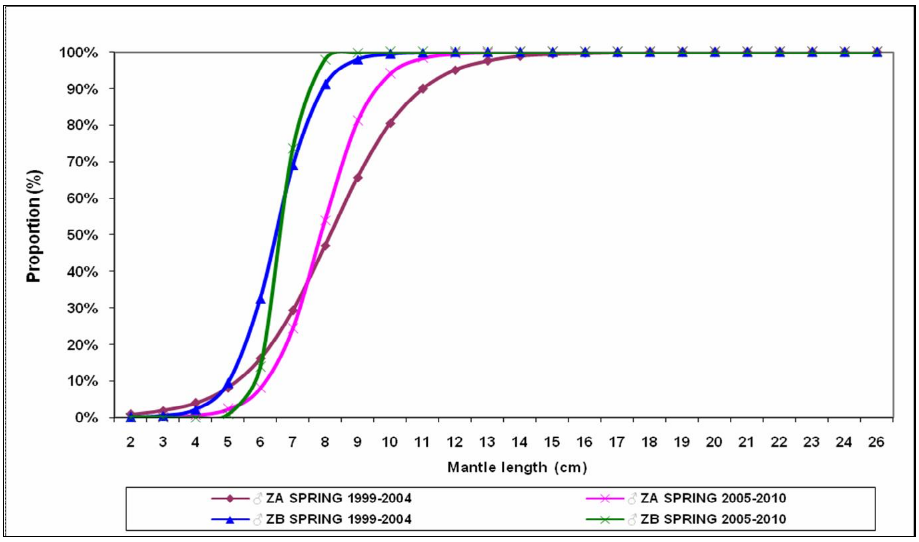

Figure 13. Size of octopus male's first sexual maturity spring season.

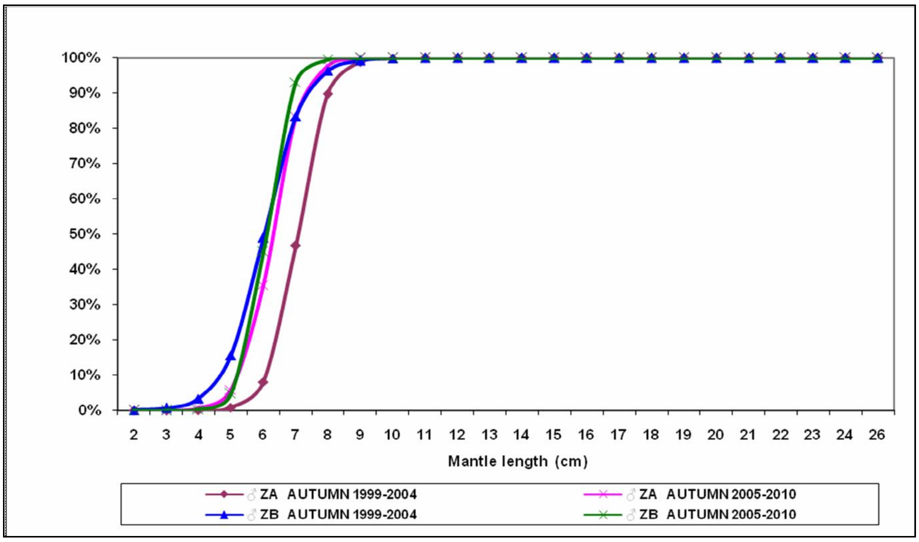

Figure 14. Size of octopus male's first sexual maturity autumn season.

Furthermore, the two zones A and B show a difference in size of the first sexual maturity which could explain either:

- the plasticity of growth;
- the possible presence of two octopus stocks in the Moroccan zone (Dakhla stock and Cap Blanc stock);
- the geomorphological structure of the two zones A and B;
- separate environmental (hydrological) factors.

Sex ratio of octopus. In zones A and B, the sex ratio rate is in favor of females for small sizes. It becomes in favor of the males which dominate exclusively at the level of large sizes (Figure 15). This result confirms the hypothesis of the death of octopus females after laying. The sex ratio becomes proportional 1:1 during the laying period. The Ki² Test has shown that the proportion of the sex ratio is linked to the season (Table 4).

Table 4

The result of Ki² test in the south of Atlantic Moroccan area

Exact binomial test DATA	*Number of successes*	*Number of trials*	*p-value*	*Probability of success is not equal to 0.5 (95 percent confidence interval)*	*Sample estimates: probability of success*
Fall zone A	10172	21292	8.527e-11	0.47- 0.48	0.48
Spring zone A	2171	4281	0.3591	0.49 - 0.52	0.51
Fall zone B	5081	10595	2.699e-05	0.47 - 0.49	0.48
Spring zone B	2288	4441	0.04434	0.50 - 0.53	0.52

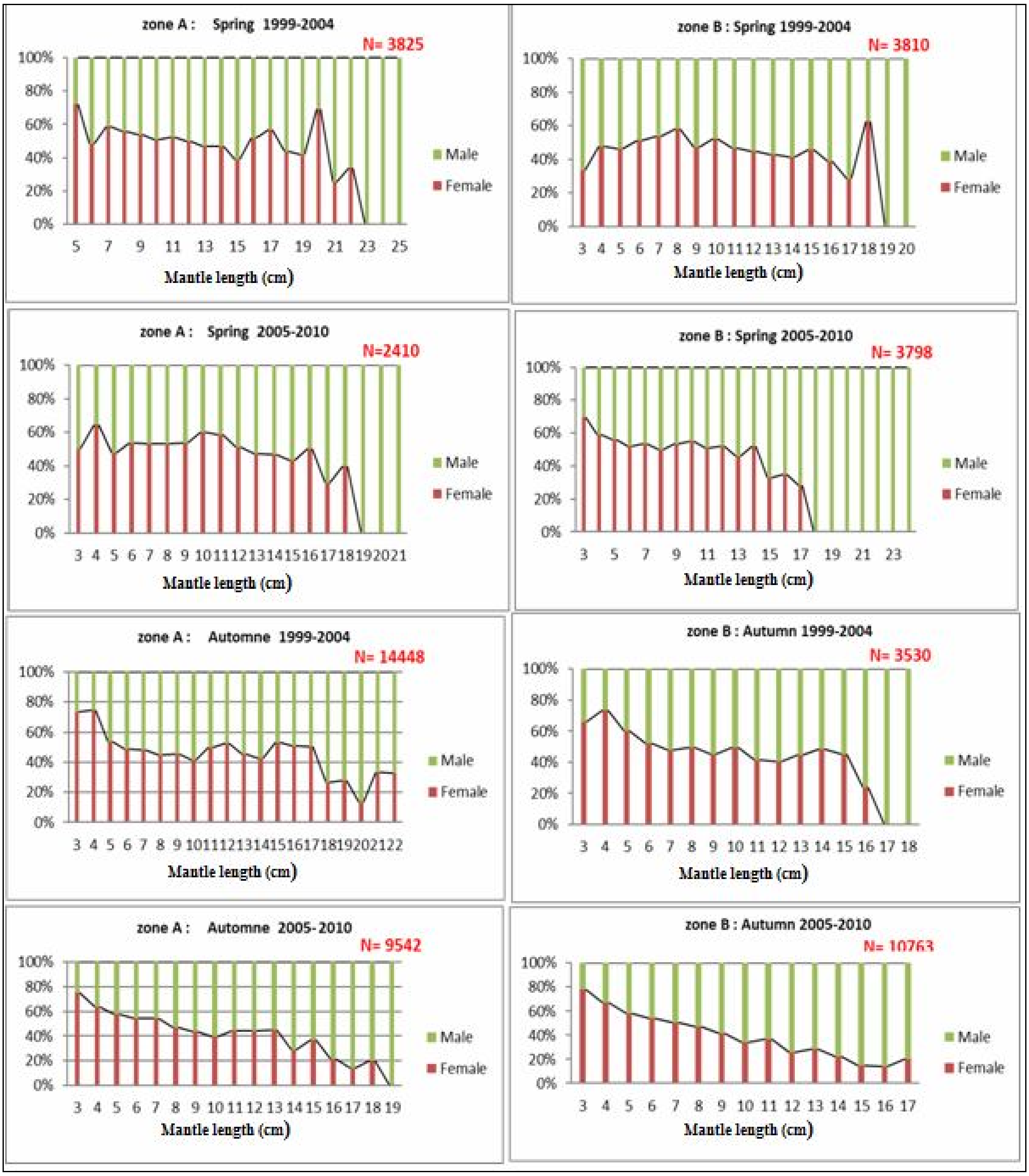

Figure 15. Evolution of the octopus sex ratio by season and size in the two zones A and B.

Discussion. The results from the analysis of the biological parameters of the octopus highlight the presence of a difference between the two zones A and B. This difference is manifested both in the intensity of the laying rate by season and in the size of the first sexual maturity of both sexes. Indeed, the size of the first sexual maturity of the males is lower than that of the females in the two zones A and B. This variability in the size of the sexual maturity can be a function of the plasticity of the growth (Forsythe & Van Heukelem 1987). However, male octopuses reach sexual maturity earlier than females. This result is similar to the results found in other regions (Silva et al 2002; Oosthuizen & Smale 2003).

The octopus has a reproductive activity which spans the whole year and takes place over the entire continental shelf, thus showing two spawning periods (spring - autumn) in the two zones A and B. The period of intense activity (main spawning) is in March-May in zone A and in September-October in zone B. The less intense period (secondary spawning) is in September-October in zone A and March-May at zone B. This confirms the conclusions of the studies carried out by Guerra (1978), Hatanaka (1979) and Idelhaj (1984).

The reproductive cycle in octopus shows a very marked seasonal periodicity which has been confirmed in other regions (Zghidi et al 2004; Otero et al 2007) and consequently an irregularity in the spawning periods (Mangold 1963; Guerra 1975; Inejih 2000).

In addition, the octopus laying period is characterized by an active dynamic of the resource, which manifests itself in a very marked spatial distribution in the spring of spawners over the entire continental shelf according to a wide coast gradient at zone A. This dynamic and biological characteristic of the octopus has been confirmed in the North West Africa area by Mangold & Boletzky (1973), Hatanaka (1979) and Guerra (1981), in East South Africa (Smale & Buchan 1981) and south of Carolina (Whitaker et al 1991). The opposite are occurred in the Mediterranean area by Sanchez & Obarti (1993). Indeed, the octopus undergoes seasonal bathymetric migrations (Mottet 1975; Boyle 1983; Mangold 1983). However, it has not been determined whether these migrations are in response to changes in temperature, salinity, mating/spawning migrations or are driven by changes in the abundance and distribution of preferred prey species. Also, this migration of laying females may be related to the search for shelter at the time of laying or a form of natural geographic extension in large individuals (Crawford et al 1983).

The size of the first sexual maturity in zone B is less than that of zone A. Hence, the sexual maturity of the octopus in zone B is ahead of that of zone A. The proportion of the sex ratio is related to the season respectively at the level of the two zones. Concerning octopus individuals whose sizes greater than 18 cm (coat length), the report is in favor of males. The present study shows that the size of octopus is between 20 and 230 mm for females, and between 20 and 260 mm for males. In the Northeast Atlantic Ocean, Otero et al (2007) found that the size of octopus range between 80-300 mm for females and 85-350 mm for males. Other investigation about the common octopus in the same area revealed that the size range is between 70-270 mm for females and 20-270 mm for males (Silva et al 2002). The difference between results is due to the difference of area of study and the environmental conditions present in each zone.

The strata of 50 meters deep in zone B are less represented because of their rock structure and / or sampling is lacking.

These biological differences, detected between the two zones A and B, should open the field to more in-depth biological investigations (genetic and morphometric) on the identity of the stock which could have implications for the management of this species.

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Conflict of interest. The authors declare that there is no conflict of interest.

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