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Spatial Analysis of Variations in Abundance of *Octopus vulgaris* (Cuvier, 1797) Populations in the Southern Atlantic Waters of Morocco

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ABSTRACT

The study of the spatial distribution of *Octopus vulgaris* in the southern Atlantic waters of Morocco was carried out by analyzing the distribution maps developed using the geographical information system (GIS) and statistical analysis of bathymetry yields. Analyses of the data collected during our boarding aboard a cephalopod freezer trawler (C.F.T) have generally shown the dominance of young individuals in coastal areas and the offshore distribution of large individuals during the entire study period, with the exception of the 2017/2018 winter trip, which was characterized by a concentration of young individuals in deeper waters (offshore) and the presence of large individuals in coastal areas south of Cintra (south of 23°00'N). The spatial distribution of *Octopus* as a function of depth is therefore characterized by a heterogeneity as a function of season and year. The most important average *Octopus* yields are found in the depth stratum at less than 50m with an average yield of 36.95kg/ h. The demographic composition of *Octopus* during this period of study showed dominance in weight of young individuals on depth strata at less than 30 meters, with a yield of 35.61kg/ h, while large individuals dominate the depth strata at more than 76 meters, with a yield of 11.05kg/ h.

INTRODUCTION

Octopus vulgaris (O.v.) is an abundant species around the entire North West African coast **(Guerra, 1981; Amaratunga, 1987; Rathjen & Voss, 1987)**. Declines in some predators such as sparids and serranidae **(Caddy, 1981; Pereiro & Bravo de Laguna, 1981; Gulland & Garcia, 1984; Caverivière, 1990)** have resulted in an increased abundance of *Octopus* in the southern atlantic waters of Morocco **(Balguerias *et al*., 2000)**.

The presence of two *Octopus* stocks, the Dakhla and Cap Blanc stocks, have been recognized since the late 1960s **(FAO, 1979; FAO, 1987; Bravo de Laguna & Balguerias, 1993)**. The high biological productivity in these two areas is also due to the presence of upwelling zones **(Minas *et al*., 1982; Balguerias *et al*., 2002)**.

The largest *Octopus* fishery is on the Saharan coast (northwest of Africa) **(Hernandez-Lopez & Castro-Hernandez, 2001)**. This species is highly targeted by the offshore cephalopod trawlers operating only in this area, as well as by small-scale and coastal fishing vessels.

Despite its abundance, *Octopus* populations in West Africa show strong inter-annual variations in abundance **(Caverivière, 1990; Jouffre & Inejih, 1997; Faure, 2000)**, mainly related to the biology of this species.

In this context, the aim of this study was to study the seasonal spatial distribution of *Octopus* abundance in the southern Atlantic waters of Morocco.

MATERIALS AND METHODS

1. Study area

The study was conducted in the southern Atlantic waters of Morocco (Fig. 1) between the parallels L: 26° 24' N (Sidi Elghazi) and L': 020° 46' N (Cap Blanc). *Octopus vulgaris* is of great socio-economic importance because of its landed weight and commercial value. This gives it a special position among the species exploited **(Idrissi *et al*., 2006)**.

For reasons of protection of *Octopus* spawning areas, CFTs are authorized to fish beyond the coast for a distance of 10 miles throughout the summer season, and at a distance of 12 nautical miles from shore for one to two months during the resumption of the winter fishing season, which is then reduced to 10 nautical miles during the remaining period of the winter trip. Bottom trawling in the southern Atlantic waters of Morocco and fishing for *Octopus* during the spring and autumn seasons are prohibited for reasons of protection of juvenile *Octopus* from overfishing.

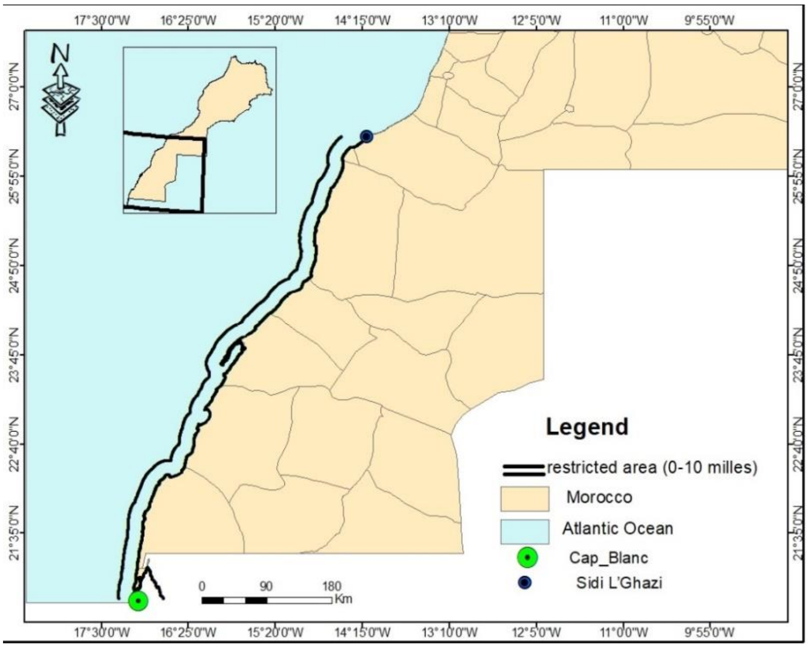


Fig. 1. Delineation of the study area between Sidi Elghazi and Cap Blanc

2. Data

Data for the present study were collected during our embarkation from 3325 bottom trawling operations. These operations were carried out during four successive trips of resumption of the *Octopus* fishery, i.e., two winter and two summer trips in authorized fishing areas (Table 1). A cartographic restitution was employed to examine our data using ArcGIS software V10.3, a GIS tool.

During each trawling operation, the *octopus* catches were systematically eviscerated and classified according to the authorized size (weight) set by the Japanese classification known as "Mitsubishi." This classification is the most widely used **(Dia, 1988; Jouffre *et al.*, 2000)**. In each operation, individuals weighing between 0.3 and 1.2 kg were categorized as small-caliber individuals (W. category 1), while those exceeding 1.2kg were labeled as large-caliber individuals (W. category 2).

The spatial dynamics of *Octopus* are studied by analyzing the yields (P. category 1 and 2 per trawl stroke, expressed in kg/h) according to the spatial factors structuring the population which are the geographical position (X and Y) and depth, and taking into account temporal factors (seasons and years).

Table 1. Information related to the study period

Trip	Summer trip (1)	Winter trip (1)	Summer trip (2)	Winter trip (2)
Start date	01 -6-2016	01-12-2016	15-6- 2017	05-12-2017
End date	31-08-2016	31-03-2017	15 -09-2017	31-03-2018
Number of trawling operations	723	953	760	889
Number of fishing days	92	121	93	117

3. Statistical analysis tools

Statistical analysis was used to process data based on the spatial analysis of the CPUE to support the differences between the spatial distribution of young individuals (small sizes) and large individuals depending on depth.

The data collected were studied as statistical variables, and the mean values per sample type were compared using the least significant difference (LSD) test at $P< 0.01$. Analyses of variance (ANOVA) were computed using General Linear Model.

Statistical analysis and graph creation were done using R Project (statistical calculation software), and R studio software, which is software for data processing and statistical analysis (version 2022.07.0-548). The means are considered significantly different at $P< 0.05$ and highly significant at $P< 0.01$.

RESULTS

1. Spatial analysis

Analysis of the *octopus* distribution maps (Fig. 2) during all trips in the study period, with the exception of the 2017/2018 winter trip, shows that small-caliber individuals were fished primarily in coastal areas. In contrast, larger-caliber individuals were more localized in the same regions, where small individuals were concentrated. However, during the 2017/2018 winter trip, high yields of large-caliber individuals were observed in coastal areas, while small-caliber individuals were found in offshore regions.

Analysis of the *Octopus* distribution maps (Fig. 2) showed a high concentration of young *Octopus* at the level of the coastal zone south of Cintra during the 2016 summer trip, and large size individuals in the area between L: 021°35’ N and L: 020°46’ N (white heading) near the coast and offshore. For the winter trip 2016/2017 the young individuals were located in the coastal zone off Cintra.

The areas of concentration of small calibers during the 2017 summer trip were spread over almost the entire area frequented by our freezer trawler (coastal and offshore areas). Moreover, the most marked was located around the parallel 22°30 N.

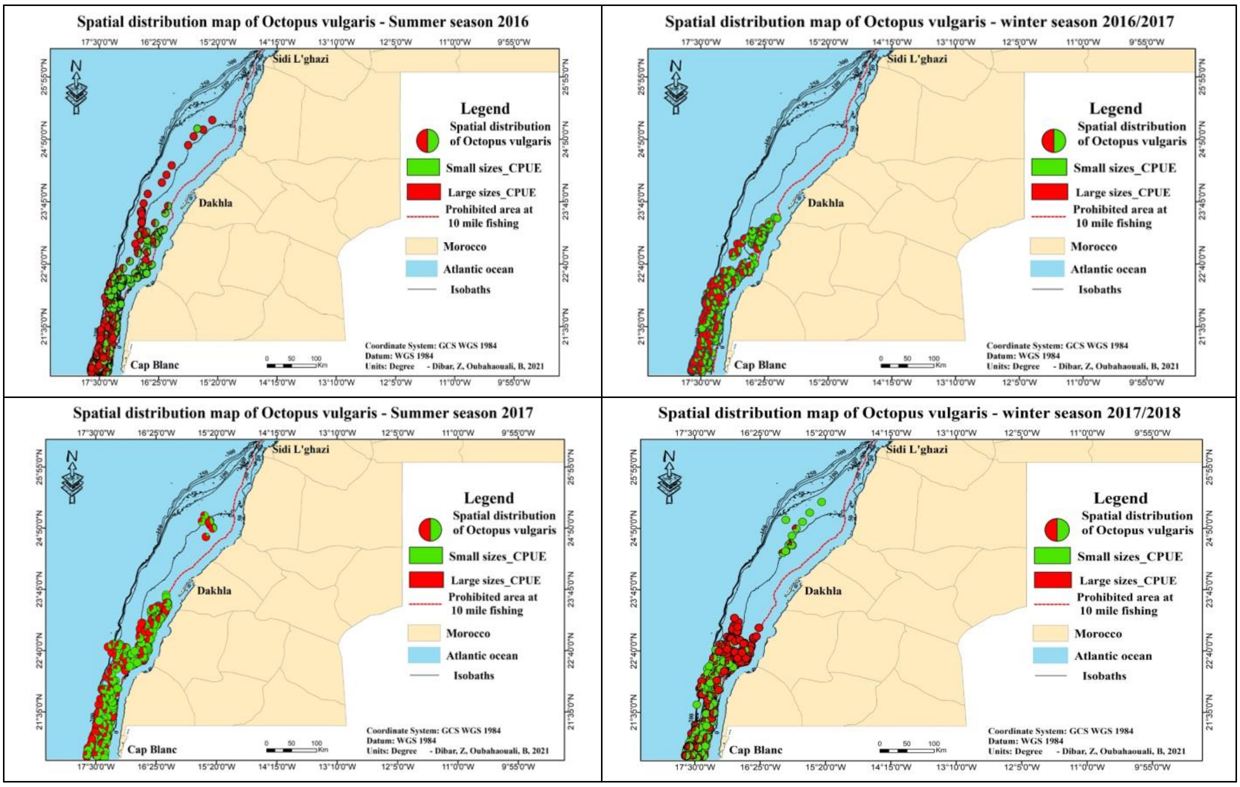


Fig. 2. Spatial distribution maps based on the weight of *Octopus* caught during four fishing trips

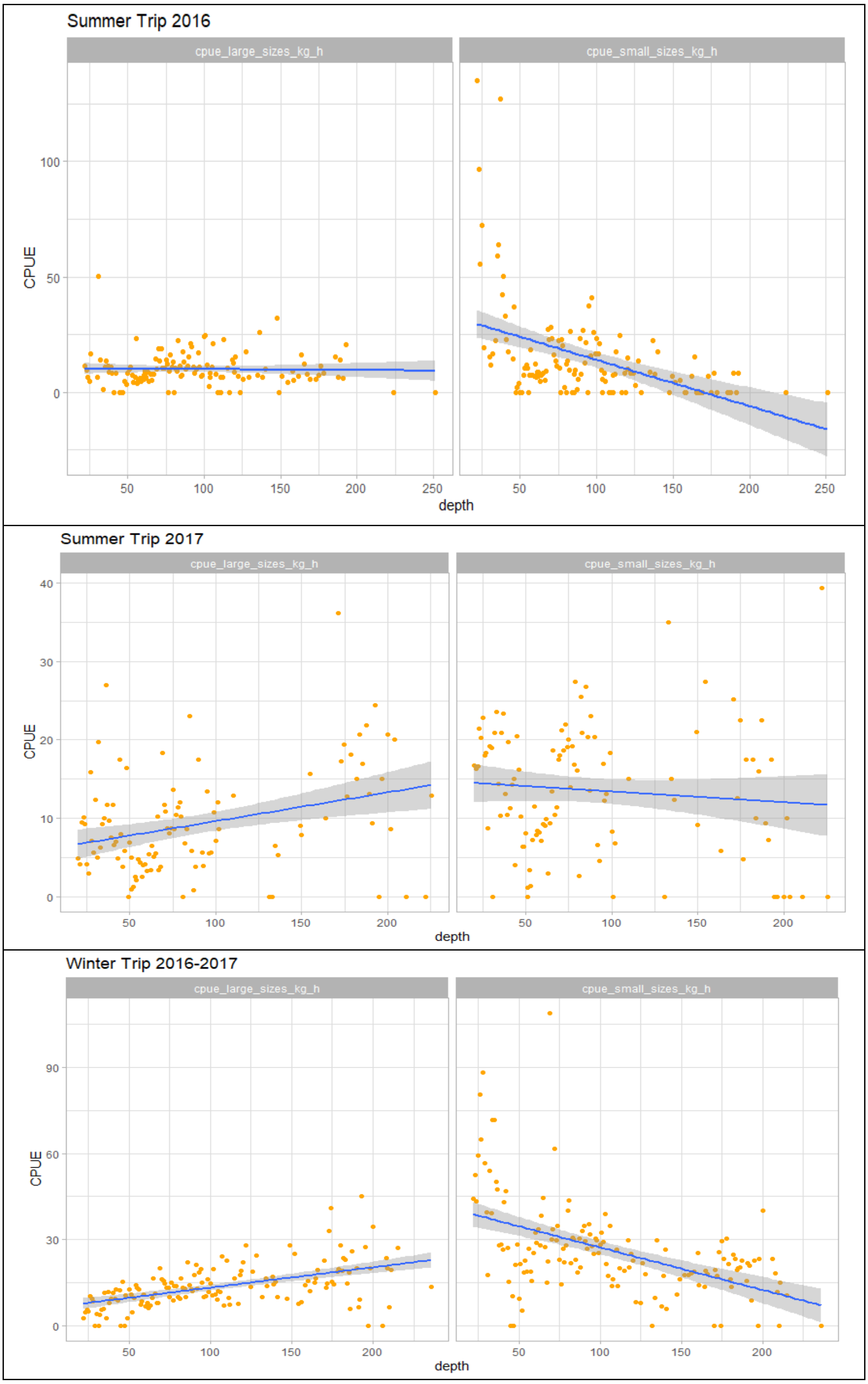
2. Statistical analysis

The results obtained confirmed the existence of a difference in yield with a highly significant difference for two variables (CPUE small size, CPUE large size) between seasons depending on the depth. The *P*-value is less than 0.01, and that term is statistically significant at the 95.0% confidence level.

The graphs related to the summer trip 2016 and the winter trip 2016/2017 in Fig. (3) showed a negative correlation between CPUE of small octopuses and depth, respectively (*P*-value 1.21e-07); (*P*-value 8.32e-11). The graphs relating to the winter trip 2017/2018 showed a positive correlation between CPUE of small octopuses and depth (*P*-value 2.49e- 3). For the summer trip 2017, the graph showed no significant correlation between depth and CPUE small octopuses (*P*-value 0.315).

The graphs related to the winter trip 2016/2017 and the summer trip 2017 showed positive correlation between CPUE of large octopuses and depth (*P*-value 4.95e-12; *P*-value

6.47e- 4, respectively). Additionally, the graphs related to the winter trip 2017/2018 showed negative correlation between CPUE of large octopuses and depth (*P*-value 2.49e- 3). Concerning the summer trip 2016, the graph did not indicate any correlation between CPUE of large octopuses and depth (*P*-value 0.75).



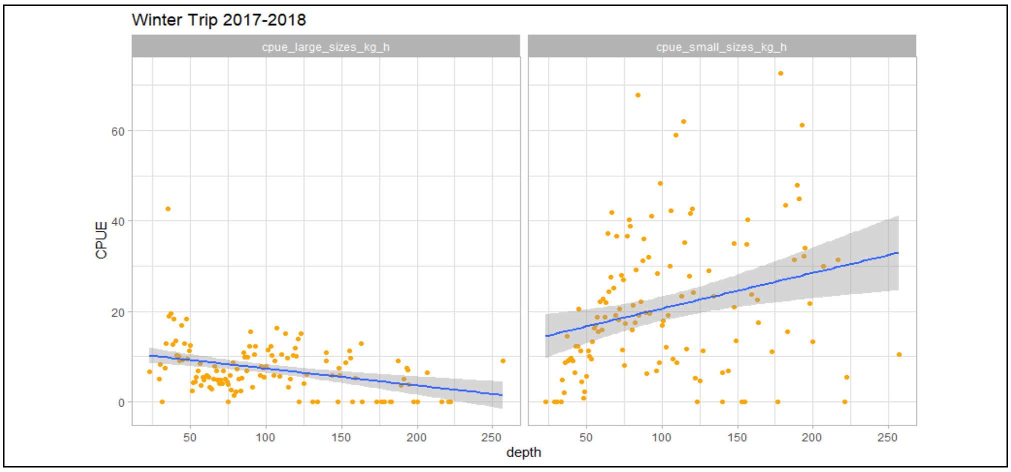


Fig. 3. Evolution of CPUE large size and small size as a function of depth during four fishing trips

3. Analysis of distribution according to bathymetry

The overall demographic composition of *Octopus* during this period of study showed a significant concentration of young individuals on deep strata less than 30m (Fig. 4) with a yield of 35,61kg/ h, while large individuals proliferated in depth strata at more than 76m (offshore areas) with a yield of 11.05kg/ h. Maximum catches per unit of effort of *Octopus* were recorded in areas with a depth of less than 50 meters with an average yield of 36.95kg/ h.

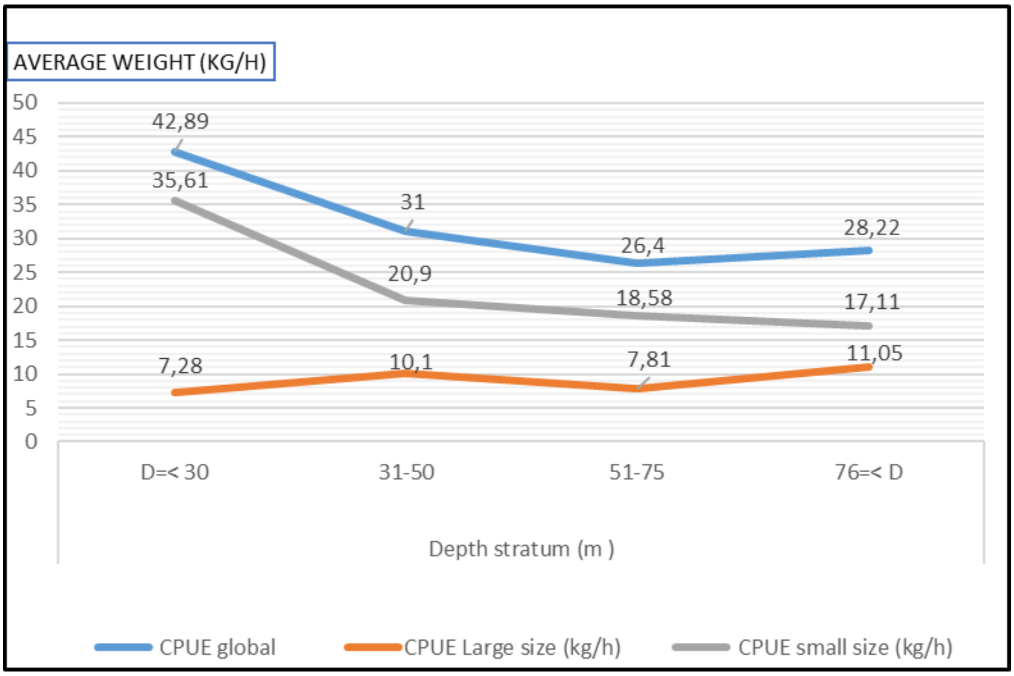


Fig. 4. Evolution of average weights as a function of depth strata

DISCUSSION

During this study, it was evident that the coastal waters are more reproductive in *Octopus*. This result is in agreement with the result described by **Boumaaz *et al*. (2002)**, who mentioned that the most productive area is located more particularly at the level of the depth stratum 10-30 meters, and also showed that in the deep strata, average sizes tend to increase, following the analysis of the evolution of the mean size as a function of the strata depth.

In our study, it was evident that there is a high frequency of catching young *Octopus* in shallow, coastal areas. As individuals grow, they move away from the shoreline (deep areas), showing dominance of large individuals in offshore waters.

The same result was published in the study of **Faraj and Bez (2007)**; these authors showed that *Octopus* juveniles are more coastal and more concentrated in depths between 20 and 40 meters and are less dispersed in space, while mature females are more localized in offshore waters between 20 and 100m. Another study argued that during the fall recruitment season, most of the *O. vulgaris* stock is concentrated in the coastal ascending waters **(Hatanaka, 1979)** and deduced that the juveniles disperse to settle in deeper waters (an ontogenic migration).

The 2017 summer trip and the 2017/2018 winter trip made the exception by yields of young octopus important even in deeper waters. This is likely related to hydroclimatic conditions (wind intensity and currents). **Sy and Chernichkov (1985)** concluded that some changes in hydroclimatic conditions were partly responsible for the high spatial and temporal variability in yields. Two studies conducted in the MANCHE **(Rees, 1950; Rees & Lumby, 1954)** also confirmed that during the planktonic (1.5-2 months) paralarval phase, *Octopus* larvae can be transported far away from their hatching site depending on the intensity of the current. This leads to a concentration of young individuals in offshore.

The 2017/2018 winter trip and the 2017 summer trip are characterized by the detection of nuclei of abundance of large individuals in coastal areas, which are individuals who have reached the maturity stage and who approach the coastal zone for spawning reasons. The same result was discovered in the Canary Islands **(Hernandez-Garcia *et al*., 1997)**. According to these authors, the maximum catches correspond to concentrations of adult individuals, which are recorded near the coast during the spawning periods of April/May and September to November. Such high concentrations of *O. vulgaris* on the coast during a spawning season would be supported by spawning migration to the coast (mature individuals moving from deeper waters to the coast to spawn).

Reproductive migration was found in the Balearic Islands *Octopus* population in the Mediterranean, with coastal concentrations of the spawners **(Sanchez & Orbati, 1993; Quetglas *et al*., 1998)**. Their finding confirmed the present results obtained during the winter trip 2017/2018 and that of summer 2016. This migration showed the same results found in our study during the 2017 summer trip and the 2017/2018 winter trip regarding the extended offshore distribution of recruits.

Ajana *et al*. (2018) found a strong inter-annual variability from 2008 to 2015 of *Octopus* yields on the Moroccan Mediterranean coast. **Oubahaouali *et al*. (2021)** reported the same result in the southern Atlantic waters of Morocco. This will have an effect on the spatial variability in abundance. Other studies have confirmed a relationship between the temporal and spatial variability of *Octopus* **(Hatanaka, 1979; Guerra, 1981; Dia, 1988; Inejih & Jouffre, 1996)**.

Fluctuations of abundance seem to be the results of environmental variability influencing the life cycle of the species **(Boyle & Boletzky, 1996; Sobrino *et al*., 2002; Vargas-Yáñez *et al*., 2009; González *et al*., 2011)**. Environmental fluctuations (upwelling, turbulence, coastal retention and temperature) partly explained the inter-annual variability in the abundance of *Octopus* populations, their spatial distribution along the shoreline and their seasonal breeding strategy **(Faure, 2000)**.

CONCLUSION

The highest *octopus* yields occur in coastal waters under 50 meters deep, with young octopuses typically found near shore and adults more offshore. This distribution varies with hydro-climatic conditions like winds and currents. Notably, the 2017 summer and winter trips revealed significant numbers of young octopuses even in deeper waters, while adults migrate to the coast for reproduction.

To protect octopus populations, it's crucial to monitor spawning areas and inform prohibition zones based on comprehensive studies of their distribution year-round, considering environmental factors during the larval phase. Sustainable exploitation hinges on understanding the species' ecology and seasonal dynamics, particularly during the vulnerable juvenile stage along the coast. Overfishing poses a significant threat, necessitating precautionary measures to ensure the sustainability of octopus fisheries.

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