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A Preliminary Analysis of the Relationship Between the Common Octopus (*Octopus vulgaris*) Juveniles Abundance and Environmental Parameters off the Moroccan Coast

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ABSTRACT

In the Moroccan ecosystem, *Octopus vulgaris* population shows high seasonal and interannual variability. Understanding the processes that influence octopus abundance is important in order to manage the fishing grounds and offer advice on the exploitation of this important resource. Fluctuations in the abundance of exploited stocks may be due to a great variety of factors. However, in short-lived animals such as octopuses, in which abundance depends on the strength of the recruitment, it is well known that population abundance is highly influenced by environmental conditions. In this study, the relationship between octopus (*Octopus vulgaris*) juveniles' abundance from the research vessel Charif Al Idrissi in the area of the south of the Moroccan coast and oceanographic parameters, such as sea surface temperature (SST), surface chlorophyll (CHL) and salinity (Sa) was investigated. A generalized additive model (GAM) was applied to investigate six years (2016-2021) variability of octopus juveniles in Moroccan waters. It was noticed that the principal area of recruitment was located between Cap Barbas and Cap Blanc in the spring and autumn seasons and between Cap8 and Aarich in autumn. Concerning the environmental parameters, the sea surface temperature (SST) showed a positive impact on juveniles' abundance. The highest abundance of juveniles was associated with SST at around 21°C.

INTRODUCTION

The common octopus *Octopus vulgaris* is today one of the most targeted species in Morocco for its commercial value. Its main fishing area is located to the south of Boujdour, between Cintra and Cap Blanc (Zone B) (Fig. 1).

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 witnesses 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. Remarkably, 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 causes of the failure of the stock management **(Faure *et al*., 2000)**. Octopus is a merobenthonic species with a short life cycle (12–15 months; **Katsanevakis & Verriopoulos, 2006; Perales-Raya et *al*., 2010)** and high fecundity (from 70,000–634,445 oocytes; **Silva *et al*., 2002; Otero *et al*., 2007)**. Due to their short life span, rapid growth, high natural mortality and sensitivity to environmental conditions, octopuses are a difficult resource to manage **(Silva *et al*., 2002; Otero *et al*., 2007)**.

Several studies have related cephalopod distribution and abundance to environmental parameters **(Bellido *et al*., 2001; Balguerias *et al*., 2002; Sobrino *et al*., 2002; Wang *et al*., 2003; Pierce *et al*., 2008)**. Seasons to seasons, fluctuations in the abundance of octopuses stocks may be due to a great variety of factors. For a short-lived animal such as cephalopods, in which abundance depends on the strength of recruitment, it is well known that abundance is highly influenced by the environmental conditions, which affect the recruitment through influences on adult fecundity, egg quality, hatching success and growth and mortality of paralarvae and juveniles **(Pierce *et al*., 2008, 2010)**.

Previous studies suggested that annual variability of octopus catch was somewhat the result of environmental changes. Annual variation in abundance and recruitment of octopus has been attributed to the variations of environmental conditions (e.g Temperature) **(Faure, 2000; Faure *et al*., 2000)**. Most studies linking octopus abundance to environmental changes were based on traditional regression techniques **(Agnew *et al*., 2000; Caverivière *et al*., 2002; Caballero-Alfonso *et al*., 2010; Thiaw, 2010; Thiaw *et al*., 2011)**.

In the current study, we investigated the relationships between octopus juvenile's abundance and various oceanographic variables using the generalized additive model (GAM) that might plausibly influence it in the south of Moroccan coast to explain such abundance in order to obtain predictive models that could be used to assist managers in providing advice on the exploitation of this resource.

MATERIALS AND METHODS

Study area

The Atlantic coast of Morocco is nearly 3000km long, extending from Cape Spartel (35°47' N) to Cape Blanc (20°50' N). It is part of the Canary Current System (CCS), which extends between the Iberian Peninsula (43°N) and the south of Senegal (8°N) and dominates most hydrodynamic processes therein **(Wooster *et al*., 1976)**. Circulation along the Moroccan coast is determined by the Azores of the Saharan depression seasonal rhythm and ITCZ (Inter Tropical Convergence Zone) as well **(Wooster *et al*., 1976)**.

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.

The South Atlantic of Morocco is the most important fishing area in the country (Fig. 1). It is characterized by permanent upwelling between Dakhla and Cap Blanc, and estival upwelling between Cap Boujdour and Dakhla **(Makaoui *et al*., 2021)**.

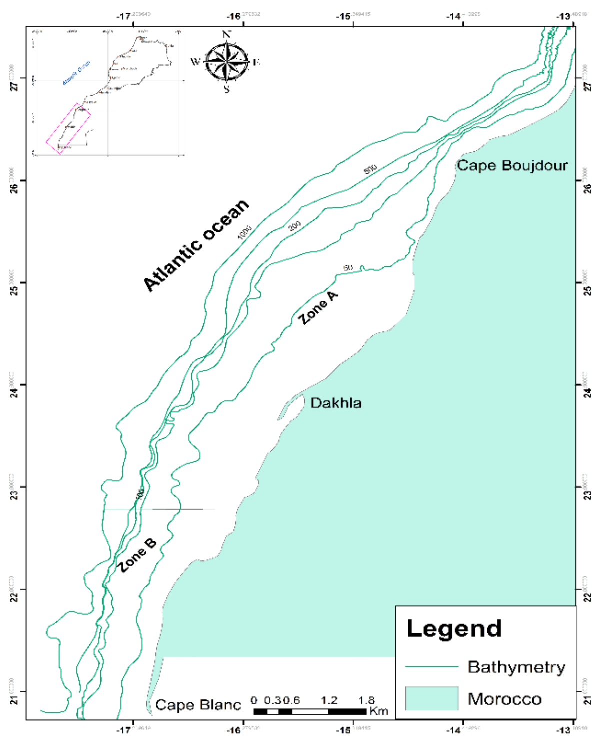

Fig. 1. Study area of *Octopus vulgaris* juveniles during 2016-2021

Biological data

The database was created from data collected during surveys carried out by R.V. Charif Al Idrissi of the National Institute of Fisheries Research (INRH) (https://www.inrh.ma) using a stratified random-sampling design within a 1-squarenautical-mile grid. The data were obtained from 12 trawl surveys (816 sampling stations) covering the periods from 2016 to 2021 during spring and autumn seasons. In the present work, we used the abundance of octopus estimated as the number of juveniles (less than 500g) per 30min of trawling.

Environmental data

Explanatory variables in *octopus vulgaris* juveniles abundances models were: the sea surface temperature (SST), water salinity (Sa) and chlorophyll concentration (CHL). Satellite data at a fine spatial scale of 0.083×0.083 degrees for SST (degrees Celsius) and Sa (psu) and at spatial resolution of 0.25×0.25 degrees for CHL ($mg.m^{-3}$) were collected (www.marine.copernicus.eu). The SeaWiFS Data Analysis System (SeaDAS) version 7.3.2 was used to read satellite maps and import ocean products data for statistical analysis.

Data analysis

The effects of abiotic variables on the spatiotemporal variations on the abundance of octopus's juveniles were determined using generalized additive models (GAMs) **(Hastie & Tibshirani, 1990)**.

The generalized additive model (GAM) was used to investigate the associations between SST, CHL and Sa and octopus recruitment. It allows depicting the complex relationships between species and their environment **(Zwolinski *et al*., 2011)**. GAM is described as a generalization of ordinary linear models **(Wood, 2006)**. In these models, the linear predictors are related to the response variables via a link function that extends the use of the regression models beyond Gaussian response variables. GAM uses data-driven functions, such as splines and local regression, which have superior performance relative to the polynomial functions used in linear models. The semi-parametric smooth functions (s) were used to fit the interactions between the predictors (SST, month and year) and the dependent variable, the octopus recruitment. The *mgcv* package in the software R (version 3.6.3) was used. This software (R) is a free software programming language and a software environment for statistical computing and graphics widely used for data analysis. The dependent variable, octopus juvenile's abundance was modelled as the additive sum of unspecified non-parametric functions of hypothesized covariates and their interaction.

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

1. Annual fluctuation of *Octopus vulgaris* juveniles' abundances

In the south of Morocco, the abundance of *octopus vulgaris* juveniles varied from year to year during the last six years. The highest juveniles' abundances occurred in 2021 (3500 Ind) ; however, the lowest abundance of octopus juveniles was in 2019 (500 Ind). Comparing the autumn and spring seasons, we always found that octopus juveniles were abundant in autumn than spring season except in 2020 (Fig. 2). The difference between the two seasons was significant ($P<0.05$). These results showed that octopus had a principal recruitment in autumn and secondary one during spring season.

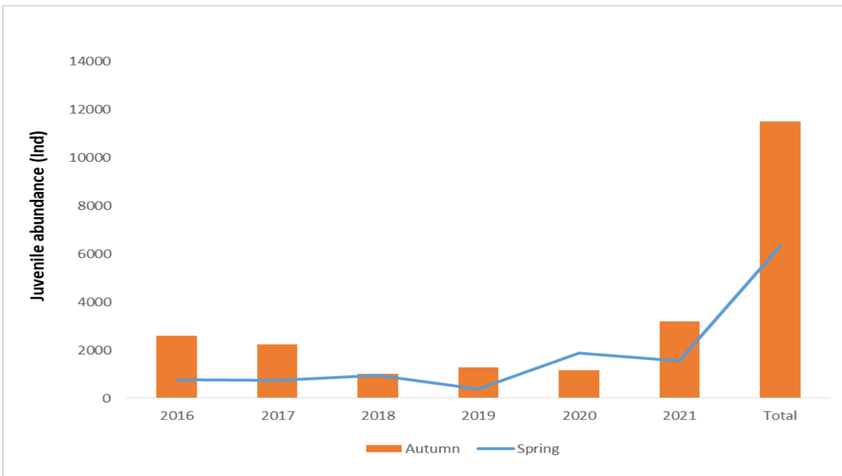

Fig. 2. Comparison between the abundance of juvenile octopus during seasons of spring and autumn

2. Recruitment areas of octopus

In spring, one area was detected which represented a high level of juveniles abundance; it is situated between Cap Barbas and Cap Blanc (Figure 3). Concerning the recruitment areas in autumn seasons, in addition to the first area (Cap Barbas - Cap Blanc), we determined three other areas of juveniles' concentrations, including Cintra, the offshore of Dakhla and between Cap 8 and Aarich (Fig. 3).

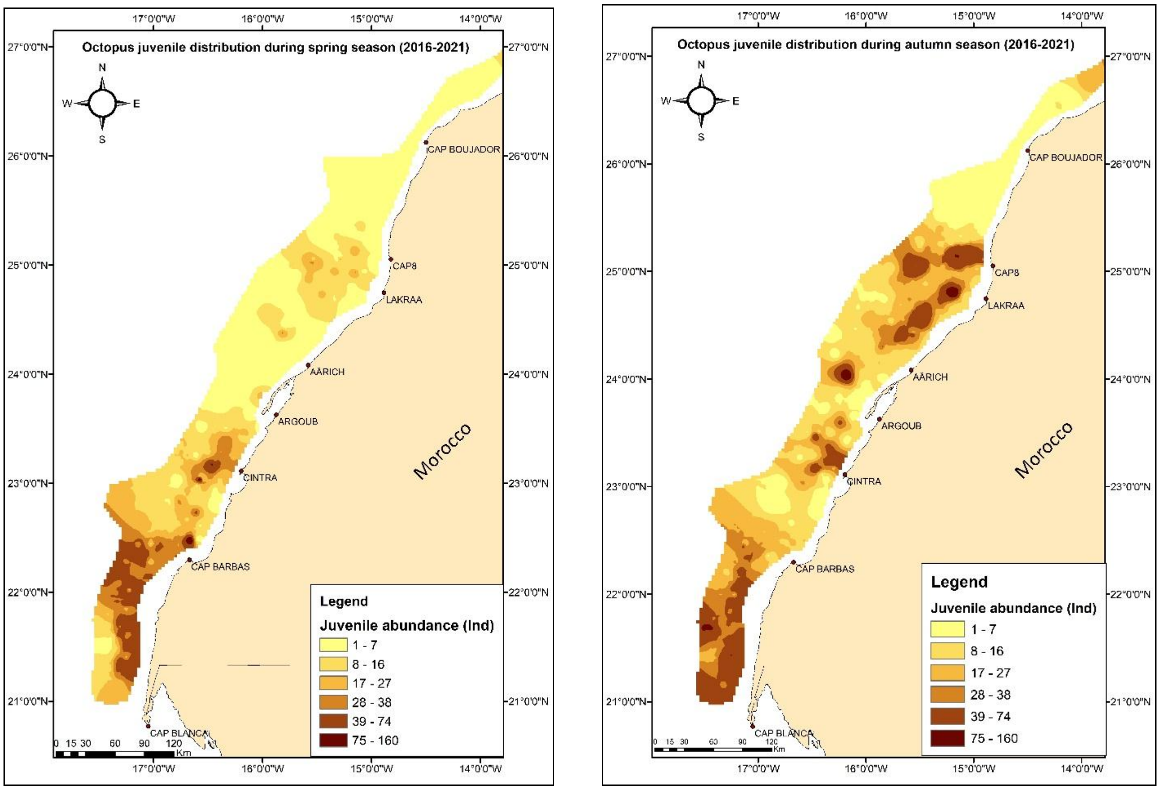

Fig. 3. Juvenile abundance of *Octopus vulgaris* during spring and autumn seasons

3. Relationships between environmental parameters and abundance of octopus juveniles

Regarding the abundance of *O. vulgaris*, the highest mean and maximum values was observed in autumn compared to spring (Tables 1, 2). The common octopus was present at the depth between 18 and 111m (Tables 1, 2). The high abundance of juvenile was located at the depth between 40 and 60m for both seasons.

Table 1. Comparison between environmental parameters during spring season

Spring (2016-2021)	Depth (m)	Juvenile abundance (Ind/30 min)	Sa (psu)	SST (°C)	CHL (mg/m3)
Mean	55.60	18	36.57	19.72	1.96
Min	19.00	1	36.29	18.25	0.22
Max	109.20	174	37.11	22.45	4.72
SD	23.05	25	0.13	0.71	0.96

Table 2. Comparison between environmental parameters during autumn season

Autumn (2016-2021)	Depth (m)	Juvenile abundance (Ind/30 min)	Sa (psu)	SST (°C)	CHL (mg/m3)
Mean	51.42	25	36.53	19.96	1.65
Min	18.00	1	35.88	17.82	0.30
Max	111.20	217	36.99	22.81	5.18
SD	22.36	32	0.23	0.95	1.03

Based on the modeling approach using *mgcv* package, the results showed that the impact of environmental parameters was depending on seasons. The abundance of *O. vulgaris* juveniles was influenced by different environmental factors (Table 3). During the six years of study, CHL and SST had a significant impact on octopus in spring (P<0.05). For autumn season, the CHL and Sa had a significant impact on common octopus (P<0.05) (Table 3).

Table 3. GAMs for the common octopus (*O. vulgaris*) during the study period

Seasons	Variables	edf*	F-test	*P*-value
Spring (2016-2021)	CHL	2.84	4.47	**<0.05**
	Sa	1	0.004	>0.05
	SST	2.28	5.83	**<0.05**
Autumn (2016-2021)	CHL	2.38	6.43	**<0.05**
	Sa	6.81	4.79	**<0.05**
	SST	6.06	1.65	>0.05

*The effective degrees of freedom were estimated from generalized additive models; they were used as a proxy for the degree of non-linearity in stressor-response relationships.

During spring season, the spine plot of sea surface temperature showed a positive relationship with the abundance. The highest abundance of juvenile was associated with SST at around 20.7°C. Nevertheless, the abundance decreased with the increase in temperature (Fig. 4). Concerning the CHL, a positive relationship was detected with the abundance for low CHL concentrations and a negative one for high CHL levels (Fig. 4). According to the maps showing the abundance of octopus juveniles in spring, SST and CHL concentration (Figs. 3, 5), we found that the area of concentration of juveniles (23°-21° N) was influenced by high sea surface temperature and low chlorophyll-a concentration.

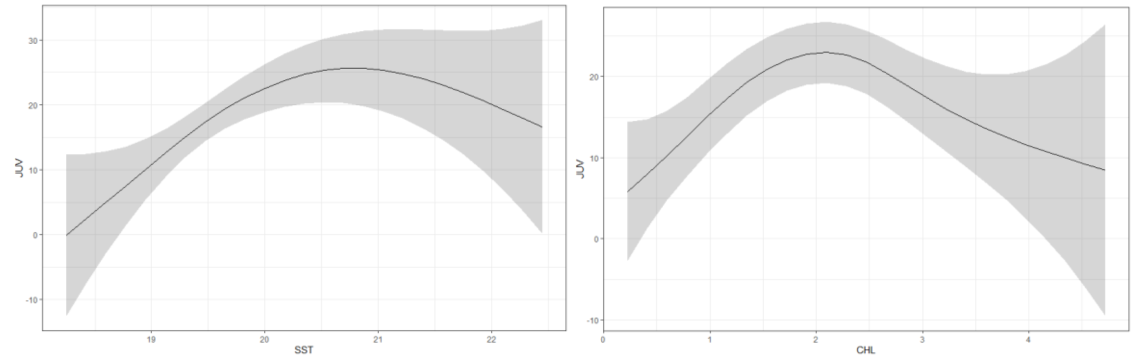

Fig. 4. Effects of significant explanatory variables on the abundance of octopus juveniles during spring seasons, as estimated by generalized additive model (GAM)

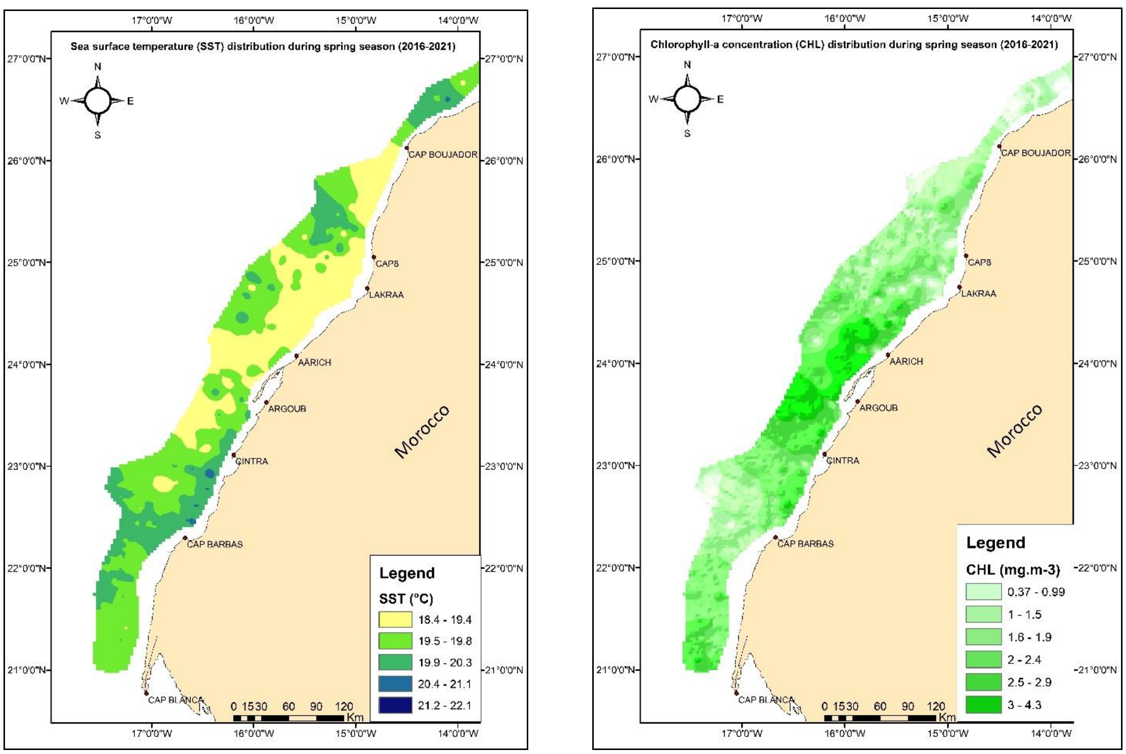

Fig. 5. Maps of distribution of sea surface temperature and chlorophyll-a concentrations during spring season for the period 2016-2021

In autumn, the spine plot of salinity showed a negative relationship with the abundance of octopus. The highest abundances of juveniles were observed in the areas with low Sa (Figs. 3, 6). For the chlorophyll-a concentration, a negative relationship was recorded with the abundance of octopus juveniles for CHL less than 2.5 mg/m^3 and a positive impact for CHL more than that level (Fig. 6). According to the maps showing the abundance of octopus juveniles in autumn and CHL concentration, we found that juveniles in the first area of concentration (25.5°-24° N) was influenced by low chlorophyll-a concentration. However, the juveniles in the second area of concentration

(23°-21° N) was impacted by high level of chlorophyll-a and low salinity concentration (Figs. 3, 7).

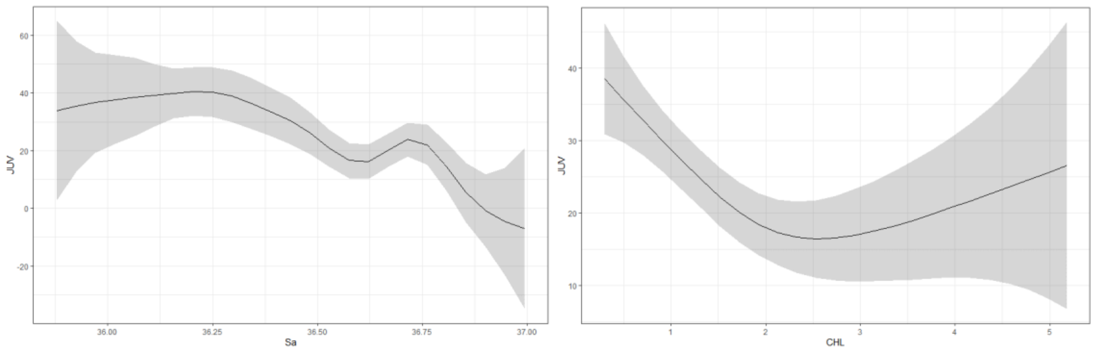

Fig. 6. Effects of significant explanatory variables on the abundance of octopus juveniles during autumn seasons, as estimated by generalized additive model (GAM)

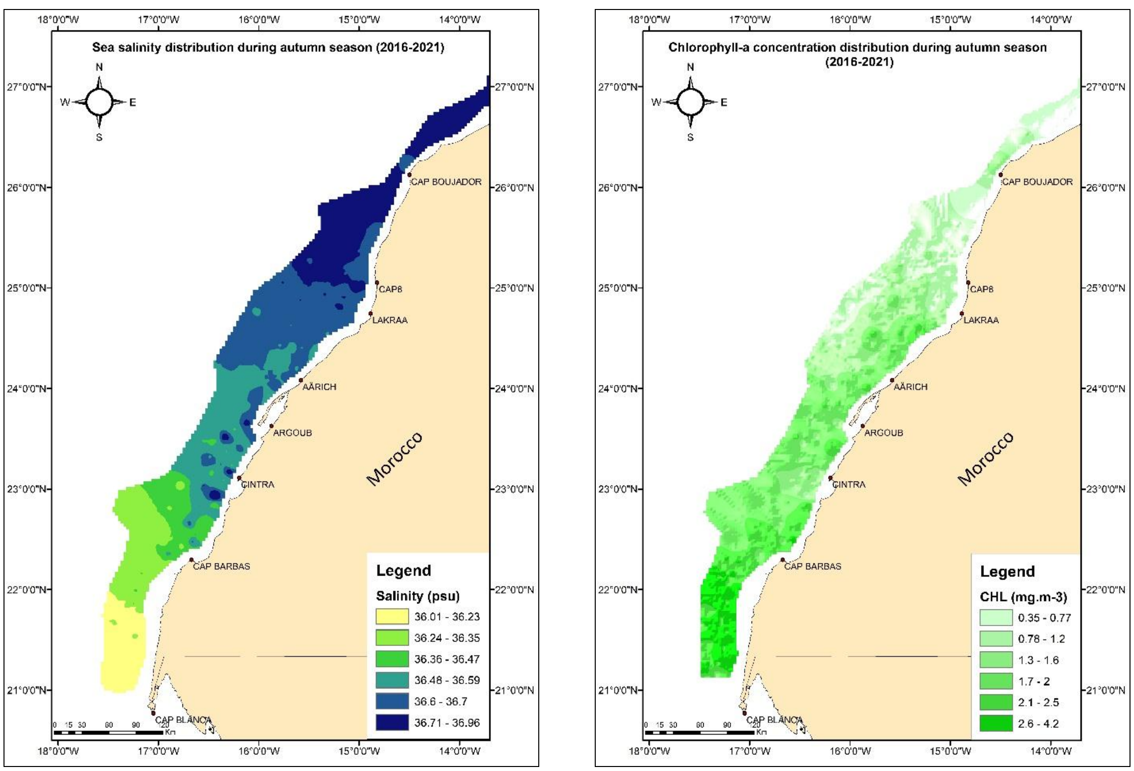

Fig. 7. Maps of distribution of sea salinity and chlorophyll-a concentrations during autumn season for the period 2016-2021

The results presented before show the seasonal variability of the impact of environmental parameters during the six years combined of the study.

To assess the impact of the environment on octopus juveniles during each year separately, Tables (4, 5) present the results of GAMs on each year and season.

Our results showed that, there is a significant difference between years and seasons (Tables 4, 5), the impact of environmental parameters vary from year to year and season to another ($P<0.05$).

In spring, the abundance of juveniles was high in 2020 and 2021, during these years we detected a significant impact of CHL and SST, respectively. For the CHL concentration in 2020, we recorded a high juvenile's abundance for low concentration, which revealed that the area was rich in zooplankton (Fig. 8). In the next year, the impact of SST on octopus abundance in 2021 was positive (Fig. 8).

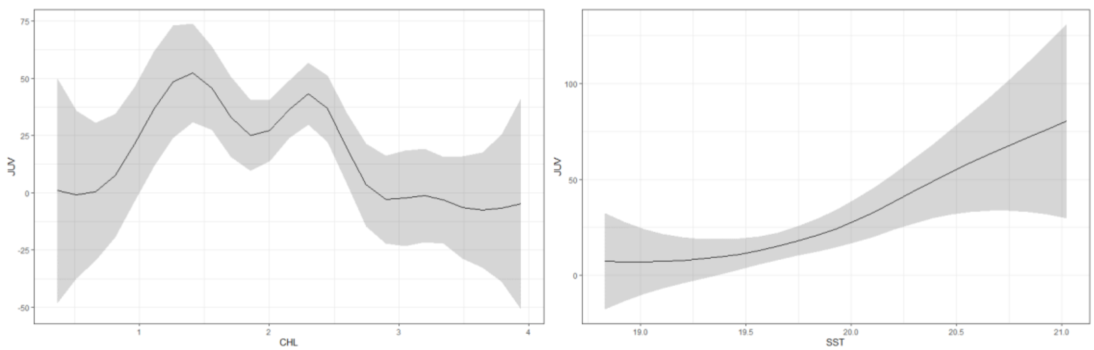

Fig. 8: Effects of CHL and SST on the abundance of octopus juveniles during spring season in 2020 and 2021, respectively

Table 4. Comparison between years for the impact of environmental parameters during spring season

Spring season	Variable	edf	F-test	*P*-value
2016	CHL	1	0.75	>0.05
	Sa	4.29	3.59	**<0.05**
	SST	4.79	4.05	**<0.05**
2017	CHL	1.3	0.81	>0.05
	Sa	1	0.2	>0.05
	SST	1.83	0.87	>0.05
2018	CHL	1	2.13	>0.05
	Sa	1	5.13	**<0.05**
	SST	1.82	1.24	>0.05
2019	CHL	4.98	2.3	>0.05
	Sa	1	0.13	>0.05
	SST	1	0.55	>0.05
2020	CHL	7.77	4.6	**<0.05**
	Sa	3.87	1.77	>0.05
	SST	1	2.85	>0.05
2021	CHL	1	0.4	>0.05
	Sa	2.58	2.06	>0.05
	SST	2.31	3.75	**<0.05**

In autumn, the highest abundance of juveniles was registered in 2021, during this year, a significant impact of CHL, SST and Sa (Table 4) was detected. The CHL and Sa concentrations had a negative relationship with juveniles abundance (Fig. 9). On the other side, SST had a positive impact on octopus juvenile's abundance in this year (Fig. 9).

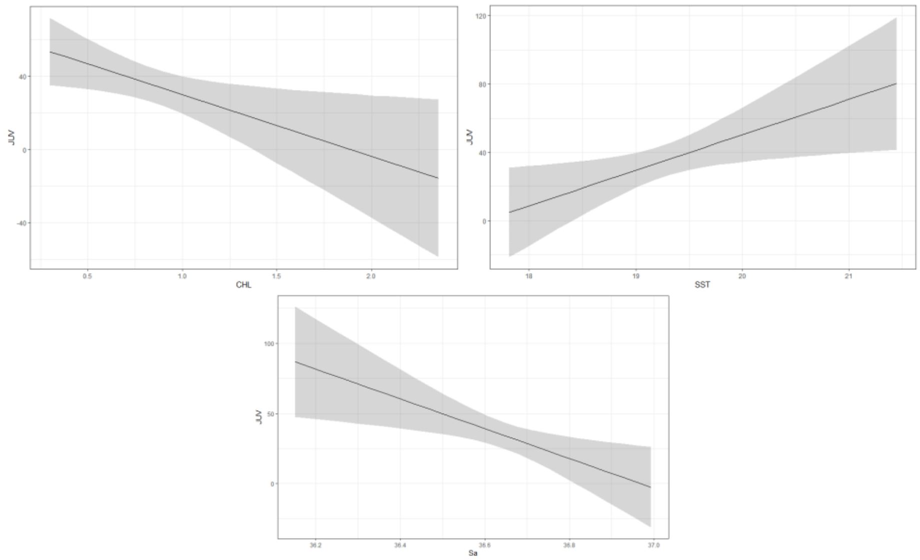

Fig. 9. Effects of CHL, SST and Sa on the abundance of octopus juveniles during autumn season in 2021, respectively

Table 5. Comparison between years for the impact of environmental parameters during autumn season

Autumn season	Variable	edf	F-test	*P*-value
2016	CHL	1	0.62	>0.05
	Sa	1	0.32	>0.05
	SST	1.08	0.41	>0.05
2017	CHL	1	3.31	>0.05
	Sa	1	12.36	**<0.05**
	SST	3.55	1.28	>0.05
2018	CHL	4.41	1.99	>0.05
	Sa	1	9.63	**<0.05**
	SST	2.64	3.88	**<0.05**
2019	CHL	1.41	0.18	>0.05
	Sa	5.58	1.93	>0.05
	SST	5.67	2.75	**<0.05**
2020	CHL	1	1.48	>0.05
	Sa	5.14	6.40	**<0.05**
	SST	2.35	0.62	>0.05
2021	CHL	1	5.54	**<0.05**
	Sa	1	7.18	**<0.05**
	SST	1	5.68	**<0.05**

DISCUSSION

This study represents the first attempt to understand *O. vulgaris* juveniles' habitat preferences and distribution in the Moroccan Atlantic waters using GAMs analysis, which integrate three environmental variables (SST, Sa and CHL). Nowadays, studies have focused on the local abundance and/or fisheries of *O. vulgaris* in relation to some environmental variables, such as SST, CHLA, season, rainfall or depth and the North Atlantic Oscillation (NAO) **(Hernandez-Lopez, 2000; Balguerias *et al*., 2002; Gonzalez & Sanchez, 2002; Sobrino *et al*., 2002; Katsanevakis & Verriopoulos, 2004; Vargas-Yanez *et al*., 2009; Caballero-Alfonso *et al*., 2010)**. Similar studies showed positive relationships between paralarval abundance and SST and upwelling **(Katsanevakis & Verriopoulos, 2006; Moreno *et al*., 2009; Otero *et al*., 2009)**.

It is well known that many cephalopod populations undergo strong year-to-year fluctuations in abundance due to high and variable paralarvae mortality rates during their planktonic stage as a result of environmental factors **(Pierce *et al*., 2010)**. In the case of *O. vulgaris*, it has a short life cycle of about one year, with almost no overlap of generations in the fishing grounds, and thus its abundance is highly dependent on recruitment success **(Sobrino *et al*., 2020)**. The paralarvae stage of octopus has a high mortality rate, possibly determined by the availability of food (zooplankton) **(Sánchez *et al*., 2015)**. Moreover, high mortality rates occur under aquafarming conditions. Feeding octopus paralarvae requires live prey, primarily composed of crustacean zoeae. This is a hurdle in the development of aquaculture for this species **(Iglesias *et al*., 2004, 2006, 2007; Okumura *et al*., 2005)**. All these conditions may suggest that the presence or absence of prey for the paralarvae should be the limiting factor that produces success in paralarvae survival.

The abundance of juveniles was detected in autumn compared to spring seasons, indicating the period of the principal recruitment (autumn) of *Octopus vulgaris.* In 2020, the abundance of juveniles in spring was higher than that recorded in autumn season. That was due to the period of the survey during the autumn, which was realized at the end of the recruitment period of the species (December 2020).

The statistical techniques used to describe the relationships between stock abundance and environmental variables are varied. In our study, we used general linear model (GLM) and generalized additive models (GAM). These techniques were used in the study of **Faure *et al*. (2000)** who analyzed octopus abundance and environmental variables in Mauritanian waters and were implemented in the study of **Sobrino *et al*. (2020)** on the Gulf of Cadiz. While, **Bellido *et al*. (2001)** and **Denis *et al*. (2002)** applied GAMs to squid numbers in the northeast Atlantic.

In the present investigation, we found that the impact of environmental parameters vary by year and season. All parameters had a significant impact on octopus juveniles. Sometimes we found a combined effect of those parameters, and other times we had a separate effect of environmental on the abundance. The results showed that there were three periods with no significant impact of the environment on octopuses' juveniles, in spring 2017, 2019 and autumn 2016. The period when all parameters (CHL, SST, Sa) investigated had a significant impact on the abundance was in autumn 2021, coinciding with the highest abundance of *O. vulgaris* juveniles.

The sea surface temperature (SST) had a positive impact on juveniles' abundance. The highest abundance of juvenile was associated with SST at around 21°C. Previous studies have shown the importance of SST in octopus habitat preferences, distribution and ecology; however, results have shown both positive correlations **(Demarcq & Faure, 2000; Balguerıas *et al*., 2002; Sobrino *et al*., 2002; Vargas-Yanez *et al*., 2009; Caballero-Alfonso *et al*., 2010)** and negative relationships **(Gonzalez and Sanchez, 2002)** with abundance and catch. In this sense, SST can mainly affect octopus paralarvae abundance **(Moreno *et al*., 2009)** in their pelagic zooplanktonic habitat where their survival depends on sea surface temperature and productivity **(Gonzalez *et al*., 2005)**. However, when octopus juveniles leave zooplanktonic habitat to live as adult benthonic species **(Belcari *et al*., 2002; Gonzalez & Sanchez, 2002)**, the importance of SST could be limited.

The level of salinity (Sa) was high in general, it vary between 35.8 and 37 psu, it is not surprising an essential variable to *O. vulgaris*. This cephalopod is known as a species that cannot tolerate low values of salinity **(Vaz-Pires *et al*., 2004)**; indeed, low salinity phenomena can be highly stressful or even fatal to this species **(Chapela *et al*., 2006)**. Therefore, bottom salinity can explain the absence of *O. vulgaris* in low salinity waters, like estuarine environments and Black Sea **(Hermosilla *et al*., 2011)**.

The Chlorophyll concentration seems to be an important variable. CHL are in direct relationship with high productivity areas and food availability, key element to cephalopod abundance, especially for octopus **(Gonzalez *et al*., 2005; Otero *et al*., 2009)**. On the other hand, CHL is not influential to its habitat preferences, which makes sense because a benthic species should not select its (benthonic) habitat according to CHL values **(Hermosilla *et al*., 2011)**.

CONCLUSION

Numerous studies reviewed in this study have underlined the high sensitivity of octopuses to environmental conditions and changes. Clearly, spatiotemporal environmental variations strongly affect the biological processes and characteristics of cephalopods during their short life cycle. To GAM, sea surface temperature is the most relevant variables to the spatial distribution of octopuses' juveniles. In general, when SST increases juveniles abundance increases. Nevertheless, other variables may influence the abundance trends besides temperature. As this analysis progresses, other impacts will be explored.

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