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Effects of environmental factors on the biomass of deep-water rose shrimp in the North of Atlantic Moroccan Ocean

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ABSTRACT

Generalized additive models (GAMs) is used to test the hypothesis that the deep-water rose shrimp, *Parapenaeus longirostris* abundances are related to the bathymetry, spatial location, temperature, salinity, dissolved oxygen and chlorophyll-based variability of the North Atlantic of Morocco. The deep-water rose shrimp, *Parapenaeus longirostris* (Lucas 1846, Decapoda: Penaeidae) is one of the main targeted species of the demersal fishery in the Moroccan Atlantic region. Data are collected during five-year periods (2015, 2018–2021) of seasonal sampling (winter and summer). We used a dataset of six scientific trawl-surveys, and multi-satellite measurements to analyze the relationship between biomass and environmental factors. The results show that temperature plays an important role in the spatial distribution of *P. longirostris*. For salinity, we observed that a high level of salinity had a negative impact on rose shrimp biomass. On the other hand, we found that chlorophyll had a positive effect on the biomass. These environmental factors vary according to years and seasons and it is more significant in summer than in winter.

INTRODUCTION

Fisheries scientists have long investigated changes in the marine ecosystem in relation to environmental changes **(Maravelias *et al*., 2007)**. The effects of environmental factors such as temperature are known to affect the physiology and population dynamics of marine organisms, thus affecting their biomass and spatial distribution **(Perry *et al*., 2005; Harley *et al*., 2006; Colloca *et al*., 2014; Sagarese *et al*., 2014; Masnadi *et al*., 2018)**. Many other environmental variables, such as primary production, chlorophyll and nutrient concentrations, salinity, upwelling, currents and river discharge, have been shown to be influential in the life cycles and dynamics of marine ecosystems **(Rothschild *et al*., 2005; Company *et al*., 2008; Maynou, 2008; Cartes *et al*., 2011; Maynou *et al*., 2011; Masnadi *et al*., 2018)**. Variations in large-scale oceanographic features can cause changes in local environmental conditions, such as physical characteristics and prey availability, which may in turn affect the distribution, survival, stability and resilience of local populations **(Elith and Leathwick, 2009; Manderson *et al*., 2011)**. As fisheries management moves towards an ecosystem-based approach **(Pikitch *et al*., 2004; Dolan *et al*., 2016)**, detailed spatial information on habitats becomes even more important **(Giannoulaki *et al*., 2013; Marzloff *et al*., 2016)**.

In the present study, the hypothesis that the distribution of deep-water rose shrimp is related to the environmental factors variability of the North Atlantic ecosystem is examined. The study area, i.e. the North Atlantic Moroccan coast is located between Cape Spartel (35°47' N) and Sidi-Ifni (29°22' N). It is characterized by an alternation of trawlable bottoms (muddy, sandy and detrital) and hard, non-trawlable substrates (rocky and coralligenous).

The biology and population dynamics of the deep-water rose shrimp have been thoroughly studied **(Benchoucha *et al*., 2008; García-Rodríguez *et al*., 2009; Kapiris *et al*., 2013; Houssa *et al*., 2016; Yalçın and Gurbet, 2016)** and the exploitation status of their stocks has been assessed in the Atlantic and Mediterranean Sea **(INRH, 2017)**. Because the biological cycle of the species shows different characteristics, especially concerning their lifespan and growth rate, the study of the spatiotemporal evolution of its biomass is of valuable interest for understanding the dynamics of deep-water ecosystems **(Company *et al*., 2008; Ligas *et al*., 2011)**.

The deep-water rose shrimp is a fast-growing, short-living species with a thermophilic preference **(Sobrino *et al*., 2005; Colloca *et al*., 2014)** that inhabits the water column layers close to the seabed of muddy bottoms of the shelf break and upper slope. Its bathymetric distribution is between 20 and 700 m, with strong concentrations between 100 m and 400 m **(Heldt, 1938, 1954; Holthuis, 1980; Froglia, 1982; Ardizzone *et al*., 1990; Chaouachi and Ben Hassein, 1998; Benchoucha, 2005; Houssa *et al*., 2016)**. Its distribution area encompasses the Mediterranean Sea and the eastern North Atlantic Ocean **(Ribeiro-Cascalho and Arrobas 1987; Ardizzone *et al*., 1990; Levi *et al*., 1995)**. A large number of fleets target the species, particularly in the eastern Atlantic **(Benchoucha *et al*., 2008)** and Mediterranean **(Politou *et al*., 2008)**, but it is also exploited in the Balearic Islands **(Guijarro *et al*., 2009)** and the Tyrrhenian Sea **(Sbrana *et al*., 2006; Milisenda *et al*., 2017)**. The shrimp fishery, dominated by pink shrimp (*Parapenaeus longirostris*), its stock is fully exploited in Morocco. It has been in an overfished state since 1999. The situation is aggravated by the use of fishing practices that can further damage shrimp populations and their benthic habitats.

Therefore, the objective of the present study is to investigate the effects of latitude, depth, bottom temperature, sea surface temperature, salinity, dissolved oxygen and chlorophyll concentration on the biomass of *P. longirostris* in the northern Moroccan coast using Generalized Additive Model (GAM). In addition, to analyzing the spatiotemporal distributions of the species biomass using GIS programs (ArcMac 10.1 of ESRI).

It was hypothesized that environmental variables, particularly temperature and salinity are playing a significant role in affecting the biomass and spatial distribution of *P. longirostris* in the northern Moroccan Atlantic coast.

MATERIAL AND METHODS

1. Study area

The Atlantic coast of Morocco is nearly 3000 km 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. 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, Parrish *et al*., 1983)**.

The North Atlantic of Morocco is one of the most important fishing areas in the country (Fig. 1). It is characterized by coastal upwelling between Cape Ghir and Cape Cantin (30°-33°N) **(Makaoui *et al*., 2005)**, by a wide continental shelf and by proximity to major outflows of the Sebou and Bouregrag rivers and land-based runoff. All three characteristics are associated with processes for nutrient enrichment **(Caddy and Bakun, 1994)**.

2. Data collection

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) using a stratified random-sampling design within a 1-square-nautical-mile grid. The data was obtained from six trawl surveys (537 sampling stations) covering the periods 2015 and 2018-2021 during winters and summers periods. In the present work, we used the catch per unit of effort (CPUE) in kg per 30 min to estimate the biomass of species.

The effects of abiotic variables on the spatiotemporal variations in the biomass of deep-water rose shrimp were determined using generalized additive models (GAMs) (Hastie and Tibshirani, 1990). Explanatory variables in deep-water rose shrimp biomass models were latitude, depth, Sea Bottom Temperature (BT), Sea Surface Temperature (SST), water Salinity (Sa), Dissolved oxygen (O_2) and Chlorophyll concentration (Chl). Satellite data at a fine spatial scale of 0.083×0.083 degrees for BT, SST (degrees Celsius) and Sa (psu) and at spatial resolution of 0.25x0.25 degrees for Chl (mg.m^{-3}) and O_2 (mmol.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.

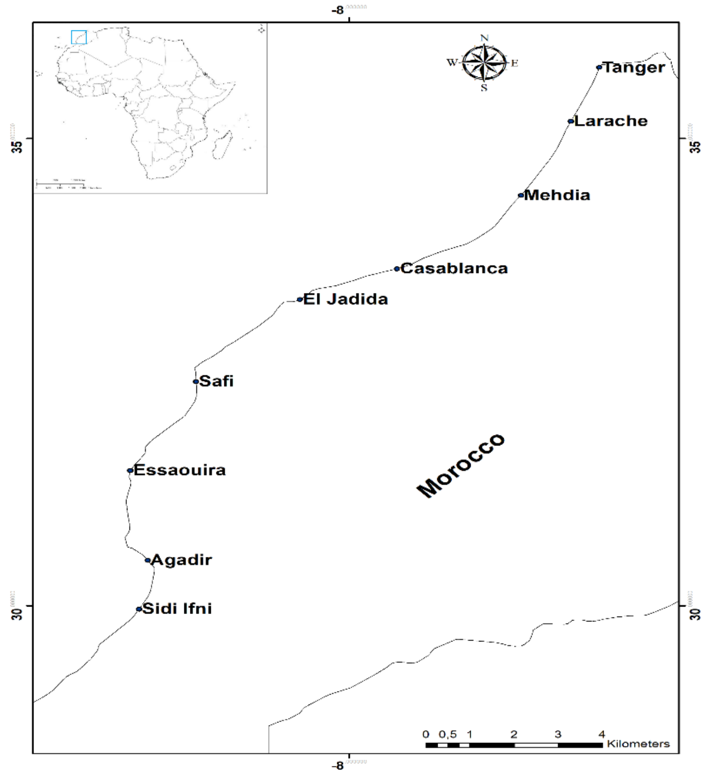

Fig. 1. Studying area, North Atlantic of Morocco

3. Data analysis

GAM models with Gaussian distribution (and identity link) **(Hastie and Tibshirani, 1990; Maravelias and Reid, 1997; Maravelias, 1999)** were used to investigate the relationships of the species with geographical and ocean environmental variables during the study period. Stepwise model selection was used to select a set of significant variables. This process starts with an arbitrary object and takes a step by adding or removing that term from the current model that reduces the Akaike information criterion (AIC) the most **(Hastie and Tibshirani, 1990)**. The AIC statistic accounts simultaneously for the degrees of freedom used and the goodness of the fit ($AIC = D + 2 * df * \varphi$; where D is the deviance, df is the degrees of freedom in the fit and φ is an estimate of the dispersion parameter). The process stops when no step decreases the AIC criterion further **(Chambers and Hastie, 1992; Planque *et al*., 2007)**, indicating the best fitting model. Once the models to be tested were defined, they were compared using Akaike Information Criterion (AIC) and total deviance explained **(Elith and Leathwick, 2009; Colloca *et al*., 2014)**.

Data exploration and analyses were carried out with R version 3.6.3 and the associated *mgcv* package (R Core Team, 2017). An assumed significance level of 5% was used in all the statistical analyses.

RESULTS

1. Spatiotemporal distribution of P. longirostris biomass

The spatiotemporal distribution of *P. longirostris* in the study area shows two concentration areas, the principal zone is situated between North of Larache and South of Mehdia, the second one is located between Essaouira and Agadir bay, except for the year 2020, the area of concentration was limited on the South of Larache and the North of Agadir (Fig. 2). The seasonal distribution of *P. longirostris* shows a clear difference between winter and summer. In winter, the high biomass was between Essaouira and Agadir bay with low concentration in the North of our study area. However, in summer, the high biomass was situated between the North of Larache and South of Mehdia and between Essaouira and Agadir bay (Fig. 3). According to these first results, we suppose that the environmental conditions in summer season are favorable for the migration of *P. longirostris* to the north of the area of its distribution.

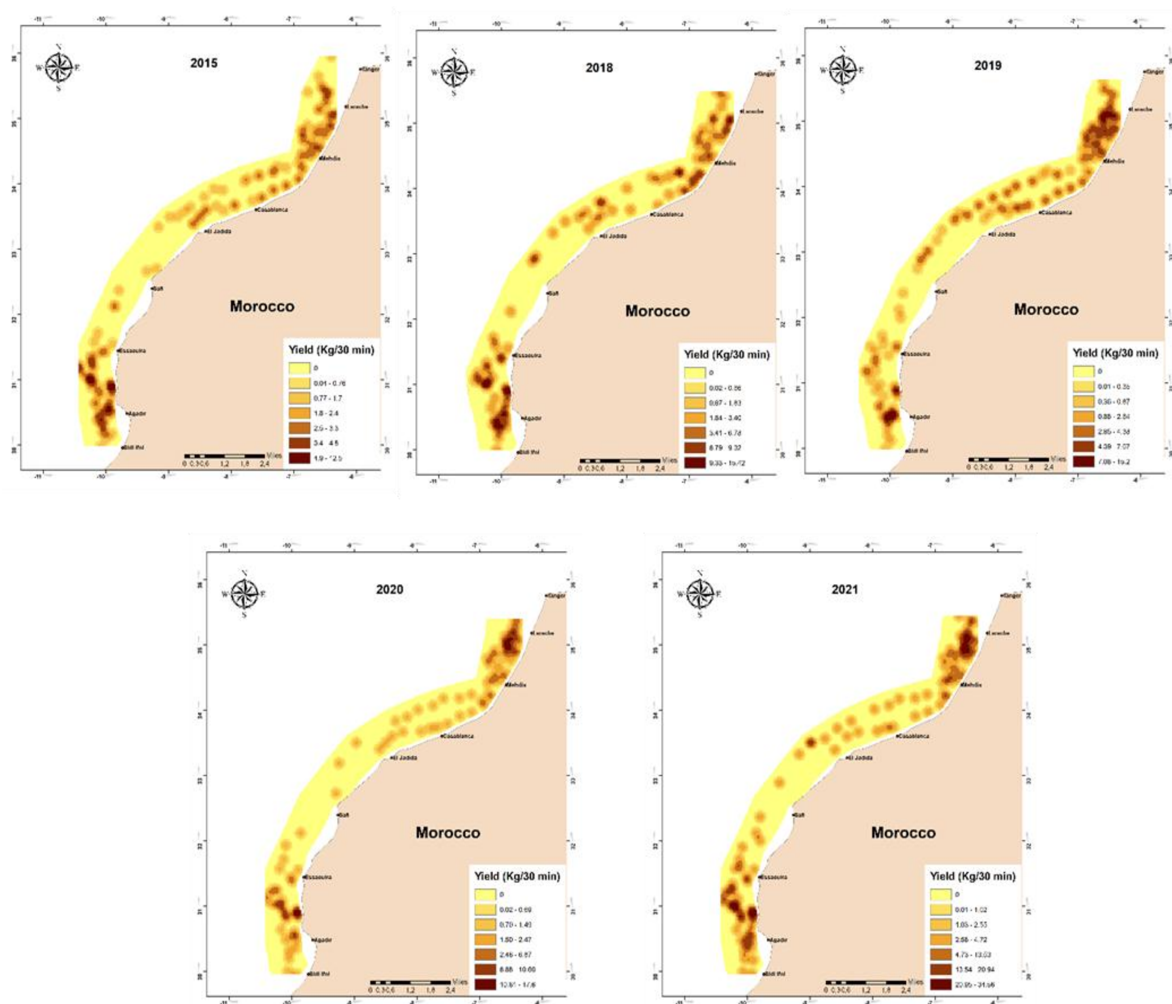

Fig. 2. Maps of deep-water rose shrimp distribution during 2015, 2018-2021

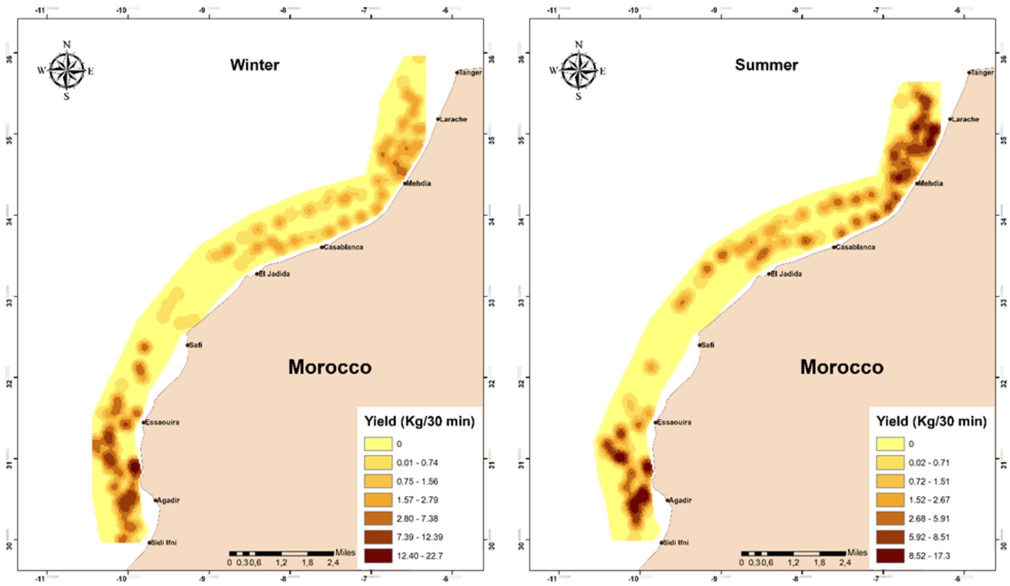

Fig. 3. Maps of distribution of deep-water rose shrimp during winter and summer season

2. Exploratory data analysis

The environmental variables occurred in winter were different from summer season. The difference between years for the same season was significant ($P<0.05$), for that we need to process the data for each year separately for the next analysis.

Regarding the biomass of *P. longirostris*, the highest mean value was observed in winter of 2021 (2.7 Kg/30min), the lowest value was in summer of 2019 (0.6 Kg/30min) (Table 1).

Table 1. Data for environmental variables according to the season/year in the North Atlantic of Morocco during the study period for the deep-water rose shrimp

Environmental variables		Winter 2015	Winter 2019	Winter 2021	Summer 2015	Summer 2018	Summer 2019
Bottom temperature (°C)	Mean	15.44	14.87	14.96	14.68	14.50	14.49
	Max	17.02	17.26	16.57	15.93	16.31	16.72
	Min	11.29	8.70	12.09	10.52	7.53	7.09
Sea surface temperature (°C)	Mean	17.07	17.60	17.39	21.57	20.74	21.67
	Max	17.97	18.53	17.93	24.12	22.86	22.97
	Min	16.26	16.68	16.99	17.99	17.42	18.01
Sea water salinity (psu)	Mean	36.48	36.29	36.26	36.38	36.38	36.73
	Max	36.67	36.52	36.48	36.61	36.64	37.12
	Min	36.19	35.90	35.81	36.23	36.19	36.49
Dissolved Oxygen	Mean	244.46	240.42	182.40	234.43	233.96	230

(mmol.m^{-3})	Max	254.26	242.63	182.95	253.02	242.18	238.97
	Min	239	237.50	180.44	219.86	226.54	225.24
Chlorophyll-a *(*mg.m^{-3}*)*	Mean	0.56	0.43	0.29	0.99	0.26	0.22
	Max	1.06	0.57	0.33	3.76	0.57	0.54
	Min	0.17	0.31	0.23	0.11	0.09	0.10
Depth (m)	Mean	200	214	216	230	207	194.89
	Max	540	524.5	65	504	494	460
	Min	60	60.5	472	65.8	57.8	36
Biomass (Kg/30min)	Mean	1.15	0.96	2.7	1.04	1.76	0.6
	Max	8.56	15.2	22.7	12.5	17.3	5.86
	Min	0.01	0.01	0.01	0.02	0.02	0.01

3. GAMs

Based on the modeling approach, using *glmulti* package for automated model selection and multi-model inference with glm and related functions, the best model, the one with lowest AIC in winter and summer for each year during the study period are shown in Table 2. The results show that the impact of environmental parameters was different depending on years and seasons. Every season, the biomass of *P. longirostris* was influenced by different environmental factors (Table 2).

Table 2. GAMs for deep-water rose shrimp (*P. longirostris*)

Season	**Model**	**AIC**	**Dev. expl. (%)**
Winter 2015	Biomass ~ BT	333.92	2.46
Winter 2019	Biomass ~ Latitude	294.96	5.02
Winter 2021	Biomass ~ Chl	235.12	3.82
Summer 2015	Biomass ~ Depth + Latitude + Chl	246.16	21.7
Summer 2018	Biomass ~ BT + Sa + O_2 + Chl	397.87	26
Summer 2019	Biomass ~ BT + Sa	201.44	19.5

*BT is the effect associated with bottom temperature, Sa is the effect associated with water salinity, O_2 is the effect associated with the dissolved oxygen, Chl is the effect associated with chlorophyll-a. AIC: Akaike Information Criterion; Dev. expl. (%): deviance explained.

To assess the effects of the explanatory variables on the biomass of *P. longirostris*, we examined the fitted contribution of each covariate of the GAMs to biomass of species plotted against the value of the variable. The 95% confidence intervals were also plotted around the best-fitting smooths for the main effects. The rug under the single covariate effects plots shows the density of points for different covariate values (Fig. 4). Fewer points lead to larger standard error bands in the analysis of the data subset. It needs to be emphasized that the effect of each variable is the conditional effect, i.e. the effect that this variable has, given that the other variables are included in the model. The significance values (*P* levels) of GAM covariates are given in Tables 3.

In winter, all parameters had no significant effect on the biomass of *P. longirostris* (*P* > 0.05; Table 3). In summer 2015, 2018 and 2019; Chl, Sa and Chl, BT and Sa respectively had significant effect on the deep-water rose shrimp (*P* < 0.05; Table 3).

Table 3. Summary of the outputs of the best GAM model for deep-water rose shrimp. Explanatory variables included depth, latitude, bottom temperature, salinity, dissolved oxygen and chlorophyll-a; SE, standard error.

Parametric coefficients	Estimate	SE	t value	Significance level
Winter				
Deep-water rose shrimp in winter 2015				
Intercept	5.19	2.66	1.95	*P*>0.05
BT	-0.23	0.18	-1.31	*P*>0.05
Deep-water rose shrimp in winter 2019				
Intercept	-10.46	6.59	-1.59	*P*>0.05
Latitude	0.35	0.20	1.78	*P*>0.05
Deep-water rose shrimp in winter 2021				
Intercept	-5.30	7.64	-0.69	*P*>0.05
Chl	31.81	25.89	1.22	*P*>0.05
Summer				
Deep-water rose shrimp in summer 2015 Intercept	-13.25	9.65	-1.37	*P*>0.05
Latitude	0.43	0.27	1.55	*P*>0.05
Depth	-0.002	0.002	-1.43	*P*>0.05
Chl	1.39	0.43	3.20	***P*<0.05**
Deep-water rose shrimp in summer 2018 Intercept	545.07	210.62	2.59	*P*<0.05
BT	-0.39	0.26	-1.51	*P*>0.05
Sa	-12.60	5.11	-2.46	***P*<0.05**
O_2	-0.35	0.20	-1.73	*P*>0.05
Chl	14.54	7.12	2.04	***P*<0.05**
Deep-water rose shrimp in summer 2019 Intercept	82.51	27.78	2.97	*P*<0.05
BT	-0.30	0.09	-3.49	***P*<0.05**
Sa	-2.10	0.75	-2.82	***P*<0.05**

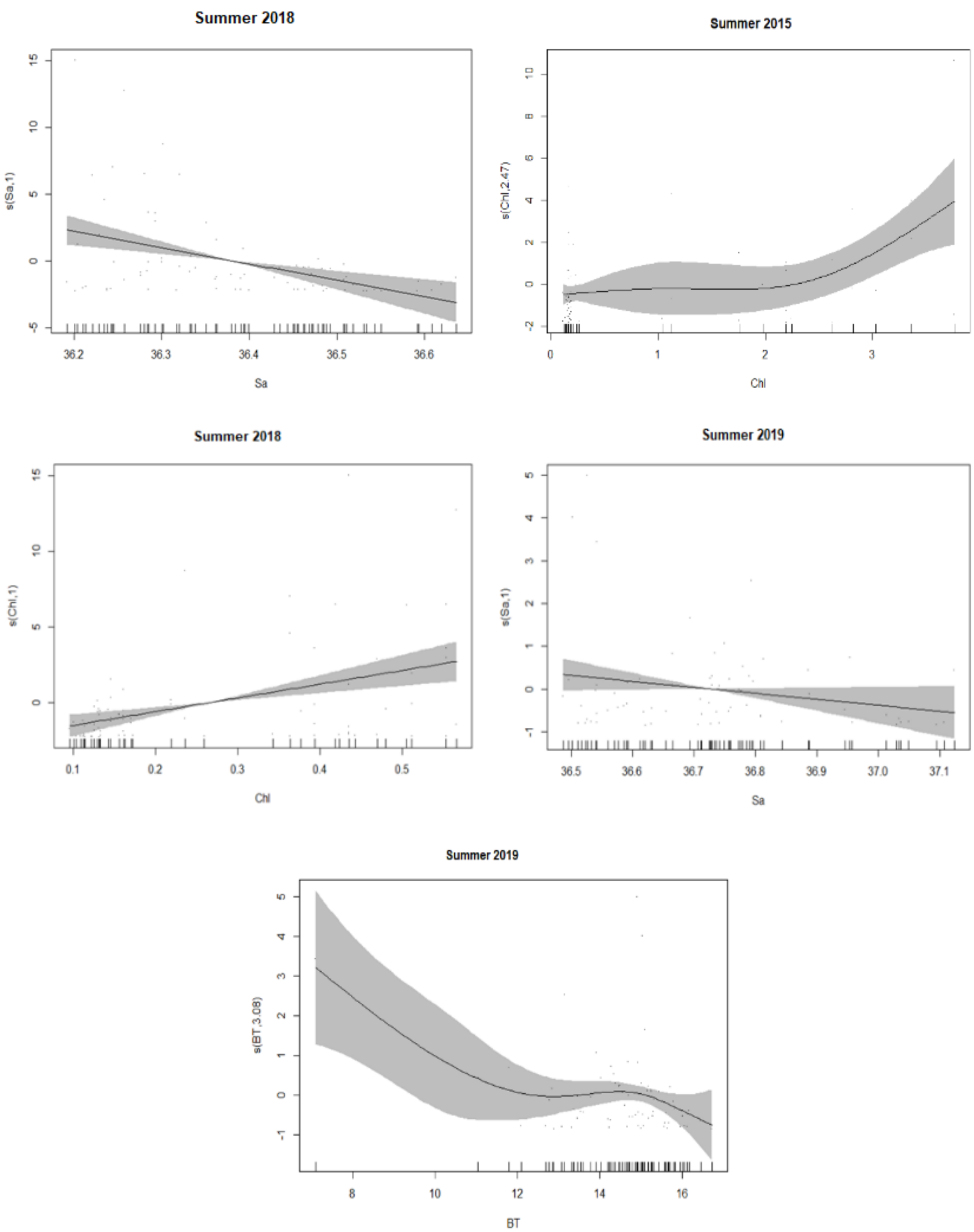

Fig. 4. Effects of significant explanatory variables on the biomass of deep-water rose shrimp during summer seasons, as estimated by generalized additive model (GAM)

The spine plot of Chlorophyll-a shows a positive relationship with the biomass (Summers 2015 and 2018). The water salinity revealed a negative effect on the biomass of *P. longirostris* during summers 2018 and 2019. As regards temperature, the spine plot shows a non-linear relationship between BT and *P. longirostris* biomass. The highest biomass of the species was associated with BTs at around 15°C, after that biomass decrease with increasing temperature (Fig. 4).

DISCUSSION

In the Moroccan Atlantic, the distribution of pink shrimp *Parapenaeus longirostris* is characterized by high level of biomass mainly located between Larache and Mehdia and between Essaouira and Sidi Ifni. The results reported by **Benchoucha *et al*. (2008)** and **Houssa *et al*. (2016)** show that high biomass of *P. longirostris* are located between Moulay Bousselham and Rabat and in Agadir surrounding region. Such distribution of the biomass of the species is probably due to the presence of extended muddy seabed and the increased productivity in this area (summer upwelling) and consequently, the biomass of food. Maximum species biomass is always situated in the Loukkos region (Larache-Kenitra) and Agadir region; this is probably due to the presence of extended muddy seabed and the increased productivity in this area, and consequently, the biomass of food especially in summer season. In Moroccan Atlantic, the distribution of rose shrimp is reported between 20 and 700 m, though the species is more abundant between 70 and 400 m **(Holthuis, 1987)**, with adults mainly observed between 150 and 350 m and juveniles between 100 and 180 m **(Ardizzone *et al*., 1990)**.

This study has focused on the effects of environmental and geographic factors, such as latitude, bottom temperature and salinity on the biomass of deep-water rose shrimp, *Parapenaeus longirostris*, stocks off the northern coasts of Morocco (Tanger – Sidi Ifni). According to **Cook (1997)**, data collected by means of trawl surveys are a more accurate source of information for estimating stock biomass than observations from commercial landing data. In addition, the latter could be biased by the heterogeneous distribution of fishing effort and strategy, the selectivity of the gears, and discarding procedures influenced by market demands **(Fox and Starr, 1996; Quirijns *et al*., 2008)**. Coastal habitats of fish are a combination of environmental factors that explain their distribution, with their presence linked to suitable conditions and density to optimum environmental conditions **(Koubbi *et al*., 2006)**. If the deep-water rose shrimp and abiotic environmental parameters are sampled simultaneously, they can provide information about the relationship between the distribution of fish and these parameters. In addition, it seems that the biomass of some stocks is closely linked to climate change. For example, **Colloca *et al*. (2014)** reported that the stock trend of deep-water rose shrimp in the central Mediterranean Sea did not appear to be driven by fishing effort, since the exploitation pattern has remained the same in the last two decades.

The present study, based on multiannual data obtained by experimental trawling surveys brings useful elements for the management of these marine resources in Morocco. The current results supported the hypothesis that deep-water rose shrimp biomass is related to ocean environmental conditions, to bathymetry and to geographic location. According to the different life cycles and behavioral strategies, our species showed different reactions in relation to changes in environmental factors. Seasonal changes in biomass of deep-water rose shrimp correlated significantly with chlorophyll-a, salinity and bottom temperature in summer and there is no significant effect in winter season. The main mechanisms driving the spatiotemporal dynamics of this species is the increase in water temperature (until 15°C) and chlorophyll-a concentration and the decrease in water salinity.

The highest yields of *Parapenaeus longirostris* are produced mostly between 70 and 400 m. Sandy and muddy sediments constitute the preferential substratum **(Viriato and Figueiredo, 1991; Benchoucha *et al*., 2008)**. The bottom water temperature usually ranges from 12° to 16°C and the salinity in those areas is 35.81-37.12 psu. In the Mediterranean Sea (Portuguese waters), **Sobrino *et al*. (2005)** found that the highest yields are produced during daytime, when the species forms concentrations, mostly between 100 and 300 m. The bottom water temperature usually ranges from 12° to 14°C and the salinity in those areas is 35.6-36.1 psu.

Our result show a significant relationship between bottom temperature and *P. longirostris* in summer 2019, with preferential range of 14-16°C. These results are in agreement with **Ghidalia and Bourgois (1961)** who found a correlation between the biomass of shrimp and the water temperature, suggesting a lower temperature limit of 13.5°C and an optimal temperature between 14 and 15°C. In the Southern Adriatic, the spatial distribution of the deep-water rose shrimp seemed to overlap with the bottom temperature pattern, and a preferential range of 14-15°C was identified **(Ungaro and Gramolini, 2006)**. **Nouar (2001)** hypothesized the same relationship for the Algerian Mediterranean coasts. In Moroccan Atlantic Ocean, **Benchoucha *et al*. (2008)** found that temperature seems to affect the catch levels of *P. longirostris*. Changes in environmental factors and particularly sea temperature, have been shown to play a key role on the temporal and spatial dynamics of the deep-sea living resources in the Mediterranean **(Ungaro and Gramolini, 2006; Company *et al*., 2008; Maynou, 2008; Ligas *et al*., 2011; D'Onghia *et al*., 2012; Colloca *et al*., 2014)**. The analysis of *P. longirostris* biomass and environmental data shows that summer season are characterized by high biomass in the North and South of our study area, on the other hand in winter the biomass of the species are concentrated just in the south of area, these was due to different factors such as the high level of sea surface temperature in the summer season and the summer upwelling which increased productivity and the biomass of food. These parameters appear to control the spatial distribution of *P. longirostris*. The expansion of the autocorrelation ranges with high thermal conditions suggests, instead, the preference of *P. longirostris* for warmer waters **(e.g. Sobrino *et al*., 2005; Abelló *et al*., 2002; Ligas *et al*., 2011)**. Nevertheless, it is important to consider that temperature is not the only environmental driver of the spatial distribution patterns of *P. longirostris*. Other factors such as the interactions between wind and current circulations **(Ligas *et al*., 2011)**, high salinity **(e.g. Benchoucha *et al*., 2008)** or high primary productivity **(Colloca *et al*., 2004)** together with fishery activities **(Abelló *et al*., 2002; Sobrino *et al*., 2005; Ligas *et al*., 2011; Ligas *et al*., 2011; D'Onghia *et al*., 2012)** have been shown to act as significant drivers for the *P. longirostris* populations biomass. However, temperature seems to play a primary role on *P. longirostris* biomass, for example **Colloca *et al*. (2014)** argued that higher temperature favors this species recruitment by improving the survival rates and growth processes. Furthermore, **Cartes *et al*., (2009)** reported that high temperatures can promote, together with both low rainfall and wind strength regimes, the increase of suprabenthos production, which is part of the *P. longirostris* diet **(Sobrino *et al*., 2005)**. In summer 2019, we observed very low mean biomass of *P. longirostris*, using GAM models, we found that BT and Sa had a significant impact in this season, the high level of Salinity was responsible of the decrease of the biomass of *P. longirostris.*

Our study illustrates that, in the North Atlantic of Morocco, the ongoing sea warming open suitable areas in which *P. longirostris* can expand. In a future scenario of increasing SST, we can expect a further expansion of deep-water rose shrimp even in areas where the species is not yet abundant. GAM models adequately described the effects of environmental parameters on *P. longirostris* biomass. This study revealed a high relationship between salinity and biomass of the deep-water rose shrimp. High salinity effect negatively the biomass of *P. longirostris* in the study area, especially in summer season. For chlorophyll concentration, we could expect an opposite effect; positive impact on the biomass was demonstrated in summers 2015 and 2018. However, these general trends may vary at smaller scale, since environmental features may influence species' regional preferences, leading to changes in the general trend. Further analyses are therefore indispensable to understand better the relationships between variations in the biomass of the species and environmental and anthropogenic factors. Additional information on sea-floor topography, sediment composition and hydro-geographical characteristics would be a useful tool for describing further temporal changes in species biomass. In conclusion, the present study provided further support to the importance of taking into account the environmental drivers in future assessment and management of fisheries resources. Under a scenario of rising salinity in the study area, particular attention should be devoted to the management of rose shrimp which shows preference for low salinity, and whose stocks are already overexploited in the North of Morocco.

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