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Modeling spatio-temporal abundance data of the Ionian sea populations of two crustaceans species

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Modeling spatio-temporal abundance data of the Ionian sea populations of two crustaceans species

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Abstract

The relationships between changes in demersal resources (in terms of density, biomass and median length) and anthropogenic and environmental variables (fishing effort, Sea Surface Temperature, precipitations, NAO and MO Indices) in the North-Western Ionian Sea were evaluated. Biological data were collected during ten trawl surveys carried out from 1995 to 2006 in the investigated area. The following commercial species, belonging to the faunistic category of crustaceans, were considered: *Aristaeomorpha foliacea* (Risso, 1816) and *Parapenaeus longirostris* (Lucas, 1846). GAM models were used to evaluated the spatio-temporal changes of deep-water rose shrimp, *Parapenaeus longirostris*. Instead, COstrained Zero-Inflated GAM's (COZIGAM) were applied to the spatio-temporal case study concerning the red shrimp, due to the high proportion of zeros in the data of *Aristaeomorpha foliacea*. The study shows a significance of the spatial variability and of the temporal evolution of the abundance of the

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resources considered. While depth, fishing effort, rainfall and baric indices significantly influence the deep-water rose shrimp distribution, the red shrimp distribution is only influenced by baric indices NAO and MO.

Keywords: *Aristaeomorpha foliacea*, *Parapenaeus longirostris*, Zero-inflated data, COZIGAM, GAM, spatio-temporal models

1 Introduction

It is well known that the abundance of the aquatic population fluctuates over both spatial and temporal scales in relation to the variability of abiotic and biotic factors in the ecosystem as well as to human activities, such as fishing (Cushing, 1982). Most of demersal resources show high fluctuation over time and are considered to be particularly susceptible to overfishing (Relini et al., 1999). Many changes in the environmental conditions (atmospheric, hydrological and ecological) occurred in the Ionian Sea at the end of 1980, due to the phenomenon called 'Eastern Mediterranean Transient' (EMT) that modified the termohaline circulation in the basin. There was a shift in the deep water formation in the eastern basin from its usual sources in the Adriatic Sea to a new source in the Aegean Sea (Klein et al., 1999; Malanotte-Rizzoli et al., 1999; Manca et al., 2002). This regime shift involved sea surface temperature, sea level pressure, surface and deep circulation of water masses, affecting the pelagic community (Conversi et al., 2010). The 1995 was considered the year of maturity of the EMT and after its declining phase, normal hydrological conditions were recovered with flux of warmer and saltier waters from the Levantine basin to the Ionian. The aim of this paper is to evaluate the relationships between the abundance of demersal resources and environmental variables and anthropogenic pressure in the North-Western Ionian Sea from 1995 to 2006.

Two species, *Aristaeomorpha foliacea* (red shrimp) and *Parapenaeus longirostris* (deep-water rose shrimp), were considered due to their commercial importance and for their abundance in the North-Western Ionian Sea. According to Tobar e Sardà (1987) *A. foliacea* has a coastal distribution in the winter-spring and moves more deeply into the summer-autumn period. Many abiotic factors influence the presence of the species in the study area: according to Ghidalia e Bourgois (1961) the species prefers high values of the water temperature (approximately 13.5 ℃) and salinity (38.5 psu) that are typical characteristics of Levantine Intermediate Water (LIW). In addition, the flux of LIW in the Ionian Sea is associated with the North Atlantic Oscillation (NAO) (Grbec et al., 2002). In the Ionian Sea the red shrimp is generally sampled at depths between 127 and 1145 m (Maiorano et al., 2010).

P. longirostris is widespread throughout the whole Mediterranean Region at depths between 18 and 711 m (Maiorano et al., 2010). The latter species prefers typical conditions of continental shelf, like high temperature and salinity (14-15 ℃ and 38 psu, respectively) (Ghidalia e Bourgois, 1961; Ungaro e Gramolini, 2006).

Statistical models used in this work are additive models, that allow to jointly estimate the influence of a number of predictors on the response variable, including spatial and temporal effects. In particular, for the density and biomass indices of the rose shrimp and for the median lengths of the two crustaceans species, Generalized Additive Models (GAM) were used, in which the mean of the response variable is related to the predictors by a link function more general than linear. Because of the high proportion of zeroes for the density and biomass indices of the red shrimp, these variables could not be analyzed by standard statistical distributions; specific models, for zero-inflated data were used, to remark that the probability of having zero values is greater than the one predicted under any distributional assumption. A COnstrained Zero-Inflated GAM (COZIGAM) is obtained assuming that the probability of non-zero inflation and the mean of non-zero-inflated population abundance indices are linearly related.

The structure of this paper is as follows. Section 2 provides a description of the analyzed data and introduces the model formulation of GAMs and COZIGAMs. The results of application is illustrated in Section 3. We conclude in Section 4 with some biological considerations.

2 Materials and Methods

2.1 Data collection

The biological data considered in this work were collected during experimental trawl surveys conducted from 1995 to 2006 in the Ionian Sea as part of the national project GRU.N.D (GRUppo Nazionale Demersali) (Relini, 1998). The study area runs from Capo d'Otranto (Le) (40 06' N - 18 31' E) to Capo Passero (Sr) (36 41' N - 15 10' E) for a total surface of 16.350

km^2 at depths between 10 and 800 m. The sampling design adopted was random-stratified by depth, with proportional allocation of hauls to the area of each depth range and geographical sector. During each experimental haul, a Scanmar Sonar System (Fiorentini et al., 1994) was placed on the trawl net with the aim of measuring the horizontal opening of the net(AoRT). Thus, the abundance data can be standardized to the swept surface unit, according to the following formula (Pauly, 1983):

$$\text{Swept Area} = \text{AoRT} * \text{VT} \tag{1}$$

where AoRT is the horizontal opening of the net, V is the speed boat and T is time of fishing haul. This standardization provides density (N/km^2) and biomass (kg/km^2) indices for each species and haul.

For the two species, *A. foliacea* and *P. longirostris*, density and biomass indices, and carapace length (mm) were considered as population indicators affected by environmental changes. Temperature is one of the primary factors which causes such changes. Sea surface temperature (SST) data were obtained using the AVHRR (Advanced Very High Resolution Radiometer) for the following geographical areas: Gallipoli (LE) (area of Salento), Schiavonea (CS) (North-Calabrian area) e Crotone (South-Calabrian area)[I]. The precipitation values (expressed in mm), often correlated to the NAO apart from local weather conditions, were recorded from meteorological archives on the web for the Salento area, with a monitoring station located in Santa Maria di Leuca [II], and for the Calabrian areas, with rain gauges in Cirò Marina (KR) and Roccella Ionica (RC) [III].

The North Atlantic oscillation (NAO) is a climatic phenomenon in the North Atlantic Ocean consisting in fluctuations in the difference of atmospheric pressure at sea level between the Icelandic low and the Azores high. Since the variations of the NAO influence the weather on a large scale over the North Atlantic and Europe and have a strong impact on the oceanic conditions, including the Mediterranean region, the winter NAO index was considered for its influence to demersal resources. In addition, another barometric index was considered in this study: Mediterranean Oscillation Index (MO). MO is defined as the normalized pressure difference between Algiers and Cairo. Also, the two barometric indices were obtained on the web [IV, V]. The MO index is generally strongly correlated with SST and precipitations and was recently found to be related to fluctuations of the red shrimp abundance (Massutí et al., 2008).

In addition, another environmental variable was considered, that is the depth at which the experimental trawling hauls were made. Though the sampling was conducted at depths between 10 and 800 m, we chose to narrow this range between 500 and 800 m for the red shrimp and between 100 and 500 m for the deep-water rose shrimp, according to the preferential bathymetric distributions of the two species.

Finally, the fishing effort was considered as an anthropogenic influence on these two resources. Due to the difficulty in obtaining detailed information about the number, the power of the fleet over a period of time so extended, fishing effort was evaluated as the number of potential working days according to weather and sea conditions, public holidays, required temporary closures of fishing activities and technical stops (Saturdays and Sundays). This was evaluated for every fisheries and for every year considered in this analysis.

2.2 Data modeling

Density and biomass data were transformed in order to obtain more regular distributions and so that the contribution of the extreme values would result as less influent. For the red shrimp, the logarithmic transformation was used, $log(x+1)$, whereas in the case of the deep-water rose shrimp the fourth root ($\sqrt[4]{x}$) of the density and biomass data was considered. In Fig. 1, it's possible to observe the distribution of the density of the two species. A high proportion of zeroes occurs in the red shrimp data (31% of 318 catches): such zeroes are structural depending on the adaptation of the species to the variable environmental conditions in the Mediterranean basin. For the deep-water rose shrimp, the proportion of zeroes (5% of 228 catches) does not prevent to analyze these data using traditional statistical methodologies.

A general approach to data modeling, for all the biological variables and for both species, consists in assuming that the distribution of the response is affected by a number of predictors.

For the median length, the density and biomass related to *P. longirostris* and for the median length of *A. foliacea*, Generalized Additive Models (GAM) were considered, while for the density and biomass variables related to *A. foliacea*, zero-inflated models were considered. The GAMs represent an extension of Generalized Linear Models (GLM). Particularly, let's assume that the response variable, Y, has some exponential family distribution but with mean μ_i, for the i-th haul, bound to the predictor through a functional form more general than the linear one, that is to say:

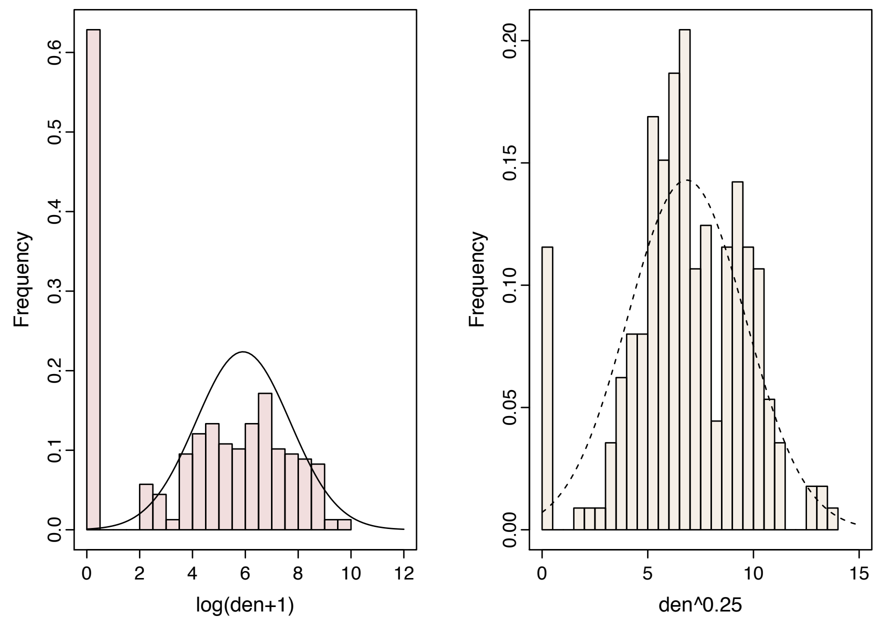

Figure 1: Distributions of trasformed density data with approximation curve. Left panel depicts *A. foliacea*; right panel depicts *P. longirostirs*

$$g(\mu_i) = \beta_0 + \sum_{j=1}^{m} s_j(t_{ij}) = \eta(t_i) \quad \text{for } i = 1, \ldots, n \tag{2}$$

where g is called link function, s_j are semi-parametric smooth functions, t_{ij} is the i-th observation of the j-th covariate and η is the linear predictor. In `R` (R Development Core Team, 2008) it is possible to fit GAMs by means two libraries: `gam` (Hastie and Tibshirani, 1990) and `mgcv` (Wood, 2006). In this study, the second one is used. The smooth functions, s_j, considered in the `mgcv` library are spline functions, with the possibility to specify different features of algorithmic and statistical efficiency, through the choice of the basis. Among the main features there is the automatic selection of the smooth parameters, that is to say of the smoothing degree applicable to every term. In the spline case this is translated as the specification of the number of effective degrees of freedom to assign to every smooth function. GAMs are usually estimated by 'Maximum Penalized Likelihood'; for every smooth function a penalty adds to the sign-switched logarithm of the likelihood function. Parameter estimate is achieved by the minimization of this sum, where the second term penalizes more complex models, thus avoiding over-fitting problems. To check the balance between the two addenda considered, every penalty is multiplied by the degrees of freedom assigned to the corresponding smooth function. For the smoothing parameters estimation, two basic approaches are useful: Generalized Cross Validation (GCV) and Un-Biased Risk Estimator (UBRE) (Wood, 2006).

A generalization of GAMs was considered for the density and biomass of *A. foliacea*. As said above, such distributions point out the presence of a high number of zero values. In the definition 'zero-inflated', the term 'inflated' is used to stress that the probability of getting zero values is higher than the one expected under any distributional assumption. Such data cannot be analyzed by standard statistical distributions (e.g., log-normal, Poisson, etc.) because of the high proportion of zeroes (Zuur et al., 2009). Zero-inflated data abound in ecological studies as well as in other scientific and quantitative fields, where the data contain an excess of zero responses. A wide range of studies have exploited statistical methods to analyze zero inflated data, which include, for example, the count of rare species (Cunningham and Lindenmayer, 2005), and the distribution of fish eggs and larvae (Fox et al., 2000), adult fishes (Bi et al., 2007), as well as pests in agricultural systems (Ruiz-Crdenas et al., 2009). For example, fisheries trawl survey data often contain a large number of zero catches, due to the fact that fishes swim in schools influenced by food availability and irregular current patterns (Ciannelli et al., 2007).

Models for zero-inflated data assume the existence of two data generating processes: one process regarding the zeroes and another one for non-zero values. If we assume that the two processes are independent and that covariates act separately on them, we are talking about Zero-Inflated Generalized Additive Models (ZIGAM). In many cases, the two processes are influenced by common factors and we can presume that they are bound by a proportional constraint. In this case we talk about COnstrained Zero-Inflated Generalized Additive Models (COZIGAM), and such an approach is considered to be more parsimonious and efficient with respect to ZIGAMs. In this study, models for the density and biomass of the red shrimp, assume that:

- the response variable is zero with probability $1 - p$ and follows a log-normal distribution with probability p

- for the i-th observation the expected value $\mu_i = E(Y_i)$ of the response Y is bound to the covariates according to the expression:

$$g(\mu_i) = \beta_0 + s_1(t_{i1}) + \cdots + s_m(t_{im}) = \eta(t_i) \quad \text{for } i = 1, \ldots, n \qquad (3)$$

The COZIGAMs are estimated by means of the method 'Maximum Penalized Likelihood', implemented in the `cozigam` function from the `COZIGAM` package which comes with the statistical software `R` (Liu and Chan, 2010).

3 Results

Tab. 1 shows the results of model fit for the two species considered. The estimates of the constraint parameters α and δ in the COZIGAM specification concern *A. foliacea* density and biomass indices. For both models, δ estimates have significantly positive values showing that the zero inflation probability decreases with the density and biomass values. For brevity reasons, we only report graphs of the smooth effects on the density of both species, due to the pattern of the effects on biomass being quite similar, whereas the effects on the length show opposite behavior when compared to density and biomass effects. As a matter of fact analogous or complementary conclusions can be drawn for biomass and length effects resulting significant in Tab. 1.

In the density and biomass models, for *A. foliacea* and *P. longirostris*, spatial and temporal semi-parametric effects are both significant. The spatial effects on the density of the two species over the study area are represented in Fig. 2. The yellow coloured areas define larger values of species density. In reverse, the warm colours indicate areas characterized by lower density of the two species. For the red shrimp, the higher density values are found in the Salento area and far from the seashore of the Calabria area next to Trebisacce (CS), Crotone, Roccella ionica (RC) and Capo Spartivento (RC) where waters are deeper. For the deep-water rose shrimp, higher densities are found in the Salento aerea and to the south of Taranto. A highest density is shown also between the north and the south of the Calabria aerea and to the south of Roccella Ionica (RC).

The temporal component effect on the density of *A. foliacea* (Fig. 3) is characterized by a peak in year 2002 and smaller values in 1998.

	Aristaeomorpha foliacea			*Parapenaeus longirostris*		
	Density	Biomass	Length	Density	Biomass	Length
Intercept	13.26 ***	7.48 ***	-1113.23 ***	6.83 ***	2 ***	21.07 ***
α	-3.16 **	-1.21				
δ	0.69 **	1.10 *				
lon, lat	14.74 **	11.23 *		11.46 ***	9.69 ***	8.59 ***
year	4.57 ***	4.20 ***	0.57 ***	4 **	6.08 ***	5.77 ***
depth	-0.01 ***	-0.01 ***	1.37 ***	3.23 ***	5.02 ***	2.82 ***
f eff				4.30 **	6.23 ***	
prec				2.80 *		
WNAO	0.19 **		2.24 **	2.68 *		
MO			3.59 ***			-11.80 **

Table 1: Coefficient estimates of the GAMs and COZIGAMs on *A. foliacea* and *P.logirostris* density, biomass and length. Linear effects of intercept and constraint parameters, smooth or linear effects of covariates longitude, latitude, depth, fishing effort, precipitation, WNAO and MO global indices respectively. The grey background indicates smooth effects, represented by respective estimated degrees of freedom. Stars indicate the effect significance: '***', '**' and '*' are respectively 0.1%, 1% and 5% levels of significance

On the other hand, the temporal effects for the *P. longirostris* are higher in years 1995 and 2003. The lowest values are observed between 1998 and 2000 and between 2004 and 2005.

The depth is in inverse ratio to the density for both species: the densities of red shrimp decrease with the increase of depth. The density and depth have linear relationship for the red shrimp (not reported). The effect of the depth on the density of deep-water rose shrimp is shown in Fig. 4: higher values of density are for depths between 200 m e 300 m. Younger individuals are located in a lower intervals of the considered range, whereas older individuals gather beyond 200 m (Ribeiro-Caschalho and Arrobas, 1987). Besides, with a further increase of the depth beyond 300 m, we observe a decrease of the density of the species.

GAMs for *P. longirostris* density and biomass fit a significant effect for the fishing effort. Fig. 4 shows the decrease of the density compared to the increasing fishing effort, with lowest value corresponding to 225 working days per year. For the faunal group of the crustaceans, because of the high vulnerability by trawl, for both the adult individuals and the recruits, a reduction of the activity days of this kind of fishing could really help the reconstruction

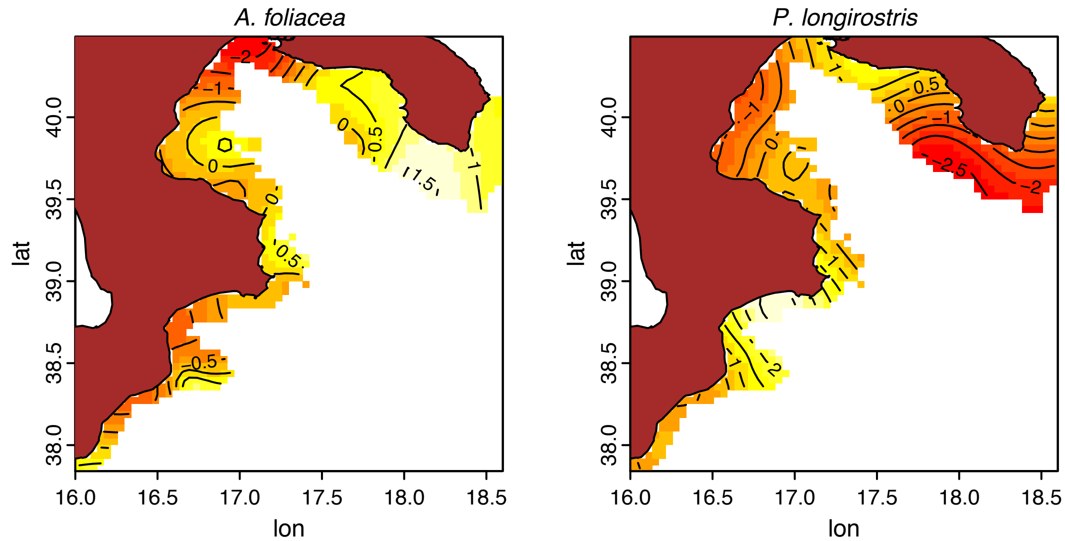

Figure 2: Spatial smooth function components of the fitted COZIGAM (left panel) and GAM (right panel) models of *A. foliacea* and *P. longirostris* density.

of the tapped stocks and, therefore, an increase of the abundance in time.

For the deep-water rose shrimp model, the effects of the environmental variables, precipitations and winter NAO, are significant. The effect of precipitations in Fig. 4, is characterized by a lower value around 100-150 mm of rain.

Instead, the effect of winter NAO effect is higher during the negative phase with a peak around 0. During the negative phase of this index, the south of Europe is characterized by temperatures higher than the average. Furthermore, the winter NAO estimate is significant in the density model related to the red shrimp and is characterized by a linear and increasing behavior, probably due to the establishment of appropriate hydrologic conditions.

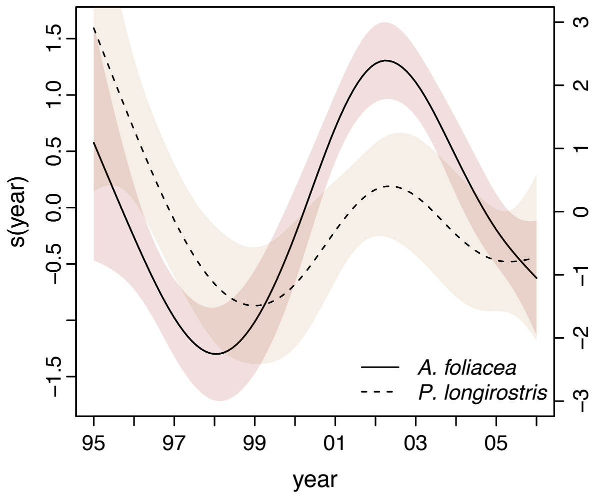

Figure 3: Fitted temporal smooth effects of the density of *A. foliacea* and *P. longirostris*. Colored shading indicates 95% pointwise confidence band.

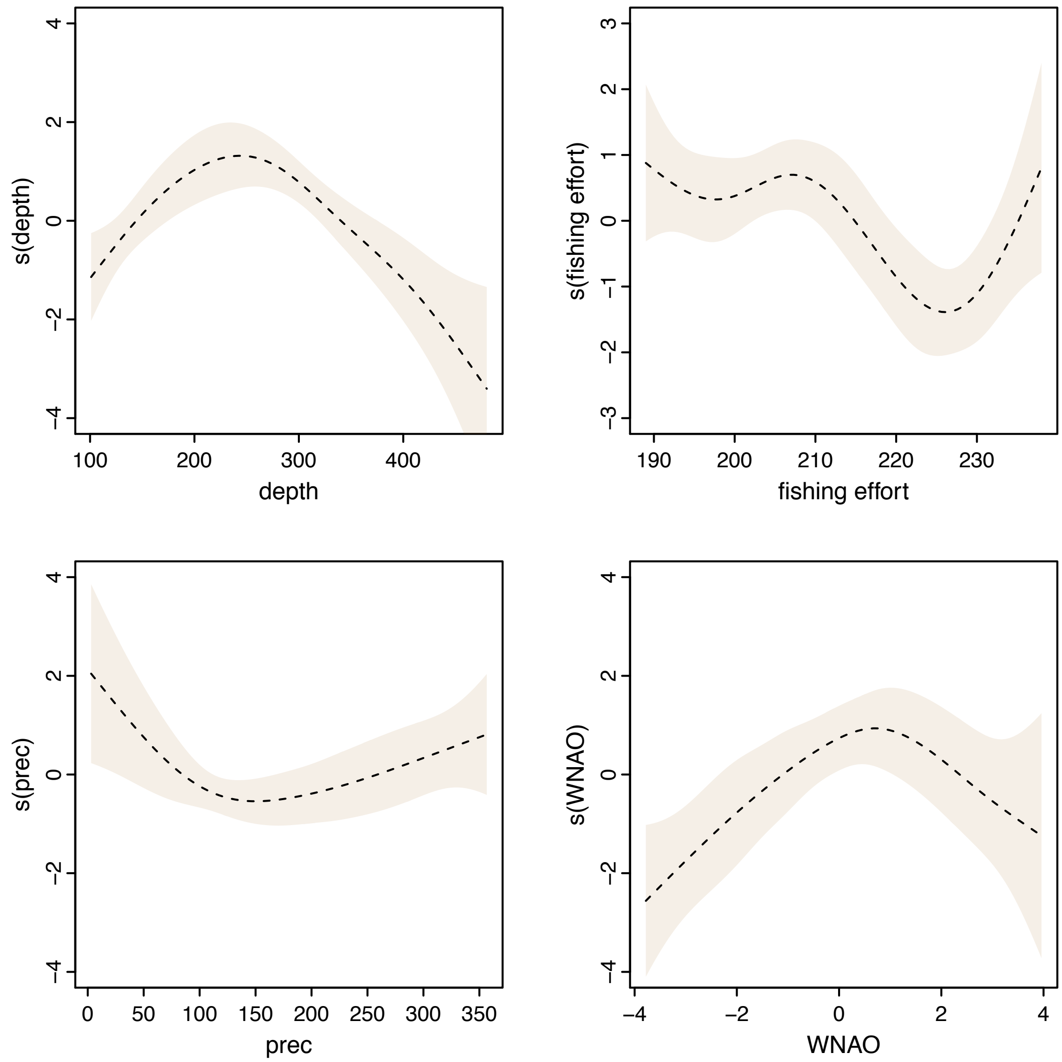

Figure 4: Function estimates of GAM for *P. longirostris* density . From top left to bottom right panels: depth effect; fishing effort effect; precipitation effect; WNAO index effect. Colored shading indicates 95% pointwise confidence band.

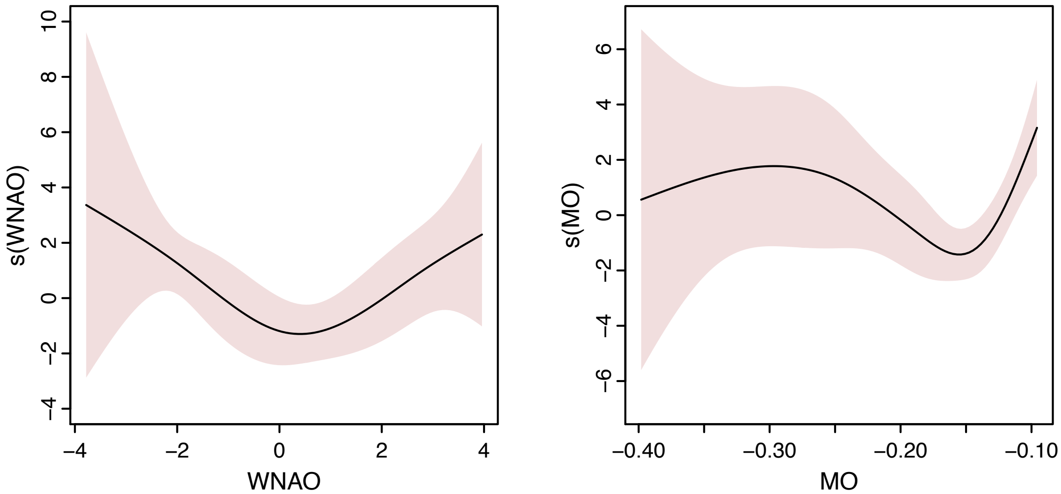

Figure 5: Plots of the smooth functions components of the fitted GAMs for *A. foliacea* median length. The left panel depicts the estimate of WNAO index effect and the right panel displays the estimated MO index effect. Colored shading indicates 95% pointwise confidence band.

The smooth effects of the global indices Winter NAO and MO in the model for the length of *A. foliacea* are significant and they are show in Fig. 5. The first effect has the lowest value around 0, while the MO effect is floating with the lowest value around -0.15 and the highest value around -0.10. In addition, the MO coefficient is significant for the length model of *P. longirostris* with a linear and decreasing effect. The MO index shows a growing trend probably leading to a positive phase, subsequent to known fluctuations. In the proximity of this positive phase an induction of LIW in the Ionian basin could produce typical conditions for the species growth.

Model diagnostics include the examination of the Pearson residuals, obtained by rescaling the raw residuals $\widehat{\epsilon_i} = y_i - \widehat{\mu_i}$ by their estimated standard deviation $\sqrt{V(\widehat{\mu_i})}$. GAMs and COZIGAMs produce very different model diagnostics. While all available data are used for GAMs, only no-zero values are considered to check the validity of COZIGAMs. As a consequence, the validity of the log-normal regression assumption for the positive data is explored using only the non-zero data for the red shrimp density (Liu and Chan, 2010). Fig. 6 shows two model diagnostic plots for the density of the

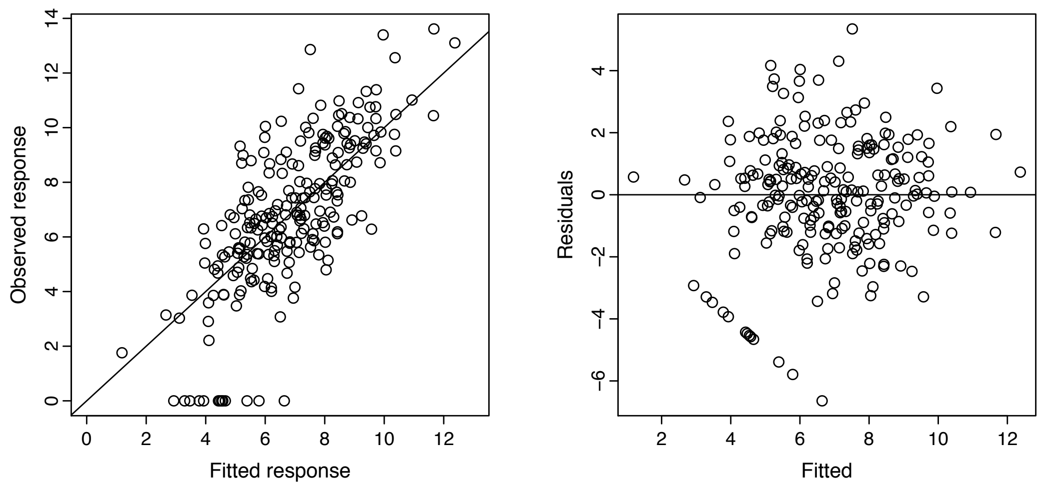

Figure 6: Model Diagnostics based on the GAMs for *P. longirostris* density

deep-water rose shrimp: residuals vs. fitted values plot and observed density (trasformed) vs. fitted values plot. These plots suggest that the model assumptions for the data are generally valid. Similar results were found for the other response variables, biomass index and median length of the deep-water rose shrimp, as well as for the red shrimp, hence these plots are not reported.

4 Conclusions

As reported in the literature the distribution of *A. foliacea* could be linked to the topography of the continental slope (Apulian region) and the presence of submarine canyons (Calabrian coasts) that could lead to an ecological refuge, are rich in nutrients (Cau et al., 1987; D'Onghia et al., 1998; Sardà et al., 2009) and, moreover, are not easily achieved by means of fishing, something would result in a form of protection for the species (Capezzuto et al., 2010). By analyzing the spatial effect on the density of the deep-water rose shrimp, the species seems to be more focused in areas where higher values of SST were recorded. Indeed, according to Abellò et al. (2002) and Ungaro and Gramolini (2006), the species prefers warm waters. The fluctuation over time of the two species could be due to a number of conditions such as the eastern Mediterranean Transient that affected the Ionian Sea at the end of the '80s with changes in the hydrological conditions. From 1995 to 2005 a rise in temperature was recorded, that could contribute to abundance peak of the species that prefer warmer water (Capezzuto et al., 2010). Carlucci et al. (2007) credited the increase of the abundance of *A. foliacea*, reported after 2000, to a success of the recruitment in the area, as well as to the stability achieved by the fishing effort. Much likely, lower values of the density reported around 1998 could depend also on the effect that the transient had on the area in the same period (Manca et al., 2003). According to other authors, instead, the dense water formation, which occurs in the northern Adriatic, and its sinking into the deeper layers of the water column, could have important effects on groundfish populations, with an initial collapse of the resource (due to excessive turbidity of these bodies of water), and subsequent increase of the population 3-5 years later (Company et al., 2008). Because winter NAO and MO indices are associated with a set of environmental variables, these are able to control the climate variation in the Mediterraean Sea. In addition, the fluctuation of barometric indices could translate into higher trophic availability for some species such as shrimps (Maynou et al., 2008). The oscillations of the barometric indices, in addition, are also linked to the flow of Levantine intermediate (LIW) and deep water able to convey nutrients, and to determine the presence of high temperatures and high salinity values (Grbec et al., 2002; Supiĉ et al., 2004). Considering the effect of the fishing effort because of the high vulnerability of the faunistic category of crustaceans to trawling, decrease in the trawl fishing activity could actually facilitate the recovery of the stocks and thus an increase of abundance over time.

The results obtained on the species analyzed and the significance of the various predictors confirm the sensitivity of the category of crustaceans, and in particular of *P. longirostris*, to the changes in environmental conditions and human pressure. In conclusion, the observed effects on the species under study would seem to be related to bottom-up actions (due to changes in environmental conditions) and top-down actions due to anthropogenic pressure (fishing effort).

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I. PO.DAAC Physical Oceanography DAAC Managing Data to Enable Understanding and Stewardship of the Ocean (PO.DAAC): `http://podaac.jpl.nasa.gov/`

II. Meteo e previsioni del tempo: `www.ilmeteo.it`

III. Centro funzionale Meteorologico, Idrografico e Mareografico della Calabria (ARPACAL): `www.cfcalabria.it.`

IV. NESL's Climate & Global Dynamics: `http://www.cgd.ucar.edu/`

V. Climate Research Unit:`http://www.cru.uea.ac.uk/cru/data/moi/`