# Is the deep-water rose shrimp, *Parapenaeus longirostris* (Lucas, 1846), a new fisheries resource in the Catalan continental margin (NW Mediterranean)?


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## Abstract

The deep-water rose shrimp, *Parapenaeus longirostris* (Lucas, 1846), seems to be a resource of increasing importance and may be one of the main targeted fishing crustaceans for the Catalan bottom trawling fleet. Then, this work is focused on the evolution of the landings of the species and its economic revenues for the Catalan coast during the last decade, determining the variables affecting this increasing trend. Official data from Secretaría General de Pesca (Gobierno de España) and Direcció General de Pesca (Generalitat de Catalunya) was used to plot different trends of the species landings and landings per unit of effort (LPUE), as for the evolution of economic contribution. GAM models were used to elucidate the effect of depth, space, and temporal variables on the increasing trends of the species' landings and the LPUE. Results showed that the total revenue from the landings increased during the last decade, as did the LPUE, which spread northwards along the Catalan coast. GAM models showed a significant effect on spatial, temporal, and bathymetric variables on the increasing importance of this species. This study demonstrates that the deep-water rose shrimp is a new fisheries resource from the Catalan continental margin. Therefore, further studies should be developed to avoid the over- or full exploitation of this species on the Catalan coast and implement accurate management plans.

# Index

# 1. Introduction

The Mediterranean Sea is under severe fishing pressure caused by different types of fishing vessels and gears, which have reduced the productivity of commercial stocks and contributed to alter the productivity and functions of the ecosystem (Colloca et al., 2017). This fragile estate has caused an increasing concern about the status of the Mediterranean ecosystem, where fishing pressure is undermining fishing productivity, highlighting the need for a new management strategy aimed at rebuilding overexploited stocks (Colloca et al., 2013; Vasilakopoulos et al., 2014). The already damaged ecological status of the Mediterranean is not improving as other issues are added to overfishing such as climate change (Tzanatos et al., 2014). Both factors combined may be worsening the fishing stocks of commercial Mediterranean exploited species (D'Onghia et al., 2012). However, despite that most Mediterranean fishing stocks exhibit overfishing conditions, some species do not show declining trends either in biomass or in average individual size, such as the deep-water rose shrimp (Ungaro & Gramolini, 2006). In this case, stock renewal might be caused by environmental changes at the ecosystem level, being favored by increases in water temperature (Ungaro & Gramolini, 2006).

The deep-water rose shrimp, *Parapenaeus longirostris*, is a demersal decapod crustacean with a wide geographic distribution in both Mediterranean and Atlantic waters (Sobrino et al., 2005). In detail, it can be found in the Mediterranean and its adjacent seas, in the East Atlantic, from Portugal to Angola, and in the West Atlantic, from Massachusetts to French Guiana (Holthuis, 1980). The species can be found in bottom mud or muddy sand between 20 m and 750 m (Holthuis, 1980; Tom et al., 1988), although its maximum abundance varies between 100 and 400 m depth (Carbonara et al., 1999). In the Mediterranean, most of the information on the deep-water rose shrimp is originated in the eastern and central basins, where the species is more abundant (Abelló et al., 2002). The studies from that area show a growing trend in the abundance of the species in the Tyrrhenian and Ligurian Seas, mainly caused by an increase in water temperature (Colloca et al., 2014; Ligas et al., 2011). Moreover, the great number of landings for some crustacean stocks, including the deep-water rose shrimp, may be determined by a decrease in fish abundances (Cartes et al., 2009) and an increase in trawlers moving from other resources to targeting crustaceans according to their abundance profitability and market conditions, thus crustaceans have an increasing fishing pressure (Colloca et al., 2017).

Landings of the deep-water rose shrimp have been reported since 1980 with a global capture of 26697 t in 2020 (FAO, 2022b). Within Spain, fisheries have a traditional meaning representing a cultural heritage, which is fundamental for the socio-economy of the coastal communities. In detail, according to official landing data from the regional government (Direcció General de Pesca, Generalitat de Catalunya) the Catalan bottom-trawling fishery, which works along 580 km of the northern Mediterranean Spanish coast, had a total revenue of € 55 million and 7854 t landed in 2019 with a multispecies focused catch. The abundance of the targeted species has changed throughout the years thus, the fishing activity and market need to adapt to the availability of the resources. This strategy includes the exploitation of the deep-water rose shrimp, a species that was present in the area, but its abundance was much lower than other commercial crustaceans, such as the Norway lobster (*Nephrops norvegicus*) and the blue and red shrimp (*Aristeus antennatus*) (Abelló et al., 1988). The deep-water rose shrimp increased its presence and abundance on the shelf and upper slope of the Mediterranean Iberian Peninsula becoming an important target species for fisheries (Abelló et al., 2002). Nowadays, the deep-water rose shrimp stocks, favored by the tropicalization of the Mediterranean Sea (Benchoucha et al., 2008; Ungaro & Gramolini, 2006), seem to be increasing in importance and may be one of the main targeted fishing crustaceans for the Catalan bottom trawling fleet.

This work aims to study the importance and evolution of deep-water rose shrimp landings and economic revenues for the Catalan coast while determining the spatial structure of the deep-water rose shrimp and its evolution over the last decade. The analyses of these data will help understand the importance of this crustacean to help sustain the fisheries, enhance the socio-economy of the coastal communities, and set the basis for the management of this resource in the Catalan coast.

## 2. Materials and Methods

### 2.1 Area of study

The trawling fishing fleet from the Catalan coast, as described in the EU Reg. 1967/2006*,* is allowed to fish between 50 and 1000 m depth, five days per week with a maximum of 12 hours per day (Real Decreto 1440/1999). There is an obligation to land all catches daily at the vessel's base port. In shallow areas, such as the Ebre delta, trawling is prohibited at less than 3 nautical miles off the coast despite the possibility to be fishing above 50 m depth. Therefore, the area of study comprises a wider range of depths, between 0 and 1300 m, to ensure the analysis of all the data generated by the trawl fishing fleet (Fig. 1).

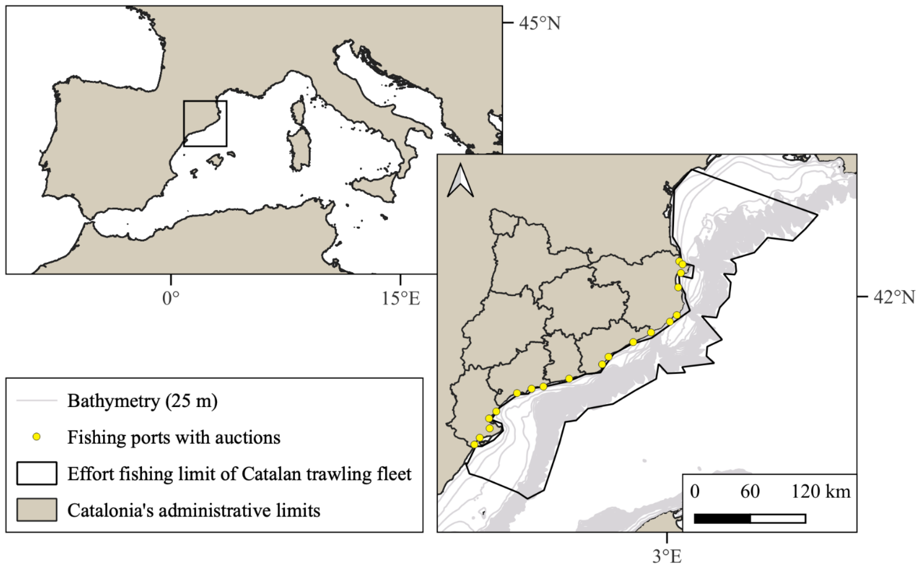


Figure 1. Map indicating the area of study including the effort fishing limit of the Catalan trawling fleet. Yellow dots indicate fishing ports with auctions. Bathymetry is shown in 25 m depth intervals.

## 2.2Dataset

The Catalan coast has 30 base ports, 19 of them with auctions (Fig. 1), which conduct a daily register for each vessel with landings grouped by species. These landings are sold fresh daily at the auction by the local fishers' guilds setting the economic value of the landed species. All data are registered in the database of the regional administration. ICATMAR, a cooperative association between *Direcció General de Pesca i Afers Marítims* and *Institut de Ciències del Mar (ICM-CSIC)*, processes this data and uses it to give scientific advice to the administration on fisheries management. This information is used to create a landings dataset with an identifying track code, unique for each fishing trip (day and vessel).

The target species for this study is the deep-water rose shrimp, *Parapenaeus longirostris* (Lucas, 1846). To assess the landings distribution of the species in the Catalan coast, information on georeferenced landings data and fishing time was needed. For this purpose, Vessel Monitoring System (VMS) data was analyzed together with the landings dataset. VMS is a satellite-based monitoring system that provides data at regular intervals, at least once every two hours, specifying the location, course, and speed of each vessel (Sala-Coromina et al., 2021). This system started to be mandatory in 2006 for vessels longer than 15 m in length and later, the system included vessels longer than 12 m. VMS transfers data to a satellite, which sends it to a receiving station on land, from where the information is transmitted to the corresponding administration (Secretaría General de Pesca, Gobierno de España) to be used for fishing activities control.

For data processing, the same protocol described in Sala-Coromina et al. (2021) was applied. *VMSbase* R package (Russo et al., 2014) was used to remove duplicate registers and points on land. Then, the point frequency was increased by interpolating points at 10 min resolution and, ping series corresponding to the same vessel tracks were identified with a unique track code, unique for each fishing trip (day and vessel). The result data was introduced in a PostgreSQL-PostGIS database for further treatment. Since there is no distinction between vessels fishing or inactive, we applied a speed filter to VMS data between 1.5 and 5 knots that included the speed range for trawling while excluding the steaming and inactive moments, and a depth filter to discard erroneous points out of the fishing zones. Then, the total fishing time (hours) was calculated for each filtered track.

The fishing VMS positions dataset was combined with the landings dataset through shared track codes. In this way, total fishing time, landings, and revenues by species were distributed equally among all fishing positions by day and vessel.

## 2.3 Deep-water rose shrimp trends

Once the final dataset was obtained, as explained above, some trends of the species were examined to understand the importance of the resource in the area. These trends included landings in weight and in euros, landings distribution, and Landings Per Unit Effort (LPUE).

To study the landings of the deep-water rose shrimp between 2009 and 2020 in weight, the yearly total biomass of the species' landings (kg) and the percentage of these landings regarding total trawling fleet landings (%) were plotted. Similarly, the revenue of these landings was plotted with the total revenue of the species' landings (€) and the percentage of these landings regarding total trawling fleet landings (%) obtained in all Catalan auctions.

The landings distribution was studied by the annual aggregation of the dataset variables (weight, money, latitude, longitude, and month) in a 1 $km^2$ grid. With these data, the distribution of the species' landings was mapped between 2009 and 2020 in the Catalan coast.

The LPUE (kg $h^{-1}$) was calculated using landings (kg) and fishing time (h), as a unit of effort. Then, the evolution of the deep-water rose shrimp landings between 2009 and 2020 was mapped with the LPUE. The calculation and analysis of the LPUE are relevant because this parameter may be used as a proxy for the real abundance of the species.

The maps were elaborated with QGIS software (QGIS Development Team, 2022) and the plots were done with *ggplot2* package (Wickham, 2016) from R Studio (R Core Team, 2022).

## 2.4 Statistical analysis (GAM models)

The effect of spatial, temporal, and depth variation in the LPUE of the deep-water rose shrimp was determined using generalized additive models (GAMs) (Hastie & Tibshirani, 1990) with Gaussian distribution and identity link. GAM modeling was applied with *mgcv* package (Wood, 2017) from R Studio (R Core Team, 2022) using *bam* function (Wood et al., 2015), which is used to apply GAMs with very large datasets. The analysis was performed using data variables aggregated annually in a 5 $km^2$ grid. The bathymetric data used in the models were obtained from the GEBCO (General Bathymetric Chart of the Oceans) portal. The response variable was LPUE which was modeled as log (LPUE+1) to approximate it to a normal distribution. Latitude and longitude, depth, and year were used as explanatory variables.

Three different models were tested to find the best GAM to fit the data. The first model included a smooth term for spatial interaction; in the second model a smooth term for depth was added; and in the third one, year was included as a categorical variable. These general models were compared using the Akaike Information Criterion (AIC) and deviance explained. The model with the lowest AIC and highest deviance explained was selected as the best one to fit the data.

Annual models were used to explore the evolution of the resource along with its depth distribution throughout the years. These models included a smooth term accounting for spatial (latitude and longitude) interaction and another one for depth.

All the resulting model plots were produced using R Studio (R Core Team, 2022).

# 3. Results

## 3.1 Importance of the resource and economic contribution

The evolution of the deep-water rose shrimp total weight landed (kg) between 2009 and 2020 and the yearly percentage of these landings (% kg) are shown in Figure 2. As observed, both landings and their percentage increased throughout the years. When landings peaked in 2020, with 350000 kg, its percentage considering all trawling fleet landings was approximately 5.5%. Then, despite that the landings of this species are rapidly increasing, the resource only represents a small percentage of the total landings of the Catalan trawling fleet.

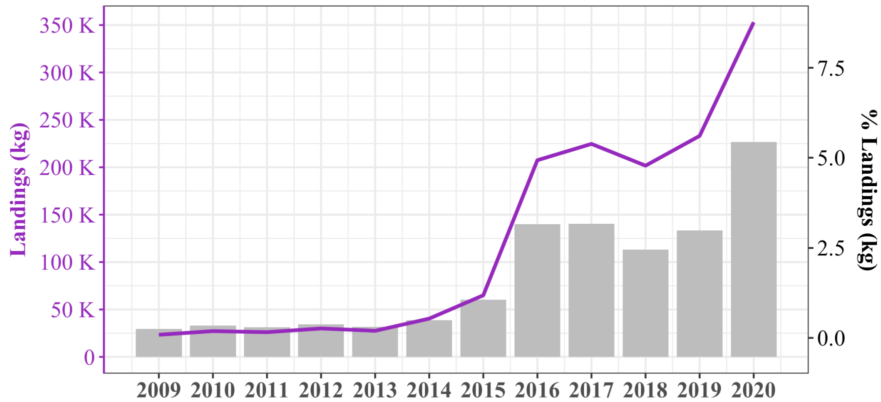


Figure 2. Evolution of landings in total biomass (kg) and percentage (%) of the deep-water rose shrimp between 2009 and 2020. The percentage is the fraction of the species landings divided by total landings from the trawling fleet. Landings are represented with a purple line; percentage is represented with grey bars.

The same kind of figure has been used to represent the evolution of the economic value (€) of the deep-water rose shrimp landings. In Figure 3, an economic (€) increase can be appreciated from 2015 onwards. In 2009, the total revenue barely reached 0.2 M€, whereas in 2020, this value was almost 4 M€. This growth was also observed in the yearly percentage: between 2009 and 2015, incomes from the species' landings were less than 2%. However, in 2020, they reached about 8% of the total amount obtained with the Catalan trawling fleet.

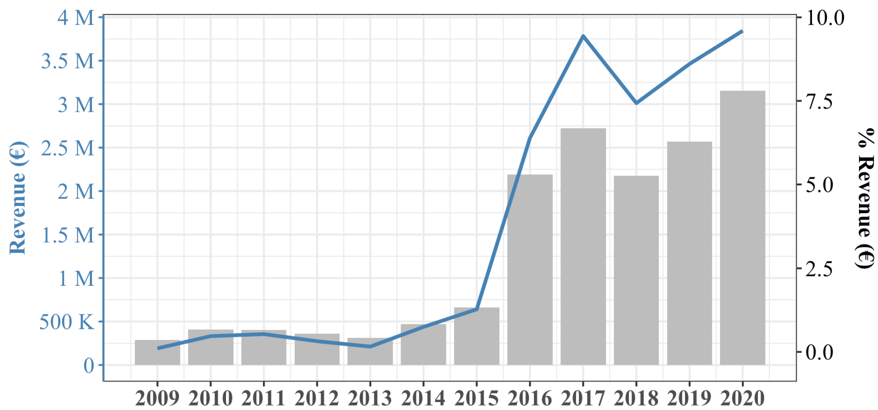


Figure 3. Evolution of the deep-water rose shrimp landings' revenue (€) between 2009 and 2020 along with percentage of money (% €). The percentage is the fraction of the species revenue divided by total revenue from the trawling fleet. The yearly revenue is represented with a blue line and its percentage is represented with grey bars.

## 3.2 Mapping

The maps show the presence and number of landings of the deep-water rose shrimp throughout the years (Fig. 4). In 2009 a few landings were located in the south of the Catalan coast. Later on, in 2013, landings started to spread along the coast, with values under 10 kg $km^{-2}$. It was not until 2016 that the resource clearly gained importance and the values reported for landings were as high as 250 kg $km^{-2}$ at some points of the coast. Landings in 2020 reached a maximum value of 452.4 kg $km^{-2}$. Thus, the maps show the increasing value of landings through time and the spread of the resource from south to north as time goes by.

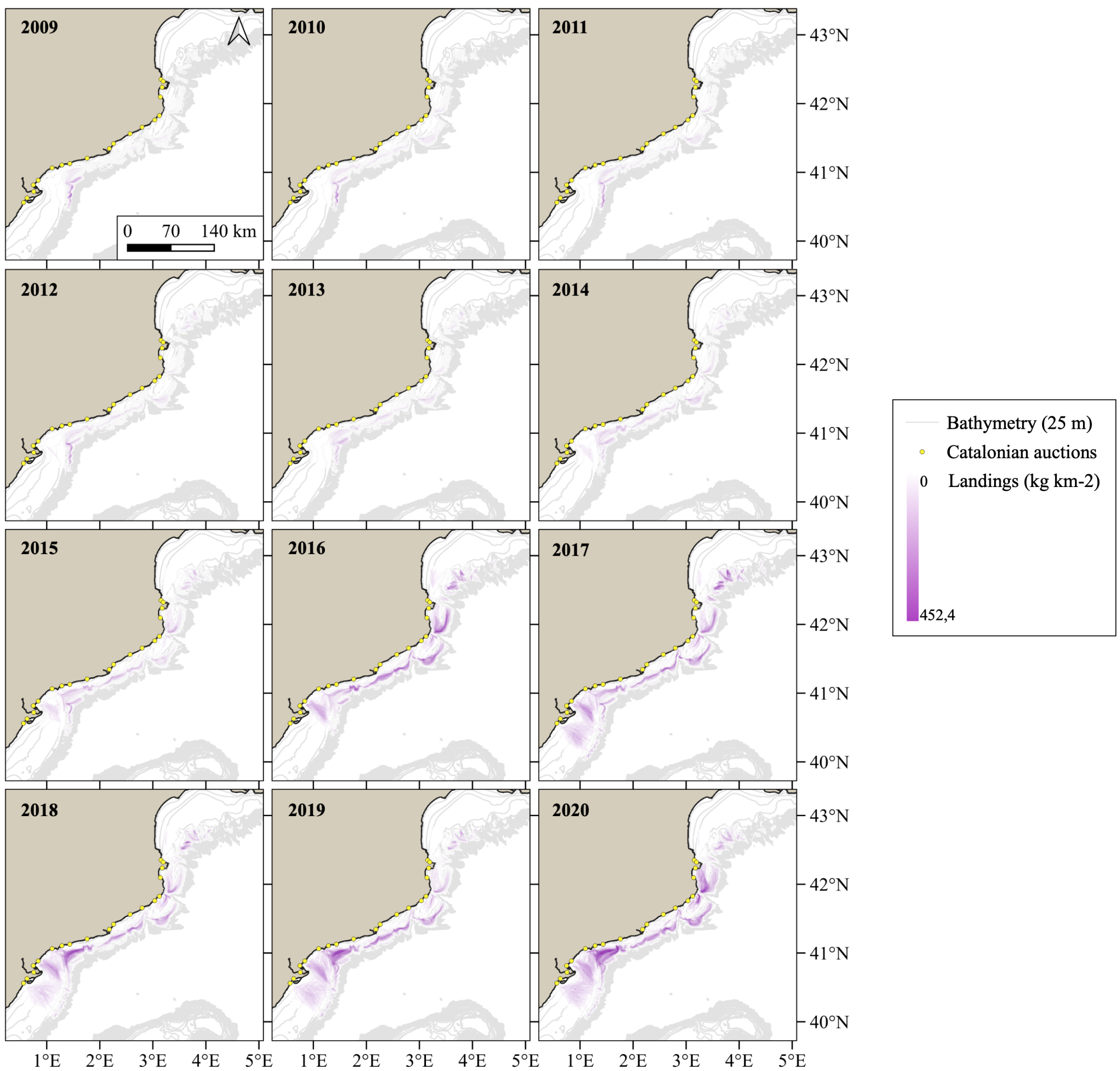


Figure 4. Evolution of the deep-water rose shrimp landings (kg $km^2$) between 2009 and 2020. Landings are represented in purple. Catalan auctions are represented in yellow dots. Bathymetry is shown in 25 m depth intervals.

## 3.3 Landings and LPUE

The evolution of landings (kg) of the deep-water rose shrimp and LPUE (kg $h^{-1}$) between 2009 and 2020 is shown in Figure 5. This figure shows the similar tendency obtained when plotting landings and LPUE together. That is, between 2009 and 2015 the values remained low but in 2015 they started to raise. In 2020, both landings and LPUE reached a peak (350000 kg and 1.25 kg $h^{-1}$, respectively).

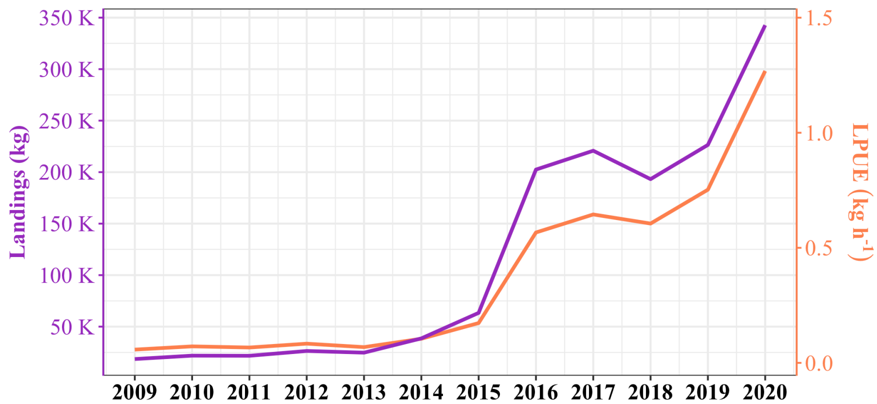


Figure 5. Evolution of the deep-water rose shrimp landings (kg) and LPUE (kg $h^{-1}$) between 2009 and 2020. Landings are represented in purple, while LPUE are represented in orange.

## 3.4 GAM models

The three scenarios selected to evaluate the best GAM are shown in table 1. The third model is the best that fits the data because the deviance explained is the highest (more than 50%) and the AIC has the lowest value of the three scenarios. It can be observed that as variables are added, the deviance explained gets higher and the AIC is lower.

Table 1. GAM results for the LPUE (kg $h^{-1}$) of the deep-water rose shrimp. s(X, Y) is the smooth term for spatial interaction, s(depth) is the smooth term for depth; as.factor(year) is the categorization of the year variable. AIC is the Akaike Information Criterion and Dev. expl. (%) is the deviance explained. The best model is in bold writing.

| Model | AIC | Dev. expl. (%) |
|---|---|---|
| log((kg_DPS/Ftime)+1) ~ s(X, Y) | 9734.6 | 16.3 % |
| log((kg_DPS/Ftime)+1) ~ s(X, Y) + s(depth) | 8620.7 | 25.5 % |
| **log((kg_DPS/Ftime)+1) ~ s(X, Y) + s(depth) + as.factor(year)** | **4604.0** | **51.0 %** |

The outputs for the best GAM model are shown in table 2. As reported, all the response variables had high significant levels, except for years 2010 and 2011, which were not significantly different from 2009 (the intercept), either in depth or space. The variables depth and spatial variation are plotted separately in Figures 6 and 7, respectively, to understand their importance within the fishing resource studied. Regarding the variable depth, the LPUE followed a distribution trend with its maximums between approximately 180 and 400 m depth, with more uncertainty as the LPUE decreased with increasing depths (Fig. 6). It is important to emphasize that there is scarcely fishing activity from 1000 m on (Real Decreto 1440/1999), resulting in less available data and more uncertainty at these depths. When plotting the spatial variable, high LPUE values were located in the northern and southern areas of the studied coast, as shown in Figure 7.

Table 2. Summary of the outputs of the best GAM model for the LPUE (kg $h^{-1}$) of the deep-water rose shrimp. Explanatory variables include year as a category, spatial interaction (X, Y), and depth. SE is the standard error, edf is estimated degrees of freedom, and df is degrees of freedom. "***" indicates significance between 0 and 0.001, "**" indicates significance < 0.001, and " " indicates no significance.

| **Parametric coefficients:** | **Estimate** | **SE** | **t value** | **Significance level** |
|---|---|---|---|---|
| Intercept | 0.0685 | 0.0107 | 6.39 | *** |
| 2010 | 0.0222 | 0.0151 | 1.47 | p = 0.14 |
| 2011 | 0.0091 | 0.0152 | 598.00 | p = 0.55 |
| 2012 | 0.0445 | 0.0151 | 2.95 | ** |
| 2013 | 0.0412 | 0.0152 | 2.72 | ** |
| 2014 | 0.0723 | 0.0152 | 4.75 | *** |
| 2015 | 0.1278 | 0.0151 | 8.38 | *** |
| 2016 | 0.4376 | 0.0152 | 28.71 | *** |
| 2017 | 0.4654 | 0.0152 | 30.59 | *** |
| 2018 | 0.3971 | 0.0153 | 25.99 | *** |
| 2019 | 0.4139 | 0.0153 | 26.97 | *** |
| 2020 | 0.6558 | 0.0154 | 42.55 | *** |
| **Smooth terms:** | **edf** | **df** | **F** | |
| X, Y | 28.4780 | 28.9800 | 60.37 | *** |
| Depth | 8.4280 | 8.9080 | 203.25 | *** |

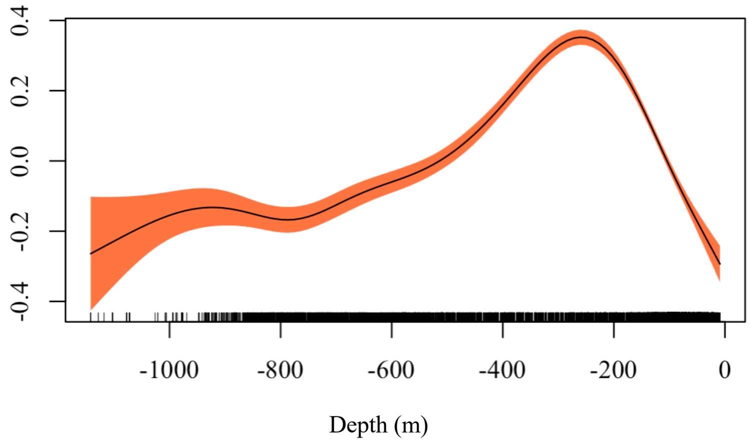


Figure 6. Effect of the depth variable on the LPUE (kg $h^{-1}$) of the deep-water rose shrimp, as estimated by the generalized additive models (GAM). The orange shade indicates the amount of uncertainty.

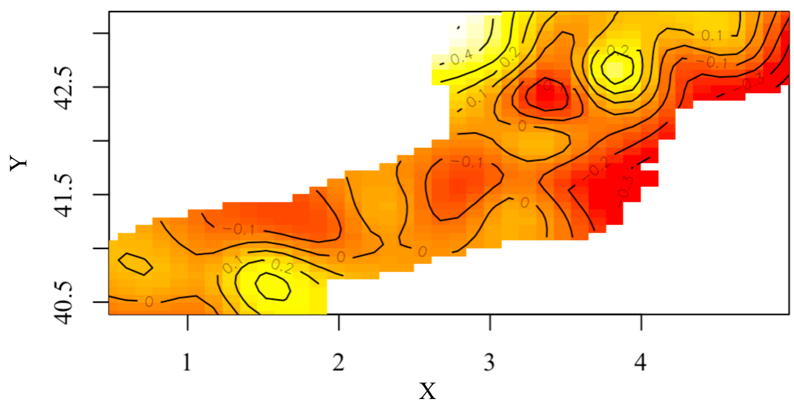


Figure 7. Effect of the spatial (X, Y) variable on the LPUE (kg $h^{-1}$) of the deep-water rose shrimp, as estimated by the generalized additive models (GAM). Yellow indicates high values of LPUE whereas red tones are low values.

The residuals distribution indicates that the general model was not well-fitted because points are not close to a normal distribution, which would be represented as a straight line in the Q-Q plot (Fig. 8a). Moreover, the plot of residual values showed that these values are dispersed and not evenly distributed around the zero value (Fig. 8b). Both plots indicate that the model is not well-fitted and that the degree of fitness of the model given in the summary is not robust enough to be trusted. Years with scarcely LPUE and consequently, a great number of zeros, probably influenced the results of this model and the distribution of the residual values.

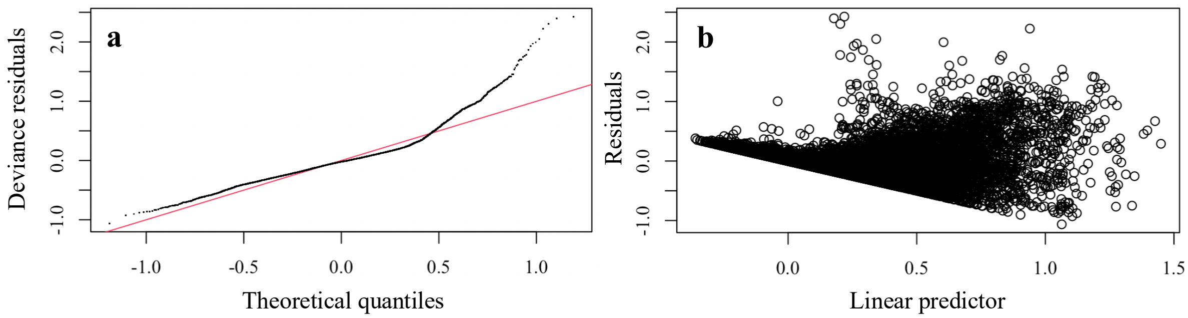


Figure 8. Fitness of the general model. a) Q-Q plot of the best model's residuals; b) Residual values of the best model fitted.

To elucidate if the non-fit of the general model could have a temporal explanation, annual models were run for the LPUE. The annual models showed an evolution in the depth distribution of the deep-water rose shrimp LPUE between 2009 and 2020 (Fig. 9). In the early time series, the LPUE started to appear in the bathymetric range, and continued growing since 2009 until 2016. In that year, there was an evident trend of the species LPUE distribution between 180 and 400 m depth. Both response variables in the models (spatial interaction and depth) showed high significant levels in all years considered except for 2009, with no statistical significance in depth (Annex I). The uncertainty of these models relied on the amount of data from each depth range. Therefore, at higher depths, where the resource was less captured, the uncertainty was bigger.

The plots of residual values from annual models showed that points are closer to a normal distribution than in the general model (Annex II). Furthermore, values from the residual values plots are nearer the zero value, indicating again that these models are better fitted than the previous one.

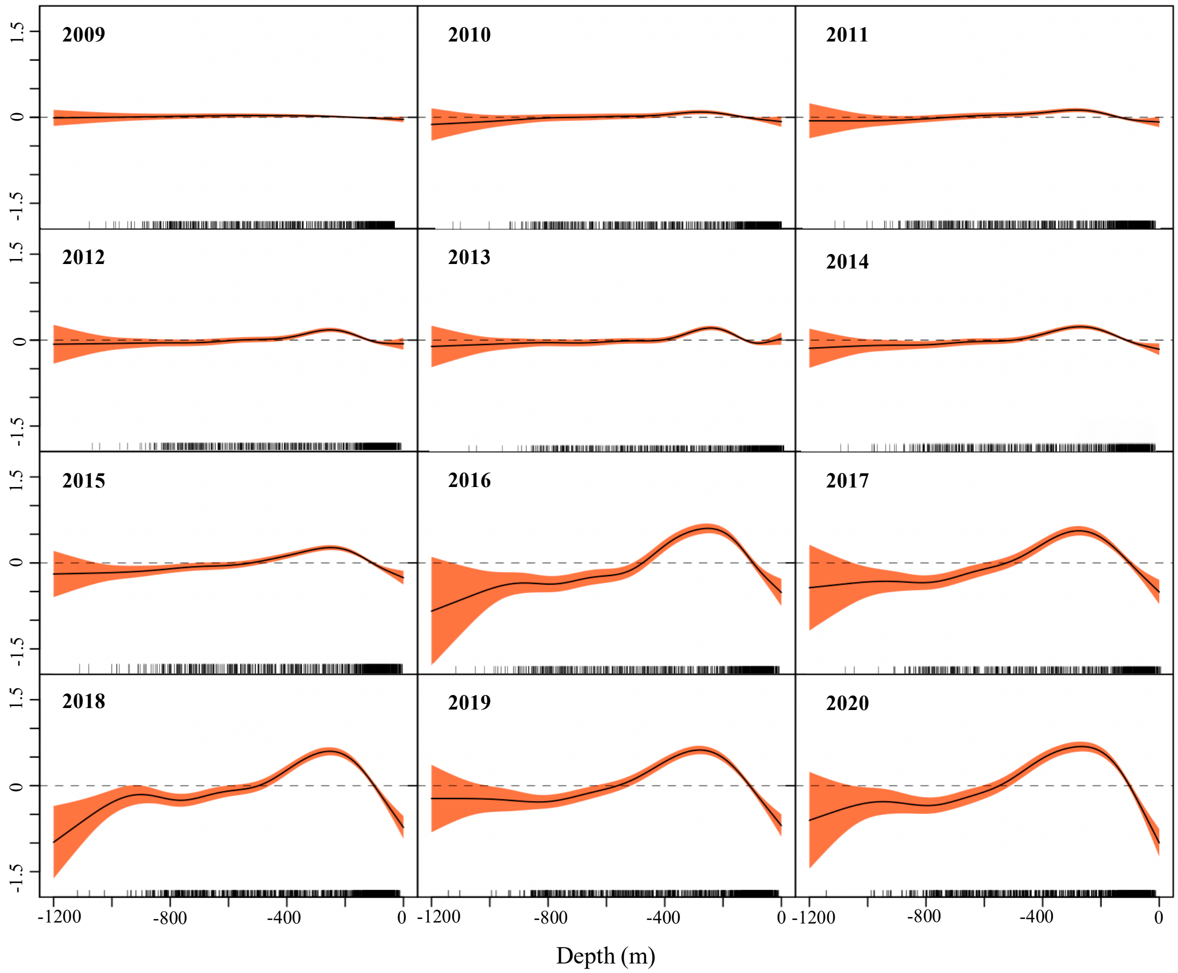


Figure 9. Annual effect of the variable depth on the LPUE (kg $h^{-1}$) of the deep-water rose shrimp, as estimated by generalized additive models (GAM).

## 4. Discussion

Landings of the deep-water rose shrimp in the Catalan continental margin had a value of 350000 kg with a revenue of 4M€ in 2020, while the total annual catch in the Mediterranean and the Black Sea, for that same year, was 1661.77 t (FAO, 2022a). In 2009, the resource in the Catalan coast was scarcely fished in the southern area but, since 2015, it expanded northwards, as observed in another study, where the distribution of the species expanded from the south to northwestern Mediterranean areas (Sbrana et al., 2019). Landings increased and the LPUE followed the same trend in time, with a maximum value of LPUE of 1.25 kg $h^{-1}$ in 2020. For this reason, LPUE was used to run GAM models. Depth, time, and spatial variability explained the distribution of the LPUE with higher values between 180 and 400 m depth, and in northern and southern areas. This increasing trend may be related to two different variables, i.e. environmental characteristics and changes in fishing activity (Ligas et al., 2011).

The increase in landings found in this study along with a broader distribution of the fisheries match with what was observed in other studies. For example, in the North Tyrrhenian–Ligurian Sea, the number of landings raised following a rapid increase in the deep-water rose shrimp stock, probably driven by higher water temperatures (Colloca et al., 2014). In agreement, despite that the optimal temperature range for this species has not been identified, it is known that it prefers warm waters (Abelló et al., 2002), so the ongoing warming of the upper and intermediate water layers of the Western Mediterranean (Vargas-Yáñez et al., 2009) could be influencing the abundance of this species, and consequently the increase of its landings. In Cartes et al. (2009), it is hypothesized that the high temperatures, low rainfall regimes, fewer river discharges, and the reduction in the flux of organic matter could be a possible explanation for the preservation of deep-water benthic communities off the Catalan coast, such as the deep-water rose shrimp. Also, the spatial expansion of the landings found in the present study could be related to enhanced habitat suitability for the species, as described for other Mediterranean areas (Colloca et al., 2014).

To further understand whether the studied resource may be related to environmental characteristics or changes in fishing activities, landings were compared with the LPUE. This value was used as a proxy for the abundance of the species because trends in LPUE are usually assumed to follow changes in the abundance of marine stocks (Maunder & Punt, 2004). The similarities between landings and LPUE trends indicate that the increase in landings is not related to a greater fishing effort but may be explained by an increase of the resource. It has been reported that the decline in catches of other crustacean species, such as the Norway lobster (*Nephrops norvegicus*), has caused the redirection of the crustacean fleet's effort to the deep-water rose shrimp grounds (Sobrino et al., 2005). However, despite that the stock of this species is captured on the same fishing ground as other heavily exploited species, the landings of the deep-water rose shrimp seem to be independent of fishing exploitation because the landings are still increasing (Colloca et al., 2014). This reinforces the idea that there are other factors, such as temperature, influencing the dynamic of the stock.

In the entire Mediterranean Sea, the deep-water rose shrimp landings have increased between 2016 and 2018, with values as high as 19955 t in 2016 and 25912 t in 2018 (FAO, 2020). Understanding the reasons of this increase is of great importance for the fishing sector to evaluate the sustainability of the resource and set appropriate management tools. The application of general and annual models helped to elucidate that the increase of the LPUE had a temporal, spatial and bathymetric trend. Regarding bathymetry, in 2016 and onwards, the LPUE was distributed between 180 and 400 m depth, indicating where the resource was more available. The fact that at the beginning of the time series there was no clear distribution suggests that the resource had recently started to be available at this depth range. This distribution coincides with the one reported by Abelló et al. (2002), in which the highest values of abundance for this species were found between 200 and 500 m depth. In the present study, the resource was less captured at higher depths, coinciding with a reduction of the density with individuals becoming rare at depths greater than 600 m (Froglia, 1982). These results confirm that the information on the abundance of the species follow the information obtained from the analysis of the LPUE. Considering the temporal variable, it explains between 43-64% of the variability of the LPUE both in general and annual models, indicating that the temporal factor is influencing the increase in the LPUE of the resource. Furthermore, the spatial distribution seen for the increase in LPUE with the annual models coincides with the one seen for landings in the maps. Thus, all this information indicates that there was an increase in the abundance of the deep-water rose shrimp throughout the years, related to variables zone and depth. However, it would be necessary to carry out further studies in this Mediterranean area focused on the relationship between the increase of abundance and other different factors, as it has been done in other locations (Quattrocchi et al., 2020).

In the Mediterranean Sea, the deep-water rose shrimp is one of the most interesting stocks from a bioecological and economic point of view. However, there are many gaps regarding its biology thus, stock assessments are based on scarce data and, consequently, they are inefficient for management plans (Perdichizzi et al., 2022). Sobrino et al. (2005) suggested that studies focused on creating a fishing ban on a spatio-temporal basis, and experiments with more selective gears would be important for the management of this resource to avoid the collapse of the stock. This present study demonstrates that the deep-water rose shrimp has become an important fishing resource in the Catalan coast for two reasons. First, the increase of the LPUE; and second, the economic contribution of the resource, which was 8% of the total revenue from the trawling fleet in 2020. These landings contrast with those from other species such as *Nephrops norvegicus*, which had a decreasing trend in landings and revenue (official data from Direcció General de Pesca, Generalitat de Catalunya, 2020). However, scientific monitoring and further studies are still needed for the deep-water rose shrimp, which lacks information to make good evaluations of the measures currently being applied to the stock. Thus, there should be an increase of knowledge on the biology and population dynamics to manage this resource and avoid its over- or full exploitation, as has happened in other Mediterranean areas (Sobrino et al., 2005).

## 5. Conclusions

The main purpose of this study was to find out if the deep-water rose shrimp can be considered a new fishing resource in the Catalan coast. The main results and conclusions derived from this research are:

- Landings of the deep-water rose shrimp followed an increasing trend between 2009-2020 and spread northwards in the Catalan coast.
- In the same period, landings of this species had an increasing contribution in the total revenue obtained by the Catalan bottom-trawling fleet.
- Landings per unit of effort (LPUE) increased during the same period, indicating that the increase in landings is not directly related to an increase in fishing effort.
- Temporal, bathymetric, and spatial variables significantly influenced the increase in LPUE on the area of study during the 12 years studied.

Thus, the main conclusion is that the deep-water rose shrimp can be considered a new fishing resource in the Catalan coast. However, there are not enough specific and robust data on the biology and ecology of this species in the Catalan coast to create accurate management plans.

Then, the recommendation is to develop further studies on the biology and dynamics of this population and resource stock, to create a management plan for this increasingly important resource in the Catalan coast.

## 6. References

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## Personal experience and valuation

During the realization of this study, learning new statistical concepts was needed. To understand the proper functioning of GAM models and its use, a free and interactive course was done (https://noamross.github.io/gams-in-r-course/). This open-source course was based on fitting, visualizing, understanding, and predicting from Generalized Additive Models, and was a very good introduction as it was the first time applying them. Dr. Nixon Bahamon helped, taught, and gave advice on the use of GAM models during the analyses process. Moreover, all the data analyses were executed with R studio (R Core Team, 2022), so there was a need in learning some tools of data processing which were taught by Joan Sala, one of the study's advisers. He also gave an introductory course on mapping with QGIS (QGIS Development Team, 2022). Dr. Eve Galimany, the other adviser, helped planning the study and specialized in writing support and scientific writing advice.

Personally, I have felt very comfortable during the progress of this study, and I appreciate very much all the lessons learned from all these professionals, who have made me feel as a part of the group. Despite the tedious and desperate moments during the statistical analyses, I value positively all the processes followed to develop this master thesis: I have learned about Mediterranean fisheries, the target species of the study, scientific writing in English, statistical analysis, and all the process to write a scientific article. I have also realized that the knowledge that every expert and researcher can provide is fundamental for learning while being a student or even as a professional. Everyone can learn from everyone, and this is something I can apply in other life situations.

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# Annex I

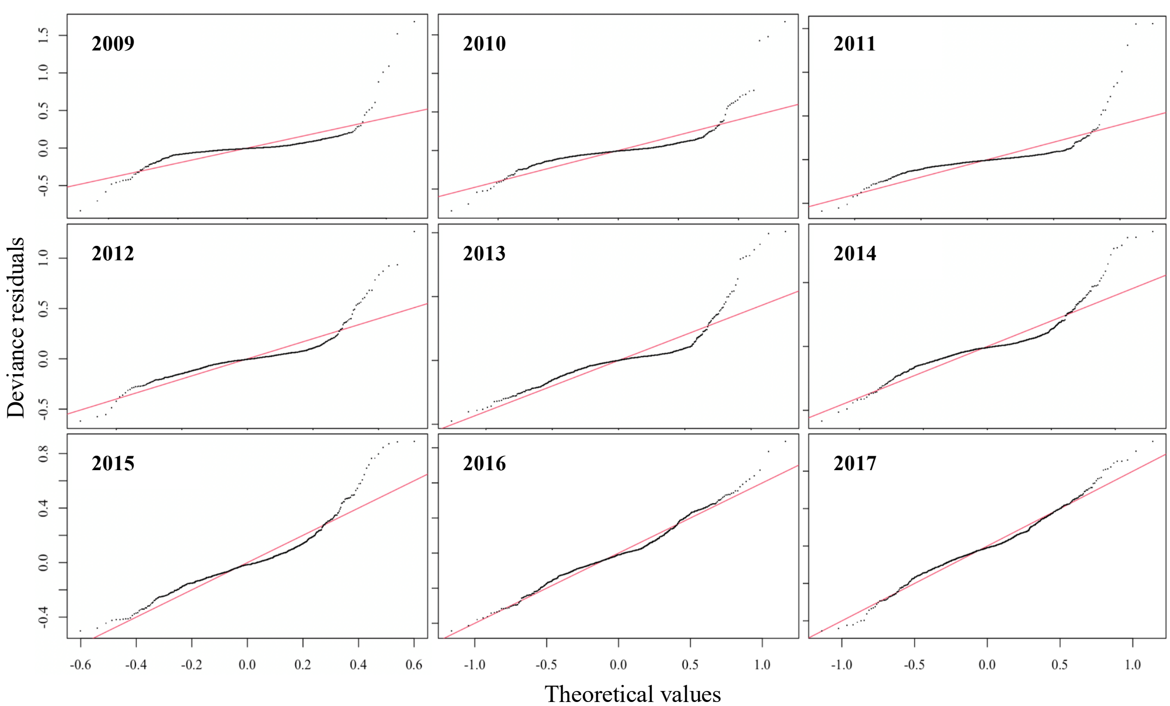
Summary of the outputs of the annual GAM models for the LPUE (kg $h^{-1}$) of the deep-water rose shrimp. Explanatory variables include spatial interaction (X, Y), and depth. SE is the standard error, edf is estimated degrees of freedom, and df is degrees of freedom. "***" indicates significance between 0 and 0.001, "**" indicates significance < 0.001, and " " indicates no significance.

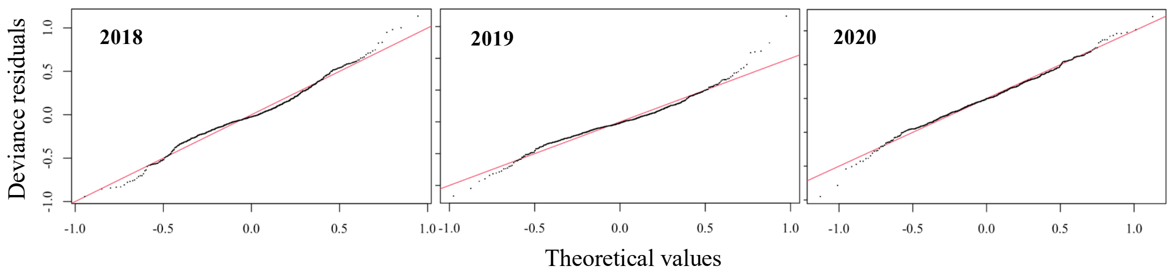
| | **Parametric coefficients:** | **Estimate** | **SE** | **t value** | **Significance level** |
|---|---|---|---|---|---|
| **2009** | Intercept | 0.065 | 0.005 | 12.56 | *** |
| | **Smooth terms:** | **edf** | **df** | **F** | |
| | X, Y | 27.914 | 28.913 | 33.52 | *** |
| | Depth | 2.485 | 3.149 | 1.46 | p = 0.22 |
| **2010** | Intercept | 0.088 | 0.006 | 14.71 | *** |
| | **Smooth terms:** | **edf** | **df** | **F** | |
| | X, Y | 27.431 | 28.822 | 20.39 | *** |
| | Depth | 5.307 | 6.499 | 4.22 | *** |
| **2011** | Intercept | 0.078 | 0.005 | 14.24 | *** |
| | **Smooth terms:** | **edf** | **df** | **F** | |
| | X, Y | 26.742 | 28.651 | 14.28 | *** |
| | Depth | 6.187 | 7.375 | 9.65 | *** |
| **2012** | Intercept | 0.113 | 0.005 | 20.68 | *** |
| | **Smooth terms:** | **edf** | **df** | **F** | |
| | X, Y | 27.471 | 28.831 | 20.64 | *** |
| | Depth | 7.383 | 8.371 | 13.45 | *** |
| **2013** | Intercept | 0.110 | 0.005 | 20.20 | *** |
| | **Smooth terms:** | **edf** | **df** | **F** | |
| | X, Y | 27.327 | 28.805 | 14.79 | *** |
| | Depth | 8.158 | 8.805 | 17.25 | *** |
| **2014** | Intercept | 0.142 | 0.006 | 25.19 | *** |
| | **Smooth terms:** | **edf** | **df** | **F** | |
| | X, Y | 26.394 | 28.544 | 10.42 | *** |
| | Depth | 7.125 | 8.174 | 26.66 | *** |
| **2015** | Intercept | 0.198 | 0.007 | 30.12 | *** |
| | **Smooth terms:** | **edf** | **df** | **F** | |
| | X, Y | 26.458 | 28.561 | 12.46 | *** |
| | Depth | 7.055 | 8.124 | 30.60 | *** |
| **2016** | Intercept | 0.508 | 0.013 | 40.03 | *** |
| | **Smooth terms:** | **edf** | **df** | **F** | |
| | X, Y | 25.892 | 28.365 | 12.26 | *** |
| | Depth | 7.355 | 8.343 | 50.19 | *** |

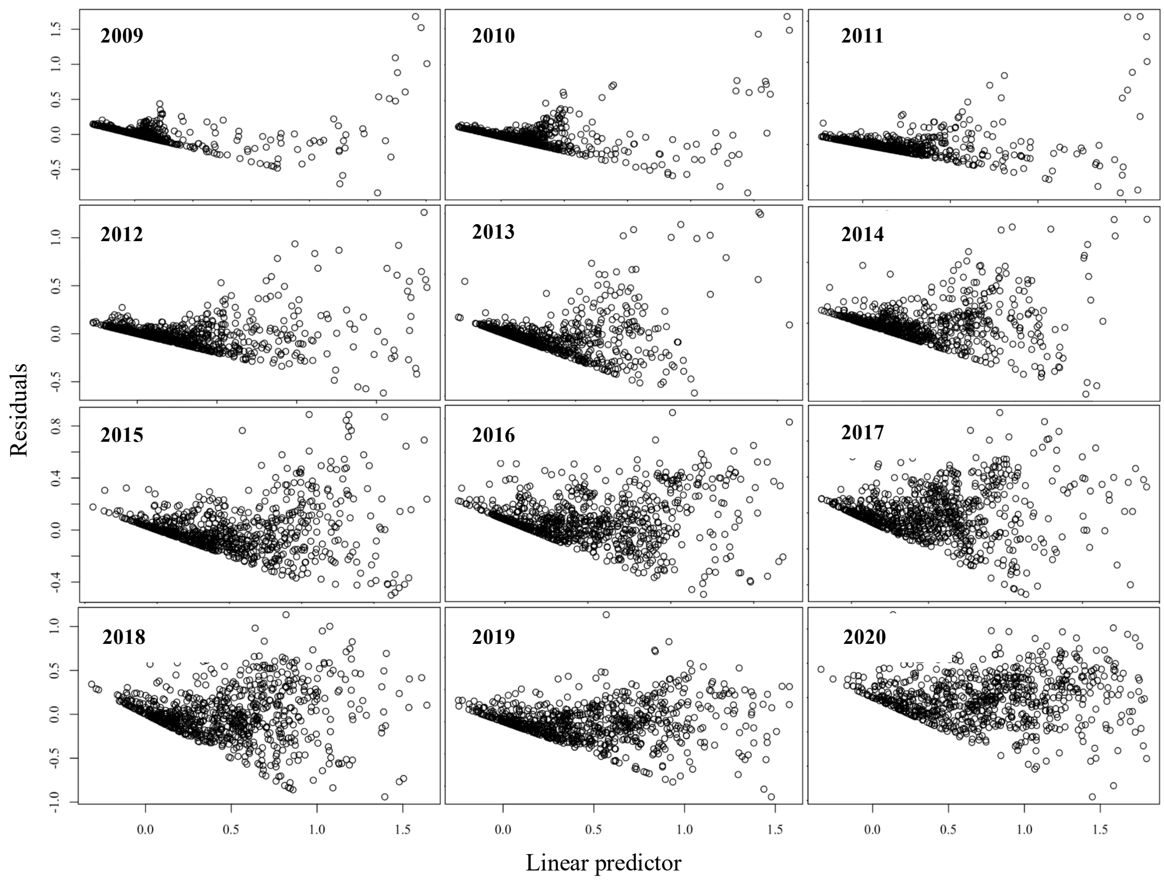
| | Parametric coefficients: | Estimate | SE | t value | Significance level |
|---|---|---|---|---|---|
| **2017** | Intercept | 532 | 12 | 42.90 | *** |
| | **Smooth terms:** | **edf** | **df** | **F** | |
| | X, Y | 25.236 | 28.108 | 15.60 | *** |
| | Depth | 6.875 | 7.974 | 43.83 | *** |
| **2018** | Intercept | 466 | 10 | 44.80 | *** |
| | **Smooth terms:** | **edf** | **df** | **F** | |
| | X, Y | 26.163 | 28.472 | 16.71 | *** |
| | Depth | 7.789 | 8.612 | 60.01 | *** |
| **2019** | Intercept | 482 | 11 | 44.50 | *** |
| | **Smooth terms:** | **edf** | **df** | **F** | |
| | X, Y | 25.916 | 28.374 | 19.67 | *** |
| | Depth | 7.289 | 8.291 | 63.18 | *** |
| **2020** | Intercept | 726 | 13 | 57.47 | *** |
| | **Smooth terms:** | **edf** | **df** | **F** | |
| | X, Y | 27.109 | 28.751 | 14.70 | *** |
| | Depth | 7.514 | 8.465 | 65.24 | *** |

# Annex II

Q-Q plot and distribution of residual values of annual models, respectively.




2018
2019
2020
Deviance residuals
Theoretical values
-1.0
-0.5
0.0
0.5
1.0


2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
Residuals
Linear predictor
0.0
0.5
1.0
1.5