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Pagellus genus catches time series in the FAO Major Fishing Areas 27 and 34: Analysis of fishery behaviour

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Pagellus genus catches time series in the FAO Major Fishing Areas 27 and 34: Analysis of fishery behaviour

Abstract

Based on ~~catch reconstructed data~~ catch reconstructed data, we constructed the fisheries of the *Pagellus* genus between 1950 and 2014 in FAO Major Fishing Areas 27 and 34 and overall by continent and by species, namely, *Pagellus acarne*, *Pagellus bellottii*, *Pagellus bogarave*o and *Pagellus erythrinus*. Additionally, we considered the group *Pagellus sp*. to include species identified to the genus level only. Regression of estimates of linear time trends, change point analysis and autoregressive integrated moving average (ARIMA) models revealed significant variations and historical changes in catch time series, the trend being a primarily downward with a progressive increase in the intensity of fishing pressure on the populations of this genus. This situation may be attributable to regulatory and technological transitions and environmental variability, as well as the biology of the species. For this reason, the results of this multi-species study may be useful ~~to guide changes to make fisheries~~ in guiding changes for more management and more sustainable fisheries, helping to achieve proper governance of this resource.

1. Introduction

The species of the genus *Pagellus* are widely distributed across the Northwest and Eastern Central Atlantic Ocean, from Norway and Iceland to the coast off Angola; the Western Indian Ocean, from South Africa to Pakistan; and the Mediterranean basin, from the Strait of Gibraltar (Southern Iberian Peninsula) to the Western Black Sea [1-8]. There are six species in this genus, four of which are found in the United Nations Food and Agriculture Organization (FAO) Major Fishing Areas 27 (Atlantic, Northeast) and 34 (Atlantic, Eastern Central): *Pagellus acarne* (axillary seabream), *Pagellus bellottii* (red pandora), *Pagellus bogaraveo* (blackspot seabream) and *Pagellus erythrinus* (common pandora) [9-13].

These four species are demersal omnivores with low-to-moderate growth rates, exhibit protogynous and protandrous hermaphroditism, with breeding seasons from the autumn to the summer, and generally have complex life cycles [10-27]. From a commercial point of view, all four species are very important in these FAO Major Fishing Areas, being the main target for semi-industrial, coastal, artisanal and recreational (small-to-medium scale) demersal fisheries. For example, *P. acarne* is economically important for commercial fisheries in the Atlantic and Mediterranean. This species is caught by artisanal and coastal fisheries of the Algarve (Southern Portugal) [28], Azores (Portugal) [29], Canary Islands (Spain) [25, 30-31] (Pajuelo and Lorenzo, 2000 (25); Pajuelo and Lorenzo, 1995 (30)), and Morocco (FAO, 2018 (31)). In the Canary Islands, this species represents approximately 10% of the total catch of demersal species [30]. Similarly, *P. erythrinus* is commercially important in this area, accounting for 16% of demersal catches [30]. This species together with *P. acarne* makes up almost 20% of the landings from artisanal gillnet fisheries in the Algarve [32].

P. bellottii and *P. bogaraveo* are also very important based on their economic value and catch volume. *P. bellottii* is a key resource for medium-to-large and small scale commercial fisheries off West Africa. It is one of the main target species of the Senegalese demersal fleet [12], it being the most abundant of the commercial demersal species in the area [21]. In Ghana, it was one of the most valuable species landed in ports and on beaches during the 1980s [33-34]. In Mauritania, it represents 85% of the catches of Sparidae carried out in the South [35]. On the other hand, *P. bogaraveo* is the main target species of the Spanish and Moroccan fisheries in the Strait of Gibraltar [22, 36] and one of the most important demersal resources of the Portuguese fleet in mainland and island waters (Azores and Madeira) [29, 37-40].

The catches of these four species in FAO Major Fishing Areas 27 and 34 are mainly for direct human consumption (around 80% the total catch since 1950). This is because they can reach relatively large sizes and are largely edible, providing high-quality proteins and fatty acids [41-44]. These species are great in demand and therefore of great commercial importance in fish markets of the main ports where they are landed [19, 24-25, 27, 36, 38, 45-46].

The high demand for these fish species has increased the fishing effort, which has resulted in significant reductions in abundance, catches and landings, in the case of some populations and driven other populations to the edge of biological collapse. For example, Velasco et al. [27] reported that total landings of *P. acarne* in the Gulf of Cadiz fell by around 60% from 1993 to 2007. A similar reduction was observed in *P. acarne* and *P. erythrinus* from the waters off the Algarve [18-19, 47], while catches of *P. bellottii* in Ghana decreased significantly from 7000 tons in 2005 to 1000 tonnes in 2009 [15].

A particularly notable case is that of the fisheries of *P. bogaraveo* in the Bay of Biscay (Northern Iberian Peninsula) and Strait of Gibraltar. In the Bay of Biscay, from the 1950s to mid-1970s, annual landings of this species by the international fleets of Spain, France and the United Kingdom summed to more than 10-20 thousand tonnes. Subsequently, the landings collapsed, falling to less than a thousand tonnes in the 1990s, and the species has become a minor incidental catch in this area [48]. In the case of the Strait of Gibraltar, the *P. bogaraveo* population fishery has declined dramatically in recent years, mainly attributable to previously high commercial catches leading to the commercial extinction of this species in this zone [46, 49-50]. All this has led to *P. bogaraveo* currently being considered a Near Threatened Species by the International Union for Conservation of Nature (IUCN) [10].

The wide distribution and biological characteristics of these four species, size of the zones where they are caught (FAO fishing areas 27 and 34), significant economic value of the catches and number of countries and fishing fleets involved make it very difficult to assess the conservation status of these species, operational status of the fleets and changes in catches. These factors, together with difficulties accessing fishing data, and their dispersion and quality, mean that it is even more challenging to obtain forecasts to estimate how catches will change in the future. Hence, the objective of this study was to identify and analyse the behaviour between 1950 and 2014 in the reconstructed catches of the *Pagellus* genus in FAO Major Fishing Areas 27 and 34, and based on these data, provide preliminary forecasts of catches by species and area. For this purpose, we used the reconstructed catch database of the Sea Around Us research initiative (www.seaaroundus.org).

2. Materials and Methods

2.1. Study area

In this study, we selected the FAO Major Fishing Areas 27 and 34. Area 27 (Atlantic Northeast) located in the Northeast Atlantic Ocean spans from the Western coast of the Iberian Peninsula to the Coasts of Greenland to the West and the Barents Sea to the East. It covers an area of 14,391,372 km^2, divided into 14 subareas, and is considered a temperate region [51]. On the other hand, Area 34 is located in the Eastern Central Atlantic off the west coast of Africa, spanning from the Strait of Gibraltar to the mouth of the Congo River (border between Congo and the Democratic Republic of Congo). It includes an area of 14,074,956 km^2, divided into 4 subareas, and is classified as an upwelling zone [51] (Fig. 1).

2.2. Fishery Databases

In this study, we used the reconstructed catch data from the Sea Around Us initiative, available from www.seaaroundus.org [52]. This database includes records of global marine catches of 1,446 commercially exploited fish species for a 65-year period (1950 to 2014) [53]. The records of the catches are presented by taxa/species for a specific year, for various defined geographical regions: Exclusive Economic Zones, Large Marine Ecosystems, Marine Ecoregions, Regional Fisheries Management Organisations, and FAO areas, as well as total values (Global data). Within each of these regions, catches are defined by fishing sector (industrial, artisanal, subsistence and recreational fisheries), country and fishing gear [54-56].

The reconstructed catch data are obtained by combining officially reported data and estimates of illegal, unreported (mainly fish discards) or unregulated fishing [57-58]. These estimates are carried out for all four fishing sectors (industrial, artisanal subsistence and recreational). The official data are retrieved from the FAO FishStat database. All data are available from www.seaaroundus.org, www.seaaroundus.org/data/#/fao/27 and www.seaaroundus.org/data/#/fao/34.

Data were downloaded on 19 December 2019 with version 47.1 Sea Around Us database. These data cover all marine resources taken corresponding to any of the four species of the *Pagellus* genus: *P. acarne*, *P. bellottii*, *P. bogaraveo* and *P. erythrinus*, as well as the group *Pagellus sp.*, which includes catches from fish identified at genus but not species level.

Within the FAO Major Fishing Area 27, we analysed data from eight countries: Germany, Denmark, Spain, France, Netherlands, Ireland, Portugal and the United Kingdom. Within FAO Major Fishing Area 34, we analysed data from 32 countries: Germany, Angola, Benin, Cape Verde, Cameroon, China, South Korea, Ivory Coast, Spain, France, Gabon, The Gambia, Ghana, Greece, Guinea, Guinea-Bissau, The Netherlands, Italy, Japan, Morocco, Mauritania, Namibia, Nigeria, Portugal, Republic of Congo, Romania, Russia, Sao Tome and Principe, Senegal, Sierra Leona, Togo and Ukraine. In the cases of Portugal and United Kingdom, we analysed the catches from the Azores (Portugal) and the Channel Islands (United Kingdom) in Area 27 and from the Madeira archipelago (Portugal) in Area 34 separately.

For each area, time series of total annual catches of each species were constructed by country. Then, the countries were grouped by continent. Once grouped by continent, total catch time series for each species were constructed by country. Having obtained the total catch series for each species by continent, these were grouped again by species, allowing comparisons between the continents. Subsequently, based on these series, comparisons were made between the areas by species. Finally, we obtained the overall catch time series for the entire area from the total catch series by species for each area.

The database was analysed using R statistical software [59]. The linear deterministic trends were determined with the least-squares regression method using the *lm()* function [60], considering catches as the outcome variable and time in years as the exploratory variable. Time was extracted using the *time()* function of the stats package [60]. These models were used to visualize the general pattern in the catch time series from a linear perspective, allowing us to interpret the sign of the estimated slope as increases and decreases. These linear trends represents long-term changes [61]. Significant differences were detected when the p-value (p) was ≤ 0.05.

2.3. Change-point analysis and preliminary projections

Multiple change-point analysis was performed seeking to detect state changes in the time series, using the *cpt.mean()* function in the R package changepoint, Version 2.2.2 [62-63] which identifies periods with distinct features based on changes in the mean. The exact algorithms employed were a segment neighbourhood algorithm [64] and the Pruned Exact Linear Time (PELT) algorithm [65]. The distribution of the time series was assessed using the non-parametric cumulative sum test [66], without applying the traditional penalty, for the segment neighbourhood algorithm and Hinkley [67] normal distribution test for the PELT algorithm, applying a traditional penalty based on the number of data points. The choice of penalty was assessed by plotting the change points to observe whether the periods of change identified by the algorithms were reasonable [62]. The total number of periods to be identified was four. The choice of four change points was made in order to standardise and facilitate interpretation of the results, moreover avoid loss of information. The multiple change-point analysis was applied to non-transformed time series.

On the other hand, preliminary projections were carried out with the seeking to visualise patterns in future catches. For this, non-stationary and non-seasonal (p,d,q) univariate ARIMA models using the Box-Jenkins methology [68]. The application of differentiations in the series was assessed by the Dickey-Füller [69] and KPSS (Kwiatkowski-Phillips-Schmidt-Shin) tests [70], using the two components of the deterministic regression: level and trend. In the case of different results (Appendix A: Table 1-2), both differentiations were examined and the model selected was the one with the lower AIC value. The residuals of the models were tested for white noise by means of the autocorrelation function (ACF) and partial autocorrelation function (PACF) plots together with the Ljung-Box test [71]. Checking that the model residuals were a white noise were tested by means of the autocorrelation function (ACF) and partial autocorrelation function (PACF) plots together with the Ljung-Box test [71] (Appendix A: Table ~~2~~ 3 and Figs. 1-3). We used the ordinary residuals (observed minus fitted values). The square-root transformation of overall catch time serie for the entire area was used with the aim to obtain a white noise in the residual. For the rest of the time series no transformation was used.

All models were run in RStudio Version 3.3.2 [59], using the *auto.arima()* function proposed by Hyndman and Khandakar [72], with parameters p and q ranging from 0 to 5. Within the function, the selection of the models was done by an exhaustive model selection according to the Akaike criterion (Stepwise = False) [73]. If the aforementioned function indicated that best model was a naïve model ($p = 0$ and $q = 0$), i.e., one in which the forecast is that the future will be the same as the previous period, the model was rejected and a new ARIMA model was generated using the *arima()* function in the package stats [60], with p and q ranging from 0 to 2, considering the model with the lowest Akaike information criterion (AIC) value to be the best [73]. The identification of the number of differences to be applied was done using the *ndfiss()* function of the R package forecast package version 8.13 [74]. The projections were carried out for a period of 6 years, using the *forecast()* function of the R package forecast, Version 8.13 [74]. The goodness of fit of the ARIMA models was assessed by applying the following accuracy criteria: coefficient of determination (r^2), root mean square error (RMSE), mean absolute error (MAE), percent standard error of prediction (%SEP) [75], coefficient of efficiency (E_2) [76-77], average relative variance (ARV) [78], the persistence index (PI) with 1 year lag [77], KGE' (modified version of the KGE-statistic, Kling-Gupta Efficiency) [79] and AIC [73]. Applying these criteria, a good model would be one that explained a high percentage of variance (r^2, ARV and E_2) and high value agree between fitted and observed values (KGE'), with a lack of time lag (PI), small loss of information (AIC) and low values of absolute (RMSE, MAE) and relative (%SEP) error. Both methods, the change point analysis and Arima models were applied to the overall time series for the area and the overall series for the area by species.

Only the global series of the species *Pagellus bogaraveo* for FAO area 34 had missing data for the years 1961, 1963 to 1966, 1968 to 1969 and 1973. To complete the series the R package impute TS was used [80], which uses Kalman smoothers based on structural time series models. We performed the imputation with KalmanSmoother and state space representation of the Arima model. This series was only considered in the trend analysis, in the application of the Arima models and in the change point analysis, and was not used in the calculation of the global series of the whole FAO area or in the descriptive results.

3. Results

3.1. FAO Major Fishing Area *27*

In terms of species, over the entire historical record, the highest catches were of *P. bogaraveo* (211,019.43 tn, 49.71 %), followed by *Pagellus sp.* (163,024.49 tn, 38.40 %), *P. acarne* (37,406.48 tn, 8.81 %) and *P. erythrinus* (13,005.51 tn, 3.06 %). Therefore, a total of 424,455.92 tn of species from genus *Pagellus* were caught in Area 27 between 1950 to 2014. Only *P. erythrinus* showed a positive trend in the historical records (Table 1). The trends were significant (p<0.05) for *Pagellus sp.* and *P. acarne* (Table 1). Overall, in this fishery for the entire genus *Pagellus* in the Area 27, the largest catch volumes were observed in two periods: (I) 1963-1970 with a total catch of 122,085.51 tn (28.76 %); and (II) 1977-1983 with a total catch of 74,634.74 tn (17.58 %) (Appendix A: Fig. 4). Between 1984 and 2014, catches decreased significantly and progressively at a rate of -76.53 tn/year (*p*<0.05) (Table 1).

A total of 10 European countries caught fish from the *Pagellus* genus in Area 27. The main countries involved were Portugal and Spain, accounting respectively for 46.65% (198,021.70 tn) and 39.74% (168,719.06 tn) of catches. Historically, Portugal has taken higher catches than Spain except in the periods 1963-1970 and 1978-1982. Though these two countries dominate this fishery, being responsible for more than 80% of the total catch, their combined weight decreased between 1988 and 2010 to as low as 68.77%, as the result of increase in fishing activity in the Azores (Portugal).

3.2. FAO Major Fishing Area 34

In the case of Area 34, catches were dominated by African countries (65.50%), followed European (30.25%) and Asian (4.24%) countries. Catch patterns were similar in Africa and Europe up until their historical peak catches, catches of African countries reaching a peak of 57,485.27 tn in 1975 and those of European countries a peak of 51,098.96 tn 5 years later. The catches from Asian fleets have oscillated, with an upward trend in the most recent years analysed.

Out of the 2,276,138.14 tn caught in Area 34 (Appendix A: Fig. 8), 69.40% corresponded to *P. bellottii*, followed by unidentified species from the *Pagellus sp* (21.45%) and *P. acarne* (7.99%). *Pagellus bellottii* was the dominant species over the

65 years analysed. Trend analysis indicated significant trends that were negative for *Pagellus sp.* and *P. bogaraveo* ($p<0.05$) and positive for *P. acarne* and *P. erythrinus* ($p<0.05$) (Table 1). Nonetheless, overall, catches of this fishery for the entire genus *Pagellus* in the Area 34 decreased progressively at a rate of -294.62 tn/year, this trend nearly reaching significance ($p=0.09$) (Table 1).

3.3. *FAO* Major Fishing Areas *27 vs 34*

Overall, catches of species of the *Pagellus* genus for Areas 27 and 34 were 2,700,594.06 tn, of which 84.28% (2,276,138.14 tn) were taken in Area 34 and the rest (15.71%; 424,455.92 tn) in Area 27. In Area 34, the trend was initially upward, to a historical peak of 106,027.39 tn in 1975; catches then declined until 1995 (14,079.98 tn), stabilising over the last 19 years of the study period at around 20,000 tn/year (Appendix A: Fig. 9 a)). The pattern in Area 27 is similar, with an initial upward trend to a historical peak of 17,483.47 tn in 1968, catches then decreasing over the following 8 years to 4,115.86 tn in 1976 and increasing back to levels similar to the 1978 peak of 15,606.28 tn. Finally, catches decreased again and stabilized over the last 16 years of the study period at around 3,800 tn/year (Appendix A: Fig. 9 a)). There are continuous records from 1950 to 2014 for both fishing areas. Percentage analysis indicated that over the entire study period, Area 34 was dominant for this fishery, catches there always being higher than those in Area 27, accounting for a mean annual percentage of 82.42% of the catch (Appendix A: Fig. 9 b)). Generally, the historical trend for this fishery is negative, catches falling by -363.80 tn/year, the trend being marginally significant ($p=0.057$) (Table 1).

In terms of the specific species, *P. bellottii* accounted for 58.49% of catches (1,579,755.17 tn), followed by *Pagellus sp*, (24.11%, 651,317.42 tn), *P. bogaraveo* (7.84%, 211,950.59 tn), *P. erythrinus* (7.22%, 195,078.53 tn), and finally, *P. acarne* (2.31%, 62,492.33 tn). Percentage analysis showed that the *P. bellottii* was the dominant species (mean 57.08% of catches) between 1950 and 1999, followed by *Pagellus sp.* (mean 27.72% of catches). Over the last 15 years of the study period, these species accounted for lower mean percentages (*P. bellottii*, 39.68% and *Pagellus sp*, 26.76%), due increases in the catches of *P. erythirnus*, this accounting for 21.70%. During this period , *P. bogaraveo* represented mean 7.58% and *P. acarne* just 4.26%.

3.4. Change points and ARIMA forecasts

Only the PELT algorithm for change-point detection was used for the overall time series of *Pagellus sp* in the FAO Major Fishing Area 27 (Appendix A: Table ~~3~~ 4 and Figs. 10-12). For the entire study area (Areas 27 and 34), the time periods that showed distinct patterns compared to the mean were [1950-1961], [1962-1973], [1974-1980] and [1981-2014], the highest mean catches (106,131.77 tn) being taken in the third period (Fig. 2).

In Area 27, the four species had similar change periods. The first period was from 1950 to 1962-63, the second from 1962-1963 to 1970-1971, the third from 1972-1973 to 1977 and the last from 1978 to 2014. For all four species, the highest mean catches were obtained in the second period: *Pagellus sp* [1956-1968] 4041.81 tn, *P. acarne* [1964-1972] 958.62 tn, *P. bogaraveo* [1963-1970] 9,726.95 tn and *P. erythrinus* 1963 1,454.68 tn (Fig. 3).

For the FAO Major Fishing Area 34, the general pattern of change was observed in the following periods: 1950 to 1961-1962, 1963 to 1973, 1974 to 1987, and 1988 to 2014. For *P. bogaraveo*, these periods varied significantly, occurring around the decade of the 1950s ([1950-1952], [1953-1954], [1955-1956] and [1957-2014]), whereas for *P. erythrinus*, the periods were established around the first decade of the 21st century ([1950-1999], [2000-2004], [2005-2011] and [2012-2014]). Finally, the highest mean catches were taken in the second period for three species (*Pagellus sp* [1962-1973] 17,708.41 tn; *P. bogaraveo* [1953-1954] 77.19 tn and *P. erythrinus* [2000-2004] 8,708.23 tn) but in the fourth period for *P. acarne* and third for *P. bellotti* (that is, [2008-2014] 914.60 tn and [1974-1980] 86,080.95 tn respectively) (Fig. 4).

Table 2 shows the results of the accuracy measures applied in the validation stage of the non-stationary and non-seasonal (p,d,q) ARIMA models. On average, All the models explained 54% of the variance, had an E_2 of 0.52 and a %SEP of 55.43%, with a time lag of 0.21 (PI) and KGE′ of 0.68. The model with the highest percentage of explained variance and better agreement between observed and fitted values was (0,1,1) from the overall time series for the entire study area, this explaining ~~80%~~ 84% of the variance and ~~0.92%~~ 92% of agreement, while the model (5,1,0) for *P. bogaraveo* for Area 34 was the model with the least loss of information and shortest time lag (AIC=558.18 and PI=0.54).

In Area 27, according to the projections from the models, the behaviour of the fisheries was stable for *Pagellus sp*, and with small variations for *P. bogaraveo* and P. *erythrinus*. In contrast, a slight increase in catches was forecast for *P. acarne*. Within Area 34, similar stable behaviour was observed for the *Pagellus sp*, group as well as for *P. acarne*, while for the trend was upward for *P. bellottii* and *P. bogaraveo* and downward for *P. erytrhinus*. Overall, for the entire fishery and FAO area, the forecasts remained stable.

4. Discussion

In this study, we constructed the historical catches of the fishery of *Pagellus* in FAO Major Fishing Areas 27 and 34 from reconstructed catch data between 1950 to 2014 by country involved, these then being grouped by continent. In relation to this, we show the behaviour and historical evolution of this fishery, as well as reflecting the most important species and the impact of fleets and fishing management on each continent. The combined use of linear regression, change-point methods and univariate ARIMA models has allowed us to identify linear trends, as well as periods or blocks of time with distinct behaviours and to explore potential future patterns in this fishery.

Species of *Pagellus* genus have been fished in Area 27 by European fleets, Portugal and Spain being the countries with the largest catches and *P. bogaraveo* the leading species in terms of catch volume. These results are in line with those of other authors [22, 81-82]. The historical pattern of landings per unit of fishing capacity (LPUC) from 1933 to 1986 in the zones in this area shows a downward trend, characterised by two cycles with larger landings volumes between the 1950s and the 1970s [81]. In our study, we also observed two cycles with higher catch volumes around these decades, identified as periods of change, as well as a downward trend. The double-cyclical behaviour of the catches of *P. boragaveo* is the result of the high commercial value of this species and various programmes for regularisation of fishing activity of this species [22].

Various studies indicate that the historical pattern of landings and estimated abundance of this species in the Strait of Gibraltar (1983-2016) shows a general downward trend. The largest landings occurred in the 1990s and 2005, coinciding in general with the biomass minima, periods in which there is great volatility caused by the biology of the species, climatic variability and regulatory transitions [46, 49-50], which may explain the downward trend observed in this study. Another factor that may have caused this decrease is movements of the species to other areas, which would lead to changes in abundance or changes in the spatial distribution of the fleet [48, 81-82].

For this fish species, the univariate ARIMA model obtained had a strong autoregressive nature, possibly indicating that this fishery is highly dependent on past behaviour [50]. In northeast Spanish waters, a reduction in the biomass has also been observed between 1990 and 2018, with two marked cycles of higher biomass between 1997-2000 and 2004-2007 and a third cycle between 2014-2017 though with less biomass than the other two [83]. In Portugal, *P. bogaraveo* is fished by northern and central fleets [22]. This species is considered an incidental catch in other fisheries, although depending on the season, a fishery may target this species [40, 84]. The periods with the highest landings coincide with the spawning season [84]. Between 2009 and 2018, the total landings of this species in various Portuguese ports in the north and south of mainland Portugal showed a continuous downward trend. Similarly, in the Azores, annual landings decreased between 1980 and 2017 by 60% from their historical peak recorded in 2005. This decrease might be related to total catches permitted under European Union regulations, this also determining factors concerning demersal fish populations (for example: the number of vessels with licenses) [40, 85], or to the low regeneration capacity of a population not able to withstand the fishing pressure it is under, this meaning that the current fishing effort has likely contributed to the depletion of this resource [86-87].

In FAO Major Fishing Area 34, the African fleet was responsible for the majority of the catches of *Pagellus* species. *P. bellottii* was the leading species in terms of catches, and in our study, we observed a downward trend in catches of this species. Traditionally, *P. bellottii* has been a commercially important demersal resource for industrial and artisanal fisheries in countries such as Senegal, Ghana and Mauritania [12, 33-35]. Data from Senegal indicated a progressive decrease in abundance between 1983 and 1998, with a historical peak in 1985 [88]. The ARIMA model identified for this fishery had autoregressive and moving average parameters that could be interpreted as suggesting that the catches are dependent on or will be influenced by past patterns and that catches are still partially independent of population density. In line with this, changes may be attributed to particular variations in age classes or fishing activity [46, 50]. A similar explanation can be given for the historical peak in abundance observed in Mauritanian waters from 1982 to 1985 [89]. The combined catches of the Gambian, Mauritanian and Senegalese fleets between 1990 and 2016 showed a general downward trend [31]. A marked reduction in catches was also observed between 2005 and 2009 in Ghana [15]. On the other hand, Gascuel et al. [89] suggested that interannual climate variability plays an important role in changes in the abundance of demersal resources in Mauritanian waters, this having an impact on recruitment and therefore on fish abundance, which undoubtedly would impact the resources available for the fishing sector. All of this is consistent with the decrease observed in the reconstructed catches of *P. bellottii* in Area 34 throughout the historical records.

In both FAO Major Fishing Areas studied, unidentified *Pagellus* species (*Pagellus sp.*) represent the second largest group in terms of catch volume. Not identifying the species represents a problem that hinders the adoption of legal measures to safeguard the sustainability of the populations exploited [90-91]. In both areas, the general trends for this group were negative, suggesting that over time, fish identification to species level has been improving. Change point analysis confirmed this to be the case and indicated that the last block of change was the one with the lowest mean catches in both study areas [1988-2014]. Although it seems that in Area 34, there was a slight increase over the last 14 years, this might be explained by the larger number of countries involved, the low level of investment in fisheries [92] and the limitations in terms of improvement in fishery management in African countries [93].

Regarding *P. acarne* and *P. erythrinus*, we found positive trends in Area 34. In this area, this species are a commercially important species for both the European (Spanish) and African (mainly Moroccan) fleets. These findings contrast with those of previous research studies [24-25, 27, 31]. This may be due to the researchers only taking into account the reported catches for the species and hence not covering illegal, unreported or unregulated catches, which would confirm the results of Pauly and Zeller [57] who suggested that the official catches submitted to the FAO for Area 34 were an underestimate compared to reconstructed catch data.

As we have mentioned above, the fishery for the genus *Pagellus* in the FAO Major Areas 27 and 34 showed a downward trend. Our study area included temperate, tropical and subtropical marine ecoregions. In these ecoregions in the Atlantic Ocean, the overall trends in fishery biomass are downward over the period 1950 to 2014 for a large number of exploited populations of fish and invertebrates [53]. As the fishery biomass decreases, catches can also be expected to decrease, in line with what we have observed in this study, with catches of the *Pagellus* genus falling.

Overall (without considering the results of Arima models of *P.bellottii* due to his not catch in FAO area 27), the goodness of fit statistics of univariate ARIMA models by species and area were better for FAO Major Fishing Area 27. The adjusted models for Area 27 yielded higher variances explained, predictions with fewer errors and better agreement between observed and fitted values. The differences observed in the goodness of fit between the models may be related to three main factors: legal measures, technological developments and scientific criteria. These factors are responsible for the historical changes observed from 1933 to 1986 in the landing patterns by the Spanish demersal fleet in Atlantic and Mediterranean waters [81].

As only the European fleet operates in FAO Major Area 27 and European Union guidelines apply in these waters, the regulations in force, the technological development of the fleets and the scientific criteria are more uniform in this area. These guidelines seek to establish minimum landing sizes, regulate fishing effort, control the introduction of technical advances in gear and conservation of stocks [94]. The negative trends observed in this area reveal progressive overexploitation of fish stocks. This is largely due to the fact that the measures put in place to manage fish resources do not guarantee their sustainability. In the case of the species analysed, at some point in time, minimum landing sizes were below or within the range of variation of the size at first maturity, this increasing the risk of overexploitation and therefore collapse of the stock due to recruitment failure [19]. Moreover, this may occur more continuously in the case of multi-species fish exploitation, where catches include other demersal fish species with different minimum landing sizes and states of maturity, as is the case of *P. acarne* and *P. erythrinus* [24-25, 27]. In this context, it is clearly essential to allow fish to reach their size at first maturity and undergo sex reversal. For this purpose, control measures must be taken in a framework of transparency and cooperation between all the parties involved to ensure successful implementation [95].

On the other hand, it is a more challenging task to achieve uniform management of the fishery in FAO Major Fishing Area 34, as a greater diversity of fleets from different continents operate in the area. Nevertheless, the first steps are being taken through international collaboration agreements, the parties involved controlling the factors related to their fishing activity in the waters of the recipient country. For this purpose, the European Union develops negotiates sustainable fisheries partnership agreements in accordance with the Common Fisheries Policy of the European Union and the United Nations Convention on the Law of the Sea [96]. In these agreements, the EU provides financial and technical support in exchange for fishing rights, generally to southern countries. African countries whose fleets could potentially catch demersal species and have entered into such agreements include Morocco (EU document: 22019A0320(01)), Mauritania (EU document: 32013D0672) and Guinea-Bissau (EU document: 32019R1089). The aim of these agreements is to achieve ocean governance, based on a clear legal framework, coherence/synergy with policies in place, evidence-based sustainability of resources, complete adherence to fishery laws and a coherent joint effort to address illegal [97], unreported and unregulated fishing.

In relation to this, the use of fleet tracking data in combination with landings is a potentially useful tool that can contribute to the adoption of ecosystem-based fishery management of these populations [98], which would help to ensure their sustainability as well as adherence to the legal framework and policies in place. Our future projections indicate that in most cases the behaviour of the fishery remains stable or shows small variations, although in some species such as *P.erythrinus* in FAO Major Fishing Area 34 the trend is downwards while *P. bellottii* and *P.bogaraveo* in the same area is upwards. If our goal is to ensure the sustainability of these populations, management and legislative measures must take into account the social, economic, technical, environmental and biological characteristics of the populations. Finally, various assessments of *Pagellus* populations have recommended reducing fishing mortality, reducing fishing effort and standardising catching methods [31, 99-100] to ensure a sustainable future for this fishery.

Conclusions

Our results in terms of reconstructed catches suggest that there have been significant variations in catches of the *P. acarne, P. bellottii, P.bogaraveo* and *P.erythrinus* studied in FAO Major Fishing Areas 27 and 34, with an overall downward trend. The populations of these species have experienced a progressive increase in fishing intensity. Area 34 was undoubtedly the region with the greatest fishing pressure during the 65 years analysed and *P. bellottii* was the dominant species in both this area and in the entire study area (FAO Major Fishing Areas 27 and 34). This multi-species analysis may help in the development of sustainable management protocols, as it provides information on the historical evolution and state of reconstructed catches of specific species for FAO areas. This study provides data on the behaviour and trends of catches of these exploited fish species in fishing areas that are complex from the management point of view, which could undoubtedly help to achieve proper governance of these resources.

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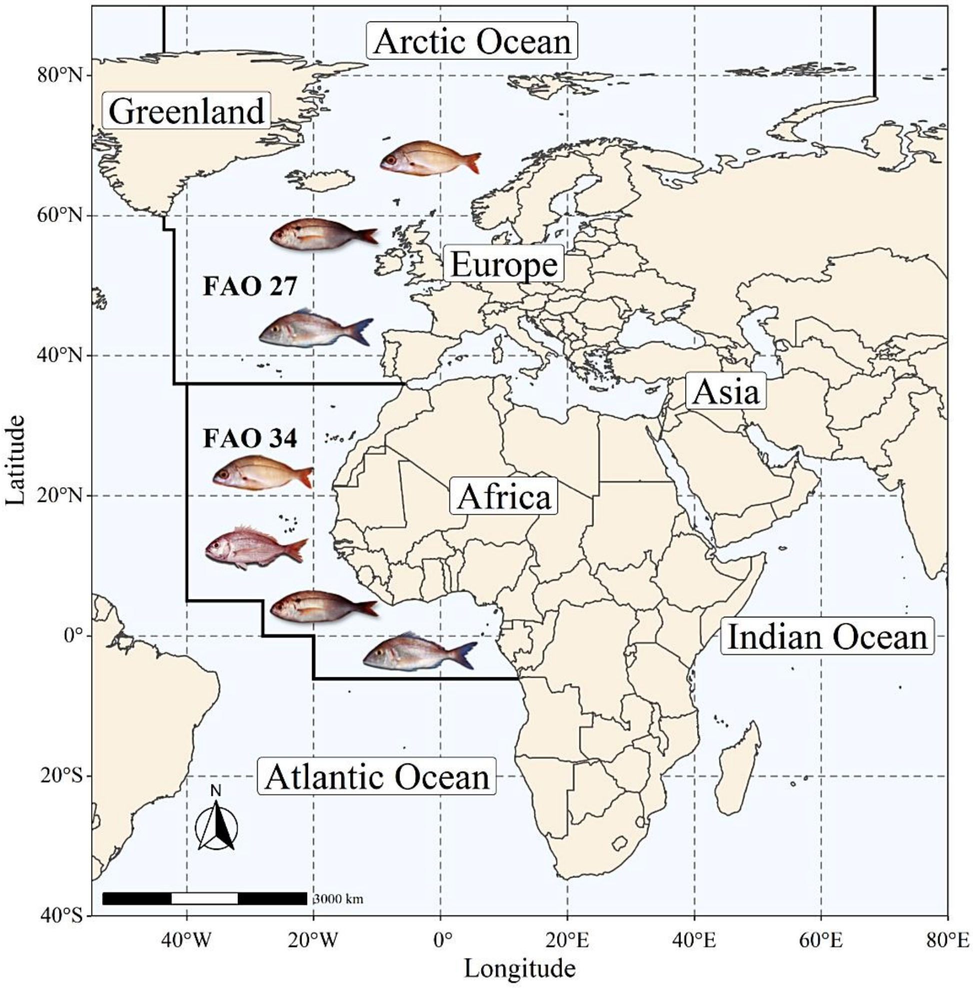

Fig. 1. Study area map, representing the two FAO Major Fishing Areas 27 and 34 together with the study species. From up to down in FAO Major Fishing Area 27: *Pagellus acarne*, *Pagellus bogaraveo* and *Pagellus erytrhinus*. From up to down in FAO Major Fishing Area 34: *Pagellus acarne*, *Pagellus bellottii*, *Pagellus bogaraveo* and *Pagellus erytrhinus*. *Pagellus* genus images from A. M. Arias at www.ictioterm.es.

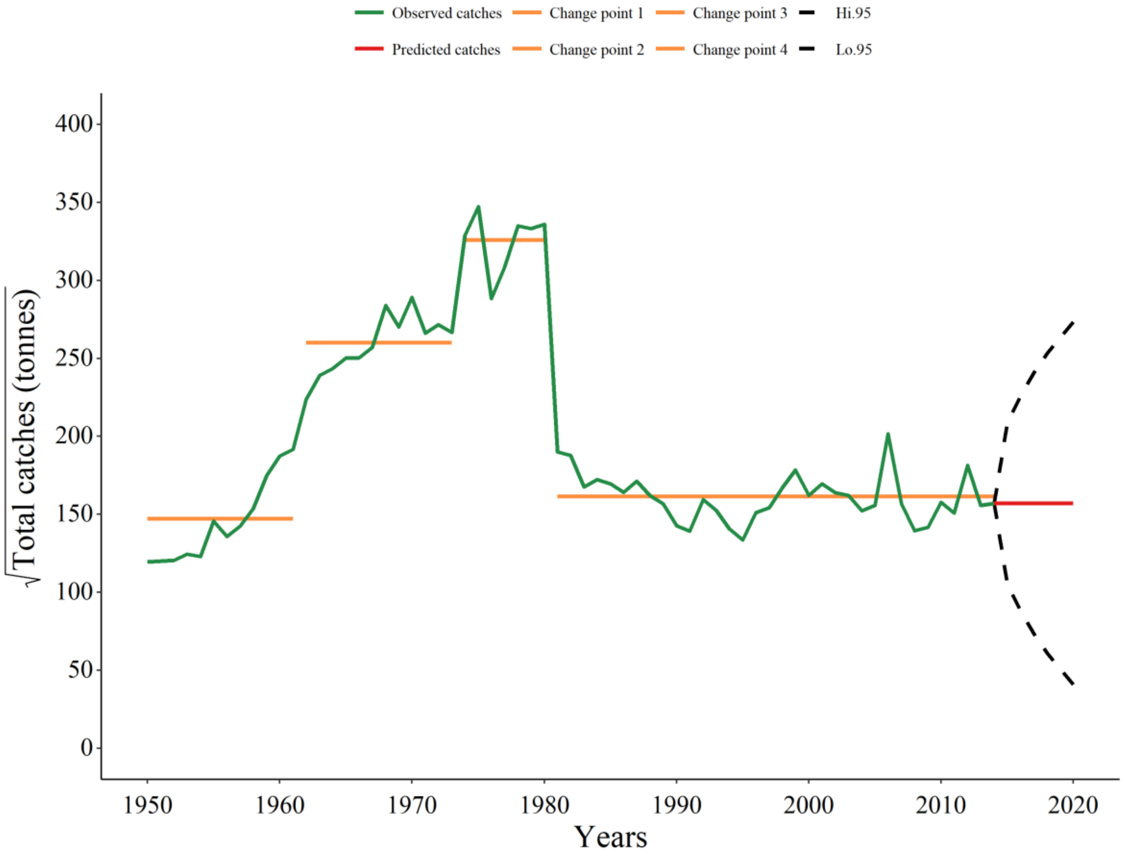

Fig. 2. Global time serie. In green the observed catches (1950-2014), in red predicted cathes (2015-2020) by the ARIMA model (0,1,1) with the lower and upper limits for prediction intervals and in orange the periods detected by means the multiple change point analysis.

Fig. 3. Global time series in FAO Major Fishing Area 27 by species. In green the observed catches (1950-2014), in red predicted cathes (2015-2020) by the ARIMA model with the lower and upper limits for prediction intervals and in orange the periods detected by means the multiple change point analysis. a) *Pagellus sp* (0,1,1), b) *Pagellus acarne* (0,1,3), c) *Pagellus bogaraveo* (2,1,1) and d) *Pagellus erytrhinus* (2,1,0).

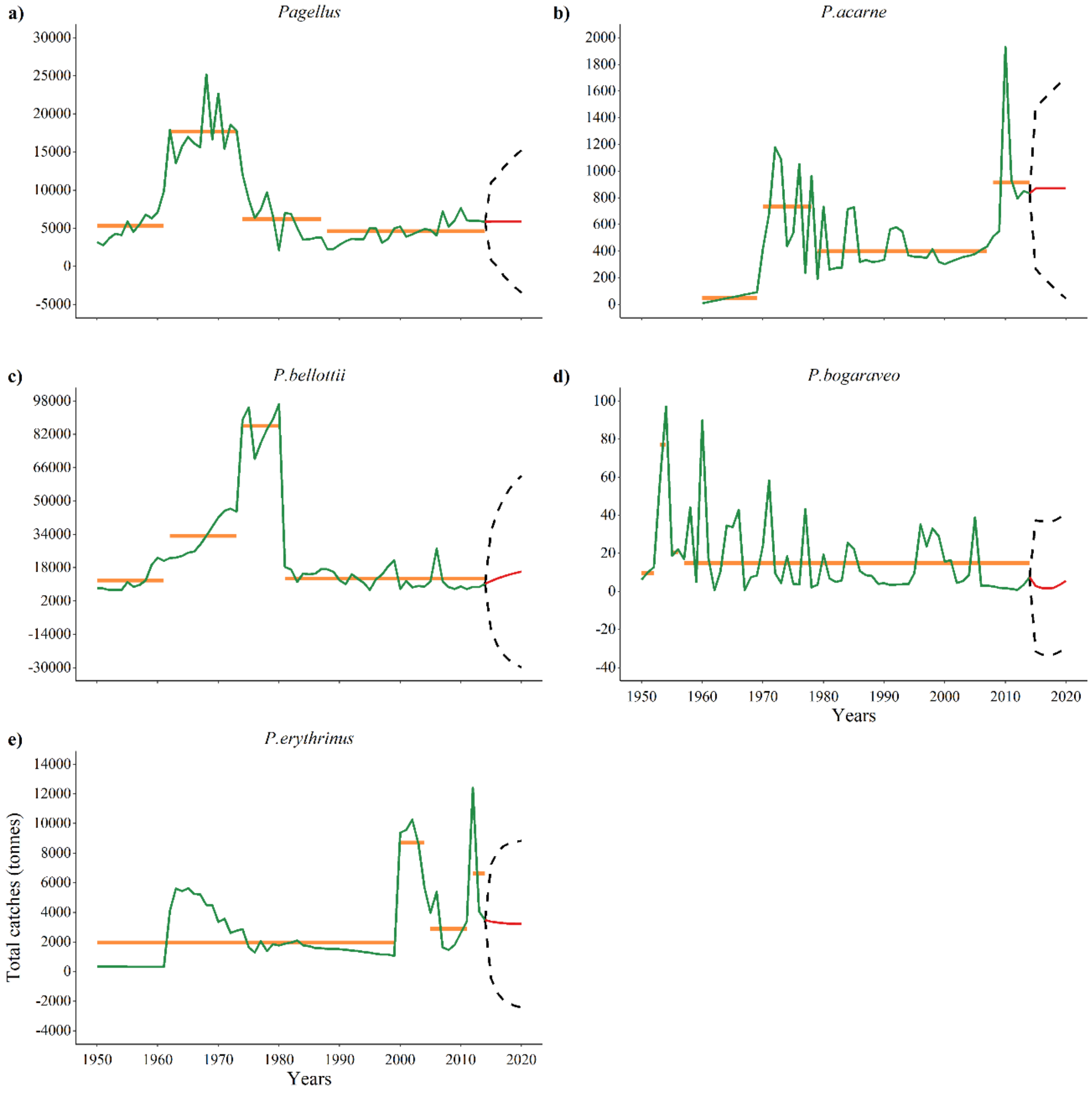

Fig. 4. Global time series in FAO Major Fishing Area 34 by species. In green the observed catches (1950-2014), in red predicted cathes (2015-2020) by the ARIMA model with the lower and upper limits for prediction intervals and in orange the periods detected by means the multiple change point analysis. a) *Pagellus sp* (1,1,0), b) *Pagellus acarne* (0,1,1), c) *Pagellus bellottii* (1,1,1), d) *Pagellus bogaraveo* (5,1,0) and e) *Pagellus erytrhinus* (1,1,1).

Table 1. Estimated parameters (intercept and slope), coefficient of determination (r^2) and p-value for the linear deterministic trends obtained using the least-squares regression method. In bold, parameters and trends significant at the 0.05 significance level. * indicates that the p-values were within the interval [0.06-0.09] presenting a nearly reaching significance. tn = tonnes. A = Appendix.

Name	Area	Initial year	Final year	Intercept (tn)	Slope (tn/years)	r^2	p-value	Figures
Pagellus global	Global (27+34)	1950	2014	**762,594.50**	-363.80*	0.06	0.06	A-5
Pagellus global	27	1984	2014	**157,398.02**	**-76.53**	0.31	**0.00**	A-6 a)
P. sp	27	1950	2014	**86,371.74**	**-42.31**	0.51	**0.00**	A-6 b)
P. acarne	27	1950	2014	**8,769.43**	**-4.13**	0.12	**0.00**	A-6 c)
P. bogaraveo	27	1950	2014	49,380.08	-23.28	0.02	0.31	A-6 d)
P. erythrinus	27	1950	2014	-876.60	0.54	0.00	0.69	A-6 e)
Pagellus global	34	1950	2014	618,949.90*	-294.60*	0.04	0.09	A-7 a)
P. sp	34	1950	2014	**207,258.79**	**-100.78**	0.12	**0.00**	A-7 b)
P. acarne	34	1960	2014	**-17,158.16**	**8.86**	0.16	**0.00**	A-7 c)
P. bellottii	34	1950	2014	535,556.40*	-257.90	0.04	0.10	A-7 d)
P. bogaraveo	34	1950	2014	**803.63**	**-0.40**	0.14	**0.00**	A-7 e)
P. erythrinus	34	1950	2014	**-103,309.00**	**53.54**	0.14	**0.00**	A-7 f)

Table 2. Results of the best ARIMA models with its goodness-of-fit measures. [*] The square-root transformation time serie. tn = tonnes.

Name	Area	Model	Error terms								
			r^2	RMSE (tn)	MAE (tn)	%SEP	E_2	ARV	PI	AIC	KGE′
Pagellus global[*]	Global (27+34)	(0,1,1)	0.84	25.83	15.31	13.33	0.83	0.16	0.01	602.83	0.92
P. sp	27	(0,1,1)	0.76	546.72	357.91	21.80	0.76	0.24	0.08	993.63	0.84
P. acarne	27	(0,1,3)	0.47	166.45	106.78	28.92	0.44	0.55	0.29	847.00	0.66
P. bogaraveo	27	(2,1,1)	0.54	2,421.52	1,254.56	74.59	0.50	0.50	0.23	1,188.96	0.73
P. erythrinus	27	(2,1,0)	0.16	195.87	68.93	97.89	0.09	0.90	0.31	864.66	0.33
P. sp	34	(1,1,0)	0.78	2,561.42	1,594.00	34.10	0.77	0.23	0.18	1,191.39	0.88
P. acarne	34	(0,1,1)	0.30	302.92	181.28	66.42	0.25	0.74	0.26	775.71	0.51
P. bellottii	34	(1,1,1)	0.75	11,991.28	5,760.89	49.34	0.74	0.25	0.06	1,392.39	0.84
P. bogaraveo	34	(5,1,0)	0.30	16.71	12.55	99.56	0.28	0.72	0.54	558.18	0.42
P. erythrinus	34	(1,1,1)	0.49	1,915.82	882.03	68.39	0.47	0.53	0.13	1,157.30	0.65