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Biology and Spatio-temporal Distribution of *Pagellus Erythrinus* (Linnaeus, 1758) In the Western Algerian Coast (Western Mediterranean-Alboran Sea)

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Abstract

The common pandora (*Pagellus erythrinus*) is among demersal species most targeted by Algerian trawlers. This study constitutes a pioneering research effort in Algeria, conducted in the southeastern Alboran Sea (western Mediterranean) and based on fishery-independent data from a decade-long series of bottom trawl surveys conducted according to the MEDITS protocol, during which 269 fishing hauls were completed and 2667 individuals collected. The objective is to analyze spatiotemporal distribution and abundance indices. Results indicate the species is more abundant in the first 50 meters, corresponding to the upper continental shelf, with an increasing trend of biomass indices in the last three years (>20 kg/km²). For effective management and conservation, identifying key habitats for recruits and spawners highlighted two regional hotspots where fishing-restricted zones are advisable. In addition, several biological characteristics were examined in 1,286 individuals: maturity analysis revealed a predominance of females; growth was found to be isometric; combined length–weight relationships were calculated for both sexes; and the spawning season was determined to occur between June and August. These baseline results provide inputs for stock assessments and precautionary management. The paper underscores the value of long-term, standardized, fishery-independent surveys for sustainable exploitation and biodiversity protection in western Mediterranean.

Introduction

Sparidae species are highly valued by Algerian consumers, particularly the common pandora (*Pagellus erythrinus*), a demersal fish of considerable commercial importance. Reported landings of this species declined markedly, from 1,427 tons in 2005 to 485 tons in 2024 (Ministère de la Pêche et des Productions Halieutiques [MPPH], 2024). A comparable decline has also been documented across the Mediterranean basin, where the species is subject to overexploitation (Lteif et al., 2020).

Within this context, the sparid family is of particular importance, especially *Pagellus erythrinus*, which is targeted by both trawlers and small-scale vessels, rendering it vulnerable to overexploitation. As early as 1955, Dieuzeide et al. described the morphometric characteristics of this species along the Algerian coast. Since then, only a limited number of studies have been carried out, including those by Cherabi (1987) in the Bay of Algiers, Rouidi (2011) in the Bay of Jijel (eastern Algeria), Mahdi et al. (2018) in the Bay of Oran (western Algeria), and more recently

Rachedi et al. (2025) in the far eastern part of the Algerian coast.

Studies on *Pagellus erythrinus* in the Mediterranean have primarily focused on three interrelated themes: growth, reproduction, and exploitation patterns. Early contributions on growth, such as those by Girardin (1981) in the Gulf of Lion and Rijavec & Zupanović (1980) in the Tyrrhenian Sea, provided baseline estimates of von Bertalanffy growth parameters. Subsequent research has revealed marked regional variability. Faster growth is generally observed in warmer and more productive environments, such as Tunisian (Zarrad et al., 2010; Fassatoui et al., 2012) and Turkish waters (Özvarol, 2016), whereas slower growth has been reported in cooler western Mediterranean sites, including Spain (Valdés et al., 2004) and Italy (Busalacchi et al., 2014).

The reproductive biology of *Pagellus erythrinus* has also been extensively investigated, with general consensus pointing to a spawning peak between spring and early summer. This pattern has been reported in Tunisia (Ghorbel, 1997; Jarboui et al., 1998; Ali et al., 2014), Algeria (Rachedi et al., 2025), Egypt (Al-Zahaby et al., 1994; Mehanna & Fattouh, 2009), and Greece (Mytilineou, 1989; Klaoudatos et al., 2004), while a somewhat extended spawning season has been observed in Cretan waters (Somarakis & Machias, 2002). Turkish populations show even greater variability across regions (Metin et al., 2011; Uyan et al., 2020), likely reflecting local environmental conditions or fishing-related pressures. Across studies, the protogynous hermaphroditism of *P. erythrinus* has been consistently confirmed, emphasizing the management importance of preserving older, larger males to sustain balanced sex ratios and reproductive potential.

Compared with growth and reproduction, research on the distribution and habitat use of *Pagellus erythrinus* has been more limited. In the Tyrrhenian Sea, Angiulli et al. (2016) and Rossi et al. (2019) reported strong associations with sandy–muddy substrates at mid-shelf depths, while recent surveys in Libya (Elbaraasi, 2019) and Lebanon (Lteif et al., 2020) have extended the known eastern distribution of the species. Comparative studies along the Atlantic margin, in Portugal (Coelho et al., 2010) and the Canary Islands (Pajuelo & Lorenzo, 1998), further indicate slight differences in demographic traits relative to Mediterranean populations, suggesting that local environmental conditions strongly shape life-history parameters.

Fisheries exploitation emerges as a recurrent theme across the region. Several studies from Tunisia (Zarrad et al., 2010; Fassatoui et al., 2012) and Egypt (Wagdi et al., 1998) have raised concerns about growth overfishing, noting that lengths at first capture frequently fall below lengths at first maturity. Comparable findings in Türkiye (Özaydın, 1997; Hoşsucu & Çakır, 2003) suggest that exploitation pressure is consistently high throughout much of the Mediterranean basin.

The present study constitutes the first of its kind in Algeria and is based on a ten-year time series of bottom trawl surveys dedicated to the assessment of demersal resources. This work was made possible through the acquisition of the research vessel *Belkacem Grine* in 2011. The study area focuses on the western part of the Algerian coast, which forms an integral part of the Alboran Sea (Figure 1). This region encompasses the widest continental shelf within the Algerian basin and is of considerable importance in terms of marine biodiversity.

The present work focuses on the spatio-temporal analysis of abundance indices, the identification of essential fish habitats (EFH) for the common pandora, and the mapping of density hotspots for both spawners and recruits, with the ultimate goal of enhancing knowledge of the species and informing the development of an appropriate management plan. Additional biological features are also addressed, including length–frequency distributions (LFDs), length–weight relationship parameters, sex ratio, and spawning period.

Materials and Methods

From 2012 and 2023, the National Center for Research and Development of Fisheries and Aquaculture conducted annual bottom trawl surveys along the Algerian coast using the research vessel *BELKACEM GRINE*. Data for 2018 are unavailable due to funding constraints, whereas the absence of data in 2020 is attributable to the COVID-19 pandemic. The study covered the area from the Algerian-Moroccan border to the tip of Kef Lasfar (Figure 1).

The survey protocol follows the standardized methodology adopted by all Mediterranean countries since 1994 (Spedicato et al., 2019), namely the MEDITS program (Mediterranean International Trawl Survey; Bertrand et al., 2002), and is also consistent with the GFCM protocol for scientific surveys in the Mediterranean Sea (Carpentieri et al., 2020). The fishing gear used is a standardized bottom trawl (GOC73) with a 20 mm stretched mesh codend. According to the SIMRAD PX system, the average horizontal and vertical net openings are 16 m and 1.9 m, respectively. All hauls are conducted during daylight hours at an average towing speed of three knots, with a duration of 30 minutes for depths shallower than 200 m and one hour for depths exceeding 200 m.

Sampling stations were selected following a stratified random sampling design (MEDITS Working Group, 2017), with five depth strata defined between 20 and 800 m: stratum A, 20–50 m (603 km²); stratum B, 51–100 m (1892 km²); stratum C, 101–200 m (1254 km²); stratum D, 201–500 m (2820 km²); and stratum E, 501–800 m (1535 km²). In total, 269 hauls were carried out between 2012 and 2023, covering an area of 8104 km².

The total catch was sorted, and all species were identified, counted, weighed, and recorded. When a species, or a fraction of a species, was particularly abundant, a subsample was taken to allow all individuals to be measured. Target species were then separated from the catch, and their total length was measured to the nearest centimeter using an ichthyometer. The total weight of each individual within the same species was determined with a MAREL M1100 PL 2262 marine scale, with a capacity of 1.5–3 kg and an accuracy of 0.5–1 g.

For the species under study, the entire catch was sorted, weighed, and counted. The total length of all individuals was recorded, except when the catch was particularly large, in which case a sampling factor of two was applied, meaning that only half of the total common pandora catch was measured. For the other biological parameters (individual weight, sex, and maturity), a representative subsample encompassing all size ranges was taken.

A stratified sample was collected according to size class, and the sex and sexual maturity stage of each fish were determined by visual inspection. Individuals were classified into five macroscopic maturity stages following the MEDITS protocol (Bertrand, 1999): (i) undetermined, (ii) immature, (iii) maturing, (iv) mature/spawner, and (v) spent. In hermaphroditic species, individuals undergoing sex change were assigned to the sex corresponding to the more developed gonads (MEDITS Working Group, 2017).

LFDs were constructed for each year and displayed as histograms. Minimum, maximum, quartile, and median lengths were estimated and graphically represented using box plots. The same parameters were also estimated for each depth stratum between 0 and 200 m.

Spearman's correlation test was applied to assess the relationship between mean lengths across depth strata and to determine whether size variations occurred over the years. A t-test was then performed to evaluate differences in mean size between males and females. Finally, analysis of variance (ANOVA) was used to test for statistically significant differences in mean length among years.

The length–weight relationship of common pandora was expressed as $W = a\,LT^b$, where W is the body weight, LT is the total length, and a and b are the parameters estimated separately for males, females, and sexes combined. The type of allometry was evaluated using a t-test, by comparing the calculated slope (P_0=b) and a theoretical slope (P=3) (Froese, 2006). An analysis of covariance (ANCOVA) was then applied to test for differences between sexes (Sokal & Rohlf, 1995). The sex ratio of *Pagellus erythrinus* was examined by length class, excluding hermaphroditic individuals from this analysis. For each sex, percentages were calculated after grouping individuals into 1 cm length classes.

Sexual maturity stages were assigned to each individual, and the dominant stage for each sex was

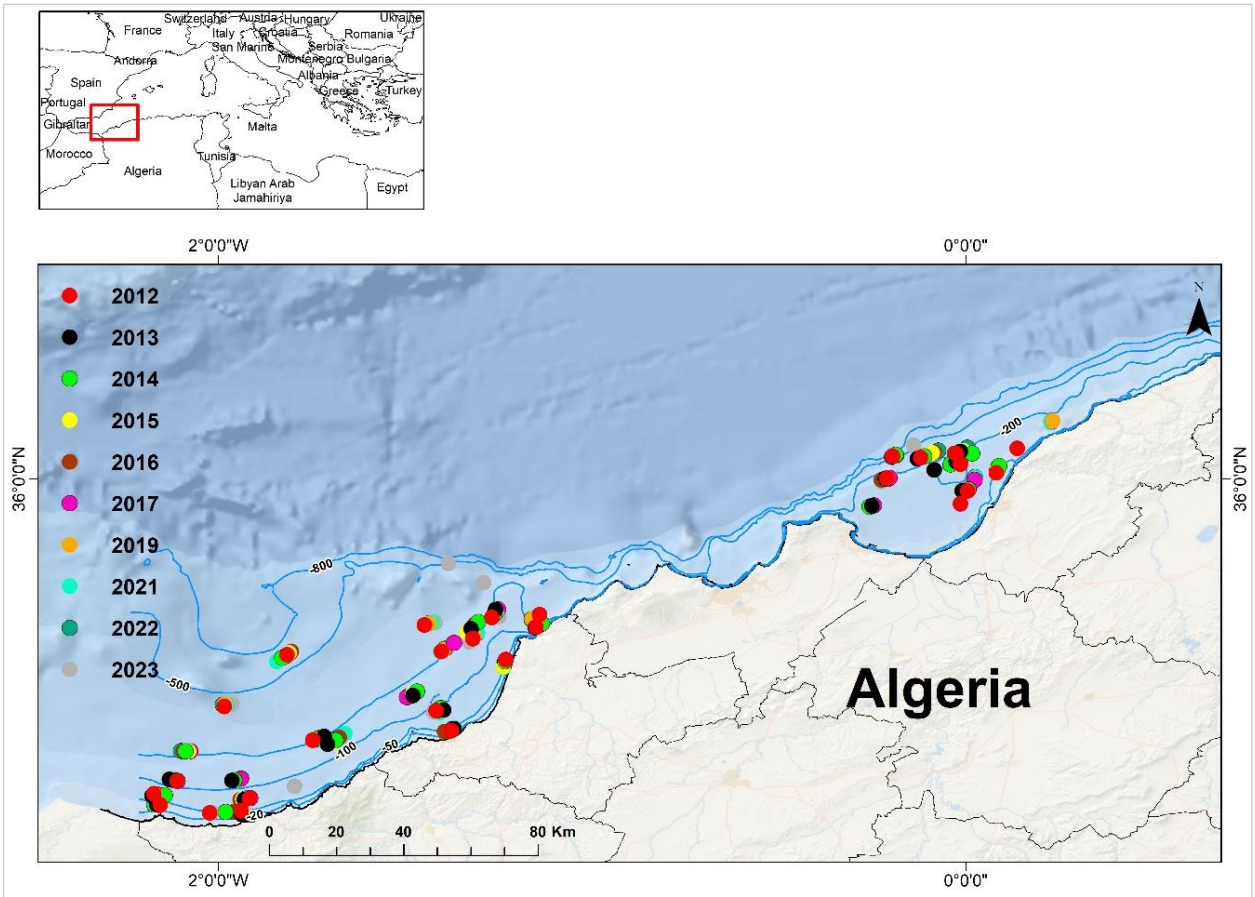

Figure 1. Map of the study area.

identified by comparing the maturity index across stages over all years in which maturity data were collected during the bottom trawl surveys.

Using the formula of Souplet (1996), the biomass index (BI, kg/km²) and density index (DI, n/km²) were calculated for each depth stratum, as well as for all strata of the continental shelf and slope in the study area. These indices were also estimated separately for recruits and spawners, with individuals equal to or larger than 16.4 cm (the size at first sexual maturity; Rouidi, 2011) classified as spawners. Data analysis was performed using the JRC MEDITS R script (Mannini, 2020).

The Kruskal–Wallis test was applied to compare median biomass and density values across depth strata, as the assumption of normality was rejected by the Shapiro–Wilk test. Spearman's rank correlation coefficient (r_s) was then used to assess temporal correlations in the computed indices by depth stratum.

To monitor the spatial distribution of the species, assess the temporal evolution of biomass indices, and identify EFH in the study area over ten years of bottom trawl surveys, the ordinary kriging method (Isaaks & Srivastava, 1989) was applied. This geostatistical interpolation technique incorporates spatial autocorrelation to predict species distribution across the entire study area (Morfin et al., 2012). In this analysis, the density index (n/km²) was used as the input variable. The variogram was automatically fitted with the *autofitVariogram* function from the automap package (Hiemstra et al., 2009), which compares several theoretical models (spherical, exponential, Gaussian, and linear) and selects the best fit to the experimental variogram based on a least-squares criterion. Using the fitted variograms, the annual spatial distribution of abundance was mapped on a 1 km² grid. In addition, the spatial distributions of both spawners and recruits were mapped.

In a second phase, hotspots for spawners and recruits of common pandora were identified using the Getis–Ord Gi* method (Getis & Ord, 1992). The annual maps produced over the ten-year time series were then synthesized into a single map illustrating the spatial distribution of *P. erythrinus* hotspots across the study area. All geostatistical analyses were conducted in R (General Fisheries Commission for the Mediterranean [GFCM], 2023).

Results

Over ten years of bottom trawl surveys, 269 fishing hauls were conducted in the western Algerian coast, from Mostaganem to Ghazaouet (Table 1). A total of 2667 individuals were measured, with total lengths ranging from 7.5 to 33.8 cm and a mean length of 19.47 cm. Females ranged from 11.9 to 31.1 cm, with a mean length of 19.19 cm, while males ranged from 10.5 to 33.8 cm, with a mean length of 20.39 cm. The LFDs are presented in Figure 2.

Changes in the mean length of *P. erythrinus* over the ten-year study period are shown in Figure 3. Analysis of variance revealed significant differences in mean length among years ($P<0.05$), although no significant temporal correlation was detected ($r_s=0.18$, $P=0.57$). The median sizes in strata A and B were similar; however, stratum C (101–200 m) exhibited larger median sizes (Figure 4). The size range observed in stratum C was narrower than in strata A and B (20–100 m). Median size was significantly correlated with depth ($r_s=0.18$, ($P<0.05$)).

The t-test revealed a significant difference in mean size between males and females ($P<0.05$); therefore, the parameters of the length–weight relationship of *P. erythrinus* were estimated separately for each sex, and combined sexes (Table 2). For males, the slope of the length–weight relationship did not differ significantly from the isometric value of 3 (t-test, $P=0.065$), indicating isometric growth. In contrast, females and sexes combined dataset showed significant deviations from isometry (t-test, $P=0.015$), revealing negative allometric growth.

The sex ratio was skewed toward females in the 13–24 cm size range (Figure 5). Beyond this range, the proportion of males increased progressively, with dominance alternating between the two sexes. From 32 cm onwards, however, all individuals were exclusively male.

The density index estimated for each gonadal maturity stage in 1,286 individuals of *P. erythrinus* (Figure 6) revealed interannual and sex-related variations, consistent with the female dominance observed in the sex ratio. With the exception of 2012 and 2022, when sample sizes were very low, the dominant maturity stages across years were stages 3 and 4, corresponding to the spawning and post-spawning periods.

Table 1. Number of hauls by depth strata and year of survey

Strata	2012	2013	2014	2015	2016	2017	2019	2021	2022	2023	Total
A	6	5	5	5	5	5	6	6	6	6	55
B	7	6	6	6	6	6	6	6	6	7	62
C	5	7	7	7	7	7	8	8	8	8	72
D	7	4	5	5	5	5	7	7	7	8	60
E	2	1	2	2	2	2	2	2	2	3	20
Total	27	23	25	25	25	25	29	29	29	32	269

On the continental shelf, the density index ranged from 67.43 to 386.84 n/km² in stratum A (20–50 m), whereas in stratum B (51–100 m) it varied between 48.27 and 222.18 n/km² (Table 3). Regarding the biomass index (Table 4), values in stratum A (20–50 m) ranged from 6.28 to 37.25 kg/km², whereas in stratum B (51–100 m) they varied between 3.05 and 18.70 kg/km².

For strata C (101–200 m) and D (201–500 m), the biomass and density indices were extremely low, ranging from 0.06 to 0.40 kg/km² and from 0.83 to 3.26 n/km², respectively. Notably, the temporal evolution of the abundance index in stratum A (20–50 m) revealed two distinct phases: prior to 2020, when the mean biomass index over seven years did not exceed 11 kg/km², and after 2020, when the average value was greater than 29 kg/km².

In stratum A (20–50 m), the temporal variation in the calculated indices was significant and showing a positive trend for both abundance indices DI (r_s=0.61, P=0.035) and BI (r_s=0.74 and P=0.005). In contrast, for stratum B (51–100 m), no temporal correlation was observed for density index (r_s=0.04, P=0.90), while for biomass index, we observed a non-significant negative trend (r_s=-0.25, P=0.43). Significant differences were identified in both the density and biomass indices when comparing values across depth strata.

Density and biomass indices by haul for spawner individuals are presented in Figures 7 and 8. Figure 9 illustrates the spatial distribution of *P. erythrinus* spawners over the past ten years. The results show that the presence of the species varied across years. During the early period (2012–2014), the biomass index was distributed relatively homogeneously across most of the study area, with only a few localized points showing higher or lower values. Between 2015 and 2017, biomass increased, followed by a marked decline in 2019.

Conversely, the last three years of the study (2021–2023) revealed a clear and dense distribution of the species, with higher abundance values, particularly in the extreme west around the Ghazaouet region. Notably, 2023 also exhibited a more pronounced spatial distribution in the central-eastern part of the area, corresponding to the Gulf of Arzew.

The annual distribution of common pandora spawners highlighted three major hotspot areas,

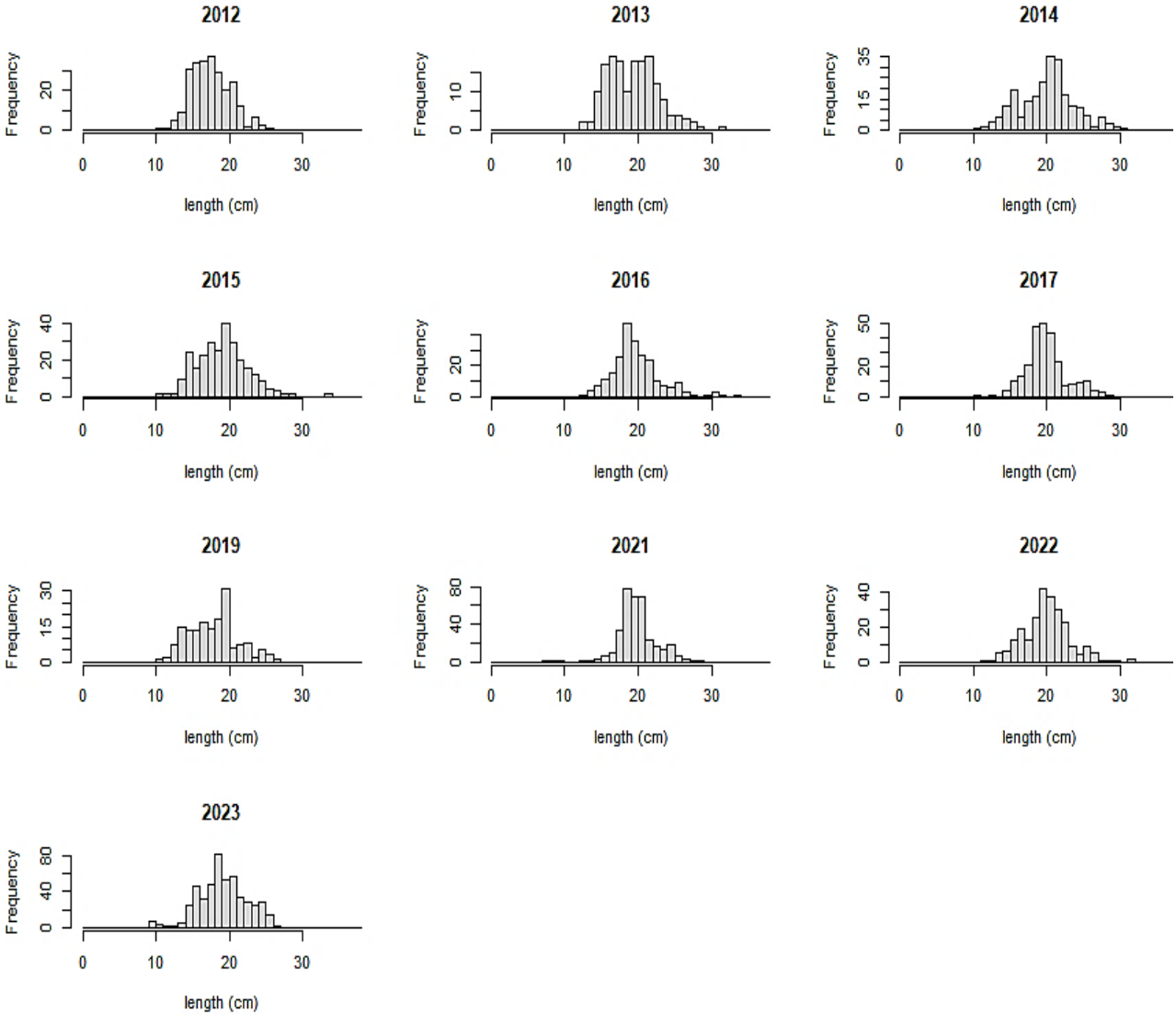

Figure 2. Length frequency distributions of *P. erythrinus* by years.

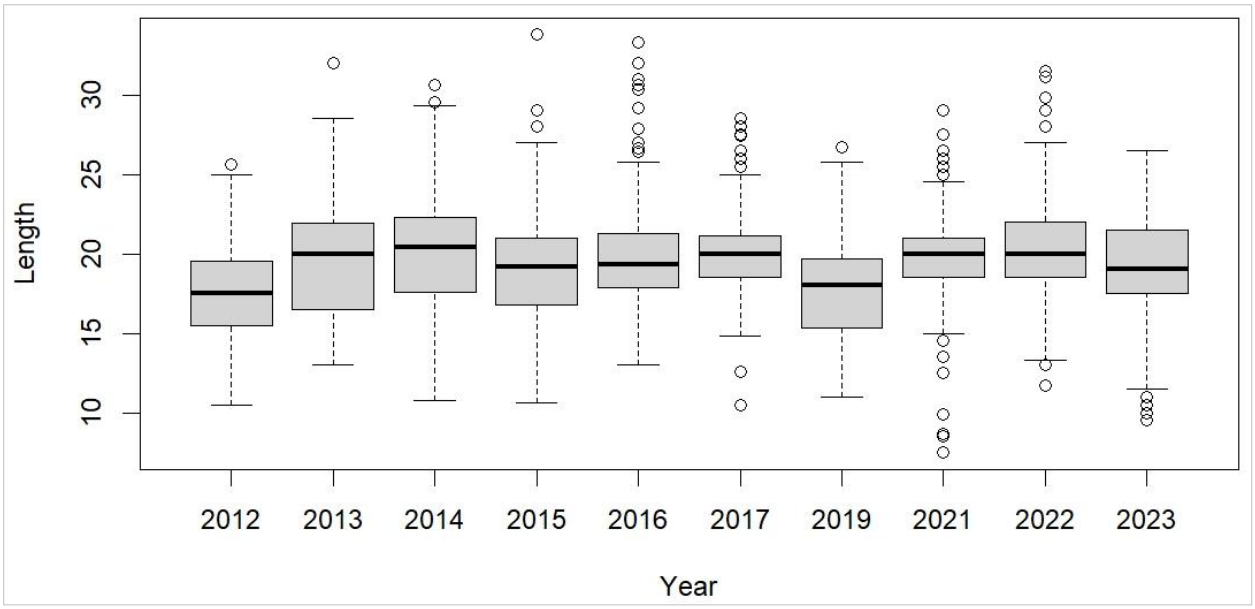

Figure 3. Box plot of total length for *P. erythrinus* by years.

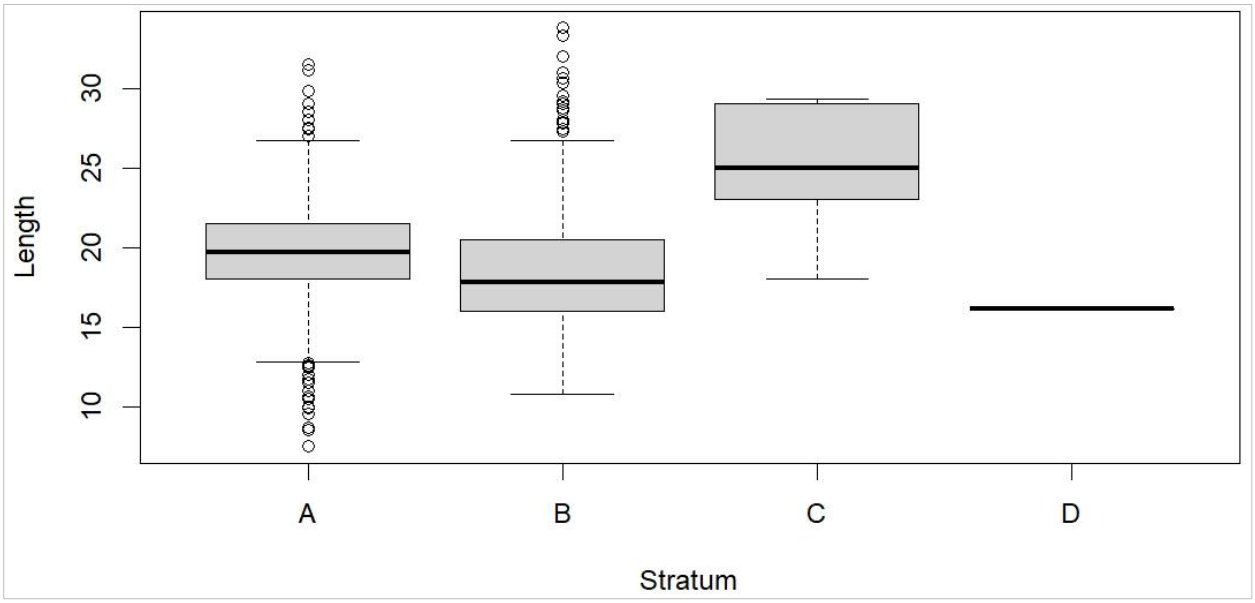

Figure 4. Boxplot of length distribution by depth strata for *P. erythrinus*.

Table 2. Parameters of length-weight relationships for males, females and combined sexes of *P. erythrinus*

Parameters	Female	Male	Combined Sexes
a	0.0155	0.0147	0.0149
b	2.9248	2.9406	2.9358
r^2	0.939	0.969	0.957
t	2.4338	1.8521	2.6975
P	0.015	0.0655	0.0071
n	502	191	730
SE (*b*)	0.0308	0.0320	0.0237
Type of growth	Negative allometry	Isometric	Negative allometry

delineated by red polygons in Figure 10. The first hotspot (192.20 km²) is located in the extreme west of the study area, corresponding to the western part of the Gulf of Ghazaouet. The second hotspot (200.19 km²) lies on the western side of the Bay of Arzew, while the third is situated in the Bouzedjar region, in the central part of the study area, covering 72.85 km².

In contrast, the distribution of recruits of *P. erythrinus* (Figure 11) was much less pronounced. Nevertheless, a few notable areas were identified, particularly in the extreme western part of the Gulf of Ghazaouet (75.79 km²) and on the western side of the Gulf of Arzew.

The synthesis of results over the study period for both spawners and recruits of *Pagellus erythrinus* identified two areas within the first 50 m depth stratum that can be considered EFH for this species (Figure 12). The first, covering 101.12 km², is located in the extreme west of the study area in the Ghazaouet region near the Algerian–Moroccan border, while the second is situated on the western edge of the Gulf of Arzew.

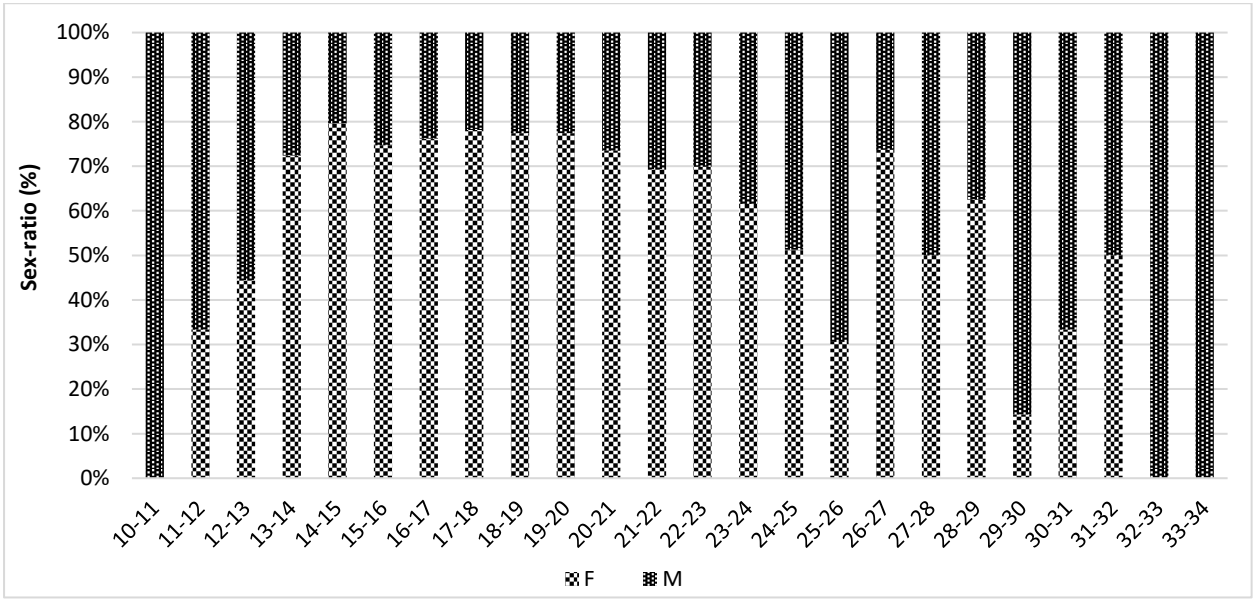

Figure 5. Sex distribution by length for *P. erythrinus*.

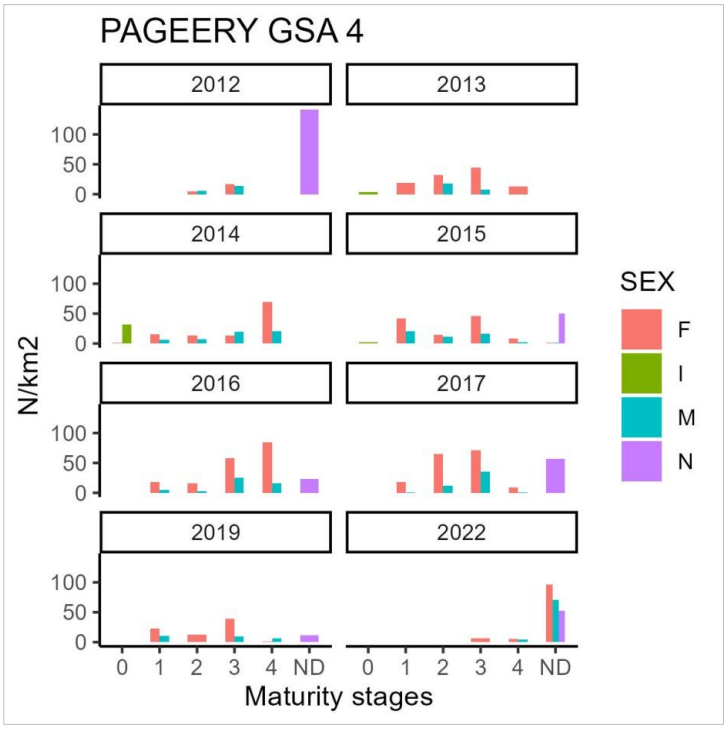

Figure 6. Interannual trends in the density index (n/km²) of *P. erythrinus* by sexual maturity stage.

Table 3. Density index and standard deviation (SD) of *P. erythrinus* by depth strata, shelf, slope, total area for each year of surveys (2012-2023)

Strata	Density index (n/km²)	Surveys									
		2012	2013	2014	2015	2016	2017	2019	2021	2022	2023
A (20-50 m)	Mean	121.94	67.43	97.10	154.58	164.26	133.03	72.94	276.16	164.97	386.84
	SD	67.77	24.19	32.25	69.26	79.78	71.72	25.83	161.22	100.10	238.30
B (51-100 m)	Mean	87.35	89.92	180.89	106.11	175.48	125.17	48.27	90.98	222.18	95.73
	SD	61.07	52.20	89.72	84.87	126.63	150.52	42.40	81.43	198.47	85.17
C (101-200 m)	Mean	3.26	0.00	1.92	0.00	1.93	0.00	0.00	0.83	0.00	0.00
	SD	3.51	0.00	1.03	0.00	1.08	0.00	0.00	0.78	0.00	0.00
D (201-500 m)	Mean	1.01	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	0.00
	SD	0.90	0.00	0.00	0.00	1.18	0.00	0.00	0.00	0.00	0.00
E (501-800 m)	Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	SD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Shelf (20-200 m)	Mean	212.55	157.35	279.91	260.68	341.67	258.19	121.21	367.97	387.15	482.57
	SD	91.29	57.53	95.35	109.55	149.67	166.73	49.65	180.62	222.28	253.06
Slope (201-800 m)	Mean	1.01	0.00	0.00	0.00	1.40	0.00	0.00	0.00	0.00	0.00
	SD	0.9	0.00	0.00	0.00	1.18	0.00	0.00	0.00	0.00	0.00
Total (20-800 m)	Mean	98.87	72.79	129.49	120.60	158.82	119.44	56.07	170.23	179.10	223.24
	SD	42.23	26.62	44.11	50.68	69.24	77.13	22.97	83.56	102.83	117.07

Note: Values of 0 indicate the absence of individuals.

Table 4. Biomass index and standard deviation (SD) of *P. erythrinus* by depth strata, shelf, slope, total area for each year of surveys (2012-2023)

Strata	Biomass index (kg/km²)	Surveys									
		2012	2013	2014	2015	2016	2017	2019	2021	2022	2023
A (20-50 m)	Mean	8.88	6.60	10.01	13.06	16.18	13.82	6.28	29.97	20.63	37.25
	SD	4.57	3.41	4.04	7.64	9.30	8.21	3.03	17.86	13.43	21.74
B (51-100 m)	Mean	7.68	8.63	18.70	8.25	17.91	11.39	3.05	8.80	10.96	6.68
	SD	3.12	3.89	9.20	6.40	13.26	12.31	2.71	7.88	9.79	5.87
C (101-200 m)	Mean	0.29	0.00	0.39	0.00	0.40	0.00	0.00	0.25	0.00	0.00
	SD	0.31	0.00	0.30	0.00	0.25	0.00	0.00	0.24	0.00	0.00
D (201-500 m)	Mean	0.09	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00
	SD	0.08	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00
E (501-800 m)	Mean	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	SD	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Shelf (20-200 m)	Mean	16.86	15.23	29.10	21.31	34.50	25.20	9.33	39.03	31.60	43.93
	SD	5.54	5.17	10.05	9.97	16.20	14.80	4.07	19.53	16.62	22.52
Slope (201-800 m)	Mean	0.09	0.00	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00
	SD	0.08	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00
Total (20-800 m)	Mean	7.85	7.05	13.46	9.86	16.00	11.66	4.32	18.05	14.61	20.32
	SD	2.56	2.39	4.65	4.61	7.49	6.84	1.88	9.03	7.69	10.42

Note: Values of 0 indicate the absence of individuals.

Discussion

The most recent studies on *Pagellus erythrinus* along the Algerian coast have focused on its reproductive biology; however, their findings are constrained by significant methodological limitations. In both cases, sampling was limited to a single annual cycle, thereby preventing the evaluation of interannual variability. Furthermore, all specimens were collected from commercial landings, introducing a substantial risk of size- and sex-selective bias due to fishing gear and effort. These limitations warrant caution in interpreting the reported differences between sites.

In addition to these sampling constraints, methodological inconsistencies—ranging from length–frequency analyses to otolith-based estimates—further complicate direct comparisons. Together, these limitations underscore the need for multi-year, standardized, and fishery-independent sampling programs designed to produce more reliable assessments of *P. erythrinus* populations.

The maximum total length recorded in this study was 31.1 cm for females and 33.8 cm for males, which is lower than the maximum size reported by Mahdi et al. (2018) in the same study area (38 cm). In the adjacent region, on the western side of GSA 05 (Balearic Islands), Guijarro et al. (2014) documented a maximum size of 31.5 cm. larger individuals have been reported elsewhere: 40 cm in Lebanese waters (Lteif et al., 2020), 48 cm in the Adriatic (Busalacchi et al., 2014), and, in Corsica and the Gulf of Lion, 27.5 cm in 2022 and 44.5 cm in 2017, respectively (Certain et al., 2024). The observed variability in maximum size may be attributed to differences in fishing gear, targeted fishing areas, bottom type, fishing season, prevailing environmental conditions, and stock status.

The parameters of the length–weight relationship indicate negative allometric growth and are broadly consistent with values reported in the regional literature for the Mediterranean and Eastern Atlantic. Similar results were obtained in Algeria by Mahdi et al. (2018)and Rachedi et al. (2025). This pattern is closely linked to the condition factor, which varies according to

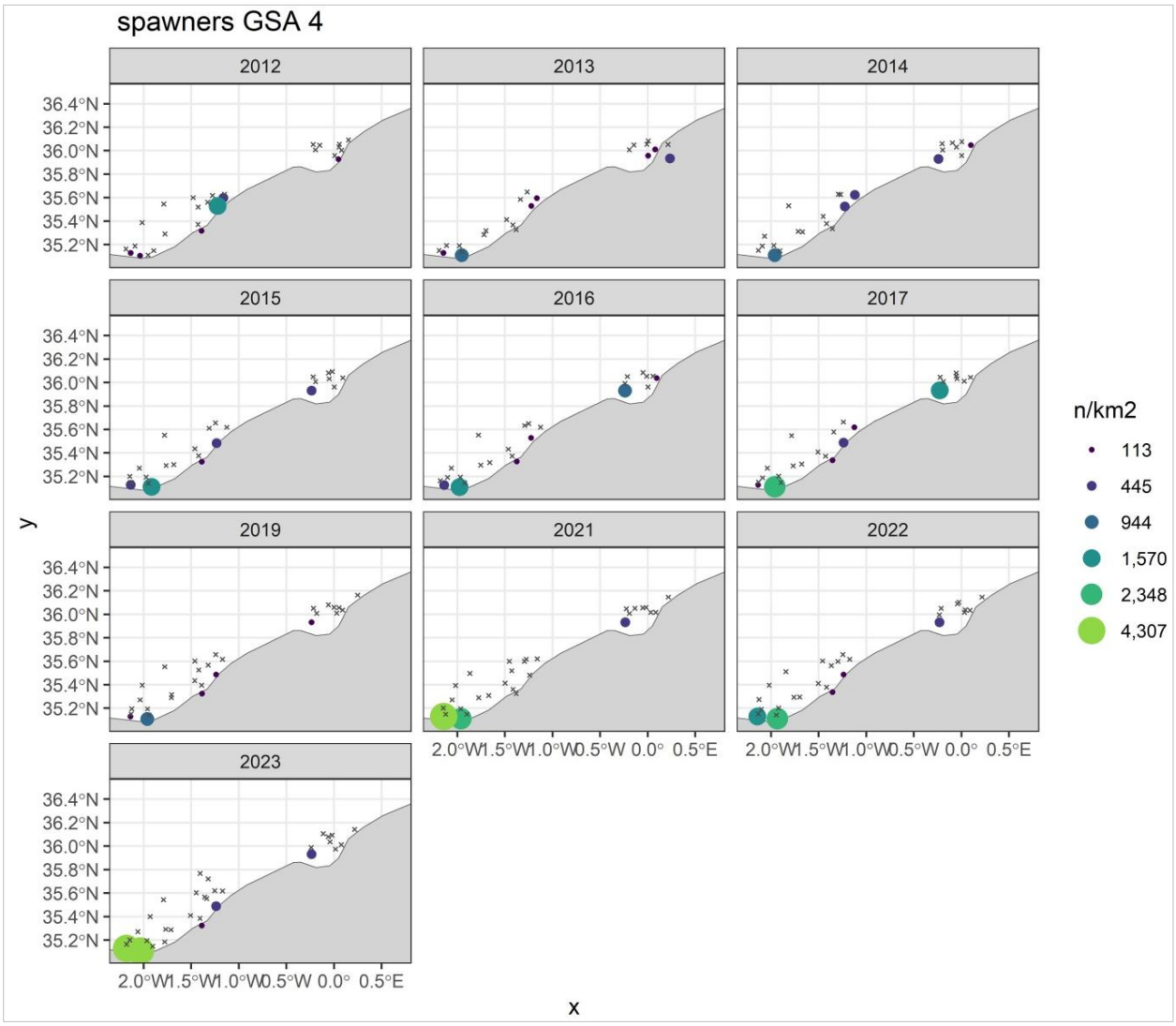

Figure 7. Density index (n/km²) by hauls for spawners of common pandora (2012-2023) in the Western part of Algeria coasts.

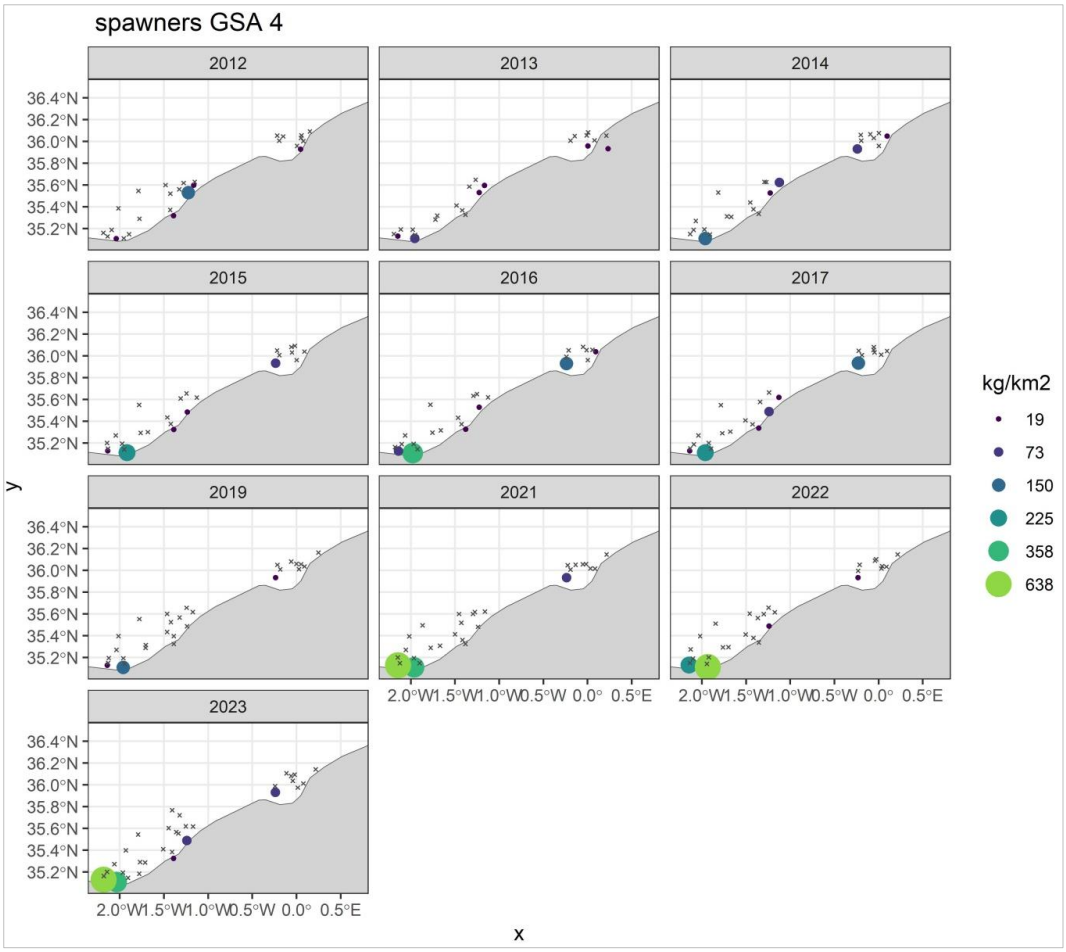

Figure 8. Biomass index (kg/km²) by hauls for spawners of common pandora (2012-2023) in the Western part of Algeria coasts.

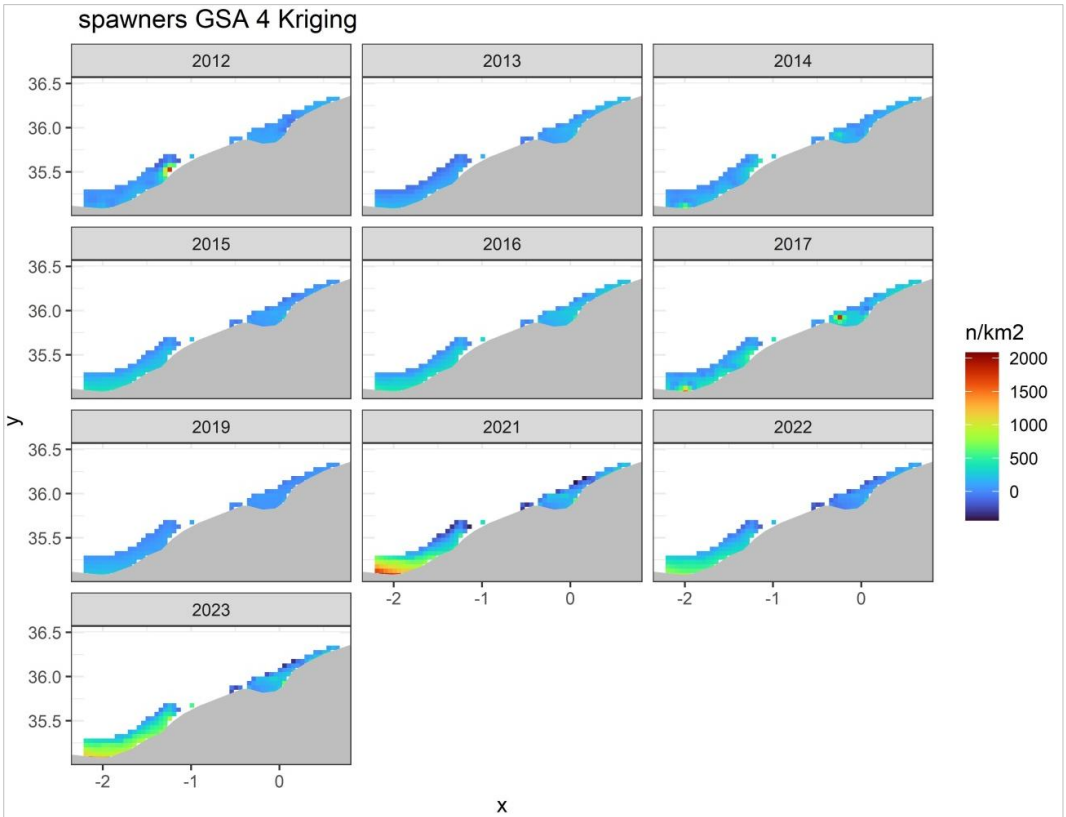

Figure 9. Kriged Annual Density Maps (kg/km²) for spawners of *P. erythrinus* (2012-2023) in the Western part of Algeria coasts.

sex, region, and season. The isometric growth observed in males may relate partly to the protogynous nature of *P. erythrinus*. However, this pattern could also result from sample structure: in our dataset, male individuals were clustered in a narrow size range, which limits variability in the length–weight relationship and tends to produce isometric growth.

In the present case, sampling was conducted exclusively during the spring–summer period, corresponding to the spawning season, when energy reserves are largely allocated to gonadal maturation. Future research should therefore incorporate year-round sampling to provide a more comprehensive assessment of condition factor dynamics and to capture seasonal variations that may not be evident in partial-year studies.

The sex ratio of *P. erythrinus* varies with size, showing an overall predominance of females. Our findings are consistent with those reported by Pajuelo & Lorenzo (1998) in the Atlantic and by Metin et al. (2011)

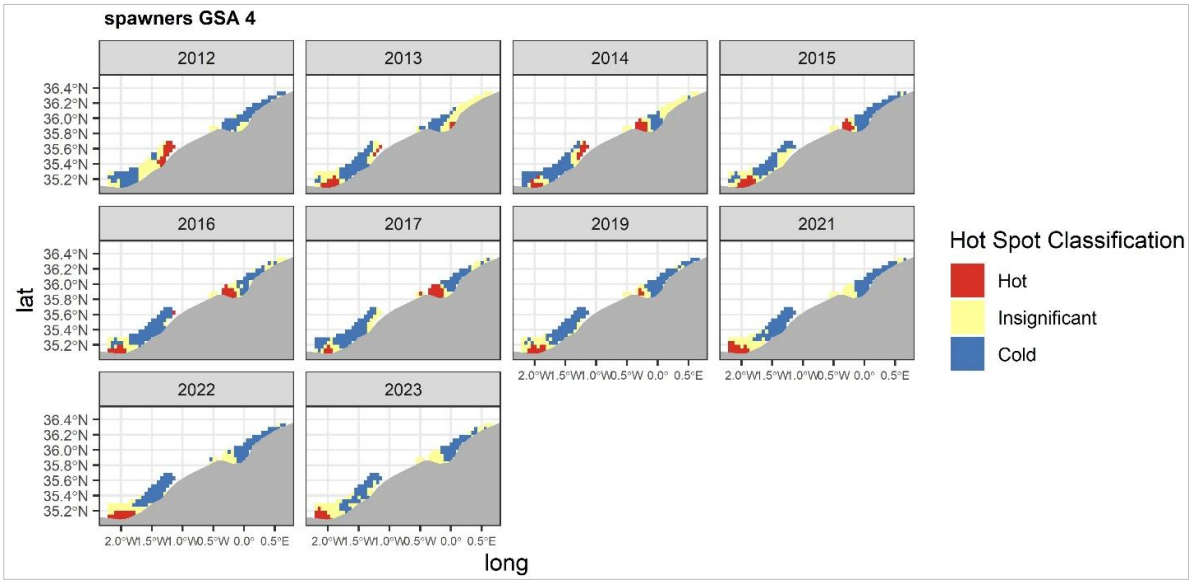

Figure 10. Annual hotspot maps of *Pagellus erythrinus* spawners (2012–2023) along the western Algerian coast. Colors represent Getis-Ord Gi* classifications: red indicates significant hotspots (areas of high abundance), blue indicates significant coldspots (areas of low abundance), and yellow represents areas with no significant spatial clustering.

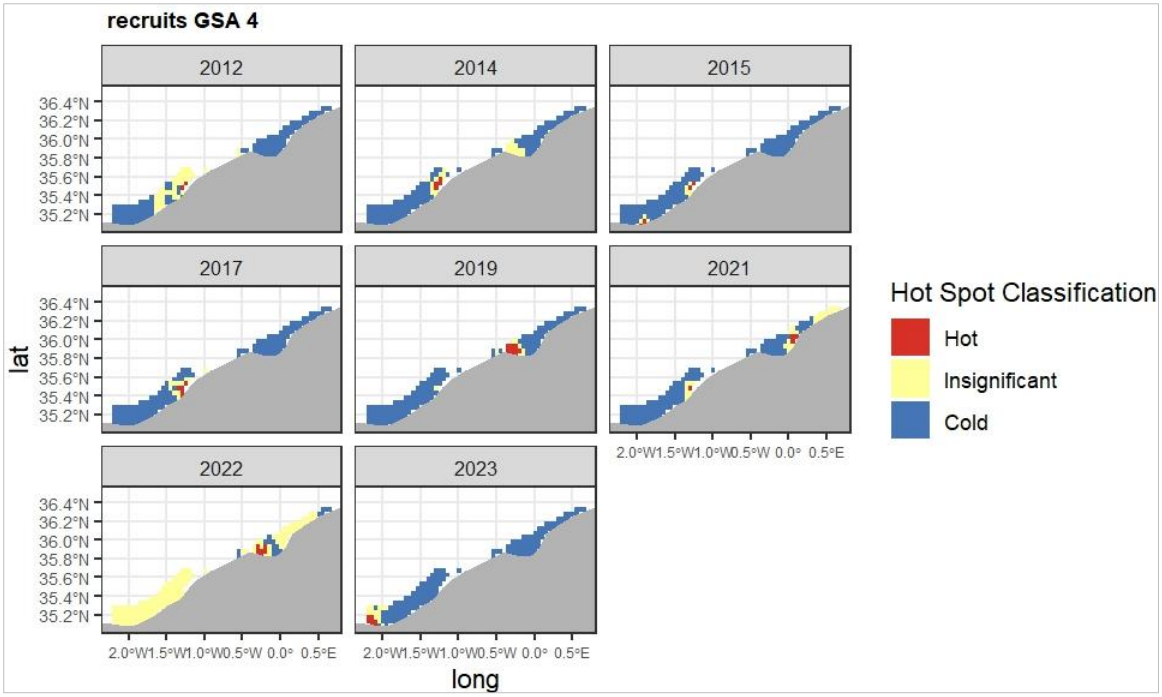

Figure 11. Annual hotspot maps of *Pagellus erythrinus* recruits (2012–2023) along the western Algerian coast. Colors represent Getis-Ord Gi* classifications: red indicates significant hotspots (areas of high abundance), blue indicates significant coldspots (areas of low abundance), and yellow represents areas with no significant spatial clustering.

in Türkiye. The dominance of females is attributed to the protogynous hermaphroditism characteristic of the species.

The sampling period of this study, from June to early September, corresponds to the spawning and post-spawning phases of *P. erythrinus*, as evidenced by the predominance of maturity stages III and IV. This finding is consistent with observations reported by several authors in the Mediterranean region (Ghorbel & Ktari, 1982; Valdés et al., 2004; Mahdi et al., 2018; Elbaraasi, 2019; Lteif et al., 2020).

In most cases, *P. erythrinus* has been observed on the continental shelf down to depths of 140 m. Its distribution is more prevalent within the first two depth strata (20–100 m) and only occasionally at depths between 100 and 200 m.

This finding is consistent with documented evidence indicating that the preferred habitat of *P. erythrinus* is largely restricted to the continental shelf (Spedicato et al., 2002; Massutí & Reñones 2005; Gaertner, 2002). Busalacchi et al. (2014) further noted that the common pandora is among the most coastal species along the eastern coast of Corsica and the southern Tyrrhenian Sea. The species is seldom observed on the slope, having been recorded only twice: one individual in 2012 and another in 2016, at depths of 226 and 311 m, respectively. These observations are consistent with earlier reports by Bauchot & Hureau (1986) and Santos et al. (1995).

Despite the paucity of recent published data on the abundance indices of the common pandora, a comparison with available sources has been undertaken. Spedicato et al. (2002) reported that, across the geographical subdivisions of the Mediterranean (GSAs) defined by the GFCM, *P. erythrinus* was most abundant in Corsica, the eastern Ionian Sea, and the southern Aegean Sea, with values generally exceeding 20 kg/km². The maximum, 58.5 kg/km², was recorded in Corsica in 1999. Conversely, the same author noted low values on the western side of the Alboran Sea and in the Gulf of Lion.

Le Corre (2011) reported that the biomass indices of *P. erythrinus* were very low in the Gulf of Lion were consistently low between 1994 and 2008, with a maximum value of 7 kg/km² recorded in 2008. These values are considerably lower than those estimated in the present study, which ranged from 9.33 to 43.93 kg/km². By contrast, in the Corsica region, biomass indices were higher than those observed here, varying between 15 and 60 kg/km². In the same area, catches of *P. erythrinus* reported by Certain et al. (2024) between 2016 and 2023 ranged from 0.012 to 69.09 kg/30', with a mean of 1.42 kg/30'. This average is markedly lower than that obtained in the present study for the same period, which reached 5.27 kg/30'.

This discrepancy can be explained by the fact that, despite the high primary and secondary productivity of the Gulf of Lion, the abundance indices of the common pandora remain low. This apparent paradox is largely attributable to the intense fishing pressure exerted over several decades, which has led to stock overexploitation and the progressive degradation of benthic habitats. According to Bensebaini et al. (2022), this area has been subject to heavy exploitation in recent decades, and most targeted species are currently considered to be in an overfished state.

Busalacchi et al. (2014) estimated abundance indices for the continental shelf of the southern Tyrrhenian Sea over a 15-year period (1994–2008), reporting values of DI = 242 and BI = 28. These figures are nearly identical to those obtained in the present study (DI = 287, BI = 27). By contrast, Lauria et al. (2020) reported much lower mean densities in the Strait of Sicily, averaging 65 n/km² between 2003 and 2016. Similarly, Farriols et al. (2019) estimated mean density indices of 179, 89, and 538 n/km² in the Balearic Islands, northern Spain, and Corsica, respectively.

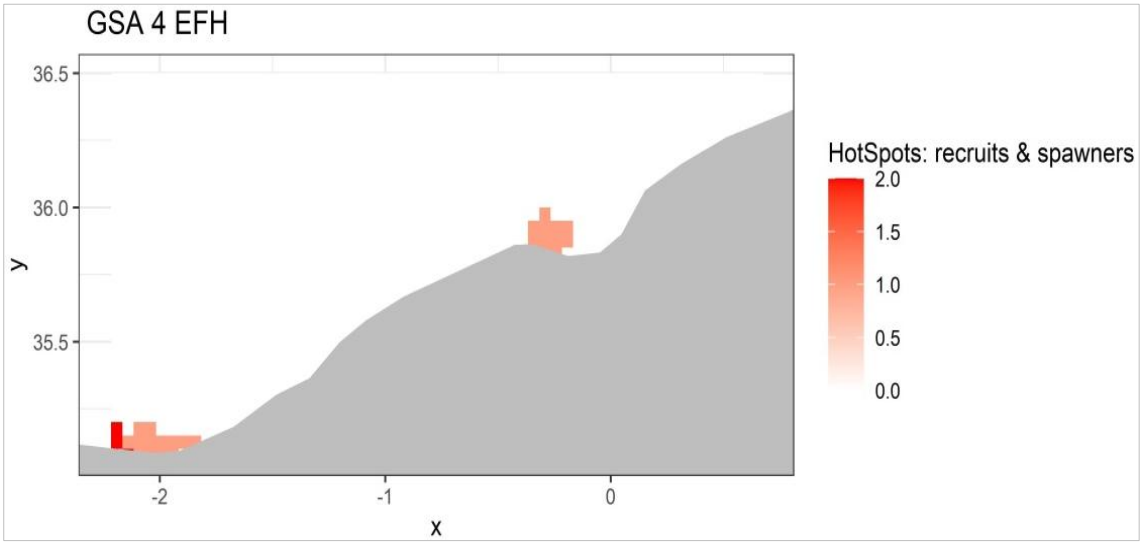

Figure 12. Map of EFH for *P. erythrinus* in the study area.

The disparities in abundance index values observed across Mediterranean regions can be attributed to the heterogeneity of habitats, seabed characteristics, continental shelf extension, environmental parameters, local fishing practices, and, most importantly, fishing pressure. In Algeria, the number of active trawlers is estimated at 559, according to the State of Mediterranean and Black Sea Fisheries (SoMFi) report (FAO, 2023), which corresponds to one trawler per 16 km². Colloca et al. (2017) ranked Algeria first in terms of trawler concentration.

Mérigot et al. (2019) conducted a study on the variability of demersal species assemblages and classified *P. erythrinus* within a group whose variability was correlated with chlorophyll a, temperature gradients, carbon biomass, and phytoplankton. Conversely, Peristeraki et al. (2019) concluded that changes in temperature were not correlated with variations in the structure of demersal fish assemblages.

The increasing trend in the abundance index within the 20–50 m depth stratum, as indicated by the positive Spearman correlation, is not unique to the western Mediterranean. Bitetto et al. (2019) observed a similar trend for *P. erythrinus* over the period 1999–2015, with increases reported in several GSAs, including areas close to the present study site, such as the northern Alboran Sea, the Isle of Alboran, northern Spain, the Gulf of Lion, Corsica, and Sardinia.

The temporal monitoring of annual variations in biomass indices using Kriging allowed us to detect changes in the distribution of the species across the study area. The advantage of this geostatistical method is its ability to predict species presence at unsampled locations (Morfin et al., 2012).

Interannual variability in abundance indices is primarily driven by physical and oceanographic factors such as temperature and primary production, Rubino et al. (2024) concluded that ectothermic organisms, such as fish, are highly vulnerable even to minor increases in temperature. It is also influenced by fish population dynamics, particularly recruitment processes that are closely linked to ocean currents, as highlighted by Quattrocchi et al. (2024), who suggested that larval transport plays a crucial role in explaining recruitment variability. In addition, anthropogenic factors—such as variations in fishing effort, which largely depend on marine weather conditions in the region, as well as unsuitable fishing practices—may have contributed to the marked decline in biomass indices observed in 2019, when values dropped to a record low of 6.28 kg/km².

Following 2019, the present study identified an upward trend in the study area, particularly evident over the last three years (2021–2023). This increase may be explained by two complementary factors. First, during the COVID-19 pandemic, fishing activity declined significantly, which allowed a greater presence of spawners. According to FAO (2021), landings in Algeria decreased by 17% when comparing the first three quarters of 2019 and 2021. Similarly, Coll et al. (2021) reported a 34% reduction in fishing effort in the Balearic Sea during March–May 2020. Russo et al. (2021) further indicated that the small bottom otter trawl fishery experienced the most significant impact, with an 85% reduction in landings and revenues. However, as fisheries progressively resumed, fishing effort increased again, as reported by Pinto et al. (2023), with French trawlers (≥12 m and <18 m) rising from 283 fishing days in 2020 to 319 in 2021, and 517 in 2023.

Second, in this border zone, the strengthening of control measures and the intensified efforts of coast guard services in response to the recent upsurge in illegal immigration have also had an indirect positive impact by limiting illegal trawling in shallow waters (<50 m), where such activity is regulated and prohibited for this type of vessel. Tserpes et al. (2019) reported that the implementation of novel trawling restrictions in inshore areas (0–50 m) led to increased abundance and biomass indices of red mullet in the Mediterranean Sea.

Conclusions

The results of this study provide the first insights into the spatio-temporal distribution of the common pandora along the western Algerian coast. Based on bottom trawl survey data, two sites were identified as significant hotspots for this species. These findings open perspectives for extending the analysis to other species inhabiting similar environments, such as the red mullet and axillary seabream, which also exhibited high abundances in the same area.

Moreover, the results support the potential establishment of Fishing Restricted Areas (FRAs) as effective spatial management tools aimed at conserving essential habitats and protecting spawning and nursery grounds. Such measures could also promote the recovery of overexploited stocks by mitigating fishing pressure, in accordance with the recommendations of the General Fisheries Commission for the Mediterranean (GFCM) for the sustainable management of fisheries resources.

Ethical Statement

The protocol employed in these surveys is the same as that used in all Mediterranean countries, namely the MEDITS programme (Mediterranean International Trawl Survey). This is also in accordance with the GFCM (General Fisheries Commission for the Mediterranean) protocol for scientific surveys in the Mediterranean. All co-authors listed in the present study have declared that the research was conducted ethically, professionally and responsibly.

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Author Contribution

Samir Rouidi: Conceptualization, Investigation, Methodology, Visualization, Data curation, Formal Analysis, Writing - review & editing, original draft. Nour El Islam Bachari: Conceptualization, Methodology, Writing - review & editing, Visualization, Supervision and Validation. Said Chaouki Chakour: Conceptualization, review, critical comments and Validation. Kamel Harchouche: Supervision, Writing - review & editing.

Conflict of Interest

The author(s) declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

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