

Integration of fisheries and ecological data to support spatial management: The case of blackspot seabream (*Pagellus bogaraveo*) in the western Mediterranean Sea

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ABSTRACT

Spatial measures are often used to support fisheries management. The European Union, for example, has emphasized the importance of the spatial aspect to protect overfished stocks and to find a better approach to fisheries management. Nevertheless, careful selection of which marine areas to manage with greater precaution is essential to optimize their benefits. In this work, we estimated hot spots of aggregation using a species distribution model developed with template model builder (sdmTMB) on density indices (number of individuals/km²) for blackspot seabream (*Pagellus bogaraveo*) for two length ranges (≤ 20 cm and > 20 cm). We applied the model to scientific bottom trawl surveys conducted in the Alboran Sea (western Mediterranean) and to a dataset of georeferenced commercial catches (CPUE, Catch Per Unit Effort or fishery-dependent data) in the Strait of Gibraltar. In addition, the effects of oceanographic variables on the distribution of species was tested. The identified best distributions for both length ranges are used to determine hot spots of aggregation for the two size classes from 1994 to 2021 in northern Alboran Sea, from 2018 to 2021 in southern Alboran Sea and from 2005 to 2009 in the Strait of Gibraltar area. Identified persistent hot spots (as an hotspot area across all years of the time series) represent key ecological areas for the species that might be considered in future management plans. In the Northern Alboran Sea, 5 ecologically important areas were identified for smaller size individuals and 2 for the larger sized individuals. The overlap with the current effort estimates revealed two areas (one for smaller and one for larger specimens) off Cabo de Gata and Almería that could have significant ecological impacts with minimal socio-economic disadvantages if further protected. These could be two future management areas (e.g. Fisheries Restricted Area - FRA) that could be important for stock dynamics. The results confirm the ecological preferences of the species that were disentangled by Species Distribution Models (SDMs) as well as its useful contribution to support the management of this depleted species in the Mediterranean sea.

1. Introduction

Fisheries resources are under increasing pressure worldwide (GFCM-FAO, 2023), and the Mediterranean region has also been facing growing challenges due to overfishing (Colloca et al., 2013), habitat degradation (Piroddi et al., 2020) and the effects of climate change on fish stocks (Sys et al., 2024; Panzeri et al., 2024). Many stocks in the Mediterranean are overfished, and although several fisheries

management measures were introduced in recent decades, 58 % of commercial stocks are still fished outside the biologically sustainable limit (GFCM-FAO, 2023). The historical dependence of coastal communities on fishing in the Mediterranean requires concerted efforts to develop effective solutions for spatial management strategies (Colloca et al., 2013; Bellido et al., 2020).

The General Fisheries Commission for the Mediterranean (GFCM), has set out a series of principles in its 2030 strategy for sustainable

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fisheries and aquaculture in the Mediterranean and Black Sea. This strategy is consistent with the Global Deal for Nature, which proposes to increase area-based conservation measures and to protect 30 % of the planet to combat global impacts (Dinerstein et al., 2019). To maximize the impact of this strategy, management areas should maximize benefits, e.g. in terms of trade-offs between long-term benefits for resources and short-term impacts for fishermen (e.g., Panzeri et al., 2023). Therefore there is a need for analyses that focus on defining optimal territorial and spatial measures, as foreseen in the multi-annual management plans (EU, 2019).

The concept of spatial management recognised the heterogeneity of the marine environment and aims to designate specific areas for different uses in order to ensure the conservation of marine habitat and species (e.g. through Marine Protected Areas) and the sustainable exploitation of commercial fish stocks (e.g. through Fisheries Restricted Areas, FRAs) (Gronrud-Colvert et al., 2021). Moreover, Essential Fish Habitats (EFHs) such as spawning and nursery areas should be protected by closing them to exploitation (Dambrine et al., 2021) to achieve the best trade-off between impacts on stock status and fisheries yields.

One main challenge in the Mediterranean region is the need to integrate data, methods and objectives from different countries. This is particularly important for shared stocks, for which the definition of management areas could also be delineated in transboundary efforts in order to optimize the potential benefits of a network of fisheries management measures (e.g. CopeMed II, 2017; CopeMed II, 2019).

The Alboran Sea, located between the Iberian Peninsula and north-west Africa (Fig. 1), is an important area for its diverse ecosystems and economically important fisheries (GFCM-FAO, 2022). The area already includes a marine protected area that extends along a coastal strip for more than 45 km around Cabo de Gata between the straight baselines and the line one mile off the coast (see Fig. 1).

Among the commercial species in the region, the blackspot seabream (*Pagellus bogaraveo*, Brünnich, 1768) is of particular ecological and economic importance. This species supports local fisheries and has contributed to both food security and economic livelihoods (GFCM-FAO, 2022; Gil et al., 2001). The most important fisheries targeting this species are fishing hooks ("voracera", minimum length catch size equal to 33 cm, EC n. 1967/2006), a monospecific Spanish fishery for blackspot seabream located in the area of the Strait of Gibraltar, which accounts for 74 % of landings of this species (Silva et al., 2002). The main Moroccan fleets for catching blackspot seabream are the longliners, mainly based in the port of Tangier and on the western coast, and the artisanal fleet in the Strait of Gibraltar (GFCM-FAO, 2022).

Over the years, increasing fishing pressure combined with

widespread environmental changes (Sanz-Fernández and Gutiérrez-Estrada, 2023) has raised concerns about the sustainability of blackspot seabream populations in the Strait of Gibraltar and Alboran Sea. According to the GFCM 2024 assessment, blackspot seabream is depleted and in overexploitation with its current spawning biomass further below the benchmarked Biomass lower limit (Blim) value of 625 tons: there are serious grounds for worrying over the collapse of the stock according to the Mediterranean Regional Fisheries Management Organisations - RFMOs, (GFCM-FAO, 2024b). A further challenge is due to the fact that blackspot seabream is a shared stock among coastal countries but its monitoring is not uniform across the Alboran Sea.

Regional and international management initiatives have been implemented to address the complex blackspot seabream fishery including catch limits, gear limitations and stakeholder cooperation (GFCM-FAO, 2022). The transitional measures for the management of the resource were mainly defined by the GFCM in 2017 (GFCM-FAO, 2017) and later in 2019 (GFCM-FAO, 2019). Due to overfishing, a reduction in fishing mortality to a sustainable level was recommended (GFCM-FAO, 2022). However, the sustainability of the blackspot seabream fishery requires greater efforts (Gil-Herrera et al., 2021). Evaluating the effectiveness of spatial management measures is crucial for rebuilding the blackspot seabream populations to sustainability levels, taking into account the interannual dynamics of fisheries and other environmental characteristics.

Research on the spatial distribution of blackspot seabream larvae (see Nadal et al., 2022) and some regional cooperation projects for fisheries in the Mediterranean have been developed and funded by the European Union, (TRANSBORAN; CopeMed II, 2017; CopeMed II, 2019), which focuses on the management of fish stocks of 3 species in the Alboran Sea, in order to establish the most accurate spatial characterisation of sardine, hake and blackspot seabream populations (especially larvae) to determine the most likely stock units in the Alboran Sea and possible structural complexity within the stocks.

However, further research is needed to fully understand the population status, reproductive biology, and, in particular, the spatial distribution of the resource and its hot spots of aggregation, especially adults and juveniles. Incorporating this knowledge into management plans is crucial to ensure the resilience and sustainability of this valuable fishery resource. An effort to identify hotspots of aggregation for blackspot seabream in Alboran Sea might necessarily be based on fisheries independent data, which, however, are not available across countries with the same resolution and sampling effort. Yet, optimizing the selection of possible aggregation sites by combining different information across the basin seems necessary.

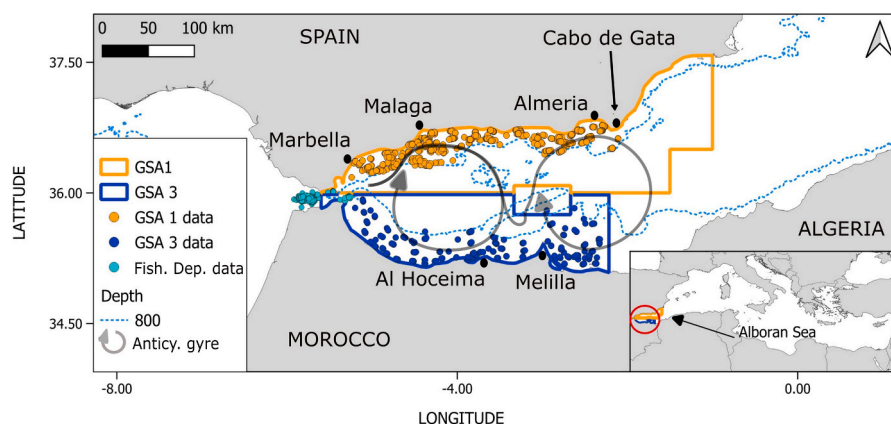


Fig. 1. Map of the study area, Alboran Sea in the western part of the Mediterranean (see bottom right panel). The central figure shows: GSA 1 (orange) & GSA 3 (blue). The orange dot in GSA 1 shows the geolocation of the MEDITS survey data from 1994 to 2021 (2020 is missing), and the blue dot in GSA 3 shows the geolocation of the survey data from 2018 to 2021. The light blue dots indicate the geolocation of the CPUE (fishery-dependent data) in the Strait of Gibraltar. The gray arrow shows the anticyclonic gyre (from Vargas-Yáñez et al., 2019). Main localities, such as Cabo de Gata (Spain) and Al Hoceima (Morocco) are also highlighted (and mentioned in the main text as important for blackspot seabream).

In this context, Species Distribution Models (SDMs) are widely used to analyze the historical distribution patterns of marine species. They are used to link spatial biotic data (e.g. georeferenced presence/absence, number of individuals or biomass density) with oceanographic data, providing information for spatial fisheries management (Robinson et al., 2011), which is essential for EFH mapping and conservation (Fanelli et al., 2021).

This study aims to answer three main questions about the source and use of data in the study area to better understand the distribution of blackspot seabream, namely:

- i) Can we combine multiple surveys with Essential Oceanographic Variables (EOVs) for improving the description of the species distribution and obtain hotspots of aggregation to support spatial management?
- ii) Is there an aggregation pattern in the population and, if so, would spatial management measures be suitable for the population?
- iii) Can the approach help in the design of the FRA network for blackspot seabream in the Alboran Sea to support strategies to prevent its collapse?

Specifically, to answer the three questions we conducted a study on blackspot seabream using a generalized additive mixed model implemented in sdmTMB (Anderson et al., 2022). We obtain potential habitats, hotspots of aggregation, relationships with environmental variables and predictions of abundances of blackspot seabream for the study area.

To answer question i), we used two data sources derived from the scientific bottom trawl survey in northern GSA 1 and southern GSA 3, as well as commercial landings data (catch per unit effort, hereafter CPUE) the latter to assess and expand the area with fish density predictions, we included EOVs and determined the species distribution using the model. For question ii) we integrated the different results by 'mapping' the areas identified in the previous point and assessing the optimal distribution for the three datasets to identify the hot spot with high aggregation suitable for spatial management, highlighting the area that maintains this hot spot over the years. Finally, iii), we have integrated fishing effort data that overlap with the aggregation hotspot to emphasize the persistence area (i.e. an hotspot occurred in the same place in all years of the time series), where two locations could have a large ecological impact with little socioeconomic disadvantage if further conservation measures are taken, due to the overlap with existing effort estimates. These two potential future management areas could be crucial for population recovery. We emphasize the importance of integrating biotic data sources and environmental variables in areas that have the same stock but belong to different GSAs with different datasets over the years, with the aim of assessing the status of the resource in the area from a spatial planning perspective.

2. Materials & methods

2.1. Study area

The study area is the Alboran Sea that corresponds to the Geographical Sub-Areas (GSA) 1 and 3 established in 2009 by the GFCM (Fig. 1). GSA 1 includes the northern Alboran Sea bounded by the Spain coasts, while the GSA 3 is the southern Alboran Sea bounded on the south by the Morocco coastline (Fig. 1).

The circulation in the Alboran Sea is characterized by the input of surface Atlantic waters through the Strait of Gibraltar which generates anticyclonic patterns in the current system and upwelling of organic-enriched deep water (Sarhan et al., 2000); and the Almería-Orán front, which forms at the meeting point of Atlantic and Mediterranean surface waters, at the eastern end of the Alboran Sea (Tintoré et al., 1988), representing a distribution barrier for several species and producing an enhancement of primary producers in its proximity (Abad et al., 2007) (see also Fig. 1).

The northern Alboran Sea is characterized by upwelling areas that generate high plankton production (Reul et al., 2005). The Alboran Sea, together with the Gulf of Lion and the mouth of Ebro River, is one of the

areas with the highest primary production in the western Mediterranean (Vargas-Yáñez et al., 2020). According to Báez et al. (2013) the area is an important spawning ground for pelagic fish species, such as the European anchovy (*Engraulis encrasicolus*) and sardine (*Sardina pilchardus*). In addition, the submarine canyons of the Alboran Sea are also important reproductive zones for demersal fish, such as the blackspot seabream (Baro et al., 2012).

2.2. Biology

The blackspot seabream is a commercially important fish species of the *Sparidae* family that is distributed throughout the eastern Atlantic and western Mediterranean (Cunha et al., 2024). It is a benthopelagic species that lives at depths between 20 and 800 m: while juveniles are found in shallow coastal waters (Cunha et al., 2024), adults are found on the continental slope, indicating an ontogenetic migration to deeper waters (Morato et al., 2001).

The blackspot seabream is a protandrous hermaphrodite species whose individuals develop as males in the first part of their life and become females at the age of 4–6 years. They grow slowly for up to 20 years and reach a maximum length of 70 cm and a maximum weight of 4 kg (Nadal et al., 2022).

To account for the ontogenic and behavioral changes that imply strong modification of habitat preferences with age and size, the analysis is carried out separately for individuals of two biological length classes based on a length threshold of ≤ 20 cm and > 20 cm (age 1–1.5 years; Sobrino and Gil, 2001).

2.3. Input data

The spatiotemporal analysis of blackspot seabream distribution is based on the integration between abundance data retrieved from scientific bottom trawl surveys and from catch per unit effort with physical EOVs.

2.3.1. Scientific trawl survey data

Abundance data for the period 1994–2021 are based on the MEDITS dataset (Mediterranean International bottom trawl survey; Spedicato et al., 2019) for the northern Alboran Sea (GSA 1, Fig. 1). Data consist of an average of 34 sampling points (hauls) per year mainly collected in spring in a bathymetric range between 38 and 800 m.

For the southern Alboran Sea (GSA 3, Fig. 1), abundance data came from a scientific trawl survey conducted with similar gear used by the MEDITS survey (GOC 73, Fiorentini et al., 1999) for the period 2018–2021. Data regard an average of 54 hauls per year, mainly collected in summer in a bathymetric range between 38 and 611 m.

In the Northern Alboran Sea, density indices (standardised for the swept area, according to the MEDITS protocol, Spedicato et al., 2019) for blackspot seabream (number of individuals per km², hereafter n/km^2 mean length 25 cm in the observed data) were considered separately for individuals of two sizes, i.e., ≤ 20 cm and > 20 cm. For the Southern Alboran Sea, where length data by individual were not available, all individuals of a haul were associated to size class ≤ 20 cm or > 20 cm in length on the basis of the mean individual length. The latter was obtained by applying the length-weight allometric curve on the mean individual weight of the haul calculated from the number of individuals and total weight measured.

2.3.2. Commercial catch per unit effort

For the Atlantic side of the Strait of Gibraltar (i.e. just outside the Alboran Sea) commercial catches per unit of effort (CPUE hereafter) from the Spanish fishery (Rueda and Gil, 2023) were available during the summer period from 2005 to 2009. These georeferenced data include the number of individuals caught per length classes per thousands hooks (CPUE). This dataset is not very robust, as the temporal sampling is not randomly and homogeneously distributed in the study area. The dataset

includes only positive catch data of individuals ≥ 25 cm. Therefore, results from the analysis of this dataset was compared with results based on trawl surveys for individuals > 20 cm, and the comparison was made in terms of predicted spatial distribution patterns and not by direct integration of CPUE data into the same model of survey data.

2.3.3. Temporal evolution of thermohaline properties in the Alboran Sea

The EOVS used for the integration with trawl survey data were taken from reanalysis datasets, available from the Copernicus Marine Service (CMS, marine.copernicus.eu; last access 20/03/2024). Only physical oceanographic reanalysis were used, covering the period 1994–2021, with a spatial resolution of $1/24^\circ$ and 141 non-uniform vertical levels, with monthly temporal resolution (Nigam et al., 2021).

The EOVS datasets are the results of the integration of modeled and satellite data through advanced data assimilation techniques that are used to best represent the past dynamics. These data are available with information on their uncertainty, which is specific for each variable (Cossarini et al., 2021).

The initial variables considered in this work were sea bottom temperature (tmp_bot hereafter, $^\circ\text{C}$), bottom salinity (sal_bot, psu), and eastward sea water velocity at the bottom (cur_bot, m/s). These variables were included because of their effects on physiological processes (tmp_bot, sal_bot), their ecological importance as proxies for favorable coastal conditions for juvenile fish (e.g., sal_bot and cur_bot), and as proxies for feeding areas also for adult fish (tmp_bot). These EOVS were used considering previous similar analyses for the selected demersal species in other areas of the Mediterranean Sea (Ben Lamine et al., 2022; Panzeri et al., 2023). We have also included in the model static variables such as bathymetry (depth, hereafter m). The explanatory geospatial, oceanographic, biogeochemical variables were preliminarily selected using the VIF approach (Variance Inflation Factor; Sheather, 2009) with a threshold of $\text{VIF} < 5$ or correlations $< |0.6|$ to avoid collinearity (Sion et al., 2019).

2.4. Modeling approach

We fitted with the Generalized Additive Mixed Models (GAMM with smooth term and thin plate regression spline, $s()$ in sdmTMB) the two available datasets, i.e. the trawl surveys dataset for the Alboran sea and CPUE data. After model fitting, the final prediction is performed on a regular lon-lat grid with the same resolution as the CMS reanalysis ($1/24^\circ$) and the same covariates. After model training and test checking (see Table S1), we predicted the final spatial density (n/km^2) for the blackspot seabream in the study area (Fig. 1). The uncertainty of the prediction is evaluated as the mean and standard deviation of 500 prediction simulations (for the test dataset, see Table 1, *nsim* in sdmTMB, Anderson et al., 2022).

For the trawl survey datasets, we used the sdmTMB package (Anderson et al., 2022) with a Tweedie family (TW-sdmTMB hereafter), using GAMM and including spatiotemporal random fields (independent and identically distributed, iid in sdmTMB). Furthermore, to highlight the potential difference between area (northern and southern Alboran Sea) we included two factors as fixed effects, i.e. year and area (see Table S1).

For the CPUE data, which is only distributed in 5 years (2005–2009) we fitted the sdmTMB model with a lognormal family (LN-sdmTMB hereafter) with log-link on untransformed density data, which resulted in the best model run with spatial random field (no temporal field included no fixed effect, see Table S1).

We fitted different model combinations (see Table S1) by using the back-stepwise approach, in which each model was subjected to k-fold cross-validation (Panzeri et al., 2021); thus, it was fitted to a spatial training dataset created by randomly selecting 75 % of the data. The remaining 25 % of the datasets were used to test the best fit of the model. Training and testing were repeated with 5 spatial fold, with the data randomly selected without replacement. In addition, prediction testing

was performed with 500 simulations for each model (*nsim* in predict::sdmTMB).

The diagnostics of the prediction skill are an average of over 500 simulations performed on the test dataset (averaged over fold, see Table S1)

2.5. Hot spots of aggregation for blackspot seabream

The areas of high aggregation (hot spots) or low aggregation (cold spots) were identified using the local Getis-Ord index (G^* hereafter; Getis and Ord, 1992) applied to the predicted density results for each year in the case of bottom trawl survey dataset and CPUE data.

The G^* equation is:

$$G_i^* = \frac{\sum_{j=1}^n w_{ij}x_j - \bar{X}\sum_{j=1}^n w_{ij}}{S \sqrt{\frac{n \sum_{j=1}^n w_{ij}^2 - \left(\sum_{j=1}^n w_{ij}\right)^2}{n-1}}} \quad (1)$$

At each grid point i , the G_i^* is positive (or negative) if the density at the grid point is greater (or smaller) than the local average. x_j is the species density value for each neighboring grid point j , w_{ij} are the spatial weights, n is equal to the total number of neighboring grid points considered, $\bar{X}$ is the local average density, and S is the standard deviation of the density. The spatial weights w_{ij} were set equal to $1/n$, where n is the number of neighboring cells around the grid point i to be used for the spatial average. A value of $n = 8$ was chosen as the best choice that avoided the marked non-uniformity of results at lower n and excessive smoothing at higher n , as evaluated in previous works (Panzeri et al., 2021, 2023). We represent in the same map the hot-spot areas in the Alboran Sea (mean value of G^* over the years) and the Strait of Gibraltar.

We also evaluated the persistence of areas of high aggregation (areas with G^* above 0) by considering the "presence" (i.e. an hotspot occurred in the same place in all years of the time series) of each grid cell for each year of our time series (presence of the same grid cell for 28 years, in this case only for the longest time series of the northern Alboran Sea bottom trawl survey).

In order to assess the ecologically more significant areas for the management of blackspot seabream and their impacts on actual fishing activities, we overlapped the persistent hot spots with fishing effort. The effort for trawlers and longliners was estimated from Automatic Information System (AIS) and retrieved from Global Fishing Watch (<https://globalfishingwatch.org/>). Data with a spatial resolution of 0.01° from 2014 to 2020 were available only for the northern Alboran sea, thus the overlap between persistent hot spots and effort was carried out only for GSA 1.

3. Results

3.1. Distribution of blackspot seabream in the Alboran Sea

The best models after the training and testing routine can be seen in Table S1, where they included bottom temperature and depth for individuals > 20 cm and ≤ 20 cm for both the bottom trawl survey dataset and the CPUE dataset.

The effects of significant covariates in the TW-sdmTMB model for the bottom trawl survey dataset and CPUE datasets are reported in Fig. 2. Partial effects show some coherence among datasets: individuals ≤ 20 cm peak influence of bottom temperature at 14°C and 16.5°C for the northern Alboran Sea and 15°C for the southern Alboran Sea. Depth partial effect showed a decreasing trend with individuals ≤ 20 cm mainly distributed between 50 and 200 m in both GSA1 and GSA3 (Fig. 2, upper left panel).

For individuals > 20 cm, tmp_bot effect peaks at around $13\text{--}14^\circ\text{C}$ for

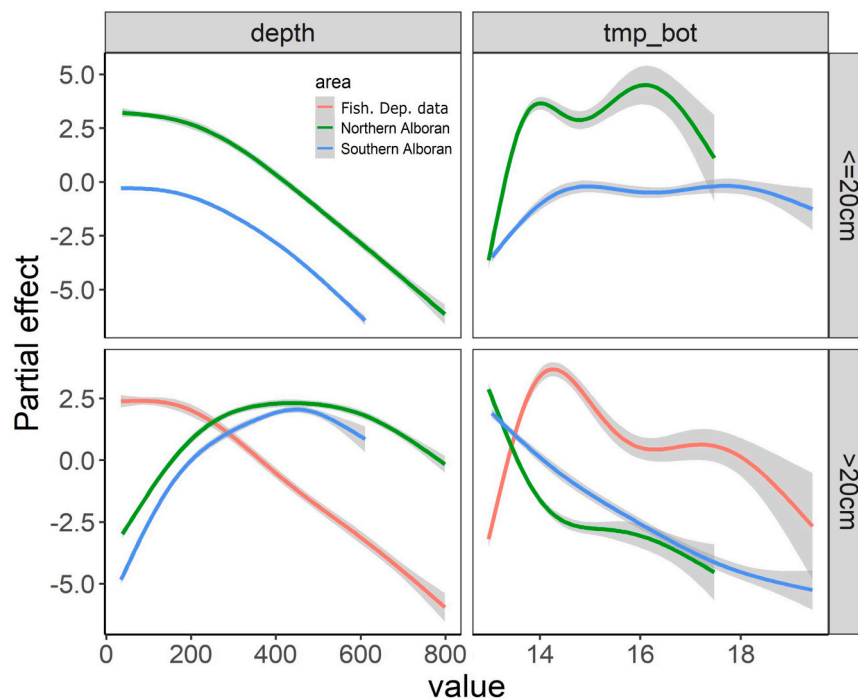


Fig. 2. Partial effect of GAMM (with sdmTMB) for each length range (≤ 20 cm or > 20 cm, row labels) and covariates (depth and bottom temperature, 'tmp_bot', in the right column).

the CPUE, while a decreasing trend was observed for the northern and southern Alboran Sea data (Fig. 2, lower right panel). For individuals > 20 cm, depth effect peaks around 450–500 m for both GSA1 and GSA3, while for CPUE high values are especially determined between 10 and 200 m (Fig. 2, lower left panel).

These results are quite reliable as the best fitted TW-sdmTMB model shows good agreement in terms of r^2 between observed and predicted values (Table S1), especially for the individuals > 20 cm ($r^2 = 0.35$). For instance, the qqplot shows a very good distribution of the residuals for the model based on trawl survey data (Figure S1, both length ranges) and fairly good for the CPUE data (Figure S5). The spatial residuals of the model are well distributed (see Figure S2 and S6) with an underestimation especially for individuals > 20 cm (Figure S2) and a good distribution of residuals with little overestimation for individuals ≤ 20 cm (Figure S2). The residuals derived from the model (Figure S6) show a slight underestimation (red dots) of -1 to -3 values and an estimate of catches (Figure S7, top panel) around values of 100 and 350 kg/km². The uncertainty shows low sd values in the center of the grid and values around 1 at the edges, where the data are less well distributed (Figure S7, bottom panel).

The map of the distribution of smaller individuals (≤ 20 cm) obtained by averaging 500 simulations (Figure S3, top panel) shows a maximum estimate of 600 n/km² in the northern Alboran Sea, especially in 2001, 2002, 2003 and 2007. For the southern Alboran Sea, this is not evident from Figure S3, but the estimate has a maximum density of 44 n/km².

For individuals > 20 cm (Figure S3, bottom panel), the highest estimate is 300 n/km² in the northern Alboran Sea, especially in 2001, 2002, 2003, 2007 and 2009. For the southern Alboran Sea (Figure S3), the estimate reaches 70 n/km².

The uncertainty map distribution (as standard deviation (sd) of over 500 simulations) for small individuals (≤ 20 cm, Figure S4, top panel) shows a low sd along the coast and medium and high uncertainty ($sd \geq 2$) occur only in 1999, 2010, 2012. For individuals > 20 cm (Figure S4, bottom panel) there is a low uncertainty ($sd \geq 1$) along the coast and in some years like 1998, 1999 or in the southern Alboran Sea in 2019 and 2020. Low sd values are distributed offshore where we

found individuals ≥ 20 cm.

The calculated G^* shows hotspots of aggregation in both length classes and highlights the essential fish habitat for each length (Fig. 3). The G^* shows that individuals ≤ 20 cm are located in the east-central part of the basin (northern Alboran Sea), but close to the coast, especially close to Cabo de Gata. After 2005, new hot-spot areas also appeared in the western area (Fig. 3, panel ≤ 20 cm, northern Alboran Sea). In the southern Alboran Sea, the hot spots are mainly concentrated in the central coastal area of Morocco nearshore of Al Hoceima (see Fig. 1). The individuals > 20 cm (Fig. 3) are mainly concentrated in the eastern part of the northern Alboran Sea, especially at depths below 200 m, offshore Cabo de Gata and Almeria and in the central part of the Moroccan coast, below 200 m, off the coast of Al Hoceima.

The result of the climatological hotspots composing the analyses on all the data sets for the Alboran Sea and the Strait of Gibraltar (Fig. 4) confirms high positive values for a few areas located in particular near the coasts of the Strait of Gibraltar, close to the Alboran Sea western boundaries (more details are also reported in Figure S8).

3.2. Persistence hot spot and overlapping effort data

Fig. 5 shows the areas of overlap between the hot spots and the AIS data in 2020 for longlines and trawlers in the Northern Alboran Sea. Persistent hot spots (also see Figure S9) for individuals ≤ 20 cm were identified in the Marbella Bay (A in Fig. 5), east of Malaga (B in Fig. 5), the coast of Almeria province (C in Fig. 5), Almeria bay (D in Fig. 5) and Cabo de Gata (E in Fig. 5). For larger individuals two persistent hotspots were emerging off Seco de los Olivos (F in Fig. 5) and Cabo da Gata (G in Fig. 5). By calculating the average current effort (2020) for both trawlers and longlines within these emerging 7 potentially key areas for management one can understand the future impact on exploitation in case of closure to fisheries. Hours of fishing per unit of surface identify areas where potential protection has minimal impact on the fishery, e.g. area F for longlines and individuals > 20 cm (Fig. 5, upper right panel) and area E for trawlers and individuals ≤ 20 cm (Fig. 5, lower right panel). Notably, persistent hot spot areas with high fishing effort are B and C for trawlers and D for both gears or E for longlines. It should be noted that

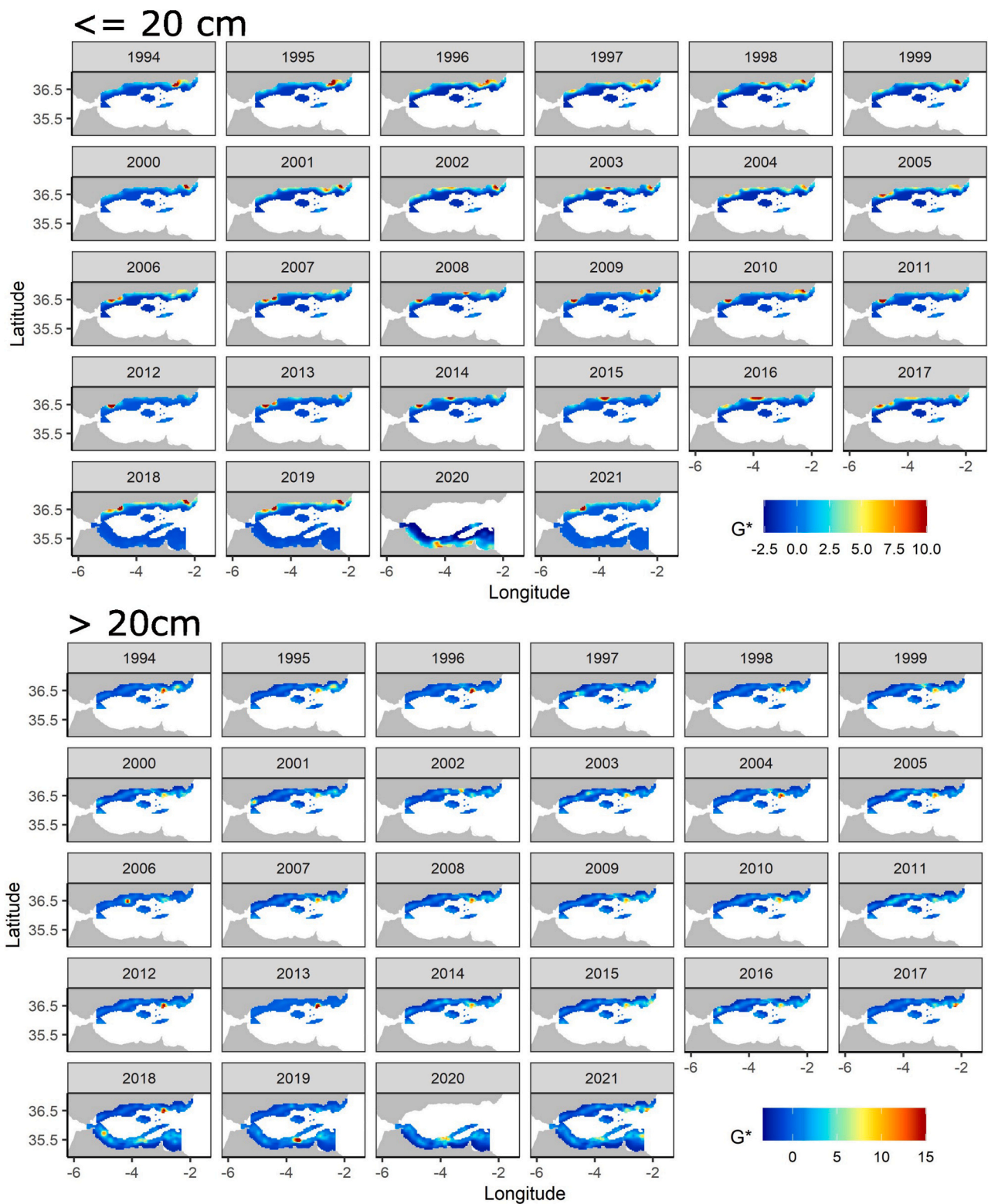


Fig. 3. Maps of the hot spot for the Alboran sea (from bottom trawl survey dataset). Hot spots with the high values of the Getis index (G^*) are identified independently for the two length classes. Individuals ≤ 20 cm (top panel), individuals > 20 cm (bottom panel).

we are not able to evaluate the impact of recreational fishery that might be important in the North Alboran Sea.

4. Discussion

The integration of scientific trawl surveys, commercial catch per unit

effort and physical environmental data provided a complete picture of the spatiotemporal distribution of two size classes of blackspot seabream in the Alboran Sea and the Strait of Gibraltar. Results shed light on the benefits of combining different data sources to describe the regional distribution of the species and the hot spots of aggregation give potential insights for priority areas for spatial management of the exploitation of

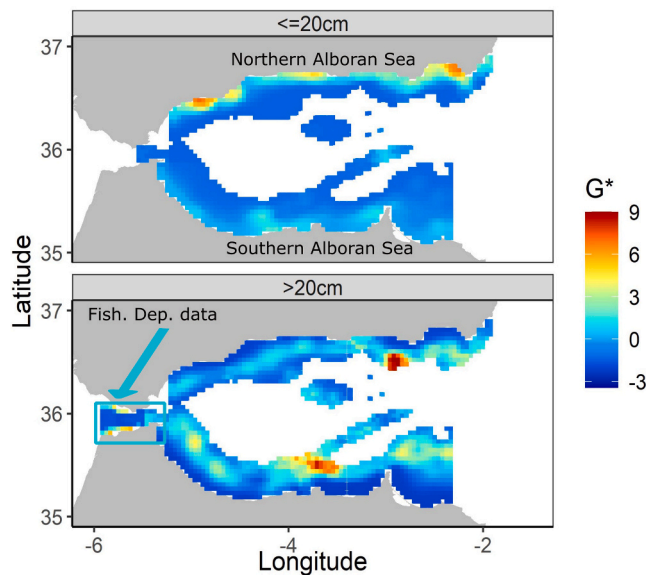


Fig. 4. Maps of the hot spot in the Alboran Sea for each length sampled with bottom trawl survey (Alboran Sea, northern and southern) and CPUE ((fishery-dependent data, light blue square, detail in Fig. S8) data set. EFH is identified independently for length by the high values of the Getis index (G^*). Individuals ≤ 20 cm (left panel), individuals > 20 cm (right panel).

this population. It is worth noting that landings in the study area, where blackspot seabream is an important commercial species, have declined over the past decade to levels approaching depletion (GFCM-FAO, 2024a, b). The GFCM has adopted a series of temporary management measures for the period 2023–2025, including catch limits, freezing fishing capacity/effort while developing an updated minimum conservation reference size, and establishing spatial measures to protect spawning and nursery areas and essential fish habitat (EFH) for this species (GFCM-FAO, 2022). The Management Strategy Evaluation (MSE) is the final step in the roadmap for work on blackspot seabream that was approved at the 24th meeting of the GFCM Scientific Advisory

Committee (SAC), to provide stakeholders with a general understanding of MSE concepts and to solicit their input on the selection of a management process, recovery horizons, and performance evaluation criteria.

4.1. Ecology and distribution of blackspot seabream in the Alboran Sea

The analysis shows large spatial and temporal variabilities of abundance of blackspot seabream over the 28 years of data. Moreover, results show a notable difference in spatial distribution between individuals smaller and larger than 20 cm for both northern and southern shores of the study area, which is also biologically consistent with other studies in the Mediterranean Sea, where it appears that the two sizes aggregate in grounds at different depths in accordance with ecological knowledge (Mytilineou et al., 2013).

In the northern Alboran Sea these grounds are spatially contiguous while in the southern Alboran Sea some spatial differences emerge from aggregation sites of juveniles of two sizes. Although the scientific sampling effort is quite different in the northern and in the southern Alboran sea and in southern part lengths were estimated, our analyses reveal similar importance and patterns for depth and bottom temperature, thus supporting the approximations made for the dataset for GSA 3.

Integrating the results from analysis of northern and southern trawl survey data and of the CPUE of the logline provided evidence of a coherent and transnational picture of the hot spots of aggregation of blackspot seabream that might be useful for regional spatial management of the exploitation of this resource (Fig. 4).

The use of the CMS dataset, in fact, illustrates the advantages of integrating EOVs into SDM (see Panzeri et al., 2021, 2023). Examination of the environmental variables included in the analysis shows that depth and temperature are the most important factors for both sides of the basin and especially for individuals ≤ 20 cm, which tend to be close to shore. Temperature is known to influence the dynamics and variability of fish populations (Free et al., 2019), and several studies have also highlighted the influence of temperature for blackspot seabream, particularly in the Strait of Gibraltar between 1983 and 2015 (Gutierrez-Estrada et al., 2017). Application to the different abundance and CPUE data show that temperatures have similar (although not

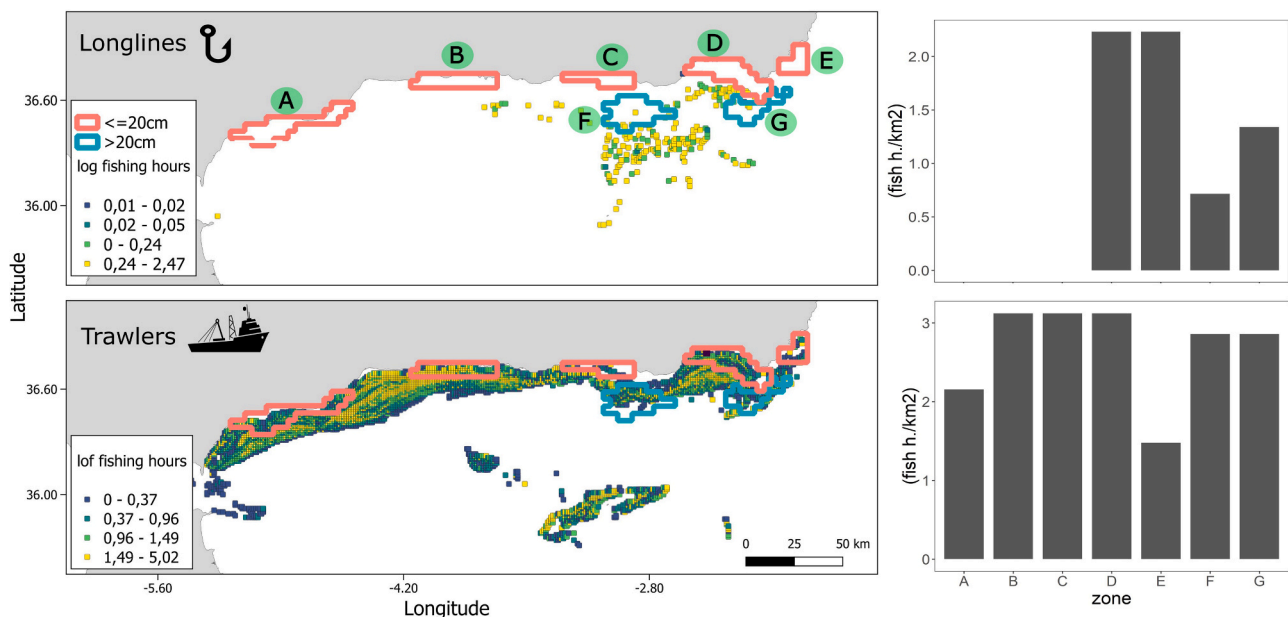


Fig. 5. Analysis of hot spots of aggregation and effort in the GSA 1. The key ecological areas for management, derived from the hotspots (see Fig. S9), are named A, B, C, D, E for individuals ≤ 20 cm, and F and G, for individuals > 20 cm and are depicted on the maps of effort for longlines (upper panels) and trawlers (lower panels). Effort is obtained from the analysis of AIS data in 2020 and is expressed in fishing hours per 0.01 degree cells. The bar chart on the right shows the average fishing effort (fishing hours per Km^2) within the 7 key ecological areas that might be potentially future management zones.

identical) influence on the distribution of blackspot seabream in the northern and in the southern Alboran Sea and the Strait of Gibraltar (Fig. 2). In particular, larger size individuals' preference is maximum for the lower range of sea bottom temperatures (around 14 °C) and decline with increasing temperature in complete agreement with effects of temperature on growth rate of individuals of 30–55 cm in length (Neves et al., 2021). Conversely, individuals of the smaller size class seem to prefer temperatures around 16 °C and higher, further explaining spatial differentiation in distribution between the two size classes.

Other anthropogenic variabilities could have played a role in the distribution pattern of blackspot seabream. For instance, the commercial fishing effort might have influenced the densities in relevant fishing grounds and might explain the discontinuity of hot spots for the two size classes in the southern part of the Alboran Sea (Fig. 5). Our correlative SDM approach highlights the importance and impact of CMS variables, but further analyses may be needed to clarify the role of fishing (e.g. Paradinas et al., 2023) and other anthropogenic activities in shaping the densities of this species in the Strait of Gibraltar and in the Alboran Sea. For blackspot sea bream, the selectivity of trawl surveys can lead to underestimation of certain size classes and data gaps, particularly in under-represented areas of the Alboran Sea. Although we partially addressed this issue by combining survey data with fishery-dependent CPUE data, both sources have inherent biases (e.g., gear selectivity, reporting accuracy, heterogeneous effort), that likely influenced the uneven predictive performance of the SDMs. Therefore, model results for poorly sampled regions should be interpreted with caution, and management recommendations must explicitly take these limitations into account.

4.2. Insights for fisheries management

It is worth noting that the area with the highest aggregation of individuals as a hotspot (in red, Fig. 4) coincides with the areas with the highest persistence for the northern Alboran Sea (Fig. 5 & S9). These key areas for blackspot seabream are off Almeria, eastern Cabo de Gata, which shows the highest aggregation and persistence over three decades, with a clear spatial separation between the two size classes considered.

It remains to be clarified whether these eastern concentrations belong to the same spawning stock as the target fishery that operates further west in the Strait of Gibraltar. Ferrari et al. (2023) reinforced the hypothesis that egg and larval dispersal are fundamental in sustaining the genetic connectivity of blackspot seabream to explain the absence of genetic population structuring in NE Atlantic and Mediterranean samples (from the Bay of Biscay till the Ionian Sea).

The aggregation areas for blackspot seabream suggest important areas that might be opportune to protect as nursery grounds: the areas in front of Almeria (D and G, Fig. 5) which are important for both size classes. Similarly the eastern Cabo de Gata area (E, Fig. 5) is a relevant hot spot for smaller individuals (20 cm TL). Note that Cabo de Gata is already a Specially Protected Area of Mediterranean Importance (SPAMI) which is a site for conserving biological diversity in the Mediterranean. These results (such as hot spots of individuals ≤ 20 cm, see Figs. 3, 4 & 5) are ecologically significant areas and could be considered in future management plans as key areas for the definition of spatial restrictions for fisheries. In particular, areas D and E, for individuals < 20 cm and area F and G for individuals > 20 cm, have low longline effort and high trawl effort and could be recognized as a possible new fishing closed area (or FRA). A partial closure (temporal or spatial) of this area could be essential to protect small individuals that could aggregate close to shore and migrate to deeper waters (Area F and G) when they grow (reaching the minimum catch size 33 cm).

In fact, hot spot and persistence area of individuals > 20 cm are mainly located in an area outside Cabo de Gata, called Chella Bank (or Seco de Los Olivos, F in Fig. 5), where a variety of habitats are distributed in a patchy mosaic (some of them related to habitat). In this area,

the bottom longline fishery is almost exclusively directed towards blackspot seabream. Fishing effort is concentrated on the southeastern and northeastern ridges, on both sides of the seamount, at depths between 200 and 500 m. Other commercially important species such as the European conger eel (*Conger conger*), anglerfish (*Lophius piscatorius*), blue whiting (*Micromesistius poutassou*) and European hake (*Merluccius merluccius*) also live in the Seco de los Olivos, which underlines the importance of this shore as an important habitat for species under fishing pressure (De la Torre et al., 2014).

In this context, while hot spots of aggregation can help identify priority areas for management on the Alboran Sea (both GSA 1 and 3) and Strait of Gibraltar considering the ecological information on the species, the detailed analysis of persistence of these hot spots undergoing commercial fishing effort reveal not only potential ecological/biological benefits but also provide some insights into the potential social acceptance of an eventual protection (Fig. 5). To enable adaptive management decisions, SDM has proven successful in identifying areas of significant biological importance for commercial or endangered species, particularly in the Mediterranean and Atlantic. Lauria et al. (2015), for example, used distribution modelling to identify the endangered habitats of demersal fish species in the central Mediterranean and proposed geographical scenarios for conservation.

In addition, the inclusion of ecological and fisheries criteria can guide the designation of new priority area for management (MPAs, e.g. FRAs) in the Mediterranean, taking into account the spatiotemporal dynamics of target species (see e.g. Ortega et al., 2023).

The prioritisation of critical areas in the Alboran Sea reflects three complementary dimensions: ecological vulnerability, as many hotspots overlap with nursery areas that are important for recruitment (Ferrari et al., 2023); economic importance, given the high value but overfishing of blackspot seabream (GFCM-FAO, 2024a,b); and management feasibility, as several areas are consistent with existing regional or international frameworks (e.g. SPAMI Cabo de Gata, GFCM Multi-annual Plan and Temporary Measures). The inclusion of these perspectives provides a balanced basis for the identification of priority areas for fisheries management (GFCM-FAO, 2022).

Notably, recent estimates of commercial fishing effort from satellite data (Marsaglia et al., 2025) show important fishing grounds far from Cabo da Gata (N Alboran) and in proximity of Al Hoceima (S Alboran), possibly explaining the patterns observed as a result of depletion of smaller individuals in coastal areas and the effects of protection measures. In addition, the potential future availability of VMS data also for the southern Alboran Sea or the availability of fishing activities that are not publicly tracked (see Paolo et al., 2024) could improve the analysis. Although the approach could have been implemented only for the GSA 1 due to data availability, it set a basis for highlighting best priority areas by roughly considering the trade-offs in a socio-ecological perspective.

Further work needs to be done to find out where the spawners come from (i.e. individuals larger than 30 cm) that produce these high concentrations of juvenile fish in Northeast Alboran. Some came from Seco de los Olivos (as was stated above), but recent ROV surveys since 2015 (including PROTEUS April 2024, funded by Spain and GFCM and led by the Institute of Marine Sciences of the Spanish National Research Council, ICM-CSIC) have also discovered aggregations of adults close to the Cabliers coral grounds (GFCM-FAO, 2024a).

Clearly, the once per year scientific bottom trawl surveys are not sufficient to capture the seasonal patterns nor the large individuals of blackspot seabream (largest specimen caught had TL = 46 cm, in 1996). Therefore, while bottom trawl surveys can give a clear indication on areas useful for spatial protection of juveniles of this species (nursery areas), the same data cannot provide a full picture of the spatiotemporal distribution of all age classes.

The main fishery which targets this species in the westernmost part of the Strait of Gibraltar, captures large individuals (TL > 33 cm) with bottom longlines, therefore, the MEDITS dataset cannot be used to determine spawning grounds and/or areas where the selectivity of the

fisheries can be improved (sensu Dolder et al., 2018; Panzeri et al., 2024) thus hampering the possibility of drawing from this dataset a full set of management recommendations (nursery, spawning and low discard fishing grounds). Tagging surveys were carried out in the Strait of Gibraltar area where no significant movements have been observed, although local migrations were noted: feeding grounds are distributed along the entire Strait of Gibraltar and the species seems to remain within this area as a spawning resident population (Gil, 2006). Inter-connected cycles of recruitment in both sides of the nearby coastal areas of the Strait are described in Nadal et al. (2022), corroborating the juveniles returning to the grounds where the fishery takes place as suggested by Gil et al. (2001). Thus, the main nursery area related to the target fishery is located in the North Alboran Sea hotspot close to the Strait of Gibraltar (A in Fig. 5).

4.3. Synthesis and Future Directions

Under the Common Fisheries Policy (CFP) of the European Union (EU), one of the objectives is the sustainability of fishing activity, and temporal and spatial information is now essential for good management of resources based on an ecosystem-based approach (EU, 2022). The main threats to the blackspot seabream in the Strait of Gibraltar and Alboran Sea come from human activities. Overfishing is one of the biggest challenges, as the seabream is a commercially very valuable species (GFCM-FAO, 2023). Intensive fishing during the breeding season can drastically reduce local populations and affect their ability to recover. In addition, trawling can seriously damage the seabed and destroy important habitats for blackspot seabream and other benthic species (Tudela, 2004). To mitigate these threats, conservation measures are needed that include sustainable management of fisheries resources, the establishment of marine protected areas and the monitoring of blackspot seabream populations.

To pursue this aim international cooperation between Spain, Morocco and other riparian countries is crucial for the protection of the marine ecosystems of the Strait of Gibraltar and Alboran Sea, as these are transboundary waters and the stock is shared. Expanding our knowledge of the potential links between the spatial and temporal displacement of blackspot seabream using data from Spain and Morocco and a range of environmental variables, was used to valorize independent datasets in an integrated manner. The approach used provides insights that could inform potential spatial management to reverse the collapse of blackspot seabream emerging from the most recent stock assessment (GFCM-FAO, 2024b).

In this context, fishing restriction zones are an important management tool, whose effectiveness is largely dependent on monitoring. To date, the GFCM has established ten FRAs in the Mediterranean to protect Vulnerable Marine Ecosystems (VMEs) or sensitive habitats from potentially significant adverse impacts and to enhance the productivity of marine biological resources by protecting EFHs (GFCM-FAO, 2023).

The importance of EFHs to the ecological and biological requirements of commercially exploited marine species is critical, as the designation of protected areas within EFH can improve the effectiveness of fisheries management by improving the status of stocks and sustaining fisheries (Dambrine et al., 2021), as also proposed by the European Union with the Common Fisheries Policy (CFP).

However, we recall that spatial planning strategies have multiple environmental and economic impacts. From an ecological perspective, marine protected areas and spatial closures can enhance biodiversity, protect important habitats and promote ecosystem resilience (Edgar et al., 2014). At the same time, from an economic perspective, spatial management measures can improve the long-term viability of fisheries by maintaining fish stocks at sustainable levels and improving ecosystem services (Costello et al., 2016; Thébaud et al., 2023). Spatial management measures, however, have short term direct impacts on fisheries (e.g. hampering access to fishing grounds), which might hinder the establishment of spatial measures itself. Therefore approaches that

balance the ecological benefits and the fisheries constraints, such as those provided here, are useful to identify priority areas for management that can represent the best trade-off.

By combining scientific trawl surveys with fishery-dependent CPUE data, important aggregation and nursery areas for blackspot seabream were identified, providing a sound ecological basis for management. Management should strike a balance between habitat protection and social and economic considerations. Partial or seasonal closures of hotspots could protect juveniles and spawners while allowing fishing to continue, providing a practical compromise between conservation and local livelihoods.

Future research should focus on improving the design and implementation of spatial management by improving resolution of the analysis and increasing data availability (also in detailed length classes) for all areas of the domain. In order to achieve long-term fisheries sustainability, moreover, it will be necessary to further improve optimization of management measures through the application of Management Strategy Evaluation (MSE; Punt et al., 2016) as well as by applying interdisciplinary approaches that also integrate economic and social aspects (Ban et al., 2019).

CRediT authorship contribution statement

Diego Panzeri: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Writing – original draft. **Juan Gil Herrera:** Data curation, Writing – original draft, Writing – review & editing. **Garcia Cristina:** Data curation, Writing – original draft, Writing – review & editing. **Rueda Lucia:** Data curation, Writing – original draft, Writing – review & editing. **Benziane Meryem:** Review & editing. **Malouli Mohammed Idrissi:** Review & editing. **Hernandez Pilar:** Writing – original draft, Writing – review & editing. **Simone Libralato:** Conceptualization, Supervision, Writing – review & editing, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.fishres.2025.107549](https://doi.org/10.1016/j.fishres.2025.107549).

Data availability

Raw trawl survey data are available at Joint Research Center Data (<https://data.jrc.ec.europa.eu/dataset/f25092c4-3f0f-449f-ba60-5fbfe385defc>). Oceanographic variables used in this work are available at Copernicus Marine Service (<https://marine.copernicus.eu/it>). Hotspots of persistence and aggre-

gation for both GSA are available as dataset on Zenodo (<https://zenodo.org>) at the following URL: <https://doi.org/10.5281/zenodo.17313068>.

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