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Socio-Ecological Overview of the Greater Amberjack Fishery in the Balearic Islands

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Abstract: This study provides the first socio-ecological overview of the *Seriola dumerili* fishery occurring in the Balearic Islands. This pelagic top-predator is among the five most valued fish resources of the Balearic community. Despite its ecological importance and potential vulnerability to aggregation fishing, few studies address the ecology of this large Carangidae species. Shining a light on its ecology is vital to ensure adequate species conservation and the sustainable and effective management of the fishery. Historical catches from 1950–1999, alongside detailed landing data for the last 21 years, were analysed to identify potential patterns in ecological and socio-economic factors. Significant inter-annual variability among the years was found in historical catches of greater amberjack, while catches and mean prices of the different size categories revealed significant results between seasons and months, respectively. Additionally, the purse seine fleet accounted for the highest percentage of *S. dumerili* catches. CPUE did not appear to change greatly between months and years after the annual 8-month fishing ban imposed in 2011 and therefore a re-evaluation of the closure was intended. Overall, this study suggests seasonality influences the *S. dumerili* fishery in the Balearic Islands, within which ecological influences show a higher regulating power than socio-economic factors.

Keywords: *Seriola dumerili*; social-ecological systems; mediterranean; historical catches; fisheries dynamics

Key Contribution: The greater amberjack fishery in the Balearic Islands is affected by both socio-economic and ecological factors, although the latter one seems to have a stronger influence on the fishery.

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1. Introduction

Fishery data is widely used to gather important information regarding the ecology of species [1–3]. Such data is also crucial to understand stock fluctuations and changes in the inherent ecosystem to help with the conservation and restoration of the resource as well as preventing a sudden collapse in the stock [2]. Especially for species exhibiting aggregation behaviour, fisheries data are a valuable source of information since species aggregations are commonly targeted by fishers and provide a predictable opportunity for large catches and an easy source of income [4,5]. While fishing on aggregations may produce short-term economic benefits to fishers, this activity also puts exploited fish stocks at risk of overfishing leading to a possible permanent loss of the resources [4,5].

The study of fishery data is particularly critical in systems that have a long history of exploitation, such as the Mediterranean Sea [6,7]. For instance, in the Balearic Islands (Spain), historical landing data was used to comprehend fluctuations in the *Coryphaena hippurus* fishery [8]. The Mediterranean Sea is a semi-enclosed basin characterised by coastal small-scale fisheries, representing 83% of the entire Mediterranean and Black Sea fleet in 2020 [9]. However, the emergence of more technologically sophisticated vessels (trawlers and purse seine) and the development of tourism after the Second World War, had detrimental impacts on traditional artisanal fisheries [10]. From the 1960s to the mid-1980s, total landings in the Mediterranean increased, potentially due to the modernization of fisheries (technological advances increased the effort and catchability efficiency) and growing nutrient load from coastal discharge [11], which consequently boosted the ecosystem's productivity. In contrast, a decline in nutrient flux from imposed regulations after the mid-1980s resulted in both low productivity and high rates of exploitation, causing the collapse of landings in subsequent years [11,12].

Ecological patterns can be difficult to comprehend when using fishery data, such as catch rates in small-scale fisheries [13], because they are incorporated within highly adaptive and complex marine social-ecological systems (SES) [14–16], posing a challenge in distinguishing between cause and effect [17].

For this reason, a fishery should not be regulated solely by ecological and biological components. Instead, it should aim to incorporate other potentially significant elements, such as social and economic factors that can equally affect the fishery in order to strive for optimal fisheries management [7,18], as considered in this study when attempting to assess the efficiency of a Marine Protected Area [19].

Price is a clear example of how an economic variable can affect fishers' behaviour and fishing strategy, according to seasonal price variations. For instance, it was found that after the adoption of a quota for *C. hippurus* fishery in 2013, to increase fishers' revenue, landings in Mallorca went from being recorded only in summer and autumn, to starting appearing all year long [8]. Additionally, tourism can have a tremendous impact on fishing activities, species abundance and even market price value, as the most targeted species and fish of ideal size are in greater demand from restaurants during the high season [10,20,21]. Likewise, fisheries management measures such as regulations have the power to influence fishing effort and catch rates [8,14], and thus should also be considered when addressing the study of the ecology of target species [22,23]. Established quotas and closed seasons can help with conservation of the fishing resource while also improving the income of fishers and retailers by increasing the demand in periods when this resource is not allowed to be fished [8,24].

Since the 1950s, tourism has been the primary contributor to economic growth in the Balearic Islands and it is still considered one the primary sources of income for what is known to be one of the main tourist destinations in Europe [20,25]. During the high season (May to October), the warmer seas attract millions of tourists to these islands, leading to changes within the fishing sector [20], for example, higher market values [21] as a function of increased demand for fish resources during these months [10,20].

Small-scale fisheries have been historically present on the island of Mallorca, with 241 out of 273 boats attributed to the small-scale fisheries sector in the last century [20] and accounting for 27% of the total income from Mallorca's landings during 2000–2014 [26]. These statistics demonstrate the considerable social weight this fishing sector adds to the fishery, since it is responsible for several hundred jobs [7].

One illustrative example of a complex socio-ecological system is supported by the small-scale fishery occurring in the Balearic Islands around *Seriola dumerili* fishery. This species, also commonly known as greater amberjack, has a circum-global distribution in subtropical and temperate pelagic waters [27] usually associated with rocky reefs or drop-offs areas [28]. In the Mediterranean, this apex-predator exists in great numbers [29] and forms spawning aggregations between late-spring and early-summer [30–32] when it reaches around 110 cm [31]. Even though it has been registered at depths of 360 m [28,33], during reproduction this species moves towards inshore warm waters, near the coast [30]. In contrast, juveniles are observed in offshore waters usually aggregated to *Sargassum* and floating objects [27,28].

Due to its aggregating behaviour, during both its early life stages and as an adult [34], *S. dumerili* is prone to being exploited by fishers who focus their effort on these key life-history events, such as *purse seiners*. This puts the species at a potential risk of being overexploited, as were their relatives in the NW Gulf of Mexico that were found to be overfished as a result of increased fishing effort and landings [27].

S. dumerili is a popular target species for recreational and commercial fishers worldwide, with distinct economic value [8,35]. In the Balearic Islands, this species represents one of the fifth most valued fish resources, which underlines its great cultural and socio-economic importance to the Balearic community (Figure 1A). Moreover, landings of this important resource suggest a seasonal pattern of vulnerability during its life cycle (Figure 1B) to different fishing gears strategically deployed in space and time to capture this species, a fact that illustrates the potential effect on the fishery caused by both ecological and social factors.

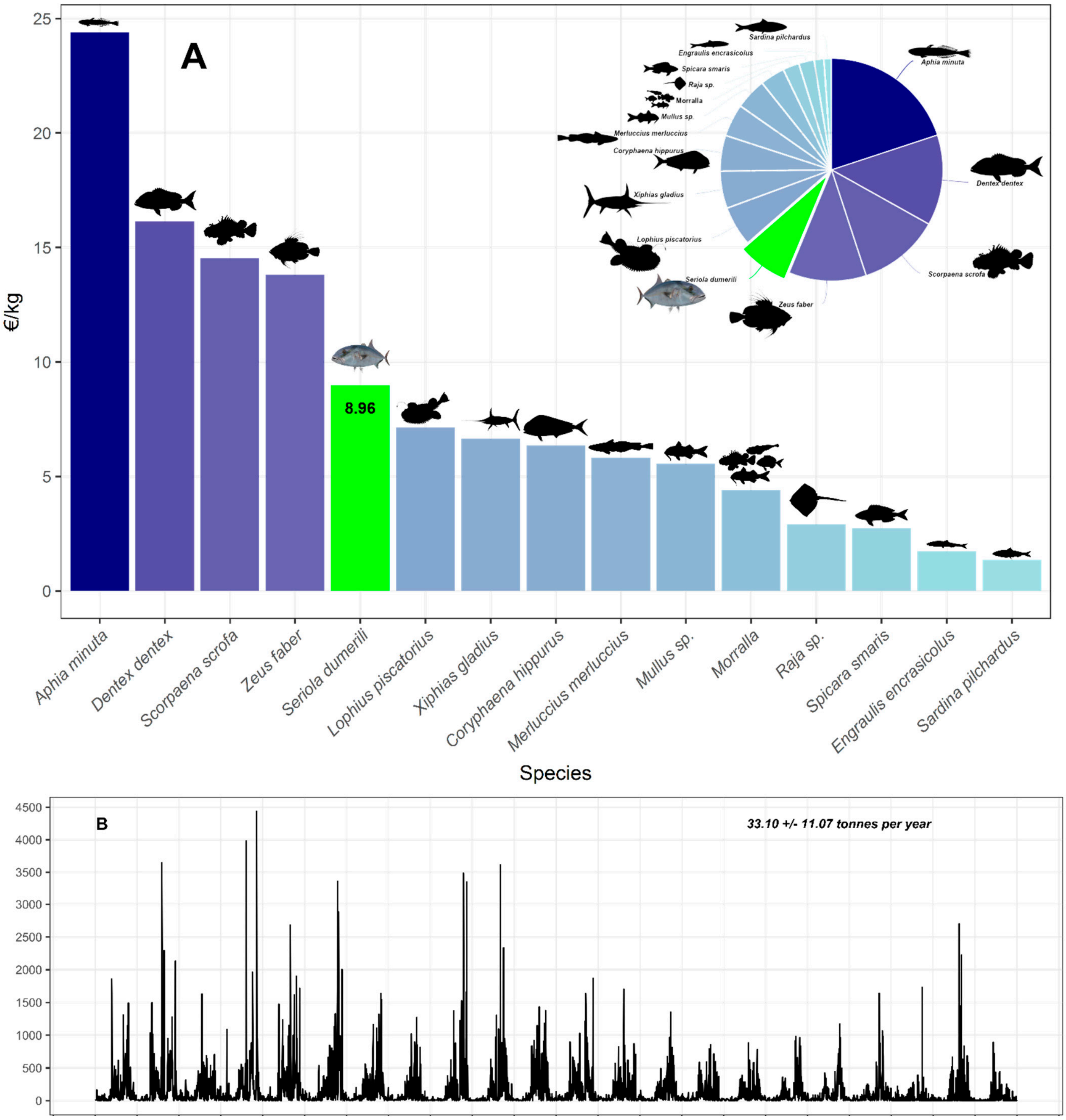

Figure 1. *Cont.*

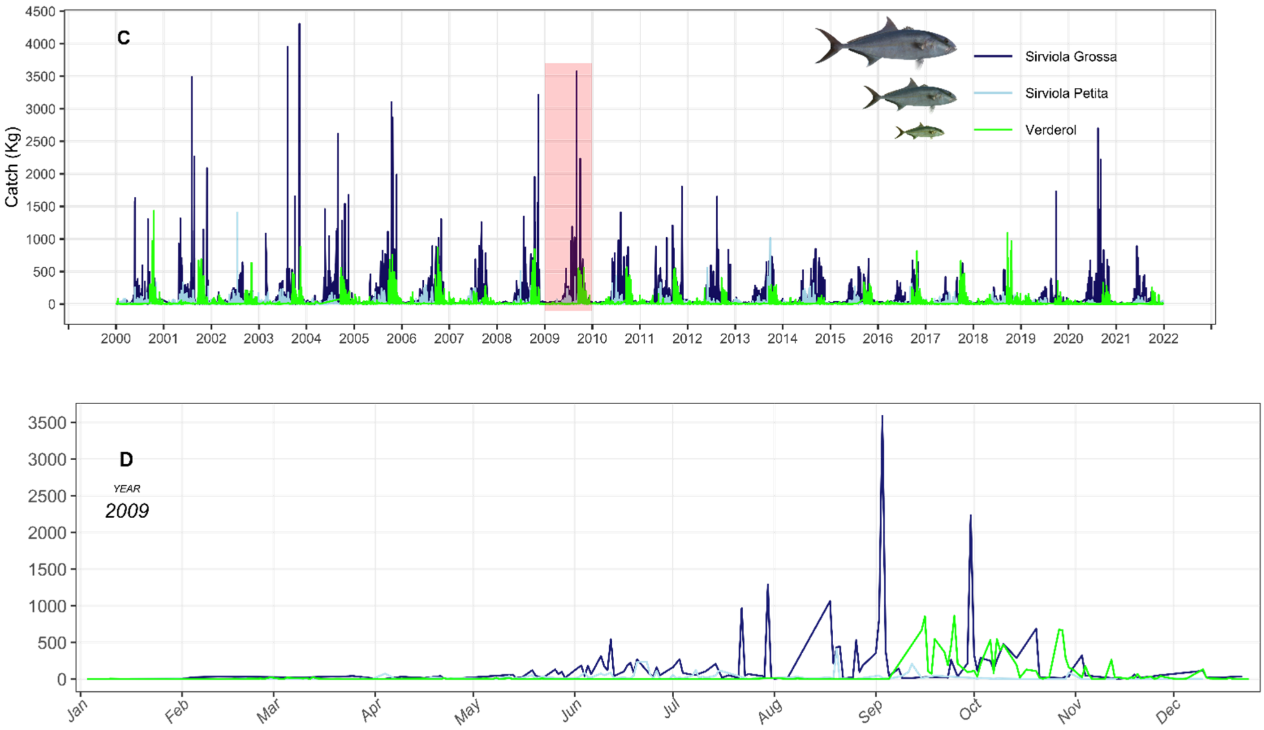

Figure 1. Socio-ecological data supporting the potential SES around *S. dumerili* fishery. (**A**) Economic importance of the main Balearic species as a function of price market value (€/Kg). Pie-chart represents the % of total price for each species as an illustration of economic importance. Graph from the Ministry of the Environment, Agriculture and Fisheries of the Government of the Balearic Islands, using the fishery statistics for 2015. Total daily catches of *S. dumerili* (**B**) and by size classes (**C**) *Sirviola Grossa* (navy blue), *Sirviola Petita* (light blue), *Verderol* (green) from the period 2000 to 2021. Monthly catch distribution from the year 2009 is represented in (**D**).

In an attempt to protect and ensure the sustainable management of this relevant fisheries resource, the Spanish Ministry of Agriculture, Food and Fisheries passed legislation in 2000 specifying a closed season for the fishery. This closed season applies to offshore waters of the archipelago with the aim of protecting *S. dumerili* juveniles, also known as *Verderol*, between the 1st of July and the 15th of September [36]. Later in 2011, an open fishing period was recognized for some species captured by purse seines, including *S. dumerili*, from 15th of July to 15th of November [37]. Finally in 2013, an exclusive open season extending from the 25th of August to the 31st of December was created in off-shore waters for the *Llampuga* fishery, a traditional small-scale fishery based on fishing aggregation devices (FAD) that targets *C. hippurus*, an epipelagic species fished alongside *S. dumerili* juveniles [8,38]. Such management strategies are focused on the protection of the recruitment phase and aggregations performed by this species. In Spain, the current major fisheries management body responsible for regulating the purse seine fishery, including the *S. dumerili* fishery in the Balearic Islands, is the national Ministry of the Environment, Rural and Marine Affairs [37].

Despite the important worldwide socio-ecological importance of this marine resource, little is known about the ecology of *S. dumerili* [35]. The majority of the studies focus on rearing and reproduction in captivity [39–41] with a view to incorporating it as an aquaculture species, given it rapid growth rate, commercial value, and good adaptation to captivity [42,43]. Therefore, due to the high commercial importance of this species, its vulnerable gregarious behaviour and the unknown effects of the imposed regulations, *S. dumerili* is at risk of overfishing with potential consequences for its conservation [44,45], hence the demand for urgent key information for an optimal evaluation and sustainable management.

In this sense, the main goal of the current study is to provide the first overview of the *S. dumerili* fishery from a socio-ecological framework, using the paradigmatic case study of this resource, which is intensively exploited by recreational and artisanal fleets in the Balearic Islands [45]. In this case-study, not only the ecological aspects such as spatio-temporal distribution (led by the spawning migrations [29] or aggregation events [33]) could moderate the exploitation of this highly-valued resource, but also the seasonal and by-size class prices and/or the fishery closed-season imposed, as potential social aspects, could interact to draw the landing patterns observed in the fishery.

This study strategically assesses the relationship with ecological and socio-economic factors of the complex SES around the *S. dumerili* fishery, through the means of historical and detailed landings data. Studying this relationship could significantly help the scientific community understand the currently scarce ecological information about *S. dumerili* within an exploited system. Such socio-ecological approaches might strongly contribute to fisheries management in the Mediterranean and to the understanding of fluctuations in catch and price rates while providing vital information for decision and policy makers to effectively and sustainably manage the fishery [45].

2. Materials and Methods

2.1. Study Area

This study was conducted in the Balearic Islands, a Spanish region, composed of four islands: Mallorca, Menorca, Ibiza and Formentera [46] (Figure 2). This archipelago is located in the NW Mediterranean between 38°35′–40°05′ N and 04°20′–01°15′ E [20] and it is recognized as an independent fisheries management unit [26,46]. Mallorca, with an area of 3620 km^2 and about 623 km of coastline [45], is the main island of the archipelago and is where most fish are landed and sold [20].

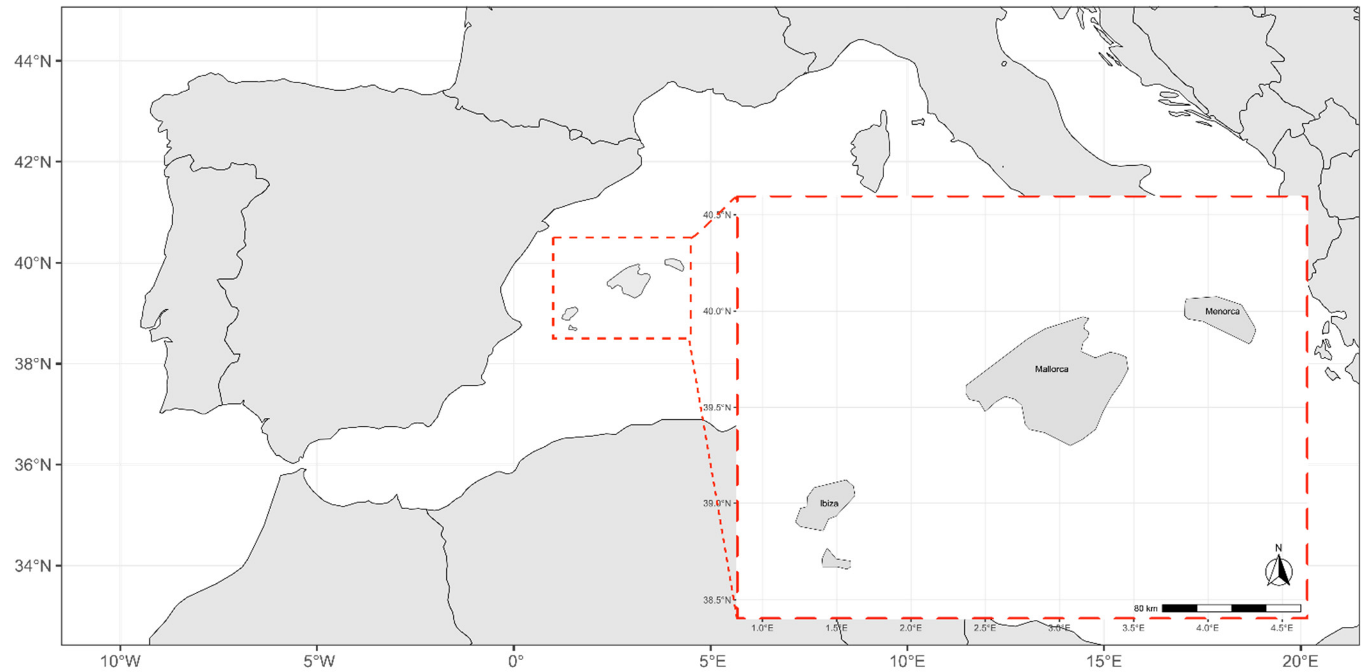

Figure 2. Overview map of the study area with main islands included: Mallorca, Menorca, Ibiza, and Formentera (below Ibiza).

2.2. Data Collection, Curation and Management

To gather information about the *S. dumerili* fishery, two different data sources were used during this study. Historical records of captures from the period 1950 until 2018 were obtained from *Sea Around Us* website (www.seaaroundus.org, accessed on 16 March 2022). This is an international project that began in 1999 in an attempt to estimate worldwide reported and unreported total fisheries catches [47]. Detailed landing data of Balearic fishing catches from the last two decades (2000–2021) were provided by the Palma Fishing Wharf in Opmallorcamar, Mallorca.

In order to provide an overview of the historical trend in *Seriola dumerili* catches (1950–2021), both datasets were combined. The period from 1950 to 1999 was covered by the historical timeseries from *Sea Around Us*, while for the last two decades (2000–2021) the Palma Wharf landing data was used. This last dataset contained extensive and detailed landing information for the last 21 years and included the daily weight of catches of *S. dumerili*, along with social and fishery information regarding the fishing vessel, gear and price per kg. Moreover, this data was available and subcategorized by the Palma Fishing Wharf in descending order of size (*Categories*), locally known as *Sirviola Grossa*, *Sirviola Petita* and *Verderol* with the latter including juveniles of the species that do not reach 30 centimetres [36]. *Sirviola Grossa*, may be considered to be all individuals larger than 100 cm since they represent adult specimens while *Sirviola Petita* sizes are those between the adults and juveniles. These categories are based on size, which can be related to the different life stages which are essential to provide information on how to properly disentangle the ecology of the species throughout the different phases of its life.

Two new categorical variables—*Regulation* and *Season*—were added to the data frame. The first was based on the law created in 2011, which established a closed fishing season (between 16th of November to 14th of July) for purse seines targeting *S. dumerili* [37], and the second one to account for potential seasonality patterns.

In order to describe the potential effect of *Regulation* on *S. dumerili* fishery, the yearly and monthly catch per unit effort (CPUE, kg/trip) was calculated by adding up the total catch of *S. dumerili* for every year and month, respectively, and dividing by the yearly and monthly number of fishing vessel trips. These estimations only accounted for purse seines given this fleet focuses on the exploitation of this resource as a target species (most important gear in terms of landings; see below in the results Section 3.2).

All data cleaning, exploration and analysis was performed using R version 4.2.0 [48]. Outliers were checked visually with the help of preliminary boxplots and kept for all variables except *Price*, to avoid removing values that could potentially be real catches and consequently create misleading results [49].

2.3. Statistical Analysis

The response variables, *Catch* and *Price*, were included in different generalized models as a function of various predictor variables, adjusting all statistical procedures according to the socio-ecological patterns found in *S. dumerli* fishery to be addressed (Table 1).

Table 1. Summary of models performed and their statistics. Respective response variables, potential transformations and explanatory variables used for each model.

	Response Variable	**Explanatory Variables**	**Model**	**Transformations**	**r^2**
Historical Trends	Catch (Kg)	Year	GAM (Catch ~ s(Year, k = 13)) [1]	Untransformed	0.689
Ecological Traits	Catch (Kg)	Categories Season	GLM (Catch ~ Categories * Season) [1]	Ordered Quantile Normalization (ORQ)	0.268
	Catch (Kg)	Gear	GLM (Catch ~ Gear)	Ordered Quantile Normalization (ORQ)	0.174
Socio–Economic Traits	Price (€/Kg)	Categories Month	GAM (Price ~ Categories + s(Month, k = 4) + s(Month, Categories, k = 7) [1]	Untransformed	0.315

[1] Interactions terms are indicated with * while smoothed terms are represented by *s*, depending on the model conducted (GLMs and GAMs, respectively).

Both Generalized Linear (GLMs) and Generalized Additive Models (GAMs) were performed during this study. GLMs [50] were used to assess linear relationships between response and explanatory variables (*glm* function from *lme4* package [51]), as this is a model that allows incorporation of non-normal response variables [50]. Whenever a non-linear relationship was observed in preliminary graphs, between explanatory and response variables, GAMs (*mgcv* package) were chosen, due to their higher flexibility when accounting for smoothness of the terms in the model [52]. For both models, when worth considering, interactions between predictors were included. When the data showed non-normality and homoscedasticity, transformations were performed using *bestNormalize* package [53], which selected the best normalizing transformation for the available data.

To provide an overview of the historical trends of *S. dumerili* catches, *Catch* (weight of *S. dumerili* by year) was modelled as a function of the *Year* using GAM (Table 1) as a data smoothing procedure to reduce the yearly variation. Meanwhile, ecological traits were assessed using two GLMs (Table 1). Transformed values of *Catch* (weight of *S. dumerili* for a given day and gear) were fitted as a function of the interaction of the categorical variables *Categories* and *Season* in order to disentangle a potential seasonal pattern of capture using the different life-stages of the species. Secondly, the same transformed response variable *Catch* was modelled as a function of *Gear*, in an attempt to relate the ecology of the species based on the fishing behaviour.

To disentangle a potential social effect of the price on the seasonal landings pattern of *S. dumerili* size classes, *Price* (€/Kg of *S. dumerili* daily sales) was fitted as a function of the categorical and numerical variables, *Categories* and *Months*, respectively, and the interaction of both using a GAM (Table 1).

In relation to the GAMs, the selection of the basis dimension parameter *k* was based on the diagnostic tests from *gam.check* function included in the *mgcv* library [54] and with the purpose of avoiding model overfitting (Table 1). A gamma value of 1.4 was also included in both GAMs for the same reason. The effective degrees of freedom (*edf*), when close to 1, was indicative of linearity between stressor and response variables [55].

For all models, the response variables were assumed to follow a Gaussian distribution with an identity-link function. Moreover, the goodness-of-fit was assessed as a function of the Akaike Information Criterion (AIC) [56], with significance of the variables and deviance explained. The distributions of the residuals were subsequently checked for normality with *qqplots* and confirmed among residuals, while the R *effects* library [57] was used to obtain the partial effects of the fixed factors. Predicted mean prices for all size categories were fitted with the function *predict_gam* of *tidymv* package and plotted using *ggplot2* library.

3. Results

3.1. Historical Trends of S. dumerili Catches

Record of catches of *Seriola dumerili* in the Balearic Islands region were analysed for a total period of 72 years (1950–2021) (Figure 3). After 1960, catches of *S. dumerili* considerably increased, reaching a peak of approximately 71 tonnes in 1969. This trend was followed by a continuous decline until the present day, with the lowest catch being recorded in 2015 (Figure 3).

Catch showed significant inter-annual variability among years ($p < 0.05$), with record values in the mid-1960s and following a decline after the 1980s. Catches increased again in the mid-2000s but immediately dropped straight after, until now (Figure 3). The residuals of the model revealed normality.

3.2. Ecological Factors

Landings of *S. dumerili* from the period 2000 to 2021 registered a mean of 33.10 $\pm$ 11.07 tonnes per year, with higher numbers occurring predominantly in the first decade (Figure 1B,C by size classes). Within a year, catches maintained low levels in the beginning until the start of the second semester, when landings of *S. dumerili* started increasing (Figure 1D), indicating a high seasonality pattern. *Sirviola Petita* (medium size) appeared throughout the year in very low and stable catches while *Sirviola Grossa* (bigger size) reached higher values in *Spring*, *Summer* and *Fall*, peaking in *Summer* months (Figure 4A,B; $p < 0.05$). Additionally, the landings of juveniles (*Verderol*) grew particularly during *Summer* and *Fall* (Figure 4C,D).

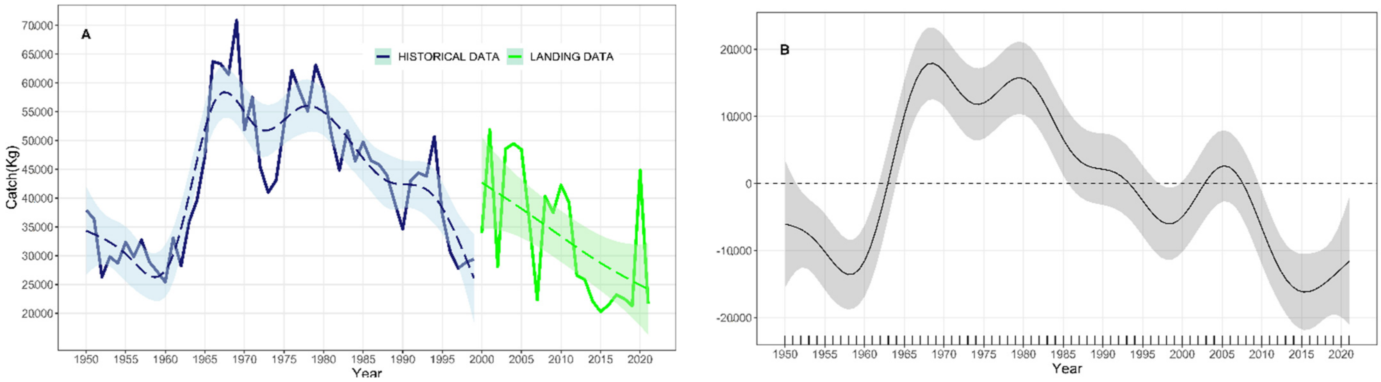

Figure 3. (**A**) Yearly distribution of *Catch* of *S. dumerili* for the period 1950–2021, obtained from both historical (blue) and landing (green) data. Dashed line is the smoothed trend estimated by the GAM method of the *geom_smooth* function. Blue and green shadows represent the confidence intervals. (**B**) GAM smooth splines of the response variable *Catch* as a function of the explanatory variable, *Year* and respective 95% confidence intervals.

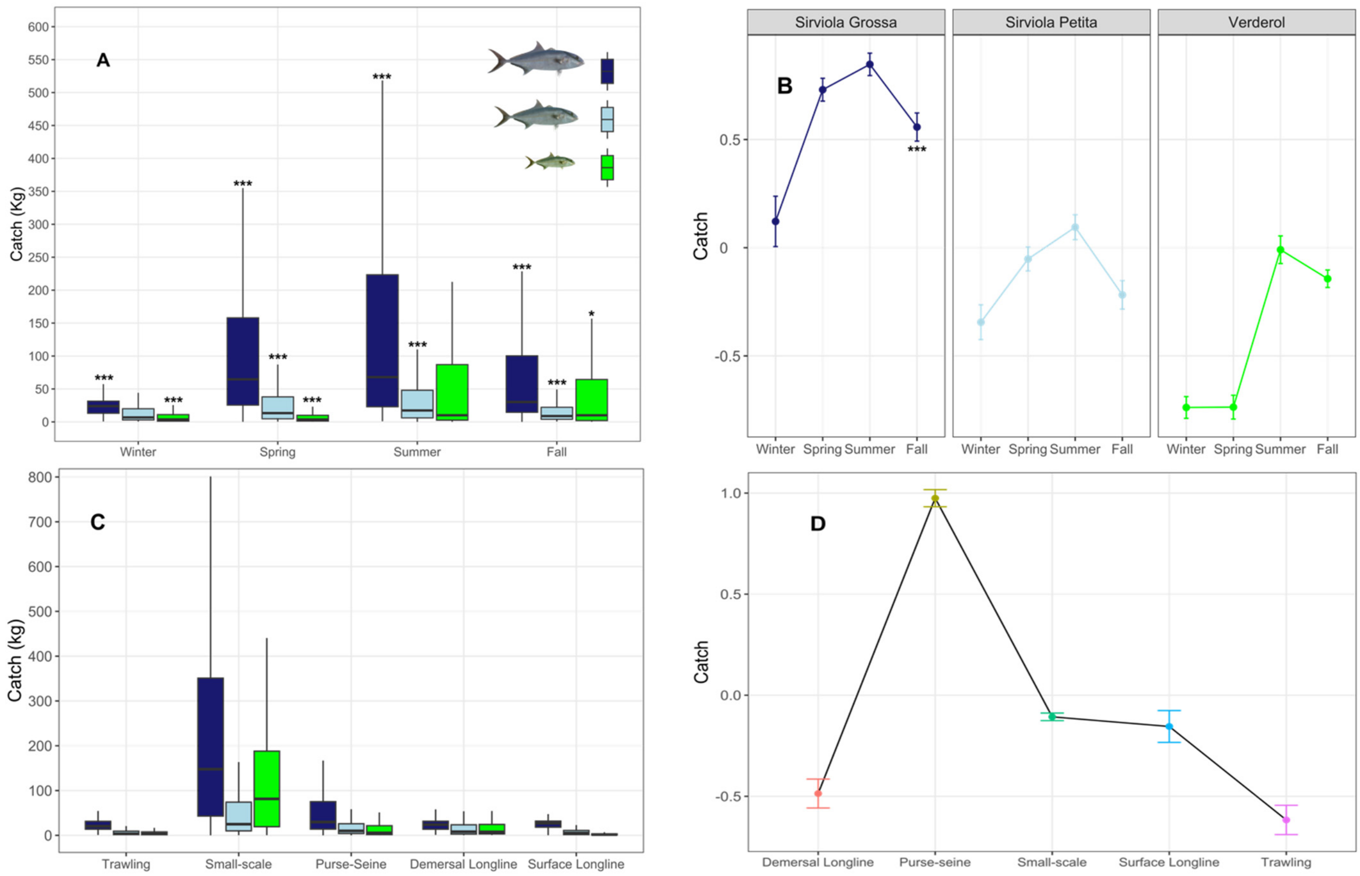

Figure 4. (**A**) Seasonal distribution of daily catches of the different size classes (asterisks above boxes indicates p-values * < 0.05 and *** < 0.001). (**B**) Partial effects of the interaction between *Categories* and *Season* on *S. dumerili* catches. (**C**) Proportion of *S. dumerili* landings (kg) for each *Gear* investigated with correspondent partial gear effect plot (**D**).

Catches from *Verderol* in *Summer* did not show significant effects ($p > 0.05$) (Figure 4A). The model resulted in a r^2 of 0.268 (Table 1) and residuals showed normality. Partial effects of the residuals revealed higher catches for *Sirviola Grossa* when compared to *Sirviola Petita* and *Verderol*, with the first two demonstrating the same seasonal pattern of landings (lower in *Winter*, peaking during summer followed by a decrease in *Fall*). Moreover, *Verderol* registered almost no catches during *Winter* and *Spring*, only appearing later in *Summer*, when it peaks (Figure 4A,B).

All gears studied revealed significant catches of *S. dumerili* ($p < 0.05$; Figure 4C,D). However, *Purse seine* is the gear that accounted for the majority of *S. dumerili* landing weight, with an average of approximately 16.1 tonnes per year ($p < 0.05$; Figure 4C,D) revealing a clear targeting pattern of *Seriola dumerili* by this fleet. In Majorca, *purse seiners* are multispecies, meaning that they target many different species throughout the year, such as tunas, squid, sparids, anchovies and sardines, while small-scale fisheries, responsible for being the second gear with the most catches, comprise a various number of passive gears that target *S. dumerili:* "solta" (February to April and September to December); "moruna" (April to September; similar to tuna traps deployed in shallow waters in search of spawner aggregations); "mussolera" (historically to catch demersal shark *Mustelus mustelus*: February to April) and "currican" (mainly *Verderol*: September to October). As a bycatch, *S.dumerili* can be caught with: "llampuguera" (mainly *Verderol*: August to November), "almadrabilla" (March and April) and trammel net (targeting spiny lobster *Palinurus elephas* and *Mullus* sp.) [58].

3.3. Socio-Economic Factors

Mean *Price* (€/Kg) of the different size categories of *Seriola dumerili* varied through seasons and across months ($p < 0.05$; Figure 5A,B). Although *Sirviola Grossa* maintained similar prices throughout the year, *Sirviola Petita* and *Verderol* disclosed seasonal patterns indicating an increase of economic value during *Summer* months (Figure 6B), reaching a maximum of 18.5 €/Kg and 19.1 €/Kg in August and July, respectively.

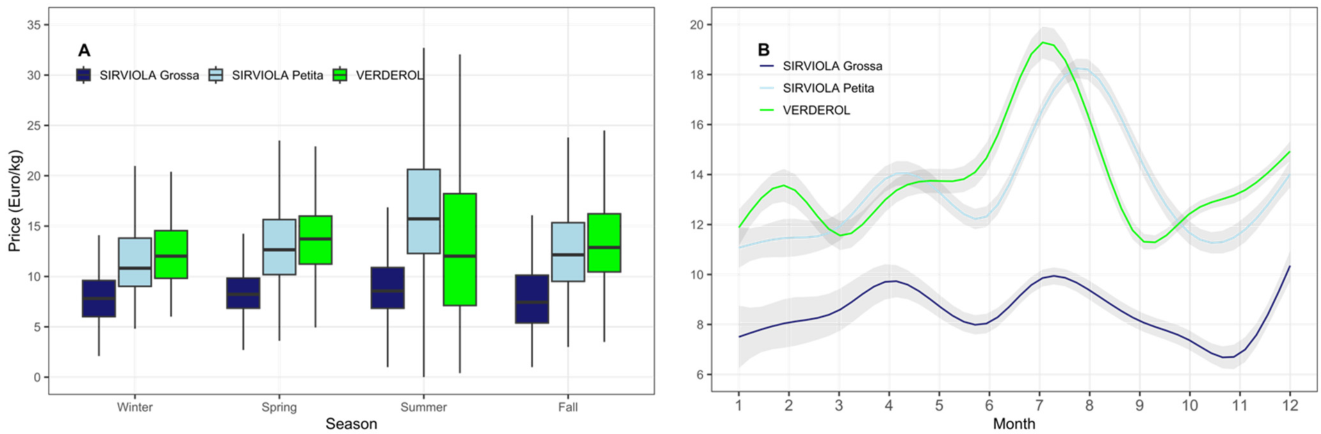

Figure 5. (**A**) Mean price (€/Kg) for all three size categories by *Season* (**B**) GAM predicted smooth splines of the response variable mean price of the different categories as a function of month ($p < 0.001$).

The GAM prediction of *Price* trend along the *Months* of the year confirmed the pattern first observed with the exploratory plots by demonstrating significant effects among *Categories* ($p < 0.05$) mean prices and through months. The predicted values of *Price* displayed, once again, a clear seasonal relationship between mean prices of *Verderol* and *Sirviola Petita* and were less prominent for *Sirviola Grossa*. These two categories of *S.dumerili* reached higher prices during optimal months of the year (July and August), after which they decrease back to lower prices (Figure 5B).

Similar CPUEs levels before and after the *Regulation* were shown for the last twenty years (Figure 6A). An increase CPUE trend along the months, peaking in August and followed by a consecutive decline, was detected (Figure 6B). Furthermore, such inter-month trends seemed to have remained fairly similar for the period affected (after 2011) and not affected (before 2011) by the *Regulation* (Figure 6B). For the months where fishing was not always allowed (January to May and December), CPUEs remained at relatively low numbers regardless of whether the regulation was enforced or not. For instance, in December there were no fishing trips occurring after 2011 while in April only one fishing trip was conducted for the same period (Figure 6B).

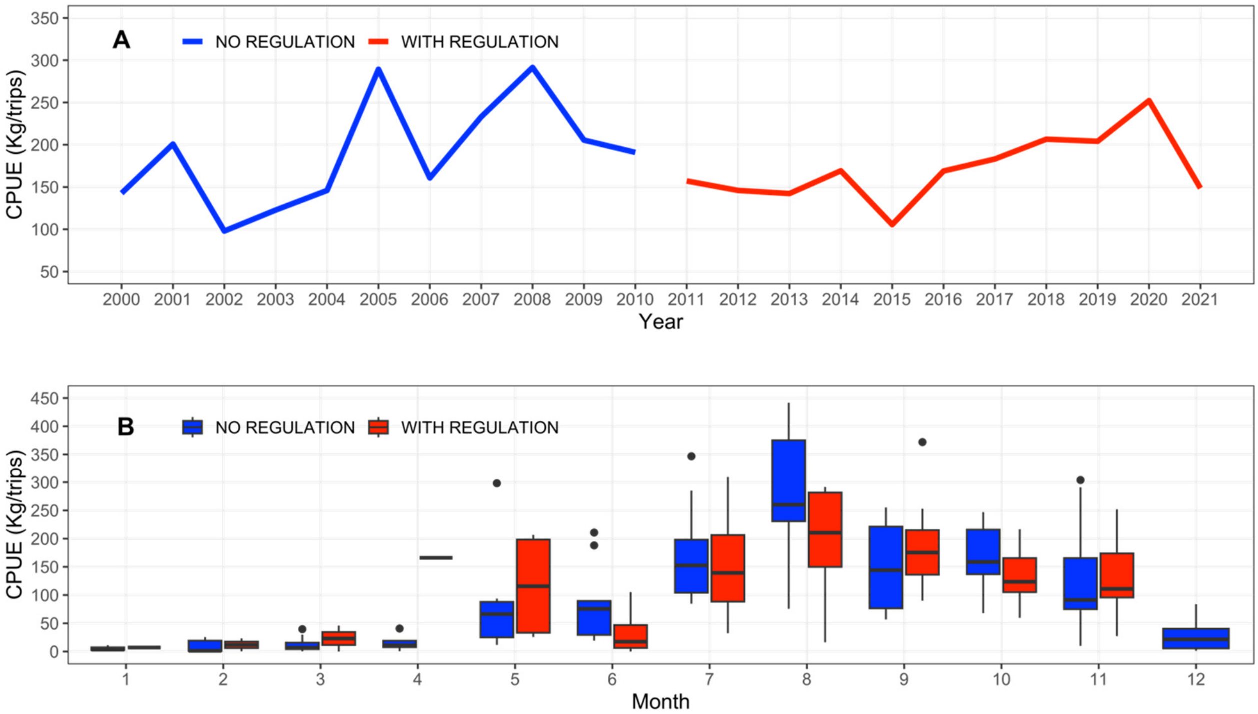

Figure 6. (**A**) CPUE distribution (2000–2021), for purse seine fleet that only target *S. dumerili*, as a function of the Regulation, (blue—before 2011; red—after 2011). (**B**) Monthly CPUE distribution, as a function of the Regulation (blue—before 2011; red—after 2011).

4. Discussion

This study represents the first attempt at investigating the *Seriola dumerili* fishery and its potential relationship with ecological and socio-economic factors. By analysing over 72 years of landing data in the Balearic Islands, evidence was found that the fishery was influenced by more than just biological components, with social and economic aspects holding regulating power as well.

Whilst reconstructed Balearic catch data between 1950 and 1999 [46] should be interpreted with caution, nonetheless, the trends observed seem to follow the common historical fishery. The big increase registered in the second half of the last century, near the 1960s, was a common pattern reported among Mediterranean fisheries [46]. The Balearic's increase of *S. dumerili* captures could be closely related to the expansion of consumption resulting from tourism and technological improvements that allowed fishing gear to become more efficient and consequently increase vessel's fishing power [10,59]. The declining trend from the 1980s can either be indicative of stock overexploitation, a decrease of fishing capacity owing to a decay in the number of fishing vessels [26,60,61] or a combination of both. Another possible explanation may be the decline of nutrient flux registered in the Mediterranean after the mid-1980s as reported by some studies [11,12]. This development in combination with high rates of exploitation might have led to the collapse of landings [6]. The declining trend has been prominent until the present day, although there was a slight increase in the mid-2000s but never comparing to levels documented in the past century.

Within this decreased scenario of landings, our results strongly suggest a seasonality pattern in landings of different life-stages, probably related to the species ecology. In fact, *S. dumerili* spawners (in most part *Sirviola Grossa*) undergo spawning aggregations between late-spring and early-summer in the Mediterranean [30,31], periods in which this species becomes more susceptible to being caught [44,62–64]. The non-significance of catches of juveniles in *Summer* can either be related to the fact that there are similar catches of *Verderol* during *Fall* or be in comparison with other size *Categories* such as *Sirviola Petita*, which has identical numbers of catches in *Summer*. Nevertheless, the increase of juveniles catches during this period is probably a consequence of the species recruitment [34,65], as they can become available for the fishery faster due to their rapid growth throughout early life stages (1.45 mm/day) and for late season cohort [27]. Meanwhile, the medium size fish (*Sirviola Petita*) was found at relatively low levels between seasons, with slightly higher catches occurring in *Summer*, just as for *Sirviola Grossa*, and possibly related to the behaviour and ecology of the species. A point to be highlighted is the lower record of landings during *Winter* months (January–March) for all three size categories. Social and economic factors could be influencing this tendency [8], however based on the results obtained in the present study, these socio-economical aspects can be discarded, considering the spatio-temporal behaviour and ecology of this species. Other fisheries, such as the transparent goby (*Aphia minuta)* fishery, register high catches during these cold months (December to April), while the dolphinfish (*C. hippurus)* fishery sustains low catches for the first two trimesters of the year (January to August), demonstrating a clear seasonality pattern in the species caught by small-scale fisheries. Besides, this colder period falls outside the temporal spawning-window [32] and therefore, a possible disaggregate schooling behaviour and migrations towards deeper waters [30] could explain the decreased availability of the resource for the fishery.

This explanation is in agreement with the fishing behaviour of the purse seine fleet which accounted for 56% of total catches. Just as for other central Mediterranean cities, purse seines stood out as the main contributor for most *S. dumerili* landings [30]. This was already expected since purse seines' main strategy is to use encircling nets to target species that are aggregated in a specific place [66]. Moreover, as mentioned above, *S. dumerili* is a reef-associated species [34] with a clear aggregating behaviour during spawning events [30] and in earlier stages, as juveniles are also known to aggregate in offshore areas starting in July [33,34,65]. Such spatio-temporal schooling behaviour during different life stages of *S. dumerili* ultimately makes this species more vulnerable and likely to be exploited by the purse seine fishery, who seem to focus their exploitation efforts on the time and place the species is available and economically profitable [61].

Regarding socio-economic factors, price and its link with tourism showed an effect on landings of the fishery, while fishing regulation seems to have had no effect. The rise for these two size categories' (*Sirviola Petita* and *Verderol*) prices strongly matches the touristic high season in the Balearic Islands [20,21]. With the increasing arrival of tourists in the archipelago, the demand grows in restaurants, hotels and local fish markets, with higher preference for small to medium average size fish, in detriment of larger fish. This pattern explains the relatively constant low price trend for *Sirviola Grossa* across the year [10,20,21]. After peaking, *Sirviola Petita* and *Verderol* mean prices suffer a steep decline, probably due to the end of the intense high season, or as a consequence of market value change, coinciding with the period of time *Verderol* becomes most vulnerable to being harvested and therefore a higher availability of this resource results in lowering prices (a clear marketing example of the supply and demand law [67]). Another social aspect that clearly influences fisheries in term of landings and spatio-temporal distributions of effort are regulations [14]. However, similar CPUEs between periods of regulation and no regulation may prove that even though socio-economic factors have the power to affect this fishery [61], it seems that the ecological aspects hold more power when it comes to influencing *Seriola dumerili* fishery.

A detailed understanding of the ecology of *S. dumerili* is fundamental to its conservation and resource management considering the economic importance of this species both in the Balearic Islands and worldwide [2]. Little is still known about *S. dumerili* ecology, as the main study focus has been on captivity rearing and reproduction [68–71]. This study provides key socio-ecological insights on *S. dumerili* fishery; however, it is vital to conduct future research to improve the successful management of this resource in the Balearic Islands and Mediterranean Sea.

Analysing historical data of catch per unit of effort would shine light on *S. dumerili* fisheries' history and help assess the current status of the stock, while telemetry experiments (e.g., acoustic and satellite transmitters [72]) could provide important information about the species distribution (previously conducted in other places with related species *Seriola rivoliana* [1]) and confirm the hypothesis of offshore spawning migrations potentially being behind the lower catches of *S. dumerili* during winter months. Additionally, as this fishery is inserted in a system with complex human–environment relationships and profound uncertainties [16], it is highly recommended to deepen the knowledge on other potential ecological and socio-economic indicators, such as the population structure and growth, reproductive traits, employment and income.

Finally, and since the current legislation did not appear to have an effect on CPUE of *S. dumerili*, an extension of the closed season (from May to August) would fully cover the spawning period of this species. Despite being suggested a short spawning period (May–June) triggered mainly by higher temperature cues [32], the gradual increase of such a variable under the tropicalization of the Mediterranean Sea [73] could expand the temporal window of the spawning. Therefore, this conservative measure (extended closed season from May to August) might ensure the protection of this important life-history trait and vulnerable event for *S. dumerili* [34] with potential consequences on its population dynamics. It is important to ensure that future regulations made by decision and policy makers are socially and ecologically fair [3] and supported by the best available information to effectively and sustainably manage the *S. dumerili* fishery [45].

5. Conclusions

The present study represents the first research conducted providing an overview of the *S. dumerili* fishery from a socio-ecological framework. The findings of this study contribute to a better understanding of the ecological, economic and social pillars of *S. dumerili* fishery. After analysing historical and detailed landing data, results revealed an important seasonal fishery occurring in the NW Mediterranean, mainly influenced by the species ecology with considerable weight given to socio-economic factors. As such, this study provides essential information for proper sustainable management of one of the most important marine resources not only in the Balearic Islands but across the world.

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