Junta de Andalucía

INSTITUTO ANDALUZ DE ADMINISTRACIÓN PÚBLICA.

(O.E.P.) ORDINARIA 2020

CUERPO SUPERIOR FACULTATIVO, ESPECIALIDAD INVESTIGACIÓN AGRARIA Y PESQUERA DE LA JUNTA DE ANDALUCÍA (A1.2200).

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4. Este ejercicio se valorará con una puntuación de 0 a 10 puntos.
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OPCIÓN 1

Marine Policy 163 (2024) 106130

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Spanish fishing industry within the common fishery policy

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ARTICLE INFO

Keywords:
Common fishery policy
Total allowable catches
Cod
Hake
Anchovy
Quotas

ABSTRACT

The main objective of this article is to study the evolution of the Spanish fishing industry, with a specific focus on examining the correlation between actual catches by Spanish vessels and recorded landings against national Total Allowable Catches, which may contribute to improving the current state of the Common Fisheries Policy. Firstly, we offer an overview of the geographical, economic, and legal factors surrounding Spanish fisheries, along with an examination of the Common Fisheries Policy and relevant international agreements impacting these fisheries. Subsequently, we analyze three species, namely hake, anchovy, and cod as they are the most traded fish in the Spanish markets. Thirdly, we conduct an examination to provide information regarding the role of Common Fishery Policy quotas and to explore potential reasons behind the observed results. The main findings reveal the identification of a significant lack of alignment between the Common Fishery Policy and its resulting implementation through the Total Allowable Catches over the last decade.

1. Introduction

Fishery management aims to achieve sustainable production and harvesting, taking into account the biological, social, and economic benefits deriving from the rich biodiversity in the oceans [10]. The overexploitation of fishery resources in aquatic ecosystems has prompted global institutions to implement various policies aimed at preventing the depletion of fish stocks. However, owing to the integral role of the fishery sector in the global economy and its fundamental significance to specific countries, policymaking encounters potential constraints and challenges. Both biological and economic sustainability must be attained to establish an effective fishery management.

The rationale for choosing Spain as the focus of this research is rooted in its status as a fishing powerhouse within the European Union (EU). Statistical data indicates that Spain contributes significantly to the overall catches, revenues, and landings reported across the European continent [4–6]. Spain's prominence in the European fisheries sector not only underscores its economic significance but also presents a compelling case for examining the intricacies of its fishery management practices.

Legal frameworks and other forms of regulations have been a key factor in the sustainable exploitation of natural resources. An illustrative example is the Common Fisheries Policy (CFP) developed by the European Union [15]. Nevertheless, the economic impact of the CFP can vary depending on the country.

Thus, our paper examines the development of the Spanish fishing industry, with a particular focus on evaluating the correlation between the current catches made by Spanish vessels and the recorded landings employed in determining the national Total Allowable Catches (TACs). In essence, our research aims to determine the extent to which the TACs are being adhered to within the context of the Spanish fishing industry.

We focus our attention on three specific species—cod, hake, and anchovies—as they represent the most sought-after fish in the Spanish market and hold significant commercial importance [7,11,23]. Besides, we gather data on quotas, prices, and the operational dynamics of the fishing industry. The obtained results are then compared with overall data, employing a relational approach procedure.

Our analytical approach aims to broaden the understanding of the topics addressed within the Spanish fishing industry. Conclusions are drawn, and results are presented, with suggestions provided for further research in specific areas.

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https://doi.org/10.1016/j.marpol.2024.106130
Received 11 January 2023; Received in revised form 1 February 2024; Accepted 23 March 2024
Available online 28 March 2024

2. Background

2.1. Geographic, economic and legal context of the fisheries exploitation in Spain

Spain, with its extensive coastline spanning 7661 kilometers, has access to a vast Economic Exclusive Zone (EEZ) [19] covering an area of 1039,233 square kilometers. The EEZ as an internationally recognized system for defining state jurisdiction areas empowers a country to determine, govern, and use marine resources within its designated zone.

The Spanish EEZ is subdivided into three distinct areas: (1) the Atlantic and Cantabrian Sea (Bay of Biscay), (2) the Mediterranean Region and the Gulf of Cadiz, and (3) the waters surrounding the Canary Islands[4] However, establishing specific jurisdictional boundaries proves challenging due to physically overlapping zones, often in close proximity to the EEZs of other sovereign nations. Consequently, Spanish authorities frequently resort to international litigation, presenting their case before international organizations [20]. The engagement in maritime activities, known as *maritime connectivity*, has had a positive impact on economic development and trading relationships for all nations involved. This reality motivates the Spanish government to express a keen interest in safeguarding potential economic assets [17].

Spain's extensive and diverse natural surroundings have played a crucial role in shaping its long and rich history. The various resources, conflicts, and opportunities arising from these surroundings have undeniably influenced the development of Spanish culture and history [14]. The influence of the fishing industry on a wide range of regions, encompassing economic, cultural, and political dimensions, has shaped Spain's standing in the global fishing sector. In 2018, the Spanish fishing industry contributed significantly to its economy, generating a value of USD 2163.72 million from fish products. This accounted for 1.081% of the global fisheries production. Moreover, employment within the sector, including processing and aquaculture, reached 30,981 individuals in 2018 [12]. The Spanish fleet comprised a total of 8976 motor ships, with small-scale boats (under 12 m in length) making up 73.2% of the fleet. Another metric for measuring vessel fleets is gross tonnage (GT), and in Spain, the total GT amounted to 331,778 tons. Notably, 4.5% of this total was attributed to the aforementioned small-scale vessels [12]. While these figures provide just a glimpse into the total scope of the fishing industry in Spain, they underscore the country's significant role as a key player in the global fishing economy.

In 2019, Spanish port landings of fresh fish captured by Spanish vessels were estimated at 205,390 GT [16]. Furthermore, when considering the overall fresh fish landings in Spanish ports by European vessels, the figures increase to 327,000 GT [4]. This accounts for one-fifth of the total catches of all forms of fish products in the EU.

Fisheries in Spain are subject to a complex regulatory legal framework at both the national and EU levels. The CFP of the EU -described in the next subsection- plays a crucial role in regulating fishing activities. Spain, as an EU member state, aligns its national regulations with the overarching policies of the CFP. The Spanish fisheries policy is based on the following key aspects: (1) Sustainable management to prevent overfishing and depletion of marine resources; (2) Quota system to manage fish stocks; (3) International cooperation with other countries and international organizations to address global fisheries challenges, including illegal, unreported, and unregulated fishing; and (4) Research and Innovation, as investments in research and innovation are integral to Spanish fisheries policy.

The main Spanish regulations in the field are set out in Law 3/2001, of 26 March, on Maritime Fishing of the State. This law is complemented by the legislation of the Autonomous Communities regarding fishing in internal waters, shell-fishing and fish farming [22].

[4] Organic Law 10/1977, of 4 January, on territorial see. (BOE No 465, of 08.01.1977). Available at: https://www.boe.es/eli/es/l/1977/01/04/10

In short, this examination of the macro-data of the Spanish industry reveals a dominant position within the European community. However, it is important to note that in global terms, this influence is relatively limited.

2.2. Common fishery policy and international agreements

In the EU, the main legal instrument for the control and regulation of the fishery industry is the CFP. Although the CFP's establishment dates back to the 1970 s, it was only in 2009, with the enactment of the Lisbon Treaty, that significant changes were implemented. The CFP transfers control over fisheries policies from each member state to the EU, granting the EU the power to decide over all the EEZs of its member states and additionally over other areas agreed with third countries by international treaties. Its main objective is to safeguard marine biological resources according to the CFP as outlined in the Treaty on the Functioning of the EU [2]. Within this framework, Spain is mandated to adhere to the regulations set forth by the CFP.

The CFP establishes quotas for each member state, overseeing the type and quantity of various species in the oceans to promote the sustainable exploitation of natural resources [15]. Each fishing season, the European Council issues its regulations specifying Total Allowable Catches (TACs) applicable to each Member State for the allocation and utilization of proposed quotas. These regulations are primarily defined by International Council for the Exploration of the Sea (ICES) unless specified otherwise.

A significant water expanse for Europe includes the Mediterranean and the Black Sea. The existing delineations in this region are governed by the Food and Agriculture Organization of the United Nations (FAO). Similar to the ICES Statistical Areas, subdivisions of different parts of this expanse are specified to facilitate standardized management among various international actors. The primary regulatory authority in this area is the General Fisheries Commission for the Mediterranean, a subdivision of the FAO.

Each delimited area features its unique fish stocks, varying in quantities and species. According to existing regulations, each area is assigned the species present within it, along with the corresponding quotas allocated to potential member states. In the case of Spain, it enjoys access to most quotas in its immediate vicinity and some additional quotas in more distant regions. The reason behind this distribution could be attributed to the larger operational capacity of the Spanish fishing fleet, accounting for 25% of the entire GT of the European fleet in 2019, as reported by Eurostat [4].

Another relevant phenomenon within the framework of this European policy (CFP) is the widespread use of quota swaps among member states. This practice implies that countries can adjust their quotas either by exchanging quotas with other countries or by requesting and being granted permission to transfer quotas of a specific species from one area to another within the same country. Quota swapping, a practice integral to the Spanish fishing industry, is devised to facilitate the exchange of species that cannot be harvested at acceptable costs for those that can be harvested profitably. Therefore, public administrations have the ability to deviate from the central goal of "relative sustainability" by intensifying efforts within the industry to ensure compliance [9].

Additional areas are covered by bilateral agreements between the EU and third countries. Although the European Council engages in negotiations within the context of various conventions and agreements, the importance of these extra areas to the European fishing industry is relatively minor. These waters fall within the EEZ of other sovereign countries, and, through specific international agreements, are accessible to European vessels. The regulation of these areas is within the jurisdiction of external institutions functioning under foreign governments. Similar to the European institutions, these external bodies provide a scientific foundation and management advice for the fisheries involved [18].

European Community and European Free Trade Association fishing vessels predominantly operate in the main internationally defined European fishery areas. These areas align with those accessible to the EU through the EEZ of member states or by way of agreements with non-member countries. Additionally, the regulation of bureaucratic processes, fleet management, and other aspects related to the operation of the fishing industry in its member state falls under the purview of the CFP (Regulation (EU) 1380/2013). The objectives of this institution encompass the conservation and management of living marine resources, including biological, economic, environmental, social, and technical factors.

3. Method and research questions

To get an overview of important issues related to the evolution of the Spanish fishing industry, the main topics were selected and a research question was identified from these topics. Our paper aims to find the relationship between the current catches made by Spanish vessels and the recorded landings used in calculating national TACs, and to what extent their adherence to TACs within the broader context of the Spanish fishing industry is:

RQ1. How do the current catches by Spanish vessels correlate with the recorded landings used to calculate national TACs, and to what degree is compliance with TAC regulations observed in the broader context of the Spanish fishing industry?

To address this research question, we collected data on quotas for three specific species: cod, hake, and anchovies. We selected these species due to their high demand in markets and their considerable commercial significance. Our analysis involves comparing the ascribed quotas with total landings. This comparison aims to determine how effective is the quota system for Spanish vessels as regards the selected species (post-swaps). Additionally, we seek to understand what is being caught, registered as landed, and counted against the quota.

Data comes from both the Spanish fishing industry and the European regulators. As mentioned, Spain, as an EU member state, aligns its national regulations with the overarching policies of the CFP, and therefore, we need to compare Spanish and European data.

Like any method, our approach has its strengths and weaknesses. A notable strength lies in our use of official data, enabling meaningful comparisons over time since the information is consistently collected under uniform conditions. However, a primary drawback is associated with the delay between data collection and the availability of this information.

In short, by observing some key variables, we provide a specific overview of the situation during the past 10 years. The reason for this period is simple: available data and the actually implementation of the CFP by the Lisbon Treaty signed in 2010. This enables us to draw some conclusions and propose a research agenda about the current state of affairs and the effectiveness of this new policy.

4. Data

4.1. Evolution of the Spanish fishing industry

Data concerning the evolution of the Spanish fisheries sector highlights a discernible decline in the overall fresh fish landings by Spanish vessels at Spanish ports from 2010 to 2020 (Fig. 1). While this could be interpreted purely from an economic perspective, it does not consider the biological implications of the results.

A notable point to remark about these data is that they pertain exclusively to vessels under the Spanish flag. A compelling vision can be gained by comparing these figures with the landing of fresh fish by every single EU vessel in a Spanish port (see Fig. 2). The data reveal that the actual quantities of fresh fish supplied by the entire European fishing fleet to Spanish ports have undergone various fluctuations, mirroring periods similar to those experienced by the Spanish fleet. This phenomenon could be attributed to the collective adherence of all member states to the requirements outlined in European Council regulations within the context of the CFP. Yet, this offers a simplified explanation for a topic that warrants further attention from the academic community.

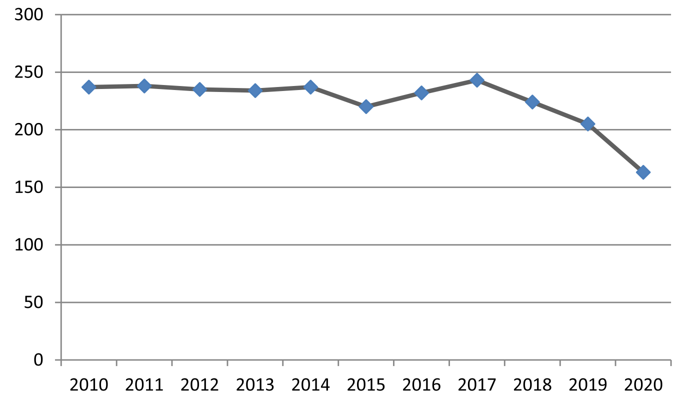

Fig. 1. Total landings of fresh fish in Spanish ports by Spanish vessels from 2010 to 2020 (in thousands of tons). Source: Puertos del Estado [16].

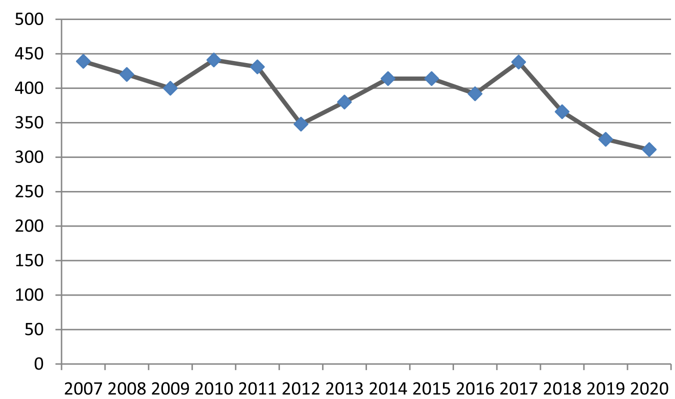

Fig. 2. Total landings of fresh fish in Spanish ports by European vessels (in thousands of tons). Source: Eurostat [4], Landing of Fishery Products in Spain.

A fundamental objective of every governmental policy is to generate positive impacts on the stakeholders involved in the targeted economic activity subject to government intervention. One of the key indicators for assessing the consequences of policies related to economic matters is the direct impact on the monetary cash flows associated with the activity. Since our primary focus lies on the participants in the fishing industry in Spain, it becomes essential to define this metric. Choosing the market value of the first catch—monetary valuation at the moment the harvested fish products are sold for the first time—can be deemed a robust indicator. This is because it represents the initial transaction between the producer and the value-added chain. The available data, measured as the total value in euros at the time of the first economic transaction related to fishery products, is depicted in Fig. 3 (at constant prices).

The economic impact has undergone various fluctuations, with a distinct drop noted after the 2008 crisis, particularly in 2011 and 2012. Additionally, there has been a generalized decline. These results, expressed in absolute terms, provide a clear view of the direct impact. On the other hand, examining the data on the cost of 1 GT of fresh fish can offer better insights into understanding its historical evolution (see Fig. 4). After 2011, there was a slight decrease affecting the Spanish industry, returning to a steady trajectory in recent years. This data leads to a significant conclusion: Despite the trend to fish less, the price per ton remains constant during the observed period. This suggests an approach aimed at both biological and economic sustainability, achieving optimal outcomes in both aspects.

It should be emphasized that net profit should also be considered

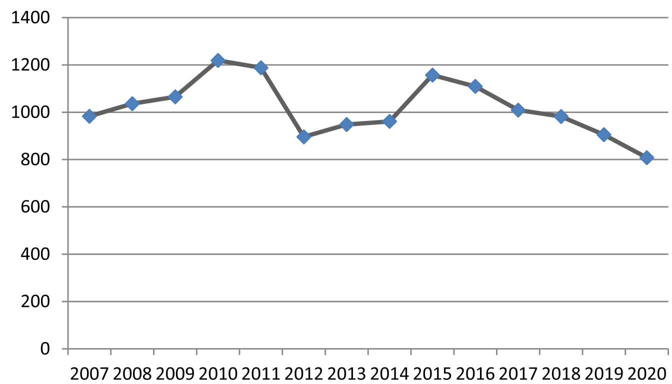

Fig. 3. Total value, in euros, for fresh fisheries in Spain (in millions). Source: Eurostat [4], Landing of Fishery Products in Spain.

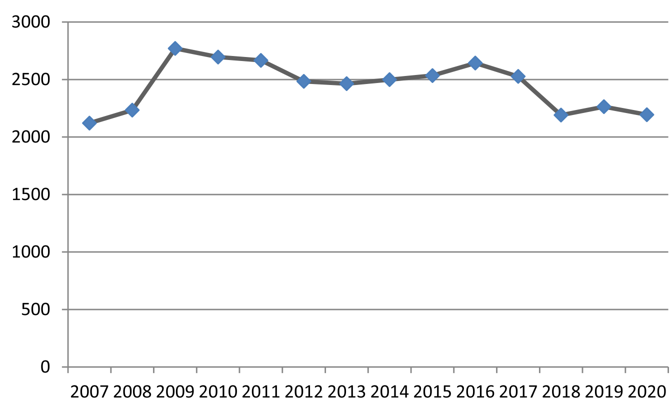

Fig. 4. Euros per ton of fresh fish landed in Spanish ports. Source: Eurostat [4], Landings of Fishery Products in Spain.

when analyzing the economic impact, rather than just focusing on income. The Annual Economic Report of the EU fishing fleet (AER) publishes data about net profits of fishing; however, this data is not available per ton and for specific species. Thus, we focus our analysis on income.

These results are portrayed to provide only a glimpse of what this article aims to achieve: a discussion on the evolution of the literature and a debate about the economic impact of various fishery management approaches currently underway. It is evident that the physical yield of fishery products has been declining, at least in Spain, and the economic impact has also decreased, though not to the same extent. Therefore, it is crucial to delve into the factors influencing the sustainability of these income sources.

4.2. Quotas per species, area, and member state

As mentioned, the CFP is the primary instrument the EU employs for the regulation of fisheries resources. The documentation encompasses all the legal components necessary to offer an accurate insight into what can be implemented during a specific period by the fishermen of a particular EU member state in a given area under European jurisdiction or a treaty with a third country. The main sources of information are the various EU Council regulations published for the relevant period [3].

In this documentation, each species is clearly identified —with its scientific name, which is the only regulatory accepted method of identification, the corresponding allocated quotas for a certain member state, and the corresponding ICES Statistical Area where such a catch is permitted. As indicated earlier, the CFP serves as the primary guide for the Spanish fishing industry. A comparative analysis of both the total allowed catch and the landing of fishery products in Spanish ports will further elucidate the significance behind the observed trends illustrated in Figs. 1 to 4.

The considerable variety of commercial species harvested for both human and industrial consumption complicates the task of establishing the relationship between actual landings and quota numbers. For a comprehensive overview of the Spanish fishing industry, only a specific subset of the most relevant fish types will be compared. The selection criterion for these fish types is based on their economic value. The following fish—cod, hake, and anchovies—are among the most economically valued in both Spanish and European markets. U.S. Department of Agriculture [21].

As previously stated, the Common Fisheries Policy (CFP), through its corresponding legislation, specifies the species and areas where the Total Allowable Catch (TAC) can take place. In this context, it is crucial to explicitly identify the proper Alpha-3 code for the selected species in the legal documents that bind them [6]. We have selected to use cod, more commonly known as *Gadus morhua,* with the corresponding identification code COD; hake, known as *Merluccius merluccius*, with the code HKE; and anchovies, identified by the scientific name of *Engraulis encrasicolus,* with the specific code ANE.

The data representing this variable will be extracted from the legal CFP documents. Guided by the Alpha-3 code identification system, the relevant fishery zones, and other minor considerations, numbers about what quotas affect Spain in the period 2010–2020 are applicable.

As previously mentioned, the swap of quotas between member states is a certainty, carrying broad consequences. By investigating the recorded exchanges—which imply the amount, the species, the area, and the actors involved—the ultimate allowable amount that is disposable for each member state at the end of each year can be subtracted. In the case of ANE, the quotas from 2010 to 2014 were set from July of the beginning period and ending at the end of June of the following year. Lastly, a note on the available swap data: There are no data available from 2010 to 2012 in this area, thus the reflected data represent only the officially established quotas for Spain.

In summary, the numbers shown as the corresponding TACs for Spain include all the amounts allowed by the council regulations, in every single area—within EU waters and international waters—with the addition/subtraction of the net quota swaps for each given year.

4.3. Value of the first sale of the fishery products and amounts landed and captured by Spanish fishing vessels

A measure of the economic benefits obtained from the collection of any given natural resource before its further processing in the value-added chain is the amount of currency received for it in the initial commercial transactions. Assessing how much capital can be garnered by selling fishery products addresses the question of how much revenue—economic impact—is generated by this economic activity and contributes to the maximization of profit, specifically as perceived by fishermen [1].

This variable is divided into two subcategories. Firstly, the total economic output was measured in euros for all the fish landings of ANE, HKE, and COD in Spanish ports. Secondly, the total economic output was measured in euros per GT of the mentioned species in landings at Spanish ports. These two measurements are considered valid as they represent the initial economic valuation of fishery products. Moreover, they are primarily the sole income perceived by the fishing boats for the harvest of these resources. The data are obtained from the Eurostat databases. While these numbers reflect an actual trend, they may not be the purest reflection of the specific situation experienced by Spanish fishermen.

Regulations delineate permissible and impermissible actions within a specified timeframe and geographical area, thereby defining the subjects bound by the constraints of these directives. Yet, they are not consistently adhered to by the stakeholders required to comply with them, leading to adverse consequences for the biosphere it seeks to safeguard [13]. Although some countermeasures exist within the CFP legislative framework to tackle this issue, it is possible that reality differs from what is written in the current legislation.

We extracted data from Eurostat and the Ministry of Agriculture, Fisheries and Nutrition of Spain [4]. We also collected data from Eurostat and the Ministry of Agriculture, Fisheries, and Nutrition of Spain [4]. The datasets obtained reflect two different contexts: on one hand, the capture of the selected species recorded by Spanish vessels—the initial stage of the harvest process—which is sourced from Estadísticas de Capturas y Desembarcos de Pesca Marítima [8], and on the other hand, the recorded amounts landed in Spanish ports. Once again, the latter corresponds to both Spanish and European vessels. It is fundamental to recall that the CFP quotas operate on TACs. Once a catch is made, it is deducted from these quotas, reducing the remaining amount available to be landed in a member state.

As previously discussed, real harvest rates and proposed harvest rates can differ. One of our objectives also was to answer whether there are any existing differences within the Spanish industry between the allocated quotas and the actual output of fishery products.

5. Results

5.1. Quotas per species

The available Spanish data begin in 2010 due to the new nature of the CFP set by the Lisbon Treaty. By consolidating the data from various already-disclosed sources, the TACs for Spain in each year are depicted in Fig. 5.

The *Gadus morhua*, identified by the Alpha-3 code COD, holds the first position. In second place is anchovy, scientifically known as *Engraulis encrasicolus,* with ANE as its Alpha-3 code. Its evolution differs from that of the cod. The changes between years for these species are much more pronounced. Compared to the 2010 figures, the quota for Spanish fishermen grew by 21.84%. The last quota corresponds to hake, designated as *Merluccius merluccius*, with HKE as its Alpha-3 code. The evolution of the allowable quotas remained constant during most of the time series, experiencing a sharp decrease in 2018. In the last year, 2020, the total allowable amount to be caught was 39,593 GT, representing an 84.99% increase compared to the initial year.

5.2. Value of sales for fishery products: total value and value per ton

Whenever a producer decides to engage in an economic activity, there is an expectation of obtaining a profit. Since the introduction of quotas, fishermen have been subjected to the additional constraint of market prices. However, in Fig. 6, we can observe how much capital has been generated from the production of the selected species. In overall terms, there are three different trends.

The total revenue for all COD captures at the first sale in the year

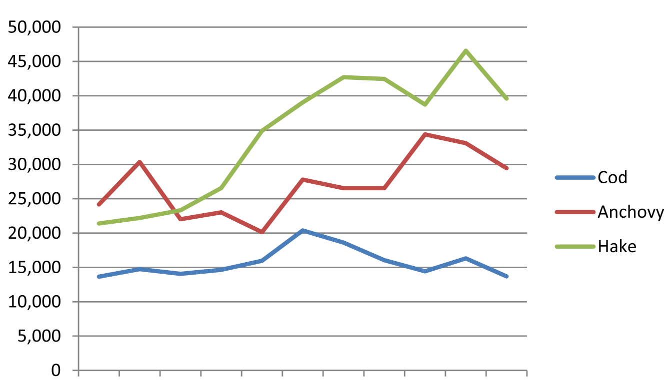

Fig. 5. TACs for Spain (tons), 2010–2020. Source: Authors' elaboration from the EU Council Regulations.

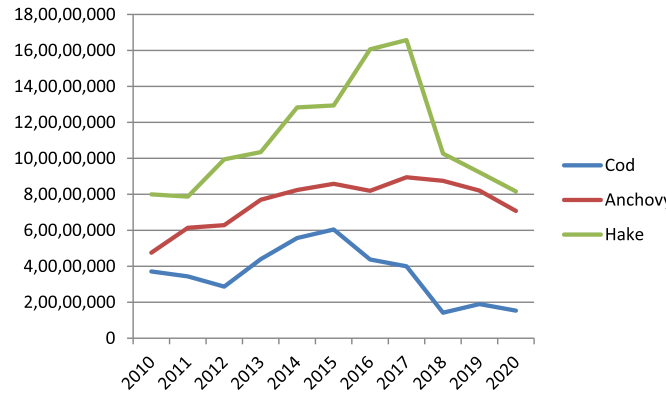

Fig. 6. Total value in euros for the total selected species landed in Spanish ports. Source: Eurostat [4].

2010 reached €37,124,311. Until 2012, the income declined to €28,700,523, representing a 29.35% total drop in revenue. Furthermore, the value in the Spanish fish markets for COD rose to €60,445,295 in 2015. This is the highest value for the landed fishery products of *Gadus morhua*. Compared to 2012, it represents a 110.60% increase. Yet, the years of abundance plummeted, and by 2018, the total value for the landed COD was €14,190,214, or a 325.96% decrease in just 3 years. In 2020, the amount reached €15,316,476. Compared to 2010, the amount of money obtained for all the harvested and landed fish in Spanish ports dropped by 58.74%.

The data for anchovies are slightly different. Starting in 2010, the value for all the captures landed in Spanish ports was €47,551,959. This number rose almost throughout the whole decade until 2017. In those 7 years, the economic valuation at the first sale increased by 88.17%, reaching its maximum value in the time series, experiencing a steady drop up to 2020. Nevertheless, the figures for 2020 amounting to €70,775,265, represent a 48.83% increase as compared to 2010.

The case of HKE presents a compelling narrative. Over a span of nearly seven years, it witnessed a significant increase, more than doubling the valuation attributed to all landings of this particular fish species. In 2010, the aggregate economic income amounted to €79,941,655. This figure exhibited a consistent upward trajectory until 2017. Assessing the comparative revenues at the decade's end against the baseline year of 2010, there was a notable 2.14% increase, indicative of potential improvements in the overall performance.

When a producer decides to engage in an activity, the initial consideration is the price received for the offered product. In this case, the value obtained per ton of the selected species is a vital indicator, serving as a guide to understanding how much revenue can be generated per ton. This information helps both fishermen and policymakers measure the optimal amount of fish to be captured, balancing economic considerations and the protection of natural fish stocks.

The observed trends in the case of the three species are quite different. Further research on price settings can be helpful in providing a proper background for the figures (Fig. 7).

COD began in 2010 with a price of €2635 per ton. In the following two years, it dropped to €2246, reflecting a 14.76% decrease. Since that year, the price steadily increased until 2015 when the economic valuation of a ton reached €3016, marking a 34.28% rise since 2012. Subsequently, a mild decline was experienced over the next two years. In 2017, the obtained money per ton was €2657, indicating an 11.90% reduction in the money received by the fishermen. After 2017, the price consistently rose until the end of the time series in 2020. In that year, the price was €4325 per ton, representing the highest point observed throughout the analyzed years. Compared with the initial valuation per ton, it signifies a 64.13% increase in the capital obtained by Spanish fishermen for this species.

The case of ANE is one of a constant downturn. From the beginning

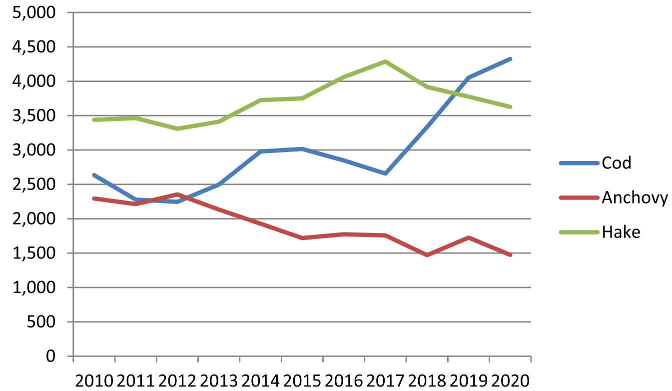

Fig. 7. Value per ton of the selected species in Spanish ports. Source: Eurostat [4].

to the end of the observed period, the price per ton declined, with some steady stages. In 2010, the price per ton was €2295. In 2012, it reached the observed maximum of €2354, indicating a 2.57% increase compared to 2010. Following this initial two-year period, the amount obtained for the captures declined until 2015. From 2015 until the end of the time series, the price remained relatively constant, around €1740 per ton, with the exceptions of 2018 and 2020. In the latter year, the price was set at €1474. Compared with the very beginning, the revenue for Spanish fishermen declined by 35.77%.

HKE prices demonstrated a relatively stable price history from 2010 to 2020. In the first year, the price paid per ton amounted to €3439. This figure experienced minimal variations during the initial years but increased steadily until 2017. Subsequently, the negotiated price at fish markets dropped, reaching around €3628 in 2020. Compared to the figures from 2010, we can observe a 5.49% increase in what the Spanish fishing industry receives as income for this product.

5.3. Amounts landed and captured by Spanish fishing vessels

When analyzing the fishing industry, a prevalent indicator of the level of activity is the quantity of "real" fish stocks captured and landed in the ports. The figures depicted in Fig. 8 are derived from records made by Spanish vessels operating globally, specifically for the mentioned species. It is essential to distinguish between what is caught and what is done with the fishing product afterwards, as it may be discarded, transformed on the vessels—altering its categorization—or landed in foreign ports, potentially explaining any discrepancies with Spanish landing records.

The most consistently observed capture of the three analyzed species is COD. In 2010, the quantity was 14,089 tons. Compared to the highest capture during the decade in 2015, which accounted for 20,767 tons, there was a difference of 47.39% between both fishing seasons. In 2020, the captured amount dropped to 12,089 tons, a negative change of 14.19% compared to 10 years earlier, in 2010.

When observing the evolution of ANE, the year 2010 started with a recorded capture of 20,725 tons. This number experienced a drastic increase in the following two years, marking an increase of 141.16%. Those numbers continued to grow, with the highest figures for catches recorded in 2018.

HKE, similar to COD, had a relatively steady and constant evolution throughout the years. In 2010, the catches amounted to 33,061 tons. This number remained almost unchanged for the next few years until 2013 at around 30,300 tons.

Although the TACs set in the corresponding CFP regulations are the ones against which the catches are accounted, observing how much of these fishery products end up in the ports of the same country is crucial. Fig. 9 illustrates all the landings of the three selected species in Spanish ports, both by Spanish and European vessels. This variable is also the most valuable when making comparisons with the other factors discussed earlier.

In 2010, the amount of COD landed in Spanish ports was 14,089 tons. By 2015, this number had increased by 42.24%. However, in the following two years, it remained steady at 15,359 tons. A drastic decline started in 2018 and continued into 2020, with only 3538 tons landed. From 2010–2020, the amount landed dropped by 74.88%.

A slightly more fortunate sector of the Spanish fishing industry is ANE. In 2010, it started with 20,723 tons landed. By 2015, the numbers had increased dramatically to 49,920 tons, marking an increase of 140.89%. The maximum value was recorded in 2018, with an amount of 59,501 tons in Spanish ports, reflecting a 19.19% increase compared to 2015. Nevertheless, after this year, the numbers began to decline.

HKE numbers started at 23,244 tons in 2010 and continued to rise until 2016, registering 39,556 tons—the maximum recorded in the time series. From the initial year, this represented a 70.17% increase. Yet, after 2016, the numbers took a downturn, a falling sharply to 22,509 tons by 2020, a 3.16% decrease as compared to 2010.

6. Discussion

Despite the regulations, in the case of cod, anchovy, and hake, the data reveal noteworthy observations. When assessing the recorded catches of each species by the Spanish fishing fleet, the results do not consistently align with the allocations stipulated by regulations. In the case of cod, there has been a pattern of overexploitation in most years—although not significantly exceeding the set limits—of the assigned marine resources under the CFP. Surprisingly, anchovy harvests have been consistently and significantly exceeding quota limits

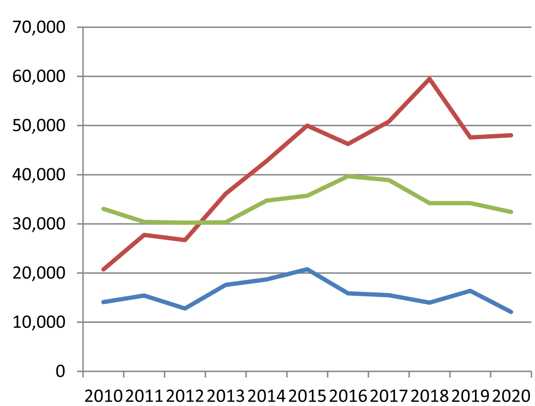

Fig. 8. Catches by Spanish vessels (tons). Source: Gobierno de España [8], Estadísticas de Capturas y Desembarcos de Pesca Marítima.

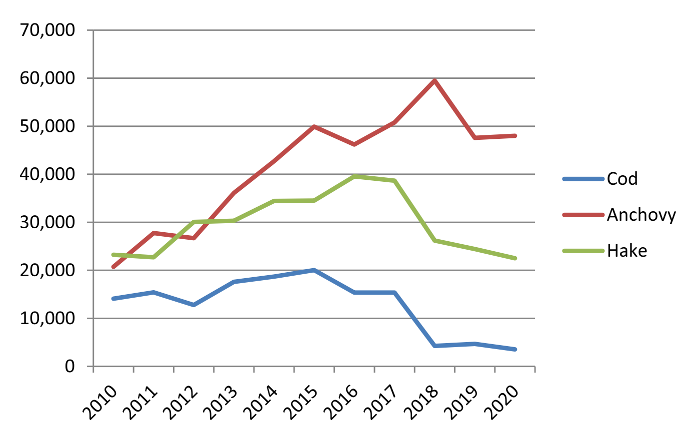

Fig. 9. Landings of fishery products in Spanish ports (tons). Source: Eurostat [4].

since 2012. This practice may pose a substantial threat to the natural stock in certain areas if scientific estimations for quota-setting are accurate. Hake's catch levels exceeded the allowed limits from 2010 until 2013, after which the trend reversed, and compliance was maintained for the subsequent observed years.

Nevertheless, there is a distinction between capturing these natural stocks and landing them in a country bound to adhere to the designated quota. Data on cod landings indicate that, until 2015, nearly all the recorded catches by Spanish vessels were landed in Spanish ports. However, after this year, the disparity grew, suggesting that these catches were either not landed at all or were deposited in foreign ports. Anchovy landings closely mirror the numbers recorded as catches, indicating that almost the entire harvest ended up in Spanish fishing ports. Hake landings varied significantly in the initial years, becoming almost stable with minimal differences between catches and landings during the 2013–2014 period and in 2016–2017. Yet, after these periods, the initial trend resurfaced with increasing variance. Markets do not consistently demand the same products, and the CFP regulations do not outline any conditions regarding the movement of these products to foreign countries for commercial purposes.

The capital funds received at the initial sale exhibited a distinctive trend. Cash flows received by Spanish fishermen for each of the selected species have varied, sometimes drastically, both positively and negatively. The total value of all fishery products landed—measured in Euros—has followed similar trends. In the case of cod, there was an initial contraction until 2012, followed by an expansion period until 2015. Nevertheless, from that point onward, there was a significant reduction in the total revenue for landings in Spanish ports. A comparison between the first and last years of the time series reveals that the total value had halved. The evolution of anchovy exhibits a more gradual progression over time, demonstrating an increase until 2017 and subsequently experiencing a slight decline.

A comparison between the initial and final years has a significantly positive impact on the funds received. Hake witnessed substantial growth until 2017, followed by a sharp decline until the end of the time series, ultimately returning to its initial position within the sector. As the landed quantities started to decline, the total amount of funds also decreased.

However, the price evolution per ton for each species has followed divergent trajectories. Cod prices have consistently increased throughout the time series, suggesting a market appreciation in its value when compared to the catches per Spanish vessel. More in-depth research should be conducted to address potential factors influencing the pricing of fish products. It could be argued that, for this specific fish type, fishermen have experienced an improvement in their economic conditions. On the other hand, anchovy progress has not been favorable over the past decade. A continual decline in prices per ton has been observed. It would be interesting to establish a relationship between the falling prices and the indiscriminate rise in the harvest of this fish.

7. Conclusions

In seeking to address our research question—examining the correlation between the current catches by Spanish vessels and the recorded landings used to calculate national TACs, and assessing the degree of compliance within the broader context of the Spanish fishing industry—our comprehensive investigation has unearthed intricate patterns and challenges within the realm of fisheries management.

The trajectory of the Spanish fishing industry reveals a consistent decline in the overall volume of landed products. Our data illustrate that, from the inception of the selected time series, quantities of all types of fresh fishery products have diminished for the Spanish fishing fleet. From an economic perspective, a noticeable reduction in the overall total market value can be observed, with price per ton as the only remaining constant factor. This leads to the following conclusion: Despite the decrease in the quantity of harvested fish stocks, prices have remained stable over an extended period. In this regard, the macro-level objective of the CFP seems to have been accomplished.

The general trend may vary among specific actors. We chose three common species—cod, anchovy, and hake—for examination in this article. Different variables were observed to provide an overview of the evolution within this more specific sector of the fishing industry. As previously explained, the primary drivers of fisheries management within the EU are the policies of the CFP, including the corresponding quotas. In the case of cod, we noted an increase in the available amount for Spanish vessels since 2010. Anchovies have experienced fluctuations over the past decade, with their overall position slightly improving compared to the beginning of the time series. For hake, capture limits have surged, nearly doubling the allowed catches over the past 10 years. The escalating demand for commercial fish products, coupled with advancements in fishing techniques, plays a significant role in the policymaking process.

In summary, quotas have proven ineffective in certain cases and specific years, posing a challenge for proper fishery management and long-term sustainability. Notably, the overall trends in captures do not consistently align with the trends observed in the most "popular" fish products. To comprehensively assess the situation, further research is necessary to investigate the sector's behaviours. From an economic perspective, similar to capture evolutions, these behaviours do not consistently follow the main trend when examining specific actors. Future research should explore the connections between demand factors, activity costs, and other elements to address the more specific questions arising from this article. Nevertheless, a conclusion can be drawn that the CFP needs to establish new guidelines of fishing activity among EU member states to achieve the goal of sustainable fishing.

Author statement

All authors have accepted responsibility for the entire content of this manuscript and approved its submission.

CRediT authorship contribution statement

Amaya Erro-Garcés: Writing – review & editing, Visualization, Validation, Supervision, Resources, Methodology, Investigation, Funding acquisition, Formal analysis, Conceptualization. **Maria Elena Aramendia-Muneta:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Aleksander Kozinski Radomska:** Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Data Availability

No data was used for the research described in the article.

Acknowledgment

This work was supported by the Ministerio de Ciencia e Innovación under Grant PID2020-115018RB-C31.

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ÁREA: Acuicultura, Pesca y Medio Marino
ORIENTACIÓN: Formación Marítimo-Pesquera

OPCIÓN 2

frontiers in Marine Science

REVIEW
published: 14 August 2017
doi: 10.3389/fmars.2017.00244

Recent Trends and Impacts of Fisheries Exploitation on Mediterranean Stocks and Ecosystems

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This review focuses on the recent data on Mediterranean fishing fleets and landings, results from stock assessments and ecosystem models to provide an overview of the multiple impacts of fishing exploitation in the different Mediterranean geographical sub-areas (GSAs). A fleet of about 73,000 vessels is widespread along the Mediterranean coasts. Artisanal activities are predominant in South Mediterranean and in the eastern basin, while trawling features GSAs in the western basin and the Adriatic Sea. The overall landings of fish, crustaceans and cephalopods, after peaking during mid 90s at about one million tons, declined at about 700,000 tons in 2013. However, while landings are declining in EU countries since the 90s, in non-EU countries a decreasing trend was observed only in the last 5–10 years. The current levels of fishing effort determine a general overexploitation status of commercial stocks with more than 90% of the stock assessed out of safe biological limits. Indicators obtained from available ecosystem models were used to assess the sustainability of the fisheries. They included primary production required to sustain fisheries (PPR), mean trophic level of the catch (mTLc), the loss in secondary production index (L index), and the probability of the ecosystem to be sustainably exploited (p_{sust}). In areas exploited more sustainably (e.g., Gulf of Gabes, Eastern Ionian, and Aegean Sea) fishing pressure was characterized by either low number of vessels per unit of shelf area or the large prevalence of artisanal/small scale fisheries. Conversely, GSAs in Western Mediterranean and Adriatic showed very low ecosystem sustainability of fisheries that can be easily related with the high fishing pressure and the large proportion of overfished stocks obtained from single species assessments. We showed that the current knowledge on Mediterranean fisheries and ecosystems describes a worrisome picture where the effect of poorly regulated fisheries, in combination with the ongoing climate forcing and the rapid expansion of non-indigenous species, are rapidly changing the structure and functioning of the ecosystem with unpredictable effects on the goods and services provided. Although this would call for urgent conservation actions, the management system implemented in the region appears too slow and probably inadequate to protect biodiversity and secure fisheries resources for the future generations.

Keywords: Mediterranean, fisheries, overexploitation, ecosystem models, fisheries management

OPEN ACCESS

Edited by:
Rachel Gjelsvik Tiller, SINTEF, Norway

Reviewed by:
Sanja Matic-Skoko, Institute of Oceanography and Fisheries, Croatia
Dimitrios K. Moutopoulos, Technological Educational Institute of Messolonghi, Greece

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Specialty section:
This article was submitted to Marine Fisheries, Aquaculture and Living Resources, a section of the journal Frontiers in Marine Science

Received: *17 March 2017*
Accepted: *18 July 2017*
Published: *14 August 2017*

Citation:
Colloca F, Scarcella G and Libralato S (2017) Recent Trends and Impacts of Fisheries Exploitation on Mediterranean Stocks and Ecosystems. Front. Mar. Sci. 4:244. doi: 10.3389/fmars.2017.00244

INTRODUCTION

The Mediterranean ecosystem has a long history of human disturbance and exploitation. A growing body of knowledge and recent single species assessments are showing a general overexploitation status of commercial fish and shellfish stocks along with a rapid decline of large predators, such as sharks (Ferretti et al., 2008, 2013; Fortibuoni et al., 2010, 2016). While the impact of poorly regulated fisheries is widely documented in EU Mediterranean waters (Colloca et al., 2013; Vasilakopoulos et al., 2014), the status of fisheries and stocks in non-EU countries, where a standardized fisheries data collection system is generally not yet fully enforced, is still unclear. However, taking into consideration the recent reports of the working groups on stock assessment of the General Fisheries Commission for the Mediterranean (GFCM), it is possible to argue that also in the non-EU countries the situation might be critical (GFCM, 2016a,b).

In recent years there are also increasing evidences on the negative impacts of fishing on the Mediterranean trophic web and ecosystem. Analyses on the impact of fishing on the ecosystem, quantified through an index of Loss in secondary production (Libralato et al., 2008) resulted a general low probability of the ecosystem to be sustainably fished in the Mediterranean Sea both from models and data (Libralato et al., 2005). Moreover, the meta-analysis of Mediterranean model outputs highlighted detectable signs of impacts of fishing from several ecosystem indicators (Coll and Libralato, 2012).

The ecosystem change was so fast during the last 50 years to be directly witnessed in different Mediterranean areas by fishermen and vessel captains (Maynou et al., 2011), highlighted from analysis of landing statistics (Fortibuoni et al., 2017), and documented in several studies (Lleonart, 1993; Abelló et al., 2002; Coll et al., 2006, 2007; Libralato et al., 2008; Azzurro et al., 2011).

In addition, there is a growing concern about the damages on the benthic habitat caused by towed gears such as otter trawls, dredges, beam trawls (Pranovi et al., 2000; Smith et al., 2000; de Juan et al., 2007; De Biasi and Pacciardi, 2008; de Juan and Lleonart, 2010).

The critical situation of commercial stocks rose the concerns also for several factors than alone or in combination with fisheries are contributing to worsening the conditions of marine Mediterranean communities. Increasing body of research is showing fast spreading of new invasive species in the Mediterranean (Lejeusne et al., 2009; Galil et al., 2014; Parravicini et al., 2015) that can have indirect effects on resident communities and fisheries difficult to quantify (e.g., Libralato et al., 2015). Pollution and marine litter are having strong attention because of the several indirect and direct impacts on both stocks and fisheries (Galgani, 2015). Nutrient loads from watershed have been regulated with important changes in the last decades resulting in direct effects on marine coastal area primary productivity and exploited resources (Caddy, 2000; Fortibuoni et al., 2017). Climatic global changes are also influencing Mediterranean marine communities by changing average temperature, productivity and water alkalinity (Lazzari et al., 2012, 2014; Cossarini et al., 2015) with potentially large effects on exploited stocks (Colloca et al., 2014).

Although there is a general concern about the lack of adequate management measures to reverse the ongoing negative trends and drive Mediterranean fisheries toward a sustainable exploitation, the overall picture of the situation of fisheries and ecosystems is still rather confused.

In this review, we used multiple source of information to summarize the current knowledge on commercial demersal fisheries in European and non-European waters. Starting from a review of the fisheries trend we considered the status of commercial stocks in the different Mediterranean FAO-GFCM Geographical sub-areas (GSAs). These data were complemented with information on the outputs of main ecosystem models available in Mediterranean to produce an overview of the overall impact of fishing on the ecosystem. In this perspective, we considered also data on non-indigenous fish species and knowledge on the conservation status of Mediterranean fish from the International Union for Conservation of Nature (IUCN) assessments.

Our main goal was to provide a general overview on Mediterranean fisheries and discuss the multiple effects generated by fishing exploitation, from commercial stocks to the whole ecosystem, in relation to the challenging long-term sustainability objectives of the European Union (*sensu* CFP Reg. no. 1380/2013) and FAO (UN; *sensu* SDG 14, FAO SO2 and the Aichi Targets).

MATERIALS AND METHODS

Fisheries Data

Data available on fishing capacity, as total number of artisanal vessels using fixed gears (e.g., trammel nets, long-lines, traps, etc.), trawlers, purse-seiners, and pelagic trawlers, in each Mediterranean Geographical Sub-Areas (GSAs, **Figure 1**) were obtained from several sources (see **Table 1**). These includes technical reports of both the FAO-GFCM and the Scientific Technical and Economic Committee of the European Commission (STECF-EC), as well as fleet data retrieved from the European vessel register (http://ec.europa.eu/fisheries/fleet/index.cfm) and scientific studies.

Landing data by main group of species (i.e., demersal fish, small-pelagics, elasmobranchs, crustaceans, cephalopods) and area were obtained from the GFCM marine capture production database 1970–2014 (http://www.fao.org/gfcm/data/capture-production-statistics/en/). This was complemented for EU GSAs with data from the JRC database on Mediterranean and Black Sea fisheries (https://stecf.jrc.ec.europa.eu/dd/medbs) as well as Italian data included in Mannini and Sabatella (2015).

Fishing mortality and F_{MSY} values were compiled from stock assessment forms produced by both the GFCM and STECF working groups in stock assessment from 2002 to 2014 and summarized by Cardinale and Scarcella (2017).

Reported landing data in each GSA were contrasted with fleet capacity, calculated as total number of trawl vessels, and dimension of the continental shelf (depth range: 0–200 m). This latter was derived from a depth layer downloaded from Marspec database (http://www.marspec.org/).

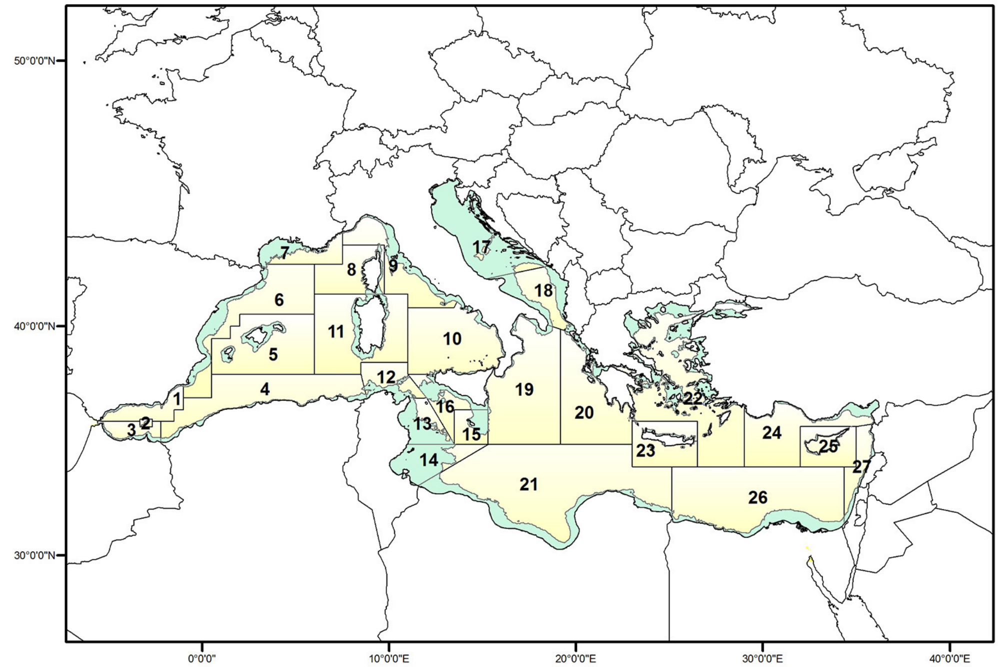

FIGURE 1 | Mediterranean FAO-GFCM Geographical Sub-Areas (GSAs). The continental shelf (0–200 m) is also shown. 1, Northern Alboran Sea; 2, Alboran Island; 3, Southern Alboran Sea; 4, Algeria; 5, Balearic Islands; 6, Northern Spain; 7, Gulf of Lions; 8, Corsica Island; 9, Ligurian and North Tyrrhenian Sea; 10, South Tyrrhenian Sea; 11.1, Sardinia (west); 11.2, Sardinia (east); 12, Northern Tunisia; 13, Gulf of Hammamet; 14, Gulf of Gabes; 15, Malta Island; 16, South of Sicily; 17, Northern Adriatic; 18, Southern Adriatic Sea; 19, Western Ionian Sea; 20, Eastern Ionian Sea; 21, Southern Ionian Sea; 22, Aegean Sea; 23, Crete Island; 24, North Levant; 25, Cyprus Island; 26, South Levant; 27, Eastern Levant Sea.

Ecosystem Indicators

Indicators were obtained from ecosystem models, which are standardized quantitative representations of main biological structure of the ecosystem, from primary producers to top predators. A set of available ecosystem models were selected to fulfill the following aspects: (i) represent substantial parts of each Mediterranean GSA (i.e., the model domain was large enough); (ii) have been well-documented in scientific literature; (iii) were developed for addressing fishing issues, thus they embed detailed description of fisheries landing and discards. The selected ecosystem models, although not available for all GSAs, permit to derive a set of indicators summarizing ecosystem effects of fishing to highlight impact of fishing on ecosystem structure and functioning. In particular we reported total ecosystem biomass (TB), total catches (TC), and the ratio between total catches and primary production (gross efficiency, GE). Moreover, from models were obtained footprint-like measure of fishing pressure, i.e., the primary production required to sustain catches (PPR; Pauly and Christensen, 1995), which together with information on primary production and the mean trophic level of the catches (mTLc; Pauly et al., 1998) provide a framework for assessing status of fisheries (Tudela, 2000; Tudela et al., 2005). These indicators are combined in the Loss in secondary production (L index), an index that allows assessing the ecosystem overfishing level since reference levels in terms of probability of the ecosystem to be sustainably fished (p_{sust}) were empirically defined (Libralato et al., 2008). Such indices collected for the set of available models provide an evaluation of ecosystem status by GSA.

As measures of the possible exposure to the indirect effects of climate change we derived the number of non-indigenous fish species recorded in each GSA. This was summarized from the CIESM Atlas of exotic species in Mediterranean (http://www.ciesm.org/online/atlas/) and complemented with supplementary bibliographic information from specific areas (Katsanevakis et al., 2009; Evans et al., 2015).

RESULTS

Effort and Landings Data by GSA

The Mediterranean fishing fleet is made up by about 72,600 vessels of which 85.5% are artisanal vessels using a variety of gears (e.g., trammel nets, gillnets, longlines, traps, etc.), about 9% are trawlers and 5% purse seiners and pelagic trawlers (**Table 1**, dredges were excluded). Fleet data show major differences across the Mediterranean GSAs. The largest artisanal fleets occur in Tunisia (GSAs 12–14), Aegean Sea (GSAs 22–23), and Northern Adriatic (GSA 17), whilst trawlers are mainly concentrated in Egypt (GSA 26), Adriatic (GSAs 17–18), and Algeria (GSA 4, **Table 1**). In terms of fishing pressure on the shelf, the area with the highest number of artisanal vessels per km^2 are the Levantine Sea (GSA 27), Cyprus (GSA 25), Morocco (GSA 3), Algeria (GSA 4), Eastern Ionian Sea (GSAs 20, **Figure 2A**). A different pattern occurs for trawlers where the

TABLE 1 | Summary of fleet capacity data in 2013 and annual landing data by Mediterranean Geographical-Subareas GSA or combination of GSAs in 2014.

GSA	Country	Total n. fishing vessels	Trawlers	Artisanal vessels	Purse seiners and pelagic trawlers	Total landing (ton)	Landings demersal fisheries (ton)	Landings purse seiners and pelagic trawlers (ton)	Continental shelf surface (km^2, 0–200 m)	References
1	Spain	788	110	588	90	18,894	6,254	12,640	3,925.8	EU fleet register
3	Marocco	2,146	106	1,916	124	31,867	16,048	15,819	4,581.4	FAO, 2016
4	Algeria	4,743	550	2,906	1,287	97,741	41,247	56,494	9,516.7	FAO, 2016
5	Spain	373	63	302	8	2,359.1	1,662.83	696.2	10,877.9	EU fleet register
6	Spain	1,631	496	1,000	135	50,656	15,246	28,529.8	24,529.4	EU fleet register
7	France	1,261	73	1,106	82	14,253	8,938.6	9,641	14,211.4	EU fleet register
8	France	194	9	185	0	355.4	257.8	97.6	4,361.1	EU fleet register
9	Italy	1,622	302	1,277	43	17,296	11,323.5	5,972.1	16,423.4	Mannini and Sabatella, 2015
10	Italy	2,657	247	2,324	86	17,396	11,602	5,794	9,361.9	Mannini and Sabatella, 2015
11	Italy	1,239	130	1,109	0	11,326	11,325	0.52	14,173.5	Mannini and Sabatella, 2015
12–14	Tunisia	11,484	374	10,702	408	11,0882	20,044	90,838	77,991.7	FAO, 2016
15	Malta	1,025	22	999	4	4,780.5	1,040	3,740.5	8,737.0	EU fleet register
16	Italy	1,172	405	728	39	19,824	15,324	4,499.5	14,325.3	Mannini and Sabatella, 2015
17	Italy, Slovenia, Croatia	5,159	1,043	3,788	328	14,9186	43,984.3	10,5201.7	79,315.3	Mannini and Sabatella, 2015; STECF, 2016
18	Italy, Montenegro, Albania	1,605	599	951	55	19,545	13,219	6,325.7	23,670.9	Mannini and Sabatella, 2015
19	Italy	1,568	227	1,319	22	10,140	9,307	599.4	6,729.9	Mannini and Sabatella, 2015
20	Greece	3,553	31	3,482	40	5,051	554	4,497	10,442.3	EU fleet register
21	Libya	4,602	263	4,196	143	25,000	1,600	23,400	54,293.5	FAO, 2016
22–23	Greece	16,526	310	15,931	285	81,661	17,055	62,227	63,069.1	Fleet register; Katağan et al., 2015
24	Turkey	1,839	202	1,577	60	6,773	5,026	1,747	35,427.0	Katağan et al., 2015
25	Cyprus	943	13	928	2	1,218.7	675	543.7	2,773.9	FAO, 2016
26	Egypt	2,989	1,124	1,657	208	61,376	16,944	44,432	32,373.9	FAO, 2016
27	Israel, Lebanon, Syria, Palestine	3,520	39	3,133	348	9,021	1,503	7,518	5,211.8	Levy et al., 2015; FAO, 2016

Total number of fishing vessels (dredges excluded), trawlers, artisanal vessels (e.g., vessels using fixed gears), purse seiners and pelagic trawlers. Landings data are summarized as total landings, landings of demersal fisheries (i.e., trawlers and artisanal vessels) and landings of pelagic fisheries (i.e., purse seiners and pelagic trawlers). The dimension of the continental shelf is also shown.

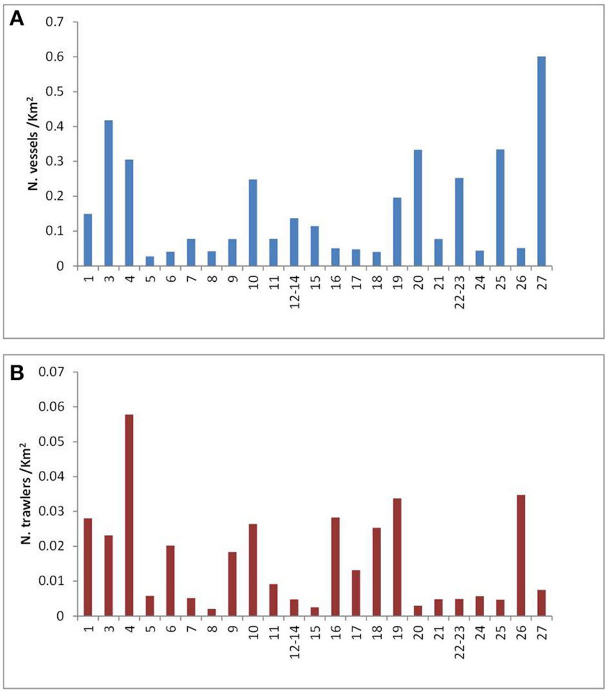

FIGURE 2 | Fishing pressure on the Mediterranean continental shelf, as n. vessel km^{-2}, by GSA and fleet: **(A)** artisanal vessels; **(B)** trawlers (data derived from **Table 1**).

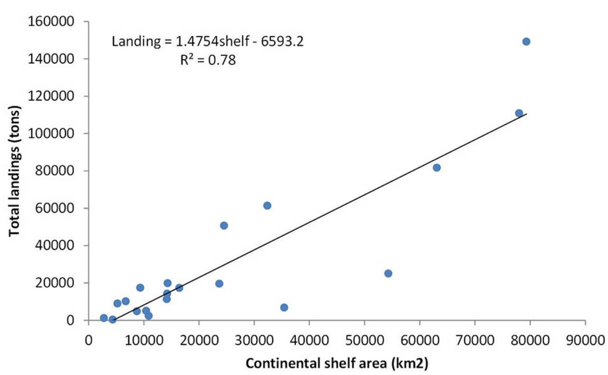

FIGURE 3 | Relationships between the dimension of the continental shelf area of GSAs and the reported total annual landings (GSAs 1-3 are excluded, data shown in **Table 1**).

highest concentration is found in Algeria (GSA 4), Egypt (GSA 26), Western Ionian Sea (GSA 19), Southern Sicily (GSA 16), Southern Adriatic Sea (GSA 18), Northern Alboran Sea (GSA 1) (**Figure 2B**).

The annual landings observed in the different GSAs resulted linearly correlated ($r^2 = 0.78$, $p < 0.01$) with the dimension of the continental shelf (0–200 m depth, **Figure 3**). This appears therefore a key factor in constraining the productivity potential of Mediterranean fisheries.

Temporal Trend in Landings

The estimated total production of demersal and small pelagics species derived from different statitical sources was about 766,600 ton in 2014 similar to the figure that can be obtained from the GFCM capture data (727,000 tons). The landings of demersal species showed large differences among GSAs (**Table 1**): the area with the highest annual production was the Central-North Adriatic (GSA 17) with about 44,000 t, followed by the Algeria's GSA 4 (41,000 t), Tunisian GSAs (20,000 t), Agean Sea and Egypt (about 17,000 t each), Morocco (16,000 t) and finally South of Sicily (14,000 t).

According to the GFCM data, small pelagics (anchovy, sardine and other clupeids) accounted for 333,174 tons while demersal species achieved 394,327 tons. The temporal trend in annual production of demersal fish, crustaceans, cephalopods and small pelagics showed a rapid increase from 70s to the beginning of 90s followed by a declining trend since then. A different picture comes out disaggregating capture data by European (i.e., Spain, France, Italy, Slovenia, Croatia, Montenegro, Albania, Greece, Malta, Cyprus) and non-European countries (i.e., Turkey, Syria, Lebanon, Egypt, Libya, Tunisia, Algeria, Morocco). The reduction trend is determined only by a decreases in the landings of European countries for all the groups but the crustaceans. The landings of non-European countries was featured by a different pattern where a reduction in small pelagics, demersal fish and elasmobranchs occurred only in the last 5–10 years and partially compensated by a continuous increasing in cephalopods and crustaceans landings (**Figure 4**).

Exploitation Status of Commercial Stocks

Data for more than 80 stocks of fish and crustaceans assessed in the period 2002–2014 (**Table 2**) showed that for 90% of them the current fishing mortality (F) is higher than the fishing mortality at MSY (F_{MSY}). The highest F/F_{MSY} values are observed for demersal fish, particularly hake (*Merluccius merluccius*), black bellied anglerfish (*Lophius boudegassa*), and red mullet (*Mullus barbatus*). Most of the assessed stocks of crustaceans and small-pelagics are featured by F/F_{MSY} values between 1 and 2. In general, there are large differences between GSAs in the overexploitation status of species. For example red mulled (*M. barbatus*) appears sustainable exploited in GSAs 10 (South Tyrrhenian) and 18 (South Adriatic) and highly overexploited in GSAs 5 (Balearic) and 11 (Sardinia).

Ecosystem Indicators

Indicators derived from models (**Table 3**) showed large variability in total ecosystem biomass, ranging from 21.31 ton/km^2 in Ionian Sea model to 130 ton/km^2 in Northern Adriatic Sea. There seems to be very poor relationship between total biomass and total catches ($R^2 = 0.0394$). Generally, higher biomasses in the system resulted in lower mTLc. Therefore, PPR% of the catches resulted positively related to total ecosystem biomass ($R^2 = 0.26$). GE was very low for Tyrrhenian and Gulf of Gabes (GE < 0.001) and high for Catalan in the 2000s and Greek Ionian Sea (0.0034 and 0.0040 respectively). Placing PPR% and mTLc in a combined context resulted in systems very likely sustainably fished (Aegean Sea and Gulf of Gabes) in

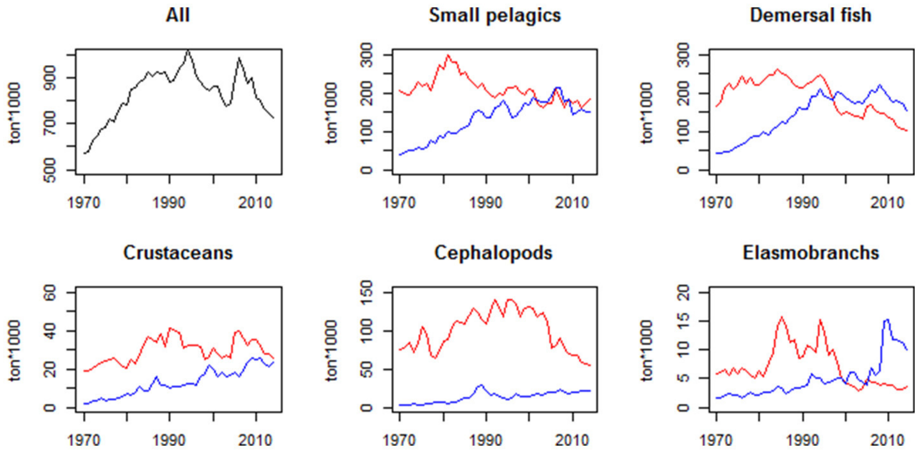

FIGURE 4 | Trend in annual landings of small pelagics, demersal fish, crustaceans, cephalopods, and elasmobranchs in EU (red line) and non-EU (blue line) Mediterranean GSAs. Data were retrieved from the GFCM capture fisheries database (http://www.fao.org/gfcm/data/capture-production-statistics/en/?platform=hootsuite).

contrast to other heavily exploited (Catalan Sea and Adriatic Sea, **Figure 5A**). The quantitative framework provided by Loss in secondary production index and p_{sust} (Libralato et al., 2008) resulted in a very critical situation for most of the exploited areas represented by the ecosystem models (**Figure 5B**). Only Gulf of Gabes, Eastern Ionian, and Aegean Sea were identified as models with sustainable fisheries. Conversely the Adriatic Sea appeared the most critical situation with a probability to be sustainable fished around 20% (**Figure 5B**).

We used the total number of non-indigenous fish species by GSA as an index to exposure to environmental change. The map in **Figure 6** shows main spatial difference among GSAs, with the Eastern basin featured by a high number of new species (94 in Levantine Sea—GSA 27). In contrast, the number of non-indigenous species is low in Central Mediterranean (e.g., Tyrrhenian Sea, Sardinia, Balearic Islands). An intermediate level of non-indigenous species can be found along the African coasts, where new species from the Red Sea and South Atlantic can overlap.

DISCUSSION

There is an increased concern about the status of Mediterranean ecosystem in relation to the sustainability of the current level of fisheries exploitation. Several studies have discussed how the unbalanced fishing in several areas of the Mediterranean is undermining the productivity of both commercial stocks and fisheries activities highlighting the need for a new management strategy aimed at rebuilding overexploited stocks (Colloca et al., 2013; Vasilakopoulos et al., 2014).

However, rarely the impact of fishing has been analyzed at the basin scale and accounting for both the status of the single stocks and the ecosystem. Most of the studies carried out in the last 10 years have focused on EU Mediterranean countries where data of transversal (i.e., catch and effort), biological (i.e., size/age composition of the commercial stocks, biological parameters) and socio-economic indicators are routinely collected on a year basis within the EU-Data Collection Framework (DCF). Since 2008, these data, used to provide advice on the status of the stocks in EU waters within the STECF working groups, have depicted an overall status of overfishing with few exceptions (STECF, 2014, 2016). Although a similar activity has been also developed by the GFCM for stocks in non-EU GSAs, the status of fisheries and stocks in these non-EU areas is less clear due to more scattered data and less commitment in performing standard data collection and stock assessments.

In this study, we revised multiple sources of data on fisheries and stocks from both EU and non-EU GSAs to provide an overall picture of fisheries trends in Mediterranean Sea accounting also for the most relevant effects on the ecosystem.

Spatio-Temporal Trend in Fishing Effort and Landings

Currently, the Mediterranean ecosystem is exploited by about 72,600 vessels most of which (85%) are artisanal boats using many different fishing gears. The artisanal fishing component of the fleet is still extremely important for the socio-economy of many coastal communities other than a source of food, also for representing an important cultural heritage with relevant implication for activities related to the tourism. The main artisanal fleets are concentrated in Aegean Sea (GSAs 22–23); Tunisia (GSAs 12–14), Northern Adriatic (GSA 17), Libya (GSA 21), East Ionian Sea (GSA 20), Algeria (GSA 4), Morocco (GSA 3). The distribution of trawlers indicate that they concentrate mostly in Adriatic GSAs (GSAs 17 and 18), Egypt (GSA 27), Algeria (GSA 4), and North West Spain (GSA 6). Another large component of trawler fleet is located in the Strait of Sicily (GSAs 12–16), where 785 trawlers from Italy, Malta, and Tunisia exploit shared resources also in international waters.

Mediterranean GSAs are however featured by large differences in the dimension of the continental shelf which in turn determine

TABLE 2 | Summary of the most recent F/F_{MSY} ratios available for Mediterranean commercial stocks in the period 2002–2014 (Source: Cardinale and Scarcella, 2017).

		GSAs or combination of GSAs																					
		1	**5**	**6**	**7**	**9**	**10**	**11**	**16**	**17**	**18**	**19**	**20**	**22**	**24**	**25**	**26**	**1–3–4**	**12–16**	**15–16**	**17–18**	**18–19**	**Mean**
Demersal fish	Black-bellied anglerfish		7.39	4.8	3.35																		5.2
	Blackmouth catshark					2.69																	2.7
	Blue whiting	3.5		11.01		1.16																	5.2
	Bogue															3.8							3.8
	Common pandora					1.31														2.4			1.9
	Greater forkbeard					3.16																	3.2
	Hake	9.38	7	5.35	14.91	4.48	5.51	9.47				4.83							6.68		5.56		7.3
	Picarel															0.63							0.6
	Poor cod					1.22																	1.2
	Red mullet		7.64	3.51	1.53	1.17	0.95	9.54		1.82	0.82	2.25			1.3	2.4		4.46		2.89			3.1
	Small-spotted catshark					5																	5.0
	Common sole									1.92													1.9
	Brush tooth lizard fish																2.6						2.6
	Striped red mullet		2.62			1.94											2.7			4.11			2.8
Crustaceans	Spottail mantis shrimp					2.22	2.63			1.31	2.44												2.2
	Norway lobster	1.65	1.76	4.33		2.01					6.32									0.75			2.8
	Giant red shrimp					0.25	1.4	1.61														1.1	1.1
	Blue and red shrimp	3.83	1.28	1.46		1.78	1.55													3.82			2.3
	Peregrine shrimp																2.6						2.6
	Deep-water rose shrimp	1.65	1.1	3.21		1.03	1.35	1.41			2.03	1.63							1.35				1.6
Small pelagics	Anchovy	0.89		1.74		4.87						1.03	1.4	0.94							1.79		1.8
	Sardine	0.89		5		2.11			0.55				1.36	1.07							1.52		1.8

TABLE 3 | Indicators obtained from main ecosystem models developed for large areas of the Mediterranean GSAs.

GSA	Country	Model name	Domain	Surface (km²)	Period	TB (t/km²)	TC (t/km²/year)	PPR%	mTLc	GE (catches/PP)	L index	p_{sust} (%)	References
6	Spain	Southern Catalan Sea	sh+sl	4,500	1976–1980	46.44	3.97	6.35	3.07	0.0025	0.058	50.8 (±17.6)	Coll et al., 2008a
6		Southern Catalan Sea	sh+sl	4,500	1990–2000	58.98	5.36	10.61	3.12	0.0034	0.088	23.1 (±10.9)	Coll et al., 2008a
6		Southern Catalan Sea	sh+sl	4,500	2003	52.64	5.17	7.92	3.11	0.0034	0.067	34.5 (±12.9)	Coll et al., 2008a
7	France	Gulf of Lions	sh+sl	20,400	2000–2009	68.90	2.13	13.58	3.24	0.0020	0.089	23 (±10.8)	Bănaru et al., 2013
8	France												
9	Italy	Central Tyrrhenian Sea	sh+sl	13,785	2007–2010	41.13	0.55	22.20	3.58	0.0007	0.075	30 (±12.5)	Lopez, 2013
12–13–14	Tunisia	Gulf of Gabes	sh	35,900	2000–2005	73.75	1.72	3.77	3.44	0.0010	0.017	92.3 (±7.5)	Hattab et al., 2013
17	Italy	North Central Adriatic	sh	55,500	1975–1980	134.33	3.17	19.44	3.28	0.0028	0.117	19.7 (±9.8)	Coll et al., 2009
17		North Central Adriatic	sh	55,500	mid 1990	130.30	2.45	15.00	3.07	0.0021	0.136	14.3 (±9.1)	Coll et al., 2007
20	Greece	North Eastern Ionian	sh+sl	1,021	1960–1970	44.31	1.03	9.46	3.14		0.075	28.9 (±12.5)	Piroddi et al., 2010
20		Greek Ionian Sea	sh+sl	49,149	1998–2006	21.31	0.60	2.93	2.81	0.0016 0.0030	0.084	59.6 (±16.2)	Moutopoulos et al., 2013
22–23	Greece	North Aegean Sea	sh	8,374	mid 2000	33.04	2.34	6.76	3.47	0.0040	0.028	171.2 (±12.6)	Tsagarakis et al., 2010

Main characteristics of the models are reported, as well as indicators used: TB, total ecosystem biomass; TC, total ecosystem catches (including discards); PPR%, ratio primary production required to sustain fisheries to PP; mTLc, mean trophic level of the catch; GE, gross efficiency (landings/PP); Loss in secondary production index (L index); probability to be sustainably fished (p_{sust}). Domain, model domain (sh, continental shelf; sl, continental slope).

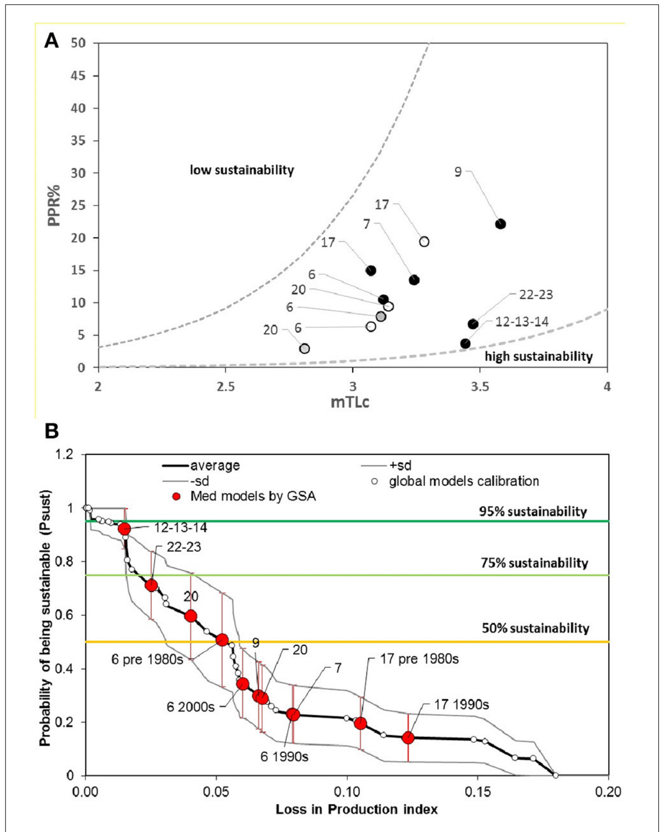

FIGURE 5 | Ecosystem state from the available food web models representing large areas of the GSAs (see **Table 3** for details). **(A)** Primary production required relative to primary production (PPR%) and mean trophic level of the catches for each model; lines divide the plane into regions with different level of sustainability of the fisheries (see Tudela et al., 2005); white dots indicate models representing ecosystems before 1980, gray dots ecosystems between 1980–1999 and black dots food web models of more recent years. **(B)** Quantitative assessment of the probability of the ecosystem to be sustainably fished using the framework provided by Loss in secondary production approach, assuming transfer efficiency as 13.7% (as the modal value for temperate shelfs; Libralato et al., 2008).

also large dissimilarities in fishing pressure (i.e., vessel km^{-2}). Our analysis show that differences in fisheries productivity between different areas can be largely explained by differences in the dimension of the continental shelf, which is thus resulting as one of the most relevant factor constraining fisheries productivity.

Landings data from GFCM capture statistics indicated that the fishing landings of the EU countries declined since mid ‘90s for the main taxa with the exception of crustaceans, whose landings was substantially stable in the last 30 years. It is worth noting, however, that the catch trend appears completely different in non-EU countries. Here the annual landings of small pelagic and demersal fish species is increasing since 70s and only in the last 5–10 years a decreasing trend is noticeable. Moreover, crustaceans, elasmobranchs, and cephalopods landings are still increasing. The stable or increasing pattern of crustaceans also in EU waters can be the results of a combination of effects, where the ecosystem

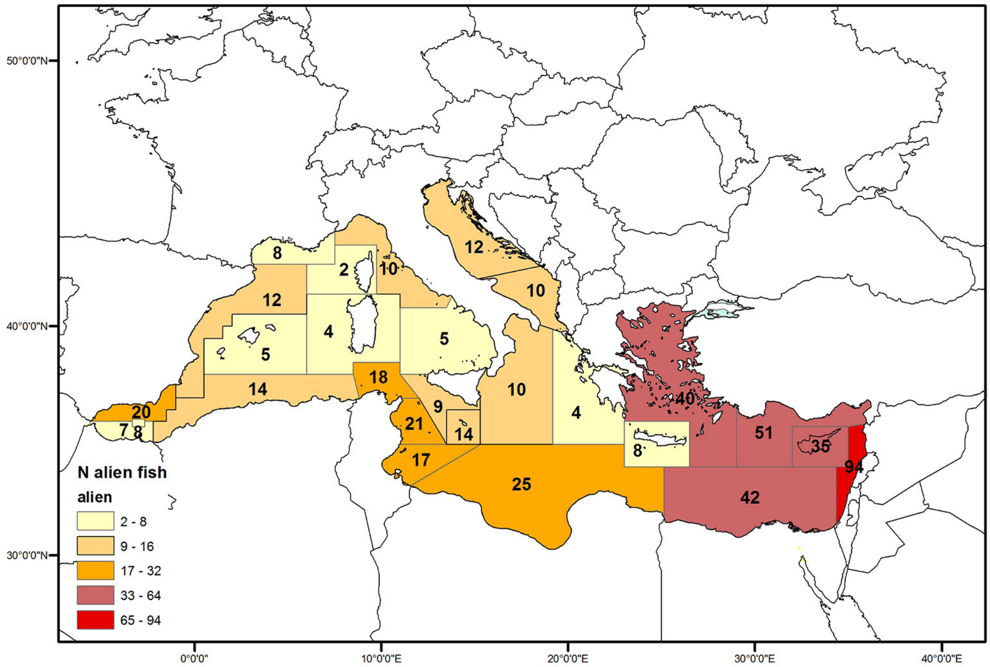

FIGURE 6 | Number of non-indigenous species by GSA. Data from the CIESM Atlas of Exotic Species in the Mediterranean (http://www.ciesm.org/online/atlas/).

change can be one of the most important. Temporal trend of increasing abundance of decapod crustaceans simultaneous with a decreasing of fish has been documented for the bathyal assemblages of the Western Mediterranean (Cartes et al., 2009). In this area, the landings of blue and red shrimp (*Aristeus antennatus*), the main target species of deep trawling, depends also by the climatic condition over the Western Mediterranean (Maynou, 2008). Similarly, the abundance of the deep-water rose shrimp (*Parapenaeus longirostris*), one of the most important commercial shrimp in Mediterranean, is increasing in the Tyrrhenian and Ligurian Seas, with an important effect due to the increasing in water temperature (Ligas et al., 2011; Colloca et al., 2014).

Current increasing landings of crustacean can also result from a sequential overexploitation with trawlers progressively moving from one resource to another in relation to their abundance, profitability and market conditions. Furthermore, a possible role might also by played by a combined effect of predation release, i.e., by the major removal by fisheries of their fish predators (e.g., as detected in N Atlantic; Worm and Myers, 2003), and of scavenging behavior, i.e., their potential advantage on feeding on large amounts of discards produced by Mediterranean fisheries (Tsagarakis et al., 2014). While these aspects need to be furtherly explored, the different temporal catch trends between EU and non-EU GSAs suggest that fishing effort in the two areas has been following an opposite development. Whilst the fishing capacity of European Mediterranean countries decreased in the last 20 years as effects of the decommissioning schemes of the EU with a subsequent reduction in landings, an increasing in fishing capacity cannot be excluded in other Mediterranean areas (Samy-Kamal, 2015).

Impact of Fishing on Commercial Stocks and By-Catch Species

Results of the stock assessments carried out in the last 10 years clearly show that the ongoing fishing pressure is determining a generalized overfishing status of commercial stocks, which appears more relevant for demersal fish. Overfishing is undermining the economic performance of EU Mediterranean fleets, as summarized by the negative trend in economic indicators (e.g., Italian fleets, STECF, 2015), thus making the sector more exposed to the negative effect of the general economic crisis. A negative picture on the effect of poorly regulated fishing activities on Mediterranean fish communities came out also by the assessment done by the International Union for Conservation of Nature (IUCN; Abdul Malak et al., 2011; Nieto et al., 2015) where among the 519 native marine fish species and subspecies assessed in term of conservation status in Mediterranan Sea, 43 species (7.5%) were classified in threatened categories (critically endangered, endangered, or vulnerable). Of this group, 31 species are elasmobranchs making the Mediterranean the region in the world with the higher proportion of threatened species of sharks and rays (Dulvy et al., 2014).

The critical status of elasmobranchs was highlighted by several studies showing a worrisome long term decline (Fortibuoni et al., 2010) accelerated in last decades. For example, pelagic sharks declined by more than 95% during the last century (Ferretti et al., 2008), whilst demersal sharks, such as smooth-hounds (*Mustelus* spp.), disappeared from most of the West Mediterranean in ‘70s and ‘80s (Massutí, 1971; Aldebert, 1997; Maynou et al., 2011; Ligas et al., 2013; Fortibuoni et al., 2016; Colloca et al., 2017).

The few geographic sectors where elasmobranchs still show viable populations for local fisheries are those featured by extended continental shelves (e.g., North Adriatic, South Tunisia and Libyan coasts, South of Sicily, and Malta). In these areas the elasmobranchs populations are likely maintained thanks to the occurrence of untrawable areas providing refuge opportunities, a moderate level of fishing intensity (e.g., Turkish coasts, Lybian waters) or a combination of these factors (see Bradai et al., 2012). However, the rapid increasing catches of elasmobranchs in non-EU waters in the last 20 years, shown by the GFCM data (**Figure 4**), can be a worrisome indication of an increased depletion risk for these “residuals” populations.

Impact of Fishing on the Ecosystem

In this study, we made an attempt to summarize the impact of fishing on the ecosystem of different GSAs to understand how much the negative signals derived from single-species models can be also detected at the multispecies level. Although the domain of the ecosystem models never encompassed the whole GSA, the models represented exploited key areas large enough to be considered indicative of the status of the GSA ecosystem, although within GSA there might be areas with contrasting local situations. Synthetic indicators directly derived from models such as total biomass, total catches and mTLc (mean trophic level of the catches) for each ecosystem highlight the difficulties in grasping the ecosystem effects of fishing without considering the productivity and the energetics behind each caught species. For instance the general pattern of higher catches and lower mTLc for ecosystems with higher total biomass (**Table 3**) is related to patterns in the primary productivity across GSAs. This highlight the difficulties for these indicators to detect impacts of fishing, because larger productivity supports ecosystem with heavier exploitation and the lowering of mTLc is simply the result of non-proportional effects of productivity across trophic level. That is why GE, which was suggested as an index of fishing pressure (Christensen et al., 2008), might be misleading in indicating ecosystem overfishing.

Primary production required to sustain catches, instead, accounts for the energy needed to produce caught biomasses at different TL and when scaled to actual PP for obtaining PPR% results in an indicator useful for comparing fishing pressure across ecosystems with very different productivity as the different Mediterranean GSAs. Contrasting PPR% with mTLc using a consolidated framework (Tudela, 2000; Libralato et al., 2005, 2008; Tudela et al., 2005; Coll et al., 2008b), moreover, allows to highlight ecosystem sustainability of fisheries. Areas that resulted exploited sustainably are Gulf of Gabes, as well as Eastern Ionian and Aegean Sea with probability to be sustainably fished (p_{sust}) of 92.3% (±7.5), 59.6% (±16.2%), and 71.2% (±12.6%), respectively. The high sustainability of fisheries in these areas is coherent with fishing pressure characterized by low number of vessels per unit of shelf area for Tunisia and for the large prevalence of artisanal/small scale fisheries in GSA 20 and 22. Conversely GSA 6, 9, and 17 showed very low ecosystem sustainability of the fisheries, with the Northen Central Adriatic Sea (GSA 17) the lowest 14.3% (±9.1). These figures are coherent with the high fishing pressure on these systems (number of trawlers per unit surface of shelf). Ecosystems in GSA 6, 9, and 17 appear thus overexploited with considerable losses in secondary productions and represent areas where exploitation is ecologically inefficient and also characterized by economically low efficient fisheries.

Unfortunately not all GSAs have exemplificative ecosystem model to analyse, and clearly the ones available suffer for representing different periods in the last decades, might embeds different biological resolution and processes, and might have different degree of accuracy according to data availability. Nevertheless, the picture is coherent with fishing capacity, effort and catches for the overlapping GSAs. Results point to general good conditions for areas dominated historically by artisanal and small scale fisheries such as the Greek Ionian Sea, GSA 20, (Moutopoulos et al., 2013) or where fisheries is developed but still working within profitable conditions such as the Tunisian GSAs (Hattab et al., 2013). Areas such as the western GSA17, with long history of fisheries exploitation (Fortibuoni et al., 2010), with very impacting gears active (such as the rapido trawling; Pranovi et al., 2000), with several ecosystem impacts documented (e.g., Giani et al., 2012) and with several stocks assessed as overfished (**Table 2**), resulted to be in a condition that can be summarized as a low profitable bio-economic equilibrium.

CONCLUSIONS

It is straightforward that the current level of fishing pressure in the Mediterranean basin, exerted by a large variety of fishing vessels and fishing gears, has impaired the productivity of commercial stocks, increased the extinction risks for sensible species, such as elasmobranchs, and contributed to disrupt the productivity and functions of the ecosystem.

We showed that single species and ecosystem models return a coherent pattern where ecosystem overfishing is combined with a high proportion of commercial stocks out of safe biological limits. This is in turn the result of a prolonged high fishing pressure where the effect of diffuse artisanal fleets is exacerbated by high pressure from vessels using towed gears (e.g., bottom and pelagic trawlers, beam trawlers). The fishing effort has increased in an uncontrolled way for decades in many Mediterranean areas (Garcia, 2011), and although measures to freeze the effort and reduce the capacity of the fleet are ongoing in EU Mediterranean countries also thanks to EU regulations, there are not yet clear signs of an inversion of the trend. As a matter of fact, Cardinale and Scarcella (2017), clearly shown that one of the major reasons for the alarming situation of Mediterranean Sea stocks can be found in the ineffectiveness of the putative effort reductions to control fishing mortalities, the continuous non-adherence to the scientific advice, and the existence of ineffective national management plans as a primary management measure.

It is widely recognized that managing multi-species, multi-fleets fisheries is a complex task where the achievement of single species targets (i.e., MSY) for a multiple stocks can be challenging due to species interactions (e.g., prey-predator relationships, competition, etc.) but also due to indirect interactions of mixed fisheries (Walters et al., 2005; Mackinson et al., 2009), especially in a fast changing ecosystem such as the Mediterranean. The rapid warming, combined with the expansion of non-indigenous species is definitely changing the suitability of the habitats for traditional commercial species with effects on their resilience to fishing (Libralato et al., 2015). The recent collapse of small pelagic fishery in the Gulf of Lions is a clear example where poor fish growth, size and body condition and ultimately biomass seem to be due to bottom-up control characterized by changes in food availability and increasing potential trophic competition (Brosset et al., 2016). Exaggerated fishing pressure represents a threat for populations making them more fragile and less resilient to other pressures and changes, and ultimately increasing the risk of collapse for the fisheries themselves.

In this context, the development of a more effective management regime for Mediterranen fisheries is extremely urgent to prevent that unregulated fishing and climate forcing might disrupt the secondary productivity of the ecosystem with major impacts on the goods and services provided.

The poor management is likely the result of the intrinsic complexity of managing human activities in the Mediterranean basin, where nations with major differences in the governance systems, socio-economic priorities and development objectives, share common natural resources (Micheli et al., 2013). However, a different result in terms of governance and sustainability was expected for fisheries in EU Mediterranean countries considering the policy objectives identified by regulations such as the Common Fisheries Policy (CFP), and the EU reg. 1967 since 2006.

Only recently were set the first attempts to develop management strategies at the international scale by GFCM with the support of the EU, as for example for deep water rose shrimp and hake fisheries in the Strait of Sicily. The ongoing process in Mediterranean European waters appears however too slow to achieve the MSY for the main commercial stocks by 2020.

The Mediterranean EU regulation 1967/2006 and the CFP have mostly failed in their mandate to achieve sustainability for fisheries in EU Mediterranean waters, thus not providing long-term sustainability and profitability to the fishing enterprises (STECF, 2015). This is in contrast to what observed in recent years in NE Atlantic, where the actions already implemented under the CFP have led to an improvement in the status of many commercially important fish stocks toward levels that are capable of producing MSY (Cardinale et al., 2013). Although the high-level seminar on the state of stocks in the Mediterranean and on the CFP approach held in February 2016 (http://ec.europa.eu/fisheries/high-level-seminar-state-stocks-mediterranean-and-cfp-approach_en) has stressed the need of urgent actions to inverse the ongoing negative trend, any major management action to quickly reverse the trend has been put in place so far.

Similar problems are being experienced throughout the world and for sure, several policy-oriented instruments have been enacted at the international level in recent years, which call upon relevant management bodies and Regional Fisheries Management Organizations (RFMOs) to be actively involved in the protection of marine biodiversity and sustainable use of fishery resources. In particular, the new CFP along with the most recently, UN SDG 14, FAO SO2, and the Aichi Targets all stress the importance of reducing overfishing and securing healthy ecosystems for the benefit of present and future generations.

AUTHOR CONTRIBUTIONS

FC: contribution to the design of the study, catch-effort review and analysis, and discussion of results; GS: contribution to the design of the study, stock assessments review, and discussion of results; SL: contribution to the design of the study, ecosystem models review and analysis, and discussion of results.

ACKNOWLEDGMENTS

This study was partially carried out within the EU project MareFrame: Co-creating Ecosystem-based Fisheries Management Solutions, Seventh Framework Programme (FP 7), grant agreement no. 613571. SL has been partially funded by the Flagship Project RITMARE—The Italian Research for the Sea—coordinated by the Italian National Research Council and funded by the Italian Ministry of Education, University and Research within the National Research Program 2011–2013.

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Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.