frontiers in Marine Science

PERSPECTIVE
published: 23 June 2021
doi: 10.3389/fmars.2021.674633

How Can We Reduce the Overexploitation of the Mediterranean Resources?

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Based on the characteristics of the fishing sector (multispecies and multi-gears) and the stock status of main resources (overfishing and overexploitation), some suggestions to improve the sustainability of demersal and small pelagic fisheries in the Mediterranean are proposed. In fisheries exploiting single or few species, such as small pelagics and deep-water red shrimps, the adoption of a management system based on catch quota approaches is suggested. In the case of mixed fisheries exploiting species with very different biological traits, it is proposed to reduce the fishing effort to a level corresponding to the lower range of the "pretty good yield" of the main target species while improving the status of the most sensitive associated species, adopting technical measures to mitigate fishing mortality. The feasibility of the proposed approaches is briefly discussed, taking into account the different levels of development of the Mediterranean countries.

Keywords: overfishing, demersal stocks, fisheries management, pelagic stocks, sustainable yield

OPEN ACCESS

Edited by:
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Specialty section:
This article was submitted to Global Change and the Future Ocean, a section of the journal Frontiers in Marine Science

Received: *01 March 2021*
Accepted: *21 May 2021*
Published: *23 June 2021*

Citation:
Fiorentino F and Vitale S (2021) How Can We Reduce the Overexploitation of the Mediterranean Resources? Front. Mar. Sci. 8:674633. doi: 10.3389/fmars.2021.674633

DESCRIPTION OF MEDITERRANEAN FISHERIES

Mediterranean fisheries are known for their strong multi-specificity and multi-gear features. Overall, fleets work mostly close to home ports, except for a few components of the fleet (trawlers, purse seiners, and surface longliners) fishing in distant waters for single target species (e.g., deep-water shrimps, tunas, and swordfish) (Caddy, 1990; Papaconstantinou and Farrugio, 2000; Stergiou et al., 2016).

The official fishing fleet operating in the Mediterranean in 2018 comprises about 76,000 vessels (Food and Agriculture Organization (FAO), 2020). They are unequally distributed, with the Eastern Mediterranean (EM) showing the largest fraction (35.1%), followed by the Central Mediterranean (CM; 26.7%), the Western Mediterranean (WM; 23.8%), and the Adriatic Sea (AS; 14.45%). Multi-gear vessels constitute the dominant group, being 77.8% of all boats. Small-scale fisheries (SSF) predominate along the southern coasts and in EM, while trawling in the WM and the AS (Colloca et al., 2017). From the economic standpoint, trawlers and purse seiners represent 64% of the total revenue, although they provide only 34% of employment (Food and Agriculture Organization (FAO), 2020). Conversely, SSF represent 26% of the total revenue, but provides 59% of jobs. However, SSF remuneration is approximately 50% lower that of trawlers and purse seiners.

Total landings increased from 1970, peaking at about 1,100,000 ton in 1994. In the last two decades, a clear decrease to 790,000 ton in 2018 was observed in the whole Mediterranean Sea, although the yield in some non-European Union (EU) countries is still growing

(Food and Agriculture Organization (FAO), 2020). Considering the main basins and using the 2016–2018 mean yield, the WM (**Figure 1**) dominates (259,000 ton), followed by the AS and the EM (179,000 ton for each), with the CM having the lowest catches (173,000 ton). Although a large variety of species contributes to the total yield, the small pelagics belonging to three species—"incomes" sardine (*Sardina pilchardus*), European anchovy (*Engraulis encrasicolus*), and round sardinella (*Sardinella aurita*)—produce about 44% of the total landing. Despite not representing the largest portion of landings, the multispecies catches of the demersal fisheries provide the highest incomes (Food and Agriculture Organization (FAO), 2020). Among the demersal species, the European hake (*Merluccius merluccius*), deep-water rose shrimp (*Parapenaeus longirostris*), and red mullet (*Mullus barbatus*) amounted to about 7% of the landings.

THE STATUS OF THE MAIN DEMERSAL AND SMALL PELAGIC STOCKS

Most of the Mediterranean fisheries are characterized by a combination of high fishing effort and high level of undersized catch and discards (Colloca et al., 2013).

From 1970 to 2010, developing fisheries and fully exploited stocks were declining at rates ranging from 18% (WM) to 24% (CM), whereas the overexploited and collapsed stocks were increasing at rates between 14% (WM) and 18% (CM) per decade (Stergiou et al., 2016).

Froese et al. (2018), assessing 181 stocks in the Mediterranean and Black Sea by using a Bayesian state-space Schaefer surplus production model, reported that less than 20% of these stocks are exploited at maximum sustainable yield (MSY), while about 60% was depleted (biomass at sea lower than the 50% of the B_{MSY}) in 2014. Simulating their dynamics under different scenarios, depleted stocks would decrease to just 46% in 2030 with 0.95 fishing mortality at MSY (F_{MSY}), while this percentage decreases to 6% with more drastic reduction of fishing effort (no fishing takes place when the stock is depleted and fishing occurs with 0.5 F_{MSY} when biomass is equal to or larger than half the B_{MSY}). A current fishing pressure exceeding several times the MSY was more recently confirmed by Hilborn et al. (2020) and Piroddi et al. (2020). In the last years, however, there has been a decrease in the percentage of stocks in overfishing (from 88% in 2012 to 75% in 2018), as well as in the average exploitation ratio (F/F_{MSY}), which has decreased from 2.9 to 2.4 times the F_{MSY} over the same period (Food and Agriculture Organization (FAO), 2020).

Regarding the main demersal species (76 stocks assessed), *M. merluccius* showed the highest *F*, with the exploitation ratio ranging between 1.7 in CM [geographical sub-areas (GSAs) 12–16)] and 8.5 in WM (GSA 3). *M. barbatus* showed lower values, from 0.3 in CM (GSA 20) to 6.3 in WM (GSA 1). *P. longirostris* showed values between 0.9 in WM (GSAs 9–11) and 3.3 in AS (GSAs 17 and 18). As the small pelagic concerns (seven stocks assessed), *S. pilchardus* resulted in overfishing, with the F_c/F_{MSY} ranging from 1.2 in the WM (GSA 6) to 3.2 in the AS (GSAs 17 and 18). *E. encrasicolus* resulted uncertain in most of the areas, being overfished (1.7) in the AS (GSAs 17 and 18) (Food and Agriculture Organization (FAO), 2020).

Although a situation of overfishing is clearly outlined both for demersals and small pelagics, available information on biomass at sea seems to depict signs of a recovering process. Coupling food web modeling with a hydrodynamical–biogeochemical model (Piroddi et al., 2020) has found increases in the biomass level of elasmobranchs, large pelagics, small and medium demersals, and meso- and bathypelagic fishes when comparing the middle of the 2010s to the late 1990s. Conversely, decreases of large demersal fishes, small pelagics, and commercial and non-commercial cephalopods and crustaceans were reported. Moreover, based on the most recent updated assessment reported by Food and Agriculture Organization (FAO) (2020), the biomass levels in 2018 showed a remarkable improvement compared to that in 2016, with only 36% of the stocks at low biomass (an 11% decrease), 19% at intermediate biomass (a 12% decrease), and 46% with high biomass (a 23% increase). The worst situation is occurring in the WM and in small pelagics. Although resources are still far from MSY, the patterns of both *F* and biomass show that demersal resources seem to react slowly, but positively, to the reduction of fishing effort implemented by the EU countries in the last decade (Maynou, 2020).

THE OBJECTIVES FOR MANAGING THE MEDITERRANEAN FISHERIES

The European Common Fisheries Policy (CFP) [reg. (EU) no. 1380/2013], the Marine Strategy Framework Directive (Directive 2008/56/EC), and the General Fisheries Commission for the Mediterranean (GFCM) mid-term strategy (General Fisheries Commission for the Mediterranean (GFCM), 2016) have adopted the MSY as the main target for fisheries together with a progressive improvement of practices able to reduce the discards of unwanted fish. Furthermore, both policies recognize the protection of essential fish habitats (EFHs) as a tool for improving the sustainability of fisheries while protecting the functioning of ecosystems, in line with the ecosystem approach to fishery management (EAFM). The main tools introduced for improving fishery sustainability in the Mediterranean include the multiannual plans (MAPs) (**Figure 1**).

To balance the fishing fleet to the productivity of stocks, the number of EU fishing units active in the Mediterranean has declined by 30% in the period 1995–2016 (Maynou, 2020). However, it is worth remembering that, while the EU countries' fleet capacity is decreasing, an increase in fishing capacity cannot be excluded in other Mediterranean countries (Colloca et al., 2017).

THE CURRENT MANAGEMENT SYSTEM

Management of Mediterranean fisheries is mostly based on effort control, limiting the number of boats or the time at sea, and some technical measures, such as minimum conservation reference size and minimum mesh sizes (Stergiou et al., 2016;

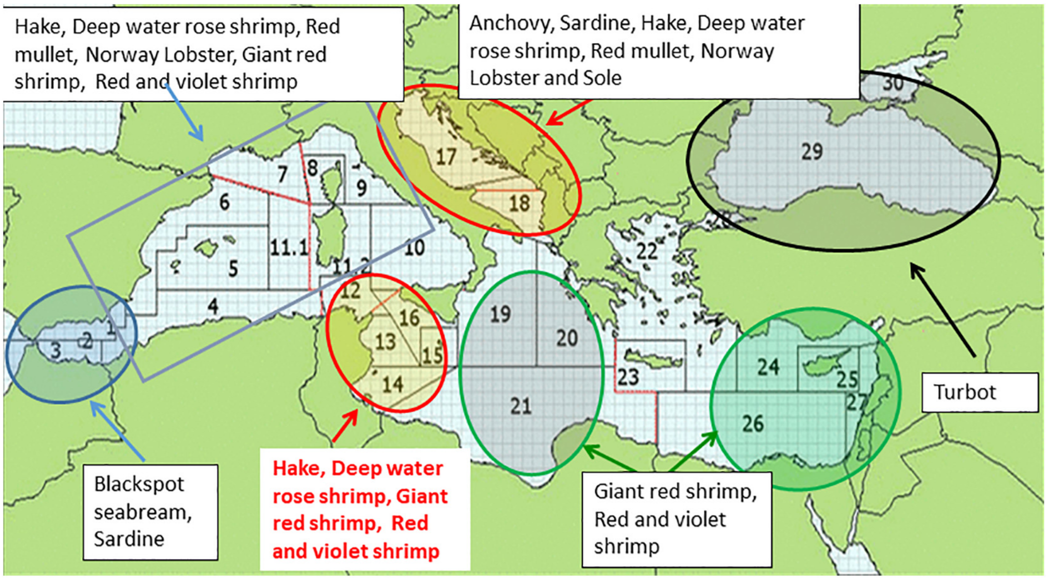

FIGURE 1 | The Mediterranean, the Black Sea, and the geographical sub-areas (GSAs) adopted by the General Fishery Commission for the Mediterranean (GFCM). The *marked areas* show where demersal and small pelagic stocks are shared. Multiannual plans (MAPs) are adopted or being prepared by the EU (*rectangle*) or the GFCM (*ellipses*).

Bellido et al., 2017). However, these approaches were unable to impede the stocks from being overfished (too high fishing mortalities) and overexploited (too low biomass at sea), up to now, without effective common implementation at the scale of the whole basin. One of the main barriers to the effective management of Mediterranean fisheries is the difficulty of less developed countries to implement an effective monitoring, control, and surveillance (MCS) system to contrast illegal, unreported, and unmanaged fisheries. According to Cardinale et al. (2017), the major causes of the critical state of the Mediterranean stocks could be found in the ineffectiveness of the current system to control *F*, the continuous non-adherence to the scientific advice, and the overall inadequacies of the existing management measure. The authors have suggested adopting alternative management measures, such as a catch quota system, currently in force only for bluefin tuna and swordfish in the Mediterranean. Although the multispecies nature of most Mediterranean fisheries and some difficulties in monitoring catches make the widespread adoption of the catch quota system difficult, it could be properly applied for a single or a few species fisheries, such as those targeted to *E. encrasicolus* and *S. pilchardus* or to deep-water red shrimps (Pope, 2009).

THE HIGH FISHING MORTALITIES

Some researchers have proposed very drastic solutions, such as a reduction in fishing effort between 50 and 80% of the present levels, to reverse the current overfishing (Vasilakopoulos et al., 2014; Merino et al., 2015; Froese et al., 2018; Demirel et al., 2020). Although rebuilding overexploited stocks is a priority to guarantee sustainable fisheries in the long term, such a drastic solution does not adequately consider the high expected socioeconomic costs that would require such impressive transformation. To improve fishery sustainability in the Mediterranean, the question cannot be realistically solved by halving the capacity of fleets or their activity, but should be declined in a more composite way.

Attention should be paid to the difficulties in targeting MSY in multispecies fisheries, which is typical of the Mediterranean coastal trawling. When several species with different biological features (first maturity, longevity, and maximum size) are fished together, the F_{MSY} of one leads to the overfishing or underfishing of the other (Sissenwine, 1978). Assessing the sustainable yield curves of mixed trawling in the Ligurian Sea for eight species, with similar weight in landing, and for the entire assemblage by a Schaefer model, Abella et al. (2010) reported that the optimal level of fishing effort in terms of MSY for the assemblage corresponds to that of *M. barbatus*, a small- to medium-sized bony fish, that of *M. merluccius* being lower and that of the horned octopus (*Eledone cirrhosa*) being higher.

Due to the frequent "flat top curves" in the relationship between fishing mortality and yield, Hilborn (2010) suggested using the *F* range delivering 80% of the MSY to provide the so-called pretty good yield. This approach seems to be promising in mixed fisheries, where maximizing the long-term yield could be pursued by choosing target fishing mortalities as the best compromise within a "pretty good yield" range of different species. However, this "pretty" approach is difficult to be applied when the F_{MSY} for species that are caught together is very different (**Figure 2**). For example, in the Strait of Sicily (CM) *P. longirostris* and giant red shrimps (*Aristaeomorpha foliacea*) are the main targets of the Italian trawlers, with more than 50% by weight and 61% by value of demersal yield in 2016,

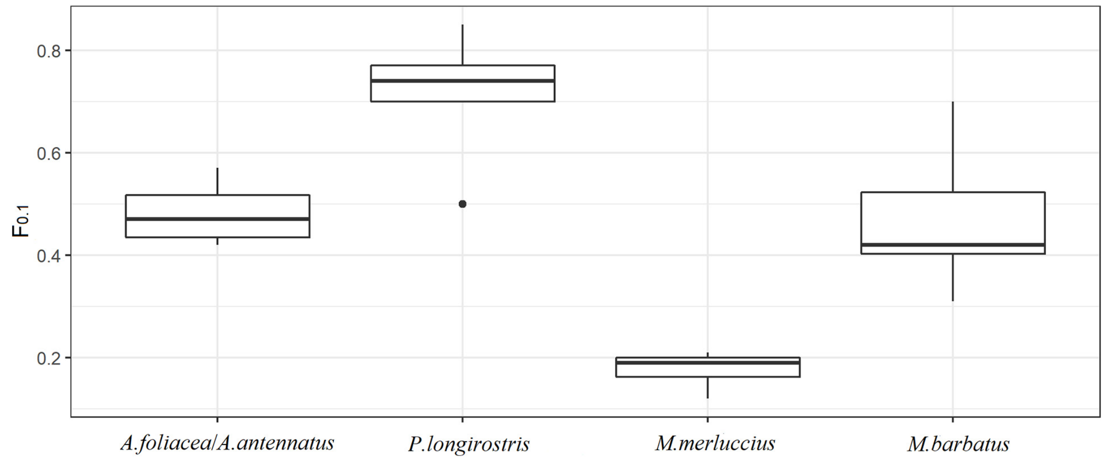

FIGURE 2 | Box plots showing the distribution of $F_{0.1}$, as a precautionary proxy of F_{MSY}, for the main target species of the Mediterranean bottom trawling. With the current exploitation pattern, achieving the F_{MSY} of hake (*Merluccius merluccius*, nine stocks) implies a strong loss of a sustainable yield of red mullet (*Mullus barbatus*, 10 stocks), deep-water rose shrimp (*Parapenaeus longirostris*, five stocks), and red shrimps (*Aristaeomorpha foliacea/Aristeus antennatus*, four stocks) [data from Food and Agriculture Organization (FAO) (2019)].

M. merluccius being the main associated commercial bycatch, with catches amounting to about 10% of the landings and 9% in value (Maiorano et al., 2019).

According to the assessment done to support the Italian MAPs for demersal fisheries in the Strait of Sicily (Ministero delle Politiche Agricole Alimentari e Forestali (MIPAAF)., 2018), the reduction in *F* to reach the *M. merluccius* MSY in 2020 should have been around 80% of the value of 2017. Conversely, to achieve the F_{MSY} for *P. longirostris*, a reduction in *F* of about 30% should be required. However, at MSY of *P. longirostris*, the *M. merluccius* spawning stock biomass would increase by 25% while catches would remain stable, whereas the achievement of the *M. merluccius* MSY would halve the *P. longirostris* yield. Furthermore, from a socioeconomic viewpoint, pursuing the *P. longirostris* MSY would provide, in the medium term, better profitability, economic sustainability, labor cost, and employment indicators compared to the *M. merluccius* MSY strategy. These analyses confirm that reaching the *M. merluccius* MSY implies a deep change in the Mediterranean fisheries with a sharp reduction of trawlers and the development of the longlines fleet targeted exclusively to the adult fraction of the stocks (Aldebert et al., 1993; Lleonart et al., 2003).

THE POOR EXPLOITATION PATTERN

To improve the exploitation patterns of the main target species should be a good objective for two main reasons: the first is that the larger the size of the individuals caught, the higher the level of optimal fishing effort and yield (Beverton and Holt, 1956); the second is that a better exploitation pattern mitigates the problems related to the landing obligation of the CFP (Bellido et al., 2017; Maynou et al., 2018).

Since undersized fishes of many large-sized species, such as *M. merluccius*, are highly vulnerable to the minimum mesh size enforced in the Mediterranean (40 mm square or 50 mm diamond) (Brčić et al., 2018; Mytilineou et al., 2018) and a further increase of the mesh size would lose shrimps, cephalopods, and medium-sized fish, the exploitation pattern can be enhanced through: (i) increasing the trawl net selectivity by adopting grids and separators that allow the undersized fish to escape (Coll et al., 2008; Massutí et al., 2009; Aydın and Tosunoğlu, 2011; Vitale et al., 2018b); (ii) delaying the size/age of the first capture of juveniles through spatial and/or temporal closures to fisheries when and where the juveniles aggregate in order to improve the fraction of fish reaching sexual maturity (Caddy, 1999, 2009; Fiorentino et al., 2003; Garofalo et al., 2011; Colloca et al., 2015; Despoti et al., 2020; Mytilineou et al., 2020; Milisenda et al., 2021); or (iii) a combination of the two approaches.

Empirical evidence of the positive effects of the closure of coastal nurseries to trawling in rebuilding the biomass of *M. barbatus* were provided by Relini et al. (1996) for the Ligurian Sea (WM) and by Fiorentino et al. (2008) for the Gulf of Castellammare (North Sicily—CM). The positive effects of seasonal closure were provided by Mion et al. (2014) for the AS and by Samy-Kamal et al. (2015) for the Catalan Sea (WM).

Furthermore, population dynamics models have highlighted the positive effects of both sorting grid/separator adoption or nursery protection. Vitale et al. (2018a), simulating the effects of a sorting grid mounted on the net of trawlers targeted to *P. longirostris*, showed a benefit for both *P. longirostris* and *M. merluccius* stocks in terms of increasing in biomass and for the fleets in terms of improving the quantity and quality of landings. Fouzai et al. (2012), modeling alternative management scenarios by ECOSPACE in the AS, suggested that protecting EFHs could rebuild the biomass of commercial fish, reporting also benefits for several commercial resources by adopting 3-month closures. Evaluating different management scenarios for demersals in the Strait of Sicily, Russo et al. (2019) showed that both temporal and spatial closures are expected to move to MSY *P. longirostris*, *A. foliacea*, and *M. barbatus*. Despite both closures leading to an improvement in the spawning stock biomass of *M. merluccius* too, the results confirmed that it is not possible to achieve MSY for *M. merluccius* without a very strong reduction of *F*.

HOW TO IMPROVE SUSTAINABILITY OF THE CAPTURE PROCESSES IN THE MEDITERRANEAN

Based on the discussed literature, improving sustainability in the mixed Mediterranean demersal fisheries without causing major social upheaval could be pursued, choosing as a target the optimal *F* of the small- to medium-sized species forming most of the catch of trawling (crustaceans, cephalopods, and fish), considering the concept of the "pretty good yield." Meanwhile, to mitigate the impact of this approach on large-sized fishes, such as *M. merluccius*, skate, sharks, and angler fish, *ad hoc* technical measures should be adopted. Improvement of the current poor exploitation patterns will be best attained by closing trawling areas where undersized fishes are concentrated or adopting sorting devices rather than further increasing the mesh size in the net. This approach, preconized by Caddy (1999) in the late 1990s, is now possible due to the availability of tools for the remote positioning of fishing vessels [vessel monitoring system (VMS), automatic identification system (AIS), and others] (Russo et al., 2016). Although North African countries have extremely few vessels using AIS or VMS technology (Taconet et al., 2019), there are growing initiatives to improve MCS in non-EU countries (Pramod, in press).

Since management based on effort regulation assumes a strong relationship between fishing effort and catch through fishing mortality, this approach should be weak in small pelagics due to the well-known hyperstability of schooling resources' catch per unit effort (CPUE) (Pope, 2009). The small pelagic fisheries in the Mediterranean being based just on two target species and two fishing systems, the adoption of an individual catch quota system should be explored to trigger capture to the productivity of the stock leaving at sea a stock size enough to not impede its renewability.

As climate changes affect strongly the productivity of stocks through changes in recruitment and other demographic parameters, causing a change in the sustainable yield of stocks (Kell et al., 2005; Travers-Trolet et al., 2020), evaluation and management should consider not only fishing effort but also climate and environmental change (Moullec et al., 2019). Consequently, the EU Data Collection Framework and the GFCM Data Collection Reference Framework should be adapted accordingly, improving real-time monitoring of commercial stocks, exploited communities, related environmental drivers, and fishing activities to move toward adaptive management.

To support a spatial-based and adaptive approach to fishery management, scientists are called to improve knowledge on the dynamics of resources and fisheries in space and time, considering climate change and taking into account socioeconomic aspects.

While it should be easier to adopt the suggested control of the spatial pattern of fishing effort or an individual catch quota for the EU vessels, it would be more difficult in those areas where the resources are shared by EU and non-EU fleets, such as the Alboran Sea, the Strait of Sicily, the Adriatic Sea, and the Aegean Sea. Hilborn et al. (2020), reviewing a lot of fisheries including the Mediterranean ones, reported a clear relationship between fishing pressure and management intensity. Although all Mediterranean countries have formally adopted the precautionary approach, the MSY and the EAFM, the different socioeconomic developments in the area suggest that less developed countries pursue reaching the high employment of low-skilled labor with low management costs (Beddington et al., 2007). Since the ecological, economic, and social sustainability of fisheries is not only a technical question but also a cultural and capability-building challenge, the FAO Regional Projects (Copemed II, Medsudmed, Adriamed, and Eastmed) and the GFCM have the main role in constructing a common vision on how to reach more sustainable exploitation of the fishery resources of the Mediterranean, taking into account the complex ecological, social, economic, and political framework.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

Both authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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Conflict of Interest: 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.