Bioeconomic Analysis of the EU *Multiannual Management Plan* for Demersal Fisheries in the Western Mediterranean. Spanish Fisheries as a Case Study

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The *Multiannual Management Plan* embedded in Regulation EU 2019/1022 of the European Parliament and of the Council of June 20, 2019, envisages to reform Mediterranean demersal fisheries to restore stocks to maximum sustainability yields by 2025. This paper leverages a bioeconomic model based on a specific case study of the Western Mediterranean Sea to analyze the objectives of this new EU reform. We complement this analysis with simulations based on alternative management strategies: the reduction of fishing effort of 1–2 days-per-week and changes to selectivity patterns. Effects on artisanal fleets are also analyzed in order to assess scenarios that could achieve sustainability for all demersal fishing fleets. The results reveal that it is not possible to achieve the plan's aims for all stocks. Furthermore, the fishing time established is insufficient, although it would increase economic, and biological indicators for medium- and long-term periods. The best scenarios would be achieved by applying selective changes that provide for faster recovery of biological and economic indicators for trawler and artisanal fleets. The results also reveal that the reduction in the number of fishing days per week complemented with selectivity changes would have a lower socioeconomic impact than a reduction in fishing effort based entirely on fishing days or number of boats. In any case, Mediterranean demersal fisheries require a significant and well-planned reduction in fishing mortality levels over the next several years to recover and maintain sustainable exploitation.

Keywords: Mediterranean fisheries, multiannual management plan, bioeconomic modeling, Common Fisheries Policy, maximum sustainability levels

INTRODUCTION

The measures adopted by the European Union (EU) Common Fisheries Policy (CFP) for more than a decade (European Commission [EU], 2006, 2008, 2013) have proven inefficient for limiting the fishing mortalities required to achieve a sustainable exploitation levels of Mediterranean fishery stocks (Colloca et al., 2017). In 2015, the Mediterranean Sea and Black Sea (FAO Fishing Area 37) had the highest percentage of unsustainably fished stocks among the 16 major world statistical

areas (Food and Agriculture Organization [FAO], 2018). Additionally, in the Malta Medfish4Ever Ministerial Declaration of March 30, 2017[1], a 10-year work program was provided, proposing that 100% of the key Mediterranean fisheries should be managed with multiannual management plans to restore and maintain fish stocks at or below fishing mortality (F) levels capable of producing maximum sustainable yields (MSY). The results of the Mediterranean stock assessments of the Scientific Technical and Economic Committee of the European Commission (STECF) revealed that it was necessary to reduce the fishing mortality of Mediterranean stocks, particularly for demersal species presenting high levels of fishing mortality with respect to F_{MSY} (Colloca et al., 2017; Libralato et al., 2018).

The new reform of the European CFP (EU Reg. 2013/1380) established the possibility of implementing science-based management plans and "multiannual plans" to ensure that fishing activities would remain environmentally, socially, and economically sustainable over the long term. The CFP also has the objective of ensuring the sustainability of the fishing sector, including artisanal and coastal fisheries that are undergoing important capacity reductions for structural reasons (e.g., low economic viability, lack of intergenerational replacement). The reformed CFP sets the stage for fishery managers and stakeholders to assume the responsibility of complementing and implementing plans for managing fisheries within their region.

A multiannual plan was implemented to help conserve the demersal stocks and to ensure sustainable operations within the Western Mediterranean Sea (West Med MAP, Regulation EU 2019/1022 of the European Parliament and of the Council of June 20; European Commission [EU], 2019), which extends along the northern Alboran Sea, the Gulf of Lions, and the Tyrrhenian Sea, covering the Balearic archipelago and the islands of Corsica and Sardinia, concerning France, Italy, and Spain. The plan included the regulation of blue and red shrimp (*Aristeus antennatus*), deep-water rose shrimp (*Parapenaeus longirostris*), giant red shrimp (*Aristaeomorpha foliacea*), European hake (*Merluccius merluccius*), Norway lobster (*Nephrops norvegicus*), and red mullet (*Mullus barbatus*). The plan aims to restore these stocks to MSY levels with the objective of ensuring social and economic viability of Mediterranean demersal fisheries. Fishing mortality that corresponds to MSY levels must be based on STECF (or other scientific bodies recognized by the EU or international level) stock assessments. Likewise, F_{MSY} should be achieved progressively by 2020 wherever possible and by January 1, 2025, at the latest. They must then be kept within the mortality levels that produce MSY.

The new reform stated that fishing effort reduction should be supplemented with relevant technical or conservation measures to achieve F_{MSY} levels for demersal stocks. Thus, to achieve this fishing mortality reduction and the F_{MSY} levels, the measures adopted were to be combined with changes in fishery selectivity to restore fishery stocks, yields, and profits (Colloca et al., 2013; Libralato et al., 2018; Sola and Maynou, 2018b).

This paper aimed to assess the likelihood that the West Med MAP will achieve the CFP objectives, especially F_{MSY}

levels for demersal stocks, *via* a quantitative bioeconomic model based on a specific case study in the Western Mediterranean Sea (GSA06). We use a bioeconomic model to assess the impacts of effort reduction and selectivity changes in demersal Mediterranean fisheries.

MATERIALS AND METHODS

Demersal Fisheries of the Western Mediterranean Sea (GSA 06)

The study area is GSA06 (**Figure 1**), a geographical region established by the General Fisheries Commission for the Mediterranean (GFCM), which manages data collection, monitoring, management, and assessment of Mediterranean fishery stocks[2].

The GSA06 demersal fleets mainly comprise bottom trawlers (OTB), bottom longlines (HOK), and fixed or bottom net gears as gillnets or trammel nets included in the same fleet (GNS). The GNS fleet represents around 60% and the OTB fleet 35% of the total demersal fleet as of 2015 in terms of the number of vessels (**Table 1**). However, the bottom trawlers represent the most productive gear in the Mediterranean fleet in terms of production (Lleonart and Maynou, 2003). Nevertheless, artisanal fisheries play significant roles in the socioeconomic and cultural heritage of coastal communities (Colloca et al., 2017).

The Mediterranean fishing fleet catches around 300 species, but only 10% are systematically represented in the market (Bellido et al., 2014), of which around 200 species are landed in GSA06. Of these, 25 species represent 83 and 80% of landings and economic value, respectively, in 2010 (Maynou, 2014). Among the Mediterranean fishing fleet, OTB represents the most diversified fisheries of all fleets (Lleonart and Maynou, 2003).

The management of Mediterranean demersal fisheries in the GSA 06, and other Mediterranean fisheries, is based on input measures that control fishing effort by limiting the capacity of the fleet (license scheme). Fishing activity is not permitted on weekends and the vessels are forced to return to base port with, a maximum of 12 fishing hours per day (Lleonart and Maynou, 2003; Bellido et al., 2020). There are minimum landing sizes for most target species exploited by demersal fleets, but they are not fully enforced, contributing to the low economic efficiency of fisheries exploitation (Colloca et al., 2013). OTB operate with gears with legal minimum mesh sizes in the codend of 40 mm (square mesh) or 50 mm (diamond mesh) (Sola and Maynou, 2018a). Also, artisanal fleets (HOK and GNS) operate with gears regulated (i.e., number of gears by vessel, mesh sizes of fixed nets, etc). Output management measures (i.e., Total Allowable Catch or Quotas) are not implemented in Mediterranean demersal fisheries (Smith and Garcia, 2014).

Bioeconomic Model

A bioeconomic model using data from GSA06 was developed to help analyze the West Med MAP's ability to achieve F_{MSY} levels of demersal stocks. The model description is based on

FIGURE 1 | GFCM division areas, including the GSA06 area of this study (coordinates obtained from http://www.fao.org/gfcm/en/).
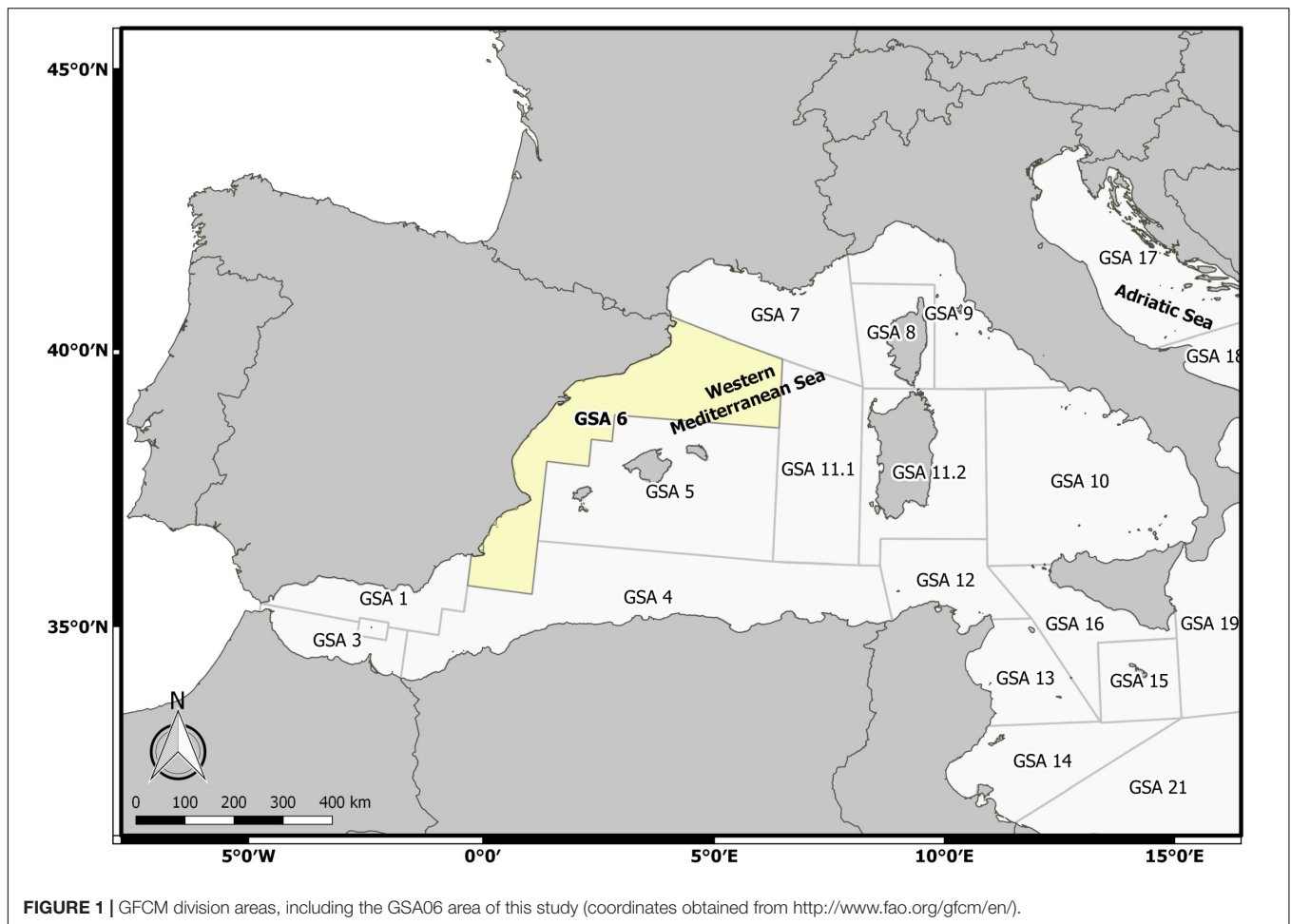
TABLE 1 | Composition and fishing effort capacity of the Mediterranean demersal fisheries fleet of GSA06 in 2015 (from https://ec.europa.eu/fisheries/cfp/fishing_rules/fishing_fleet_en).

Demersal fleet	Number of vessels	Average Declared Power (HP/vessel)	Average Gross Tonnage (GT/vessel)	Average days at sea* (day/vessel)
Bottom trawl (OTB)	485	196.1	59.9	215
Bottom longline (HOK)	64	75.0	9.2	175
Fixed nets (GNS)	833	39.8	4.9	170

*Considering fisheries closures.

the research of Sola and Maynou (2018b), who developed a bioeconomic model to analyze the economic impact of EU Landing Obligation (European Commission [EU], 2013) and selectivity improvements based on results obtained using a modified trawler designed to reduce unwanted catches in the northern part of GSA06 (Sola and Maynou, 2018a). The novelty of our approach lies with its assessment of the interaction between trawler (OTB) and artisanal fleets (HOK and GNS) to analyze the objective of West Med MAP to achieve F_{MSY} levels of stock assessments species on assessed by the STECF.

The Mediterranean subgroups of STECF and GFCM assess the fisheries stocks of each GSA *via* the data collection of the Data Collection Framework of the European Commission

(EU Reg. 665/2008: European Commission [EU], 2008). The most important GSA06 demersal species in economic terms, evaluated by stock assessments, are hake (*M. merluccius*), red mullet (*M. barbatus*), anglerfish (*Lophius piscatorius*), blue whiting (*Micromesistius poutassou*), red shrimp (*A. antennatus*), Norway lobster (*N. norvegicus*), and deep-water pink shrimp (*P. longirostris*) (Scientific Technical, and Economic Committee for Fisheries [STECF], 2013, 2014, 2015a,b, 2017). These species were used to develop the bioeconomic model of GSA06 demersal fisheries.

The bioeconomic model was developed using the Mediterranean Fisheries Simulation Tool (MEFISTO, Lleonart et al., 2003) that is a multispecies and multigear model.

On the one hand, the biological submodel is based on an age-structured fish population dynamics model that include stock recruitment relationships, growth, natural mortality, maturity and length–weight relationships (Shepherd and Pope, 2002). On the other hand, the economic submodel is based on the economic units of fishing fleets as single firms. The revenues of the economic units derive from the sale of the main species described by the biological submodel, complemented by catches of other commercial species whose population dynamics are not explicitly modeled. Thus, the revenues of fishing fleets result from the catches of the main fisheries stocks and their commercial by-catch species, modeled as a proportion of main fisheries stocks (see Lleonart et al., 2003). The costs considered to obtain the net profits (relationship between revenues and costs) of fishing fleets are described in Sola and Maynou (2018b) and basically include common costs related to effort (primarily, energy costs), all other variable costs (such as vessel maintenance or engine repair, among others), fixed operating costs (such as fishing license, among others), depreciation cost and opportunity cost of capital. The biological model and the economic model are related via the fishing mortality that is proportional to the fishing effort. The fishing mortality obtained from fish stock assessments for each species and age was divided among each demersal fleet, proportionally to the catches. For more detailed information of MEFISTO model, see Lleonart et al. (2003), Maynou (2014), and Merino et al. (2015).

Mediterranean Fisheries Simulation Tool allows to study different economic metrics of fishing fleet, such as net profits by fleet, and the response of the stock under different management scenarios, like changes to fishing effort (reduction of fishing days, fleet reduction, ...) or technical measures (e.g., selectivity, catchability). It has been used in various studies of GSA06 (Lleonart et al., 2003; Maynou, 2014, 2019; Sola and Maynou, 2018b; Martín et al., 2019) and in other areas of the Mediterranean Sea (Merino et al., 2007; Silvestri and Maynou, 2009; Maravelias et al., 2014). MEFISTO is a free software that can be downloaded at http://mefisto2017.wordpress.com/.

The results of the stock assessments must remain robust to build an accurate bioeconomic model of Mediterranean fisheries (Maynou, 2014, 2019). Thus, the biological parameters obtained in the assessments and their results are used to parameterize the bioeconomic model using the most recent stock assessments of demersal species (Scientific Technical, and Economic Committee for Fisheries [STECF], 2013, 2014, 2015a,b, 2017). The economic parameters of the model were compiled using economic data from the Economic and Transversal data tables published by STECF[3] complemented by surveys conducted in the MINOUW project[4]. Furthermore, stock assessments were used to distribute fishing mortality results among the different fishing fleets according to catches per species (Scientific Technical, and Economic Committee for Fisheries [STECF], 2013, 2014, 2015a,b, 2017) (see text footnote 4).

Simulation and Management Scenarios

The management scenarios applied to the bioeconomic analysis are presented in **Table 2** and are in line with the effort reduction required to reach the long-term F_{MSY} for red mullet. This requires nearly a 73% reduction in the number of fishing days per year (215 to 56). We selected the F_{MSY} for red mullet (**Figure 2**), because it represents an intermediate situation between hake, the most overexploited species in the GSA06 area according to the available stock assessments, and red shrimp, the least overexploited species (Colloca et al., 2017). This scenario may be similar to the result of applying multispecies MSY (Quetglas et al., 2017).
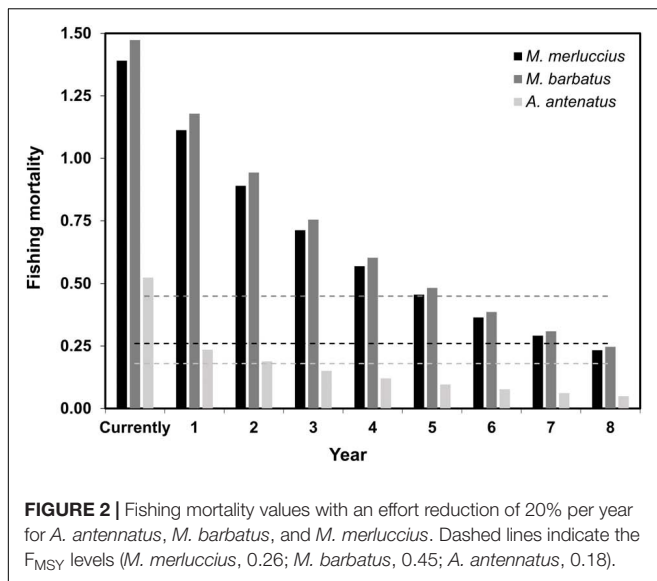
Scenario 0 reflects no changes in fishing conditions and maintaining current levels of fishing mortality assuming an annual increase in catchability of 2% per year. Scenarios 1 and 2 imply an annual reduction of demersal fleet's effort of 20% (Scenario 1) and 10% (Scenario 2) to achieve F_{MSY} levels without introducing changes in fishing patterns. Scenario 3 introduces a modified bottom-trawler design as discussed by Sola and Maynou (2018a) to reduce the catches of undersized *M. merluccius* and *M. barbatus*. This modification introduces the T90 mesh net of 50 mm mesh knotting (90°; Herrmann et al., 2013) replacing the current EU legal mesh sizes [diamond mesh of 50 mm knotting (0°) and square mesh of 40 mm knotting (45°)] in the extension piece forward of the cod end in the trawl net. The T90 mesh net was also introduced in the codend to improve the selectivity

TABLE 2 | Management scenarios considered in the bioeconomic model for demersal fisheries in GSA 06.

Scenarios	Management scenario	Total fishing days reduction (%)
Scenario 0	Business as usual, no management change.	0
Scenario 1	Annual reduction of 10% to reach *M. barbatus* F_{MSY}	74
Scenario 2	Annual reduction of 20% to reach *M. barbatus* F_{MSY}	74
Scenario 3	Change selectivity with T90 mesh net (see Sola and Maynou, 2018a)	0
Scenario 4	T90 mesh net + 10% annual effort reduction over 4 years	34
Scenario 5	T90 mesh net + 20% annual effort reduction over 4 years	59
Scenario 6	Reduction 2 days a week in 3 years	40
Scenario 7	Reduction 1 day per week in 3 years + T90 mesh net	20
Scenario 8	Reduction 2 days per week in 3 years + T90 mesh net	40

FIGURE 2 | Fishing mortality values with an effort reduction of 20% per year for *A. antennatus*, *M. barbatus*, and *M. merluccius*. Dashed lines indicate the F_{MSY} levels (*M. merluccius*, 0.26; *M. barbatus*, 0.45; *A. antennatus*, 0.18).

of *A. antennatus* by Deval et al. (2016). For other species no studies with T90 mesh net in Mediterranean demersal fisheries were found and no changes in selectivity pattern were modeled. Selectivity changes were modeled using the selectivity parameters L_{50} (length at 50% of the catch is retained) and SR (selection range) for *M. merluccius* (21.1 and 7.4 cm TL), *M. barbatus* (20 and 6.9 cm TL) and *A. antennatus* (23.3 and 8.4 mm CL). Scenarios 4 and 5 include a progressive annual reduction in the demersal fleet fishing effort with changes in the selectivity of bottom trawlers (viz., Scenario 3). Scenario 6 includes a 40% reduction in fishing effort over 3 years, which is equivalent to a 2-days-per-week reduction for demersal fleets. Finally, Scenarios 7 and 8 include a reduction of 1–2 days per week for demersal fleets and changes in selectivity of bottom trawling (viz., Scenario 3). All the management scenarios are introduced in 2020 based on West Med MAP (European Commission [EU], 2019).

The results of the stock assessments in Mediterranean fisheries are robust to parameterize a bioeconomic model for Mediterranean fisheries. Nevertheless, data from the spawning-stock biomass/recruitment (SSB/R) relationship are insufficient due to the short assessment period used to build medium term predictive models for Mediterranean fisheries (Maynou, 2019). Thus, recruitment was kept stochastic around a constant mean value over time as a result of the geometric mean of the most recent 3 years. This approach was applied to other bioeconomic models of the Mediterranean (Maravelias et al., 2014; Sola and Maynou, 2018b).

The given bioeconomic model was projected for the period 2015–2035 (2040 is an exception for Scenarios 0–2 for reaching F_{MSY}), assuming 2015 is the first year of the simulation according the most recent stock assessments. The uncertainty was treated assuming 1,000 iterations for each scenario analyzed in order to estimate the mean and 95% confidence interval of the indicators analyzed. **Table 3** presents the biological parameters used to develop a bioeconomic simulation. **Tables 4**, **5** present the economic parameters of the bioeconomic model.

The average prices in 2014 of target species (p_i) (**Table 3**) and commercial by-catch (p_s, estimated at 5.80 € kg^{-1}) were estimated for the fleet from the price data series from the Fisheries Directorate of Catalonia and were assumed constant throughout the simulations. Finally, the net present value (NPV) of the management scenarios evaluated was estimated for net profits comparing gains and losses between management scenarios at different times, using a discount rate of 5%.

RESULTS

Reduction in Fishing Effort to Reach F_{MSY} Levels

Scenario 0 (*status quo*) shows the overexploited status of selected stocks where F > F_{MSY}. A subsequent gradual increase in fishing mortality caused by the increase in catchability with decreases of SSB and catches of the main species is expected. Additionally, a gradual economic loss (i.e., profits and crew wages) for trawler and artisanal fleets is expected (**Figures 3–5**).

Management scenarios based on the gradual reduction in fishing effort needed to reach *Mullus barbatus* F_{MSY} (Scenarios 1 and 2) require an extended period of declining catches and economic loss lasting several years for trawlers (**Figure 3**), but not for artisanal fleets. These would see a one- to three-fold catch increase above the initial levels in the medium to long term. Scenario 1 (10% reduction) shows a more progressive increase in the short–medium term for catches and a lower short term loss than Scenario 2 (20% reduction) for trawler fleets.

Scenarios 1 and 2 would expect an increase in economic and catch terms for artisanal fleets (HOK and GNS) over the short term (**Figures 4**, **5**). However, faster effort reductions (Scenario 2) exhibit a higher increase in catches and economic indicators (i.e., profits and crew wages) than slow effort reductions (Scenario 1).

Scenario 1 leads to a more progressive rebuilding of red mullet catches with a lower short term loss than Scenario 2. However, Scenario 2 shows a better recovery of SSB for red mullet and hake and, consequently, higher catches (**Figure 6**) in the medium to long terms (4% vs. 14% for hake and -1.2% vs. 11% for red mullet in 2030); see **Supplementary Tables S3**, **S5**. Over the long term, both scenarios reduce fishing mortalities for the main species assessed, with a roughly 68% reduction for red mullet. For more detailed information, see **Supplementary Tables S4**, **S6**.

Selectivity Change Introducing the T90 Mesh + Effort Reduction

The modification of the selectivity pattern just with the T90 net (Scenario 3) or combined with effort reductions (Scenarios 4 and 5) would produce a short term loss for the trawler fleet during the first year compared with the *status quo*. However, in most scenarios, a rapid recovery of catches, and profits would be expected within a few years (**Figure 7**). More detailed information is presented in **Supplementary Tables S7**, **S8**. Nevertheless, our results indicate that, if effort reduction is too large (Scenario 5), the recovery will take longer, and

TABLE 3 | Biological parameters used in the bioeconomic model of GSA 06. *F* is the fishing mortality distributed among fishing fleets.

Stock name	Age class	Number (000s)	Maturity ogive (*Mat*)	Natural mortality (*m*)	*F* (OTB)	*F* (HOK)	*F* (GNS)
M. merluccius	0	100806	0.00	1.24	0.12	0.00	0.00
M. merluccius	1	26126	0.15	0.58	1.22	0.00	0.00
M. merluccius	2	2788	0.82	0.45	1.54	0.03	0.03
M. merluccius	3	225	0.98	0.40	1.16	0.09	0.09
M. merluccius	4	30	1.00	0.37	0.23	0.03	0.01
M. merluccius	5	4	1.00	0.35	0.20	0.07	0.01
L. budegassa	0	11817	0.09	1.08	0.01	0.00	0.00
L. budegassa	1	4387	0.14	0.48	0.35	0.01	0.02
L. budegassa	2	2481	0.21	0.37	1.52	0.03	0.08
L. budegassa	3	295	0.30	0.32	1.25	0.03	0.07
L. budegassa	4	50	0.41	0.29	0.27	0.01	0.01
L. budegassa	5	24	0.54	0.27	1.23	0.03	0.07
L. budegassa	6	10	0.66	0.26	6.56	0.14	0.35
L. budegassa	7	0	0.91	0.25	2.73	0.06	0.15
L. budegassa	8	0	1.00	0.24	2.73	0.06	0.15
P. longirostris	0	109502	0.00	1.25	0.00	0.00	0.00
P. longirostris	1	27656	0.13	0.82	0.11	0.00	0.00
P. longirostris	2	11657	0.50	0.39	0.93	0.00	0.00
P. longirostris	3	2779	0.79	0.28	1.52	0.00	0.00
P. longirostris	4	396	0.90	0.24	2.01	0.00	0.00
P. longirostris	5	44	0.97	0.22	1.49	0.00	0.00
P. longirostris	6	3	1.00	0.21	1.49	0.00	0.00
M. barbatus	0	93000	0.46	0.99	0.12	0.00	0.00
M. barbatus	1	29100	0.76	0.46	2.13	0.00	0.10
M. barbatus	2	2050	0.88	0.30	1.92	0.00	0.17
M. barbatus	3	103	0.93	0.24	1.66	0.00	0.00
M. barbatus	4	50	1.00	0.21	1.67	0.00	0.00
A. antennatus	0	279420	0.08	1.25	0.00	0.00	0.00
A. antennatus	1	72120	0.77	0.58	0.61	0.00	0.00
A. antennatus	2	15798	1.00	0.44	0.27	0.00	0.00
A. antennatus	3	2291	1.00	0.39	0.69	0.00	0.00
A. antennatus	4	609	1.00	0.35	0.27	0.00	0.00
A. antennatus	5	200	1.00	0.31	0.27	0.00	0.00
N. norvegicus	1	34479	0.10	0.48	0.01	0.00	0.00
N. norvegicus	2	31867	0.25	0.36	0.32	0.00	0.00
N. norvegicus	3	16107	0.80	0.30	0.78	0.00	0.00
N. norvegicus	4	4264	1.00	0.27	0.73	0.00	0.00
N. norvegicus	5	1289	1.00	0.26	0.65	0.00	0.00
N. norvegicus	6	448	1.00	0.24	0.48	0.00	0.00
N. norvegicus	7	105	1.00	0.23	0.44	0.00	0.00
M. poutassou	0	103067	0.00	1.18	0.02	0.00	0.00
M. poutassou	1	34144	0.01	0.53	1.11	0.00	0.00
M. poutassou	2	3709	0.61	0.39	2.38	0.00	0.00
M. poutassou	3	253	1.00	0.34	1.51	0.00	0.00
M. poutassou	4	25	1.00	0.31	1.97	0.00	0.00
M. poutassou	5	3	1.00	0.29	1.97	0.00	0.00

Data were obtained from the stock assessments (Scientific Technical, and Economic Committee for Fisheries [STECF], 2013, 2014, 2015a,b, 2017).

the long-term profits will be lower, although crew wages per day would increase.

Artisanal fleets would improve their catches and profits in all scenarios from the first year of the introduction until the implementation of management measures. The same is true

for the demersal longline fleet (**Figure 8**), which increases their catches roughly by 64.7%, and the gillnet fleet, which increases their catches by 66.3% during the medium term. For more detailed information, see **Supplementary Tables S9**, **S11**. The modification of trawl selectivity (Scenario 3)

TABLE 4 | Economic parameters of the three fleets assessed for bioeconomic simulation of the GSA06.

Fleet	Initial effort (Number days by fleet * day)	Share coefficient	Commercial costs	Energy costs (€/fleet * day)	Other variable and fixed costs (€/fleet * day)	Capital value (000s€/fleet * day)
Bottom trawl (OTB)	104275	58	19	321167	14393.3	192637
Bottom longline (HOK)	11200	38	19	8739	2889.0	9083
Fixed nets (GNS)	141610	58	19	50227	11913.0	60799

TABLE 5 | Average price of the main species assessed in GSA06, calculated from the 2000–2010 price data series from the Fisheries Directorate of Catalonia.

Fleet (f)	Species	Mean price (€/kg-1)
Bottom trawl (OTB)	*Merluccius merluccius*	6.8
Bottom trawl (OTB)	*Lophius budegassa*	7.8
Bottom trawl (OTB)	*Parapenaeus longirostris*	9.9
Bottom trawl (OTB)	*Mullus barbatus*	5
Bottom trawl (OTB)	*Aristeus antennatus*	29.8
Bottom trawl (OTB)	*Nephrops norvegicus*	19
Bottom trawl (OTB)	*Micromesistius poutassou*	3.1
Longline (HOK)	*Merluccius merluccius*	12.5
Longline (HOK)	*Lophius budegassa*	9
Longline (HOK)	*Parapenaeus longirostris*	0
Longline (HOK)	*Mullus barbatus*	0
Longline (HOK)	*Aristeus antennatus*	0
Longline (HOK)	*Nephrops norvegicus*	0
Longline (HOK)	*Micromesistius poutassou*	0
Fixed nets (GNS)	*Merluccius merluccius*	8.1
Fixed nets (GNS)	*Lophius budegassa*	9.1
Fixed nets (GNS)	*Parapenaeus longirostris*	0
Fixed nets (GNS)	*Mullus barbatus*	7.7
Fixed nets (GNS)	*Aristeus antennatus*	0
Fixed nets (GNS)	*Nephrops norvegicus*	0
Fixed nets (GNS)	*Micromesistius poutassou*	0

implies a direct benefit for the artisanal fleet, which will improve their catches, and profits without effort reductions (**Supplementary Tables S10**, **S12**).

According to our results, with the selectivity changes of Scenario 3, fishing mortality will decline by 54% more for red mullet than for hake (~28%), but hake catches will increase by 36% more than red mullet (16%) during the medium term (**Figure 9** and **Supplementary Tables S4**, **S6**). The modification of selectivity will allow for a reduction in fishing mortality but will require effort reduction (Scenarios 4 and 5) and will allow attainment of red mullet F_{MSY} levels. Under Scenario 4, catches for red mullet will increase over the medium term compared with Scenario 3, but a larger effort reduction (Scenario 5) will not yield the results enjoyed by the trawler fleet (**Figure 7**). Additionally, the three selectivity scenarios will significantly increase the SSB of the main species assessed (**Figure 9**).

Reduction of Days Per Week

The progressive reduction of 2 days per week in 3 years (Scenario 6) will produce a sustainable smaller short term loss but will
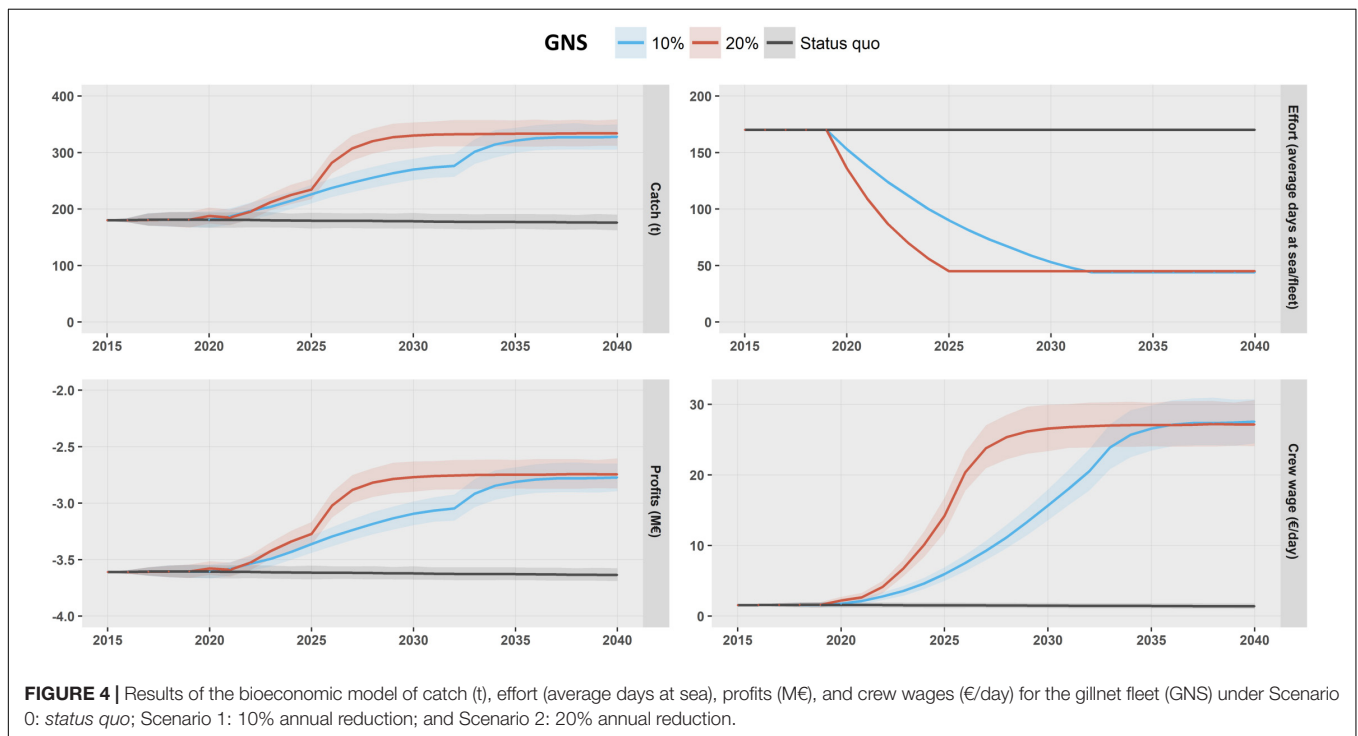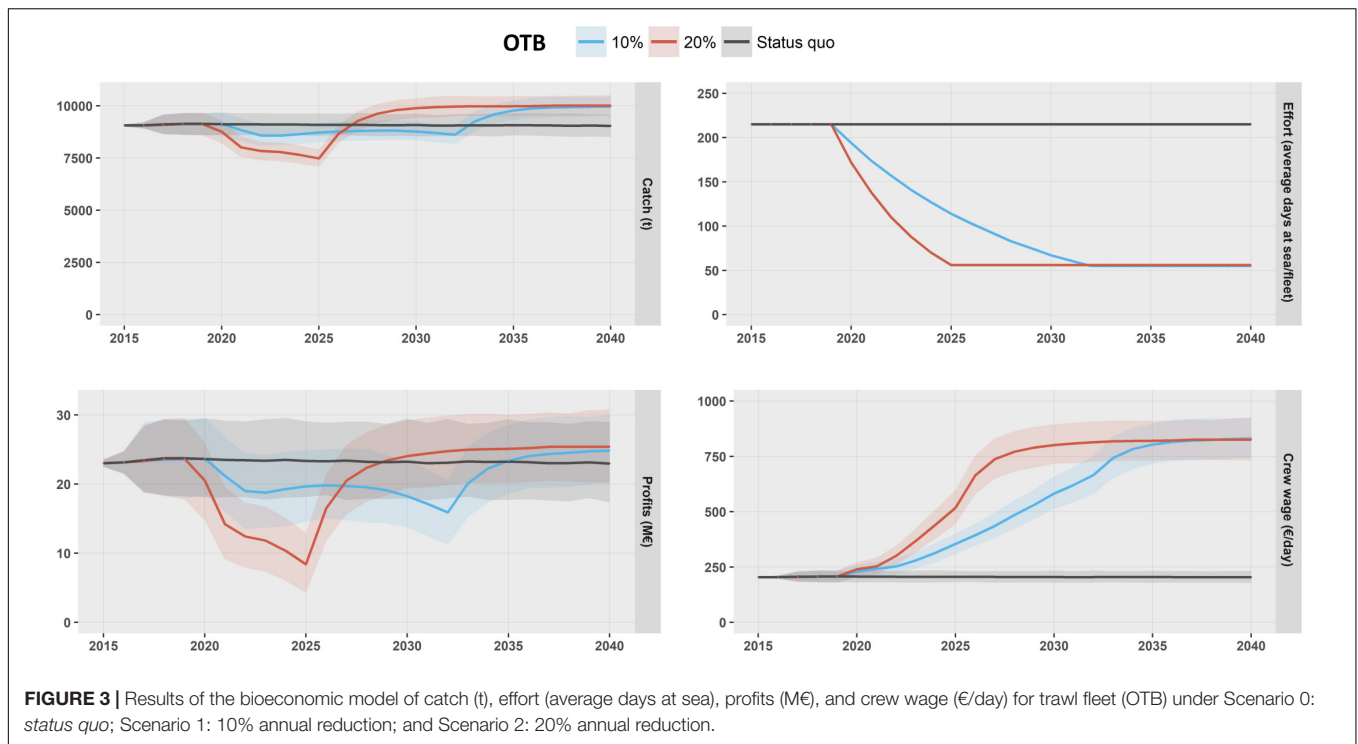
significantly improve the biological and economic perspectives. Combining this strategy with an improvement in selectivity (Scenarios 7 and 8) on the trawl fleet will result in a higher loss during the short term but higher profits during the medium and long terms (**Figure 10**), which is estimated to be between 68 and 72%. Additionally, the average daily wages could increase by 76 to 148%, respectively.

For artisanal fleets, results will improve more when both selectivity improvements and effort reductions are applied to the trawler fleet (Scenarios 7 and 8) than when only the effort reduction is implemented (**Figure 11**).

In terms of biological parameters, scenarios having selectivity changes (Scenarios 7 and 8) result in larger SSBs, and catches of the main species during the mid-term (**Figure 12**) compared with the effort reduction without selectivity improvements (Scenario 6).
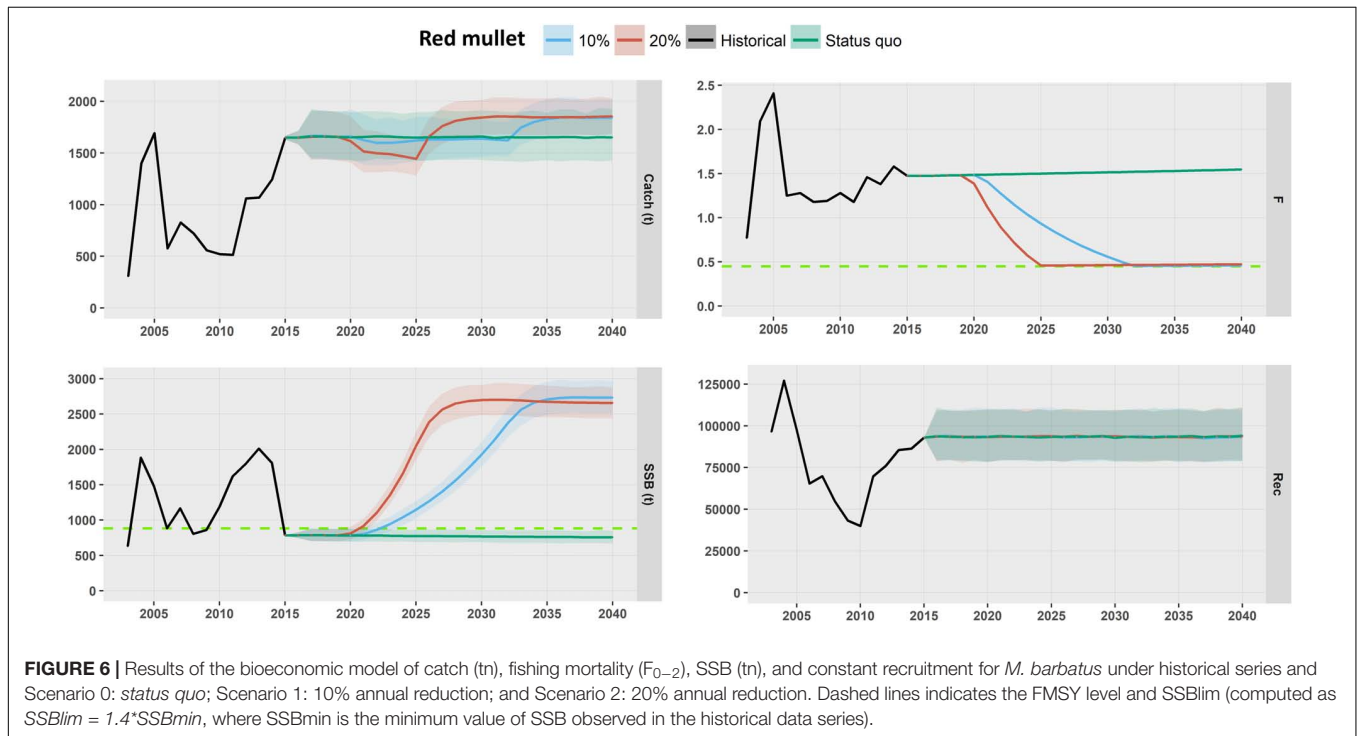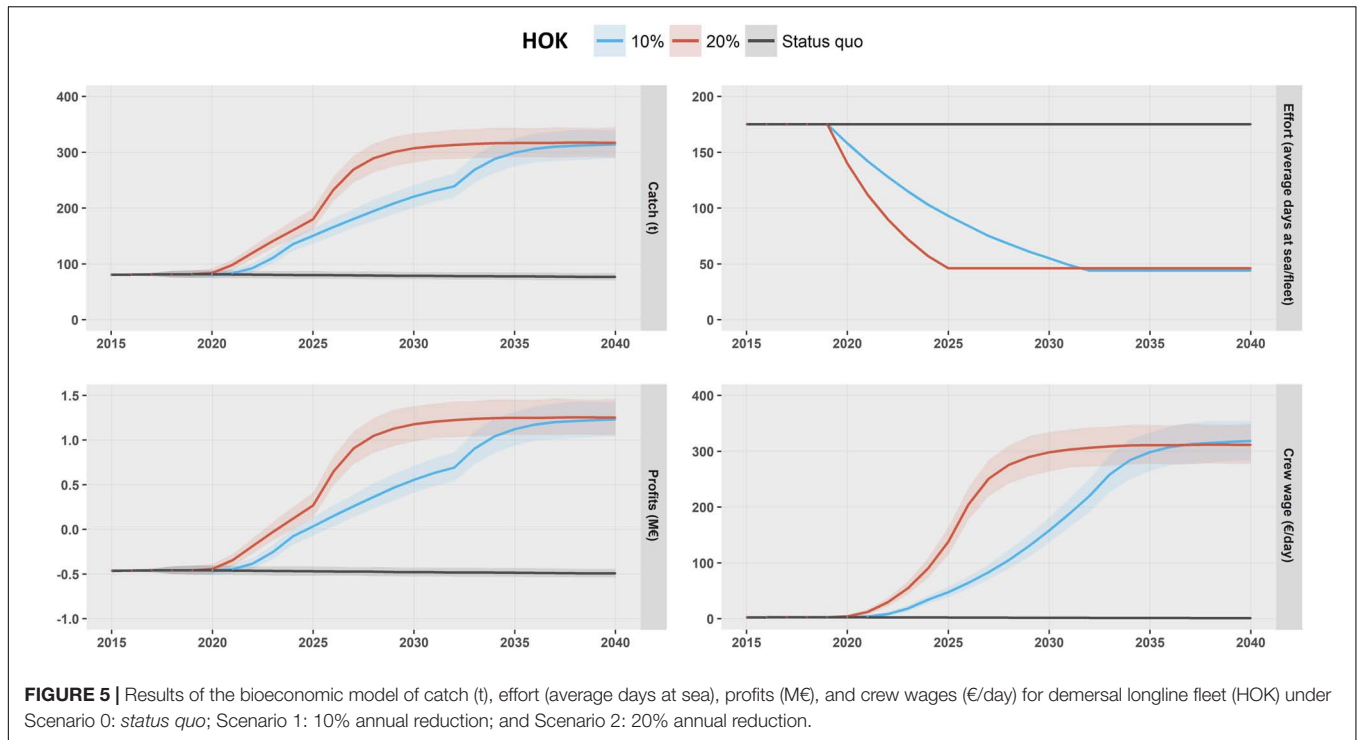
DISCUSSION

The previously published results of stock assessment point to an overexploited status of demersal fishery stocks ($F > F_{MSY}$) in all species assessed in the GSA06 region (Scientific Technical, and Economic Committee for Fisheries [STECF], 2013, 2014, 2015a,b, 2017). Our results reveal that the *status quo* scenario will not revert this situation, with other bioeconomic simulations for the Mediterranean demersal fisheries (Sola and Maynou, 2018b; Maynou, 2019), a significant reduction in fishing mortality is necessary. The West Med MAP goal suggests that the MSY level of the most vulnerable stock should be achieved by 2025. However, this goal requires a drastic reduction in fishing mortality, such that its application in practice would be unrealistic (Maynou, 2014; Martín et al., 2019), because it will require an 80% reduction in fishing time. Moreover, the reduction in fishing time established in the West Med MAP is insufficient to achieve F_{MSY} levels in 5 years, and more time would clearly be necessary to reach MSY levels. However, our bioeconomic model results reveal that, with an effort reduction of 40% in the West Med MAP, catches of hake, and red mullet could increase. A faster approach to these reference points could be achieved if the reduction in fishing time were complemented with technical measures, such as selectivity improvements and temporary or permanent closures. In economic terms, the best results for demersal fleet according to our model (**Table 6**) would be achieved under scenarios that contemplate selectivity changes with or without effort reductions (Scenarios 3, 4, 7, and 8) because they provide the best economic indicators over the short term. However,

FIGURE 3 | Results of the bioeconomic model of catch (t), effort (average days at sea), profits (M€), and crew wage (€/day) for trawl fleet (OTB) under Scenario 0: *status quo*; Scenario 1: 10% annual reduction; and Scenario 2: 20% annual reduction.

FIGURE 4 | Results of the bioeconomic model of catch (t), effort (average days at sea), profits (M€), and crew wages (€/day) for the gillnet fleet (GNS) under Scenario 0: *status quo*; Scenario 1: 10% annual reduction; and Scenario 2: 20% annual reduction.
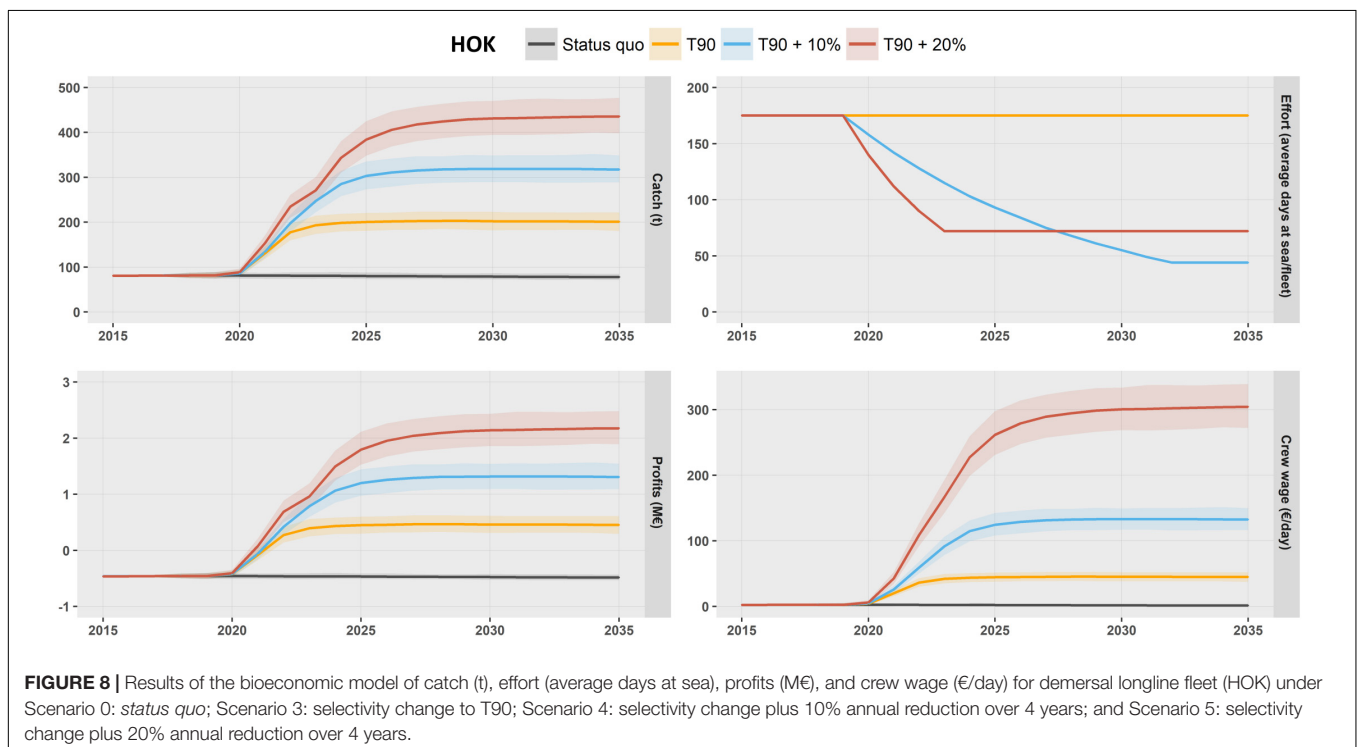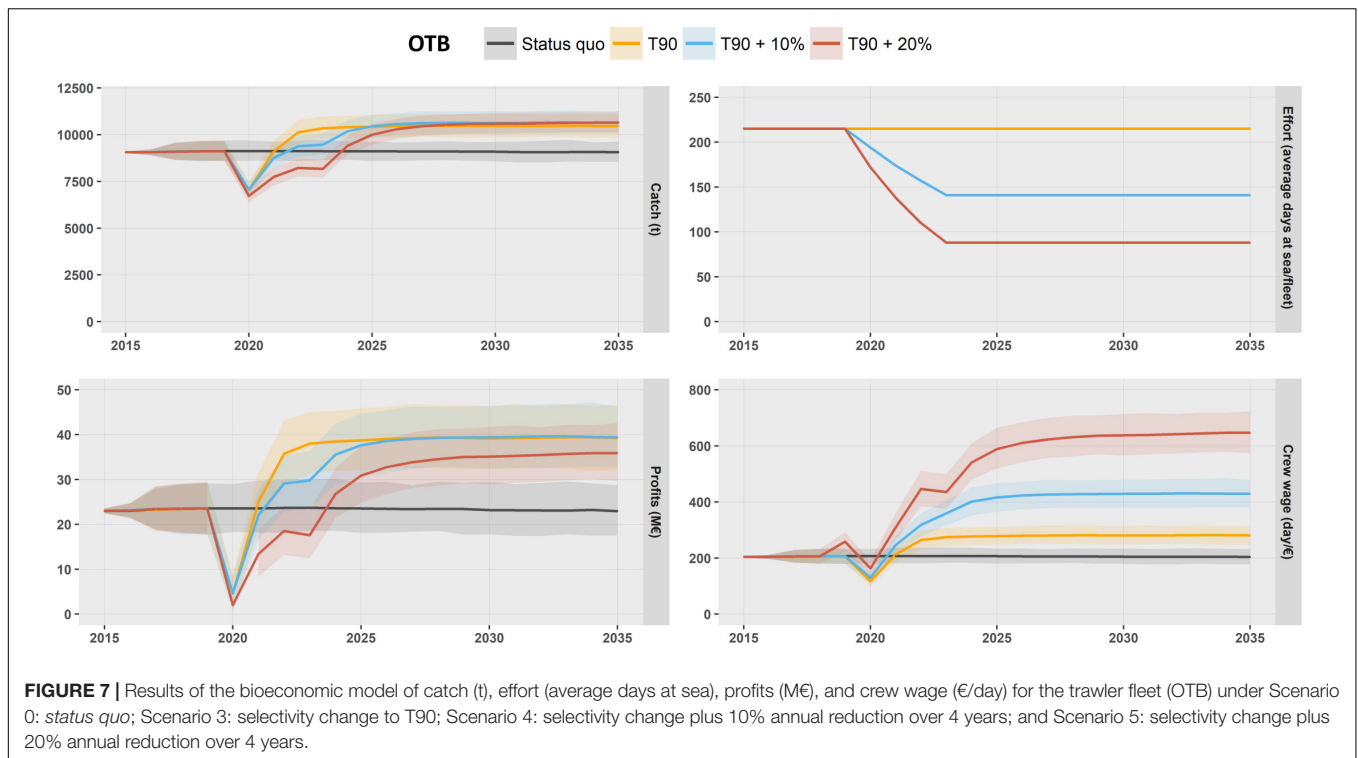
the best results for trawlers, according to our model, would be achieved under scenarios that contemplate selectivity changes with or without effort reductions (Scenarios 3, 7, and 8), because they provide a faster recovery of economic indicators over the short term and they produce higher profits and better working conditions for fishermen in the medium-long term. In the case of artisanal fisheries, the best results would be achieved under scenarios that contemplate selectivity changes with the higher effort reductions (Scenarios 4, 5, and 8) because they provide the higher profits and working conditions for fishermen with better crew wages and lower working days. In addition, both best results for trawlers and artisanal fisheries provide

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FIGURE 5 | Results of the bioeconomic model of catch (t), effort (average days at sea), profits (M€), and crew wages (€/day) for demersal longline fleet (HOK) under Scenario 0: *status quo*; Scenario 1: 10% annual reduction; and Scenario 2: 20% annual reduction.

FIGURE 6 | Results of the bioeconomic model of catch (tn), fishing mortality (F_{0-2}), SSB (tn), and constant recruitment for *M. barbatus* under historical series and Scenario 0: *status quo*; Scenario 1: 10% annual reduction; and Scenario 2: 20% annual reduction. Dashed lines indicates the FMSY level and SSBlim (computed as *SSBlim = 1.4*SSBmin*, where SSBmin is the minimum value of SSB observed in the historical data series).

a fast recovery of biological indicators with high levels of SSB stocks. The management scenarios that include changes in the selectivity pattern for trawlers reduce fishing mortality more for red mullet than for hake, but the catches of hake increase faster than that of red mullet. This is caused by the fishing patterns of the trawler fleet, which inflicts a larger
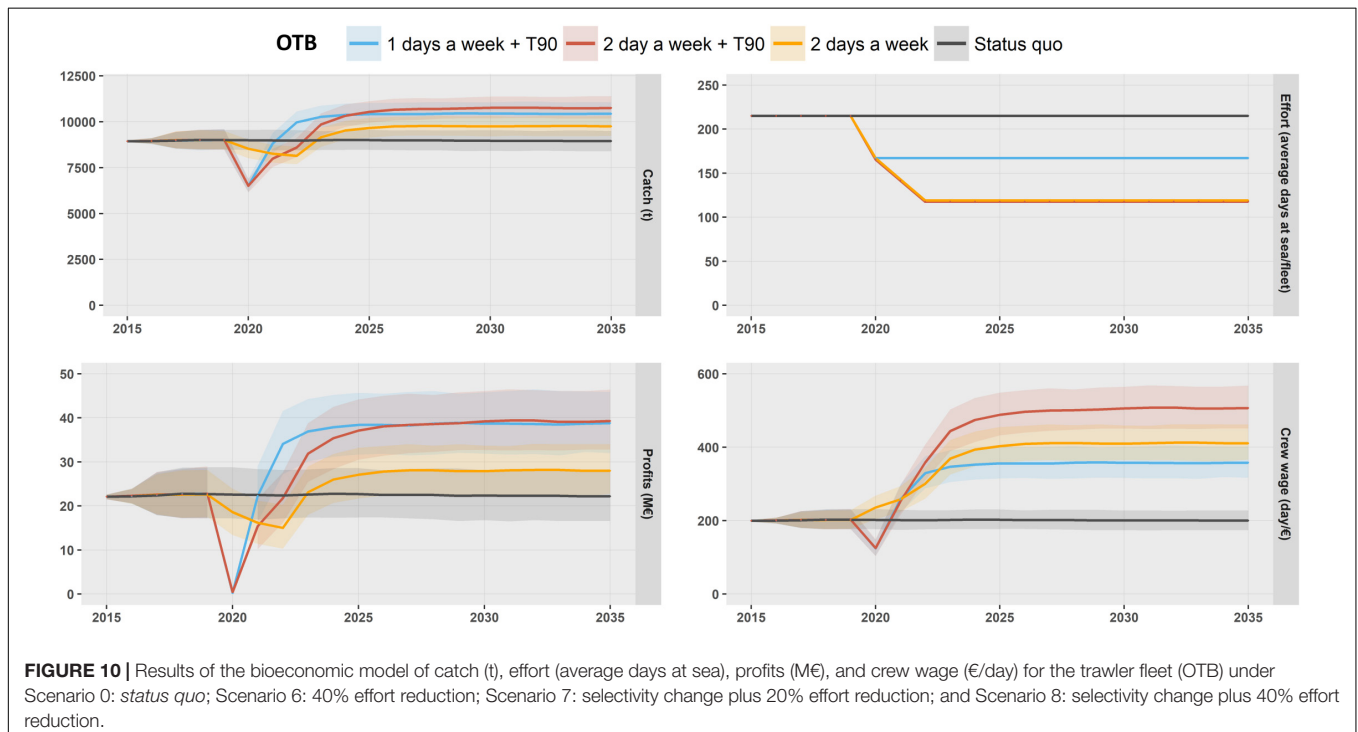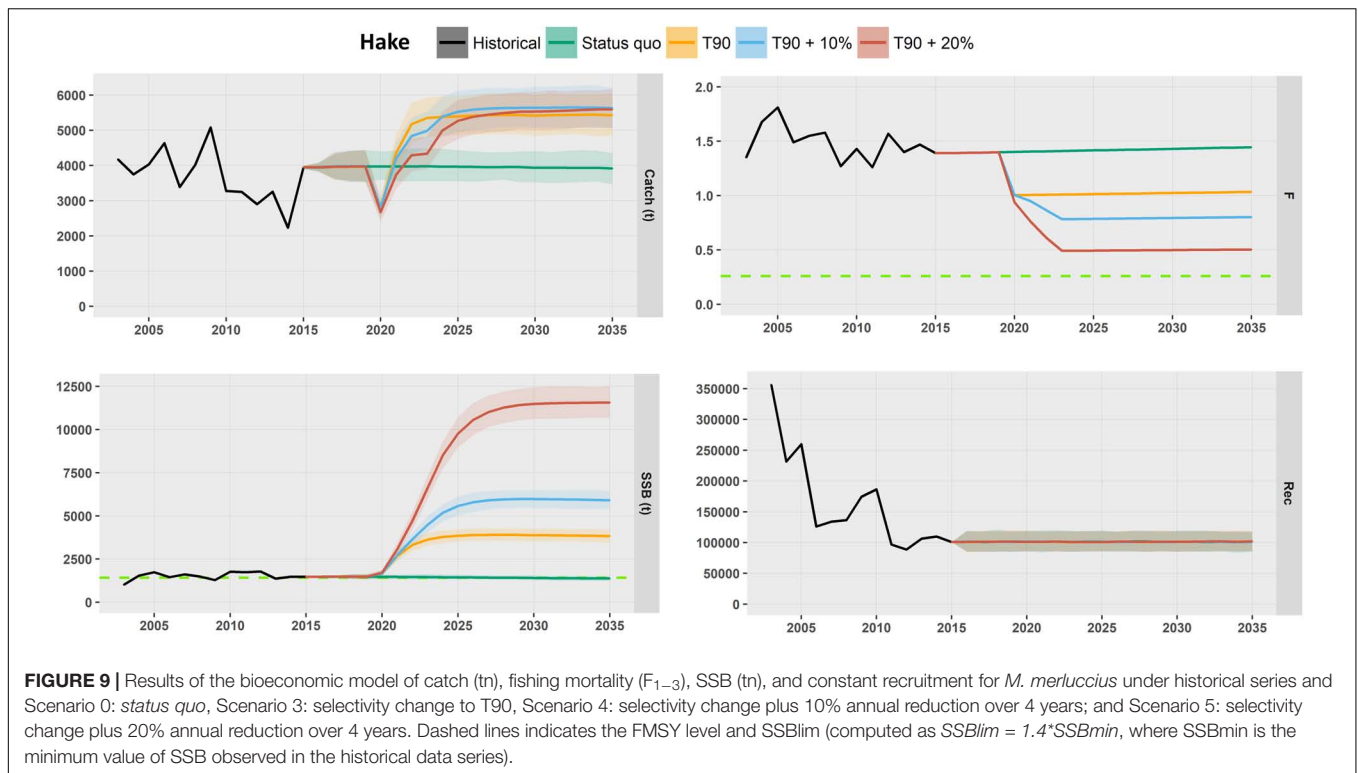
mortality on hake below the minimum conservation reference size than for red mullet (Sola and Maynou, 2018a). Changes in selectivity patterns have been recommended as more practical and efficient ways to recover Mediterranean stocks than mere effort reduction measures (Colloca et al., 2013; Maynou, 2014). Moreover, selectivity improvement would modify the reference

FIGURE 7 | Results of the bioeconomic model of catch (t), effort (average days at sea), profits (M€), and crew wage (€/day) for the trawler fleet (OTB) under Scenario 0: *status quo*; Scenario 3: selectivity change to T90; Scenario 4: selectivity change plus 10% annual reduction over 4 years; and Scenario 5: selectivity change plus 20% annual reduction over 4 years.

FIGURE 8 | Results of the bioeconomic model of catch (t), effort (average days at sea), profits (M€), and crew wage (€/day) for demersal longline fleet (HOK) under Scenario 0: *status quo*; Scenario 3: selectivity change to T90; Scenario 4: selectivity change plus 10% annual reduction over 4 years; and Scenario 5: selectivity change plus 20% annual reduction over 4 years.

points while increasing $F_{0.1}$ and approaching current target fishing mortalities (Sánchez Lizaso et al., 2020).
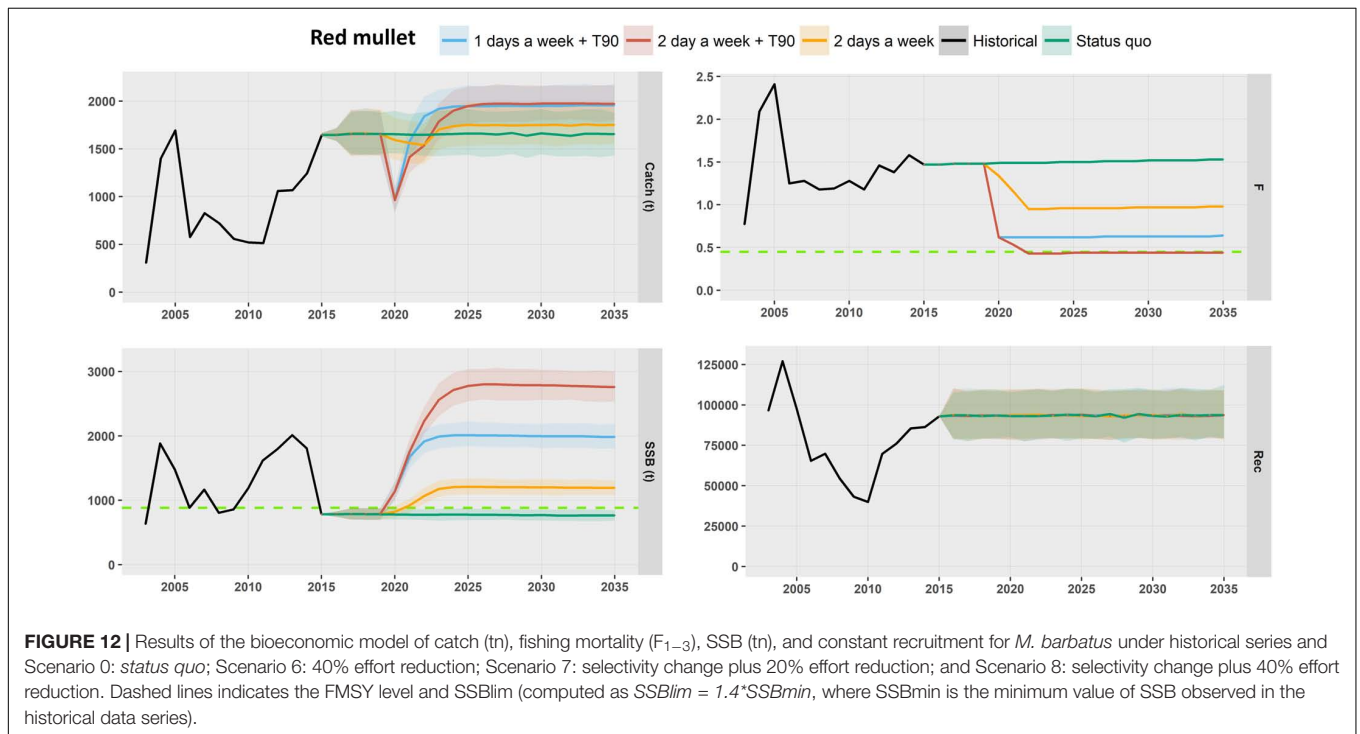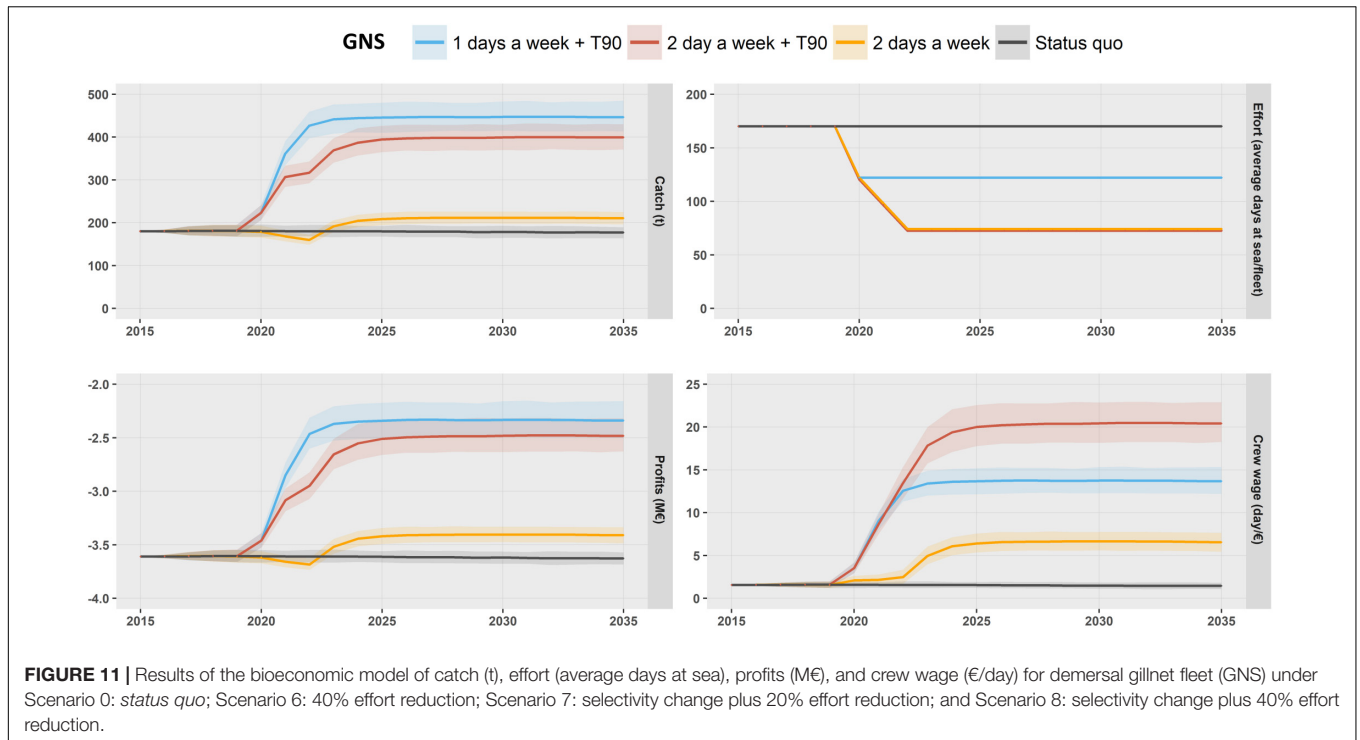
Any reduction in fishing mortality will produce a reduction in revenues over the short term with a marked increase over the long term. The reduction in fishing mortality is directly related to short term losses and higher long-term benefits for fishing fleets (Lleonart et al., 2003; Merino et al., 2015). The progressive reduction of 20–40% fishing days per year with a modification of selectivity for trawlers would result in small short term losses and higher profits for demersal fleets, resulting

FIGURE 9 | Results of the bioeconomic model of catch (tn), fishing mortality (F_{1-3}), SSB (tn), and constant recruitment for *M. merluccius* under historical series and Scenario 0: *status quo*, Scenario 3: selectivity change to T90, Scenario 4: selectivity change plus 10% annual reduction over 4 years; and Scenario 5: selectivity change plus 20% annual reduction over 4 years. Dashed lines indicates the FMSY level and SSBlim (computed as *SSBlim = 1.4*SSBmin*, where SSBmin is the minimum value of SSB observed in the historical data series).

FIGURE 10 | Results of the bioeconomic model of catch (t), effort (average days at sea), profits (M€), and crew wage (€/day) for the trawler fleet (OTB) under Scenario 0: *status quo*; Scenario 6: 40% effort reduction; Scenario 7: selectivity change plus 20% effort reduction; and Scenario 8: selectivity change plus 40% effort reduction.

in lower short term losses compared with other scenarios. However, improving the selectivity pattern would contribute to the reduction in the juvenile mortality of commercial species (e.g., *M. merluccius* or *M. barbatus*) (Sala and Lucchetti, 2011; Sola and Maynou, 2018a) and overall improvements to the health

productivity of marine ecosystems. It would also improve the reduction of discards as per the aim of reforms (European Commission [EU], 2013) for improving the stock status of target species and reducing the impact on Mediterranean ecosystems (Colloca et al., 2013; Maynou, 2014; Tsagarakis et al., 2014;

FIGURE 11 | Results of the bioeconomic model of catch (t), effort (average days at sea), profits (M€), and crew wage (€/day) for demersal gillnet fleet (GNS) under Scenario 0: *status quo*; Scenario 6: 40% effort reduction; Scenario 7: selectivity change plus 20% effort reduction; and Scenario 8: selectivity change plus 40% effort reduction.

FIGURE 12 | Results of the bioeconomic model of catch (tn), fishing mortality (F_{1-3}), SSB (tn), and constant recruitment for *M. barbatus* under historical series and Scenario 0: *status quo*; Scenario 6: 40% effort reduction; Scenario 7: selectivity change plus 20% effort reduction; and Scenario 8: selectivity change plus 40% effort reduction. Dashed lines indicates the FMSY level and SSBlim (computed as *SSBlim = 1.4*SSBmin*, where SSBmin is the minimum value of SSB observed in the historical data series).

Gullestad et al., 2015; Sardà et al., 2015; Prellezo et al., 2017). Moreover, improving selectivity would modify reference points and decrease the current levels of fishing mortality on F_{MSY} (Scott and Sampson, 2011). Changes in selectivity and effort reductions could be complemented with permanent closures designed to protect a significant portion of extant marine habitats or local

co-management plans to protect both juveniles and spawners (Maynou, 2014; Sánchez Lizaso et al., 2020).

It should be considered that technical measures having the same biological effect may have different socioeconomic impacts. In Mediterranean fisheries, it is important to consider not only the fishing time reductions but also the distributions of

TABLE 6 | Average net present values (NVP) for net profits of demersal fleet according the introduction of the different management measures in 2020 (Scenarios 1–8).

Year	Scn. 0 (Status quo)	Scn. 1 (10%)	Scn. 2 (20%)	Scn. 3 (T90)	Scn. 4 (T90 + 10%)	Scn. 5 (T90 + 20%)	Scn. 6 (2 days)	Scn. 7 (1 day + T90)	Scn. 8 (2 days + T90)
2015	18.0	18.0	18.0	18.1	18.1	18.0	18.1	18.0	18.1
2016	18.1	18.1	18.2	18.1	18.2	18.1	18.1	18.1	18.2
2017	18.3	18.5	18.5	18.3	18.5	18.4	18.4	18.5	18.6
2018	18.5	18.5	18.6	18.5	18.6	18.5	18.4	18.6	18.6
2019	18.6	18.5	18.5	18.5	18.6	18.6	18.5	18.6	18.7
2020	18.6	18.5	18.5	0.7	0.7	−1.7	14.6	−2.7	−2.7
2021	18.6	18.6	11.5	21.0	18.2	10.0	12.0	19.2	12.2
2022	18.7	16.2	9.0	31.8	25.8	15.8	10.8	31.5	18.6
2023	18.7	14.2	8.5	34.2	26.9	15.2	19.1	34.5	29.2
2024	18.6	14.3	7.9	34.7	32.8	24.8	22.2	35.4	33.4
2025	18.6	15.0	6.4	35.0	35.0	29.1	23.3	35.9	35.0
2026	18.5	15.6	8.2	35.3	36.0	31.1	23.9	36.3	35.7
2027	18.4	16.0	14.9	35.4	36.4	32.3	24.2	36.3	36.3
2028	18.4	16.2	18.4	35.6	36.7	33.0	24.3	36.2	36.5
2029	18.4	16.3	20.1	35.5	36.8	33.5	24.4	36.3	36.6
2030	18.2	16.1	21.1	35.3	36.8	33.6	24.5	36.5	36.8
2031	18.1	15.5	21.7	35.4	36.9	33.8	24.6	36.5	37.0
2032	18.1	14.3	22.0	35.5	37.0	34.0	24.5	36.4	37.0
2033	18.1	13.2	22.2	35.6	37.0	34.2	24.5	36.3	37.0
2034	18.2	17.7	22.4	35.6	36.9	34.4	24.4	36.2	36.9
2035	17.9	20.1	22.4	35.5	36.8	34.4	24.4	36.3	37.0
NPV	**294.0**	**349.6**	**347.2**	**603.7**	**598.6**	**519.1**	**437.3**	**609.2**	**584.7**

A discount rate of 5% has been used.

the reductions across the year to ensure that they do not affect market supplies (Sánchez Lizaso et al., 2020). In this model, the prices of the assessed species are assumed to be constant over time. Nevertheless, changes in trade can alter fish supplies and revenues for fishermen (Sánchez Lizaso et al., 2020). Concentrating the reduction during a single season can cause price decreases because of the irregular supply of fresh fish to the market (Samy-Kamal et al., 2015b). On the other hand, if effort reductions do not affect the continuous market supply (i.e., reducing 1–2 days per week; Scenarios 6–8), the reduction in the amount of catches over the short term would be balanced by an increase in the market price value because of the elasticity of supply and demand (Macher et al., 2008; Samy-Kamal et al., 2015a). During the medium to long term, the increase in the amount of catches will produce a higher supply to the market that may also affect prices if demand does not increase. However, the increase in average sizes of species (e.g., hake) must also be considered (Asche and Guillen, 2012).

A relevant aspect to consider is the distribution of fishing possibilities among vessels approved for the West Med MAP. The *status quo* scenario will produce a progressive reduction of the fleet but will allow the transfer of fishing times among boats, accelerating fleet reduction and the concentration of fishing rights to a fewer number of companies (Sánchez Lizaso et al., 2020). The highest amount of fresh fish in markets and harbors would be provided *via* trawlers that economically sustain fish markets and landing ports. In the absence of trawlers, artisanal fisheries could also disappear due to the unsustainability

of landing, and marketing logistics rather than the gain of market opportunities.

Finally, the reductions of fishing effort would benefit artisanal fleets (GNS and HOK) more than trawlers in economic terms. These benefits would be significantly maximized when selectivity scenarios (Scenarios 4–5 and 7–8) were applied for trawler fleets since GNS and HOK target large hake while trawlers target smaller hake. Catches and profits for the artisanal fleet are directly related to effort reduction of the trawler fleet because of the negative effect of the trawler fleet on the artisanal fleet in gear competition for demersal stocks. In multispecies fisheries, as Mediterranean demersal fisheries, there is competition between fishing gears due to the dependence on the same pool of target species. Trawler fleets in Spanish Mediterranean area are clearly more dominant than artisanal fleets (GNS and HOK) because they produce a larger amount of species that are shared with the artisanal fleets. Therefore, reducing fishing effort for the trawl fleet directly benefits the artisanal fleet through competition for shared species, such as hake or red mullet (Lleonart et al., 2003, 2013; Merino et al., 2007). Thus, fishing effort reductions for trawlers would have higher benefits for artisanal fleets and would allow for their sustainability.

CONCLUSION

Management and regulation measures applied to date have not enabled the Mediterranean fisheries to move toward levels of sustainability (Colloca et al., 2017; Sánchez Lizaso et al., 2020).

The current situation of Mediterranean stocks reflects the necessity to adopt proper management to recover sustainable exploitation levels of Mediterranean fisheries. This would protect ecosystems from indirect risks, such as global warming, while increasing the number of exotic species to the Mediterranean (Colloca et al., 2014; Corrales et al., 2018).

It is not possible to achieve the aim of West Med MAP to reach F_{MSY} levels simultaneously for all stocks of Mediterranean demersal fisheries. It is, instead, necessary to find new reference points for introducing a multispecies approach that would not focus only on a single-species MSY. This approach should be combined with changes of selectivity patterns for trawling fishing to alter the carried out to date to produce the maximum levels for biological and economic indicators. In any case, it will be necessary to implement a significant and well-planned reductions to fishing mortality over the next few years to lead different stocks to meet F_{MSY}.

A reduction in fishing time will also be required to reduce current fishing mortalities to target stocks, but the socioeconomic impact of this reduction must also be considered. Different approaches to achieving the same reductions may have different socioeconomic impacts. The results of bioeconomic simulations reveal that the reduction of the number of fishing days per week with selectivity will have a lower socioeconomic impact than a reduction based only on fishing days or number of boats. It would also produce higher profits for demersal fleets.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/**Supplementary Material**.

AUTHOR CONTRIBUTIONS

IS and JS-L contributed to the conception and design of the study. IS and FM processed and analyzed the economic and biological data to perform bioeconomic model. IS performed the bioeconomic analysis and wrote the first draft of the manuscript. IS, FM, and JS-L wrote sections of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

FUNDING

ACKNOWLEDGMENTS

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2020.00459/full#supplementary-material

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