Journal of Environmental Management 300 (2021) 113794

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Scenarios of profitability of western Mediterranean demersal fisheries in an effort control regime

Negar Akbari [a,*], Francesc Maynou [b], Trond Bjørndal [c], Pierre Failler [d], Benjamin Drakeford [d], Andy Forse [d]

[a] Operations and Systems Management Group, Faculty of Business and Law, University of Portsmouth, Richmond Building, Portland Street, Portsmouth, PO1 3DE, United Kingdom
[b] Institut de Ciencies del Mar (CSIC), Psg. Maritim de la Barceloneta 37-49, Barcelona, 08003, Spain
[c] SNF Centre for Applied Research at NHH, Helleveien 30, Bergen, N-5045, Norway
[d] Centre for Blue Governance, Faculty of Business and Law, University of Portsmouth, Richmond Building, Portland Street, Portsmouth, PO1 3DE, United Kingdom

ARTICLE INFO

Keywords:
Mediterranean sea
Demersal fisheries
Socio-economic indicators
Scenario analysis

ABSTRACT

In 2019 a multiannual plan for Mediterranean demersal fisheries came into force with the objective to reduce the overexploitation of fisheries in the region by implementing effort control regimes. These measures, however, have the potential to adversely impact the local employment and profitability of the fisheries. In this paper, we examine scenarios on the short term and long term levels of economic yield of the sector using the two main drivers of fuel price and employment. Three main scenarios are defined as i) maintaining the average status quo, ii) effort control regimes implemented in the 2019 multiannual plan, and iii) flexible effort control regimes. For each of the aforementioned scenarios, three main fleets and five main conditions are considered, and the results will be compared and contrasted. The results in this paper show that the future rise in fuel price, which is anticipated due to global efforts to reduce emissions, along with the current effort reduction strategies could significantly threaten the sustainable profitability of the sector, and policy measures that could balance this issue should be implemented. Policy interventions and investments should be directed at technological advancements such as modernisation and increasing efficiency of fleet to reduce fuel use, utilisation of highly efficient gear technologies, shortened trips to fishing grounds, and increase in value creation in other parts of the fisheries supply chain to mitigate the serious challenges in terms of local employment and profitability facing the Mediterranean fisheries.

1. Introduction

Mediterranean fisheries show clear signs of overexploitation of the main fish stocks (FAO, 2020), important modifications to marine ecosystems such as habitat degradation, decreasing trophic level or facilitation of invasive species (Colloca et al., 2013) and low economic performance (Cardinale et al., 2017) (Gomez and Maynou, 2020). This low economic performance has resulted in a substantial decrease in the number of fishing units from 56 705 vessels in 2005 to 31 077 vessels in2018[1] for the EU Mediterranean member states, a reduction of 45%. Mediterranean fisheries are characterised by relatively small vessels, multiple landing sites, multispecies harvesting with low catch per unit effort (CPUE) and relatively high prices (Sanchez et al., 2020) (Lleonart and Maynou, 2003).

The 2013 reform of the Common Fisheries Policy (EU Reg. 1380/2013) included the concept of regionalisation based on Multi Annual Plans (MAPs) to promote cooperation on conservation measures across member state boundaries. This included the introduction of the concept of maximum allowable fishing effort, which consists in a reduction of fishing time available to demersal fleets adjusted to the available stocks (Sanchez et al., 2020) as the main fisheries management measure to control fishing effort. In particular, the multiannual plan for demersal fisheries in the Western Mediterranean (WM MAP) concerns all fishing areas in Mediterranean Spain, Mediterranean France and Western Italy.

---

* Corresponding author.

E-mail addresses: negar.akbari@port.ac.uk (N. Akbari), maynouf@icm.csic.es (F. Maynou), Trond.Bjorndal@snf.no (T. Bjørndal), pierre.failler@port.ac.uk (P. Failler), ben.drakeford@port.ac.uk (B. Drakeford), andy.forse@port.ac.uk (A. Forse).

[1] Reported in Maynou (2020) by combining data in (Franquesa et al., 2008) with data in SOMFI (2018).

https://doi.org/10.1016/j.jenvman.2021.113794
Received 25 May 2021; Received in revised form 3 September 2021; Accepted 18 September 2021
Available online 24 September 2021

The plan was recently adopted by the European Parliament (February 2019) and the Council (June 2019) and entered into force on January 1st'2020.[2]

Among other things, the WM MAP establishes a 40% reduction in fishing effort over the period 2020–2024, the temporal prohibition of trawling between 50 and 100 m depth in designated areas, and promoting more selective fishing gears. The specific implementation details of the WM MAP are left to individual member states. For operative purposes, the plan divides the demersal trawl fleet in two broad segments: vessels operating on coastal mixed fisheries and vessels operating on deep-water crustacean fisheries. Each fleet segment is in turn divided into four sub-fleets, according to vessel length (6–12 m, 12–18 m, 18–24 m and larger than 24 m length overall). The objectives of the plan are to align fishing opportunities with biological productivity, based on the biological reference point "fishing mortality at maximum sustainable yield" (Fmsy) for the main five target species European hake (*Merluccius merluccius*), red mullet (*Mullus barbatus*), Norway lobster (*Nephrops norvegicus*), deep-water rose shrimp (*Parapenaeus longirostris*) and red shrimp (*Aristeus antennatus*)), which should be achieved by Jan. 1, 2025.

Measures on when, where, what and how to fish are becoming ever more circumscribed affecting short term and longer term business planning (Symes et al., 2015). The purpose of this paper is to compare scenarios based on effort limitation, as the main management measure in the WM MAP, to assess under which conditions economic yield could be maximised in Western Mediterranean demersal fisheries. In this paper a modelling approach based on three steps is pursued:

1) A bioeconomic model is applied for projecting the expected landings of the target species in the case study region. Three main management scenarios are defined as i) maintaining status quo, ii) exertion of effort control regimes suggested in the 2019 multiannual plan, and iii) flexible effort control regimes.
2) An optimisation model is adopted that determines the maximum profitability and harvest while taking into account the constraints related to fuel price and employment.
3) Multiple scenario analysis is adopted to model the different permutations of input parameters i.e., fuel price, fish price and crew cost, and to compare and contrast the results.

This paper aims to enhance the understanding of the long- and short-term impacts of effort limitations and climate change scenarios in the NW Mediterranean case under study using the two main drivers of fuel price and employment. For each of the aforementioned scenarios, three main fleets and five main conditions were considered, and the results are compared and contrasted.

This paper is organised as follows. In Section 2 the case study is presented followed by the methodology in Section 3. The results of the analysis are reported in Section 4, and the discussions and conclusions are presented in Section 5 followed by the appendices containing the details of the bioeconomic model.

2. The case study: demersal fisheries in the NW Mediterranean

The case study is demersal fisheries in the NW Mediterranean, focusing on geographical subarea GSA06,[3] the Mediterranean coast of Spain as illustrated in Fig. 1. Demersal fisheries are exploited mainly by otter bottom trawl (about 80% of landings), typically with fishing vessels from 14 to 28 m length overall (LOA). The small-scale fishing fleet produces the remaining 20% of demersal landings employing a large variety of fishing gear (set nets, longlines and traps) on board polyvalent vessels from 6 to 18 m LOA.

The target demersal resources exploited by the otter bottom trawl fleet are European hake, red mullet and a variety of crustacean (Norway lobster, deep-water rose shrimp, blue-and-red shrimp) and cephalopods (octopus, cuttlefish, squid). Small scale polyvalent vessels using a variety of static gear interact technically with bottom trawlers for certain demersal species, such as hake and cephalopods. However, because the regulations in the demersal plan WM MAP only affect the five main target species caught primarily by bottom otter trawl fleets (95% of landings) and because these fleets produce the highest biological and economic impacts (Table 1), the present bioeconomic study concentrates on simulations of the main segments of the OTB fleet. Small scale polyvalent units produce a low proportion of total demersal landings (18%), but are disproportionately more important in value (37% of the income generated by demersal species) and employment –up to 45% of Full Time Equivalent hour (FTEh) jobs are in the small scale fleet.

The production (landings) of the main demersal fisheries target species are shown in Table 2. For operative purposes (and in our model) the bottom trawl fleet is categorized in three segments, defined by the length-overall (LOA) classes: VL1218 (12–18 m LOA), VL 1824 (18–24 m LOA), and VL2440 (24–40 m LOA). The data show that hake is the main species caught by the three fleets. The high-value crustaceans caught in deeper waters are proportionally more important for the fleet with the largest vessel size (VL2440). Note that for all three fleets the amount of landings due to species other than the main five ("Stock 6") is 50% for fleets VL1824 and VL2440, while it is 65% for VL1218.

The fisheries are managed by means of technical measures and input controls, as elsewhere in the Mediterranean Sea (Mediterranean fisheries regulation: EU Reg, 1967/2006) (Sanchez et al., 2020). Specifically, fishing effort is controlled by limited entry (a license scheme to limit the capacity base), as well as regulation restricting fishing time to five days a week, 12 h a day. There is also a one month fishing ban, usually in February, for all bottom trawlers. This results in a maximum of about 240 days fishing days per year. Technical measures specifying the minimum conservation reference sizes (i.e., minimum landing size) (EU Reg. 1963/2006 Annex III), obligation of landings all catches not subject to exemption (EU Reg. 1380/2013) and the characteristics of fishing gear defined in national regulations (e.g. BOE 2012[4]) complement effort limitations (see Appendix 1, section 8.5).

3. Methodology

In this paper the modelling approach is based on three steps as follows: Firstly, a bioeconomic model is applied for projecting the expected landings of the target species in the case study region. An optimisation model is then developed that determines the maximum profitability and harvest while maintaining a balance between employment, fuel price. Lastly a multiple scenario analysis is adopted to model the different permutations of input parameters (i.e., fuel price, fish price and crew cost) and to compare and contrast the results.

3.1. Bioeconomic simulation model

We use a bioeconomic management strategy evaluation (MSE) approach (Punt et al., 2016), which uses mathematical simulations to compare the relative effectiveness for achieving management objectives. MSE can be used to identify a 'best' management strategy among a set of candidate strategies, or to determine how well an existing strategy performs.

In our paper, the primary objective is to compare the performance of the management plan adopted in 2020 for the Western Mediterranean demersal fisheries (WM MAP: COM/2018/0115 final – 2018/050

---

[2] COM/2018/0115 final – 2018/050 (COD).

[3] "Geographical SubAreas" are the official fisheries management areas in the Mediterranean sea, established by the General Fisheries Commission for the Mediterranean (GFCM).

[4] Official Journal of the Spanish State (BOE, 29-12-2012) Order AAA/2808/2012 of 21 December.

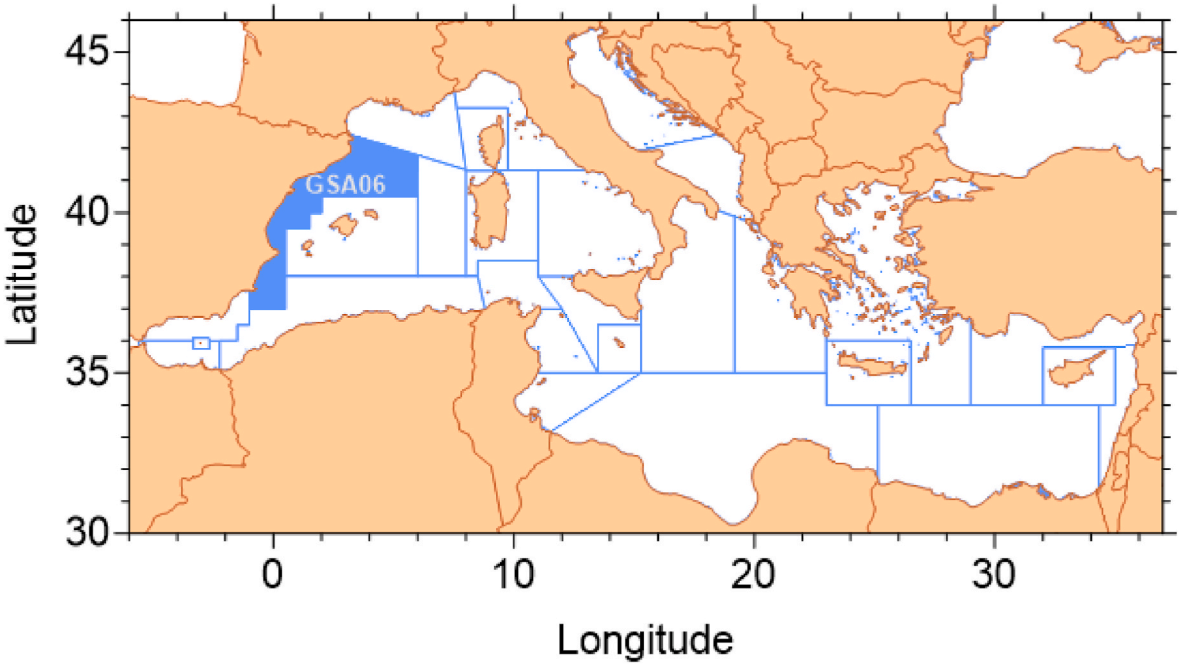

Fig. 1. Location of GSA06 ("Northern Spain") in the context of Mediterranean fisheries management subareas defined by the General Fisheries Commission for the Mediterranean Sea (GFCM**).** Modified from: http://www.fao.org/gfcm/data/maps/gsas/en/).

Table 1
Contribution of OTB fleet to the total production of demersal fleets in GSA06 (average 2016–2018). Other fleets comprise small scale polyvalent fishing units using a variety of set nets, longlines and traps in vessel length categories VL0612 and VL1218.

Indicator	OTB	Total (OTB + other fleets)	% OTB
Demersal landings (t)	14 600	17 800	82%
Fishing income (M€)	97.7	155.0	63%
Landings of 5 target species (t)	4414	4637	95%
Income from 5 target species (M€)	47.25	51.74	92%
Effort (000 kW days)	22 190	29 600	75%
Capacity (000 GT days)	7230	8507	85%
Employment (FTEh)	2441	4492	55%

Source: The data are averages for the period 2016–2018 in GSA06, combining DCF data and fish price data for Catalonia. DG Fisheries, Autonomous Government.
http://agricultura.gencat.cat/ca/ambits/pesca/dar_estadistiques_pesca_subhastada/.

Table 2
Catch (t) by species and fleet segment in GSA06. Data represent annual averages for the years 2016–2018. HKE: hake (*Merluccius merluccius*), MUT: red mullet (*Mullus barbatus*), NEP: Norway lobster (*Nephrops norvegicus*), DPS: deep-water rose shrimp (*Parapenaeus longirostris*), ARA: red shrimp (*Aristeus antennatus*). "Stock 6" is a pool of all other species landed by the fleets, modelled as a surplus biomass model. Price (€/kg) represent the average for 2016–2018.

Species	VL1218	VL1824	VL2440	Total OTB	Price (€/kg)
HKE	220	1145	817	2182	6.53
MUT	150	820	350	1320	5.06
NEP	29	155	109	293	22.20
DPS	70	370	250	690	14.93
ARA	92	460	335	887	36.50
Stock 6	1040	2910	1850	5800	3.99
Total	1601	5860	3711	11172	

(COD)) against an alternative management strategy based on harvest control rules similar to those adopted by the International Council for the Exploration of the Sea (ICES) for some Atlantic demersal fisheries (Prellezo et al., 2017) in the Spanish Mediterranean fishing area GSA06 in terms of economic yields and employment. The ability of MSE to provide advice to fisheries management depends critically on how well uncertainty is represented (Punt et al., 2016) and in this application we identified uncertainty on the parameterisation of the stock-recruitment model for the fishery target species as the main source of uncertainty. Uncertainty in the evolution of prices in the long run (e.g. beyond 2030) was explored by running the proposed management under scenarios of oil and ex-vessel fish prices produced by (Hamon et al., 2021) using global forecasts by the MAGNET model under climate change scenarios (Woltier and Kuiper, 2014), based on the International Panel for Climate Change (IPCC) framework of Shared Socio-economic Pathways (SSPs).

We built a bioeconomic simulation model based on FLBEIA (Garcia et al., 2017a,b,c) to obtain the input values of the economic variables in the optimisation model. The FLBEIA model application is described in Appendix 1. The FLBEIA simulation runs were projected for the period 2019–2060.

3.2. *The optimisation model*

Three main scenarios for projecting the short term (2020–2025) and long term (2050–2060) economic yield and employment of the fleet has been defined for three segment of trawl fleet according to vessel length class, as: FL1 (VL1218), FL2 (VL 1824) and FL3 (VL2440). The scenarios are defined as following (see previous section and Appendix 1 for details):

S0: projection of 2016–2018 average annual effort level over time, i.e., constant effort level for 2019–60.

S1: effort levels 2020–2025 as imposed by the official NW Mediterranean Multi Annual Plan and subsequently kept constant for 2026–2060.

S2: flexible effort levels from 2020 onwards according to ICES harvest control rule, whereby fishing mortality limits are set by as a function of stock biomass. S0 is a baseline of "business as usual" (i.e. no changes in management), S1 simulates the implementation of the official WM MAP in force for the period 2020–2024, and S2 is an alternative scenario base on the current practice in Atlantic European fisheries which follows a "harvest control rule" (HCR) set from the scientific advice provided by ICES. This management model is working well for Atlantic European fisheries (Cardinale et al., 2017) and its validity is explored for Mediterranean fisheries.

Each scenario is projected according to five possible future conditions as follows (Woltier and Kuiper, 2014) (Hamon et al., 2021):

CC: Current Case-All economic parameters projected into the future without taking into account any climate change effect. This means projecting all prices to their average current values, without taking into account the increase in fuel price and fish price projected by IPCC SSPs.[5]

WM: World Markets scenario from IPCC (RCP.[6]85 with SSP5).

NE: National Enterprise scenario from IPCC (RCP8.5 with SSP3).

GS: Global Sustainability scenario from IPCC (RCP4.5 with SSP1).

LS: Local Stewardship scenario from IPCC (RCP6.0 with SSP2).

All economic results are presented as real prices based on 2010 values.

3.2.1. *Sets and parameters*

The following notation will be used in the optimisation model in this paper.

$j \in J$ is a set of fleets.

$i \in I$ is a set of species.

$t \in T$ is a set of harvesting periods (years).

p_{ijt} denotes the price of fish in period. $t \in Tcf_{jt}$ denotes the cost of fuel for harvesting in period $t \in T$(€/t).

cc_{jt}denotes the crew cost for harvesting in period $t \in T$(€/t).

TC_j denotes the total cost of harvesting, i.e. sum cc_{ij} and cf_{ij} (€/t).

R_{ij} denotes the revenue from harvest of species i by fleet j (€/t).

q_{ijt} is a continuous decision variable indicating the amount of harvest in time period. $t \in T$

3.2.2. *Objective function and constraints*

A maximisation model has been developed to determine the maximum sustainable economic yield (i.e. the value of the difference between total revenues and total cost of fishing) in each scenario for the time period under consideration such that:

$$Max\ \pi = \sum_{i \in I}\sum_{j \in J}\sum_{t \in T} p_{ijt}q_{ijt} - \sum_{j \in J}\sum_{t \in T} TC_{jt} \tag{1}$$

s.t:

Total cost of crew:

$$\sum_{j \in J}\sum_{t \in T} CC_{jt} \leq a \tag{2}$$

Total cost of fuel:

$$\sum_{j \in J}\sum_{t \in T} CF_{jt} \leq b \tag{3}$$

Revenue function:

$$\text{Cost Function}: R = \sum_{i \in I}\sum_{j \in J}\sum_{t \in T} p_{ijt}q_{ijt} \tag{4}$$

$$TC = \sum_{j \in J}\sum_{t \in T} CF_{jt} + \sum_{j \in J}\sum_{t \in T} CC_{jt} \tag{5}$$

$$CC_{jt} = cc_{jt} {}^{*} q_{jt} \tag{5.1}$$

$$CF_{jt} = cf_{jt} {}^{*} q_{jt} \tag{5.2}$$

$$0 \leq q \leq q' \tag{6}$$

$$p, q, cc, cf, \pi \geq 0 \tag{7}$$

Equation (1) shows the objective function, which is to maximise the economic yield for the period under consideration, equations (2) and (3) show the constraint in the model related to crew cost and fuel cost. In this application, we set the constraints such that the crew cost is within 40% and the fuel cost is within 50% of total revenue. Equation (4) shows the revenue function and equation (5) shows the total cost function. Equation (6) shows that catch levels should not exceed the target levels q' which are predefined and based on the bioeconomic model results (summarized in Appendix 2). The non-negativity constraints are stated in equation (7). In the first step, the expected maximum sustainable economic yield (eq. (1)) and the amount of harvest (q)for each fleet has been obtained. The profitability of each fleet is then captured through the total cost (eq. (5)) to income i.e. revenue (eq. (4)) ratio (C/I), expressed as percentage, which is an important financial metric in determining the profitability and efficiency and has been used in the fisheries economic literature in (Adeogun et al., 2009) (Baki and Yucel, 2017), such that the C/I ratio is inversely proportional to the financial performance. The model is solved for each of the aforementioned conditions separately and the final results show the values for the entire time period under consideration. The Genetic Algorithm method from Palisade Decision Suite software has been used to solve the models and the experiments are run on a x-64 based PC.

4. Results

In the remainder of this section results for the three scenarios including S0, S1, S2 are presented. Two projection periods are defined namely the short term (2020–2025) and long term (2050–2060), the former capturing the scenarios under which no climate change condition is applied, and the latter showing the long term effects of policies taking into account five different climate change based conditions For making a meaningful comparison between the three fleets' performance with respect to the profitability, the C/I ratio of the fleets are compared. The long term projections of profitability have been obtained by running the model for three scenarios and the five different conditions specified above (i.e. a total of 15 alternatives).

4.1. *Short term projections*

The results for the short term projections [year 2020–2025] for the three categories of S0, S1 and S2 are reported for the CC scenario. As shown in Table 3, fleet 1 and fleet 2 have slightly better results in Scenario 1, based on the C/I indicator. However, fleet 3 has a slightly higher economic yield ratio (lower C/I) under the S2 scenarios. These results may imply that in the short term, where the fleets are operating under the no-climate change scenarios, larger fleet sizes with flexible quota may show better financial performance as they are able to take advantage of economies of scale and Small scale units are the less efficient fleet segment (Gomez and Maynou, 2020).

Table 3
Short term projections for years 2020–2025 (S1, S2, S3).

Scenario	Condition	Profitability	FL1	FL2	FL3
S0	CC	C/I	49%	50%	51%
		q	1400	5200	3300
S1	CC	C/I	47%	47%	49%
		q	2500	4700	2900
S2	CC	C/I	52%	53%	45%
		q	3100	4100	3800

---

[5] Intergovernmental Panel on Climate Change - Socioeconomic Pathways.

[6] RCP stands for "Relative Concentration Pathways".

4.2. Long term projections

In this section the results for the long term projections (year 2050–2060) for the three Scenarios of S0, S1 and S2 are reported for all five different conditions, i.e., NE, WM, LS, GS, CC, and the q levels are the yearly maximum quota levels that could be achieved given the constraints related to fuel and crew cost (App. 2 shows some points in the middle (2030) period for each fleet. In practice, from 2025 to 2050 all the indicators grow steadily).

4.3. S0: projections based on recent average effort levels

The results for Scenario 0, reported in Table 4, show that for 4 out of 5 conditions (WM, GS, LS, NE) no feasible solutions are found while meeting constraints related to fuel and crew cost. These results could be explained by the fact that under the four aforementioned conditions, the amount and cost of fuel increase (as shown in App. 1- Fig A1.1) would result in losses and cannot be sustained under current effort levels. The only condition in which future economic yield is feasible is the CC condition which is because the fuel cost in that condition is projected significantly lower compared to the other four conditions (however, that may not be a likely scenario in future due to the global efforts to reduce CO_2 emission which may result in increases in fuel price).

A sensitivity analysis is conducted for the four scenarios of WM, NE, LS and GS to understand the effect of changes in important parameters, namely the price of fish, and fuel cost on the final solution. The sensitivity analysis shows that the results are highly sensitive to fuel cost, and a decrease of 80% or more in fuel cost may result in profitability while the yearly target levels could be achieved without compromising the employment level. This is reasonable since the fuel cost is a significant cost component of fisheries and changes in this parameter affect the economic performance of fleet significantly. Table 4 shows the results for S0. The original models are labelled as condition (a), and the models where 80% reduction in fuel cost is applied are labelled as condition (b).

4.3.1. S1: effort levels as imposed by the Mediterranean MAP

Table 5 presents the results for S1, under which the effort reduction has been implemented. The C/I ratio shows that under this scenario and for all four conditions (GS, LS, WM, NE) the average economic yield is estimated to be around 12%, and that under the CC scenario the economic yield will be much higher.

Compared with the gross profit margin of the Mediterranean fishing fleet which was estimated at around 30% in 2017 (STECF, 2019), these results show that for the four scenarios of GS, LS, WM, NE, a decline in profitability under the effort control scenarios is predicted in the long term, and the highest yield would be under the WM condition related to Fleet 3 (18m–24m). This may imply that larger size vessels would yield higher profit levels compared to the smaller size fleets. The only condition where improved economic yield is observed is under the CC condition under which the fuel costs are significantly lower compared to the other conditions. One of the main drivers of decline in economic yield is the increase in fuel price which along with limitations on effort levels could severely affect the economic yields and impact on the employment levels.

Table 4
Longterm projections-S0 under different scenarios of future conditions.

Condition	Profitability	Fleets					
		1(a)	2(a)	3(a)	1(b)	2(b)	3(b)
GS	C/I	–	–	–	0.99	0.82	0.91
	q	–	–	–	1200	4500	2800
LS	C/I	–	–	–	0.78	0.88	0.85
	q	–	–	–	1200	4500	2800
WM	C/I	–	–	–	0.79	0.88	0.85
	q	–	–	–	1200	4500	2800
NE	C/I	–	–	–	0.94	–	–
	q	–	–	–	1200	–	–
CC	C/I	0.45	0.46	0.48	–	–	–
	q	1200	4500	2800	–	–	–

Table 5
Long term projections-S1 under different scenarios of future conditions.

Condition	Profitability	Fleets		
		FL1	FL2	FL3
GS	C/I	87%	88%	88%
	q	2500	10000	4700
LS	C/I	87%	88%	91%
	q	2500	10000	4700
WM	C/I	91%	88%	85%
	q	2500	10000	4700
NE	C/I	–	–	91%
	q	–	–	4700
CC	C/I	39%	40%	42%
	q	2500	10000	4700

4.3.2. S2: Flexible effort levels

Under the flexible effort scenario, for the LS and WM conditions, Fleet 3 marginally outperforms the other two fleet sizes, showing higher profitability margin which may be explained by economies of scale and efficiency (Table 6). However, under the NE condition, no feasible solutions are found that could meet constraints related to fuel and crew cost (i.e. harvest is not justifiable since costs would outweigh the gains). Similar to the other two scenarios, the only condition in which profit margins are considerably higher is CC condition under which the fuel prices are significantly lower compared to the other conditions.

5. Discussion and conclusions

The current and recently implemented multi-annual plan which is grounded in the concept of maximum allowable fishing effort introduces a significant reduction in fishing effort(time) for achieving fishing mortality at F_{MSY} (Sanchez et al., 2020). However, the proposal does not regulate the distribution of fishing days throughout the year and across fleets which may have impacts on employment, market supply and price, leading to economic losses to the fishery sector. Based on the results by different stock assessment working groups, the fleet reduction in the Mediterranean region has not been sufficient to allow the recovery of targeted populations (STECF, 2017) and complementary management measures may be required to adjust fishing mortality to stock status. The challenges faced by the Mediterranean fisheries such as habitat loss, pollution, eutrophication, the accidental introduction of alien species, industrial overfishing and volatile fuel prices (Kleitou et al., 2021) (Colloca et al., 2013), put pressure on income, and while production costs have increased considerably, the price of fish has been relatively static in many areas (Prosperi et al., 2019).

In the short term and without considering the impact of climate change on the fisheries-that is during the horizon of application of the

Table 6
Long term projections-S2 under different scenarios of future conditions.

Condition	Profitability	Fleets		
		FL1	FL2	FL3
GS	C/I	87%	90%	86%
	q	4500	6800	6200
LS	C/I	87%	87%	82%
	q	4500	6300	6200
WM	C/I	87%	87%	82%
	q	–	6800	6200
NE	C/I	–	–	–
	q	–	–	–
CC	C/I	40%	40%	43%
	q	4500	7000	6300

management plan-the results show that all scenarios show an acceptable C/I ratio, with scenario 2-FL3 showing a slightly higher economic performance compared to scenarios 0 and 1. Scenario 2 is based on flexible effort corresponding to ICES harvest control rules, an alternative fisheries management scenario in line with responsive (or adaptive) management in European Atlantic fisheries. In the longer term, and considering the IPCC projections, the overall profitability margins are significantly reduced. In fact, in some conditions such as NE, feasible solutions with respect to fuel and crew constraints may hardly be reached, showing the low profit margin of such scenarios. However, the larger fleets under the World Market condition under the flexible effort regimes show (relative) better performance. In the long term however, it is difficult to establish an "optimal" scenario due to high uncertainty in the "future". Nonetheless this analysis compares and contrasts scenarios with or without climate change considering forecasted prices for fish and fuel and shows their strong influence on the results. Therefore, it is necessary for policy makers to take into account the scenarios based on climate change and rising fuel prices to be able to react to these changes effectively. Based on the results from the modelling, we will present a number of policy recommendations.

In comparison to other European fisheries, especially the Atlantic region, research on the Mediterranean fisheries is under-funded with lower levels of scientific stock assessments incorporated in the fishery management plans which could make the implementation of output control measure more difficult (Sanchez et al., 2020) (Colloca et al., 2013). While the output limits are flexible and could link fishing mortality to stock status, their enforcement has to be carefully controlled and is in need of accurate stock assessment models. Furthermore there is a displacement factor between legislations and social practice that does not consider local socio-cultural specificities as highlighted in a study by (Gomez and Maynou, 2021a,b). Their study suggests that scientists tend to agree more with the WM MAP compared with the fishers, and fishers perceive the new MAP regulations as another layer of restrictive regulations for an industry that faces socio-economic and environmental challenges. Additionally, the discarding of marketable fish which may be a consequence of output limits, becomes particularly important especially in the highly diversified Mediterranean region and improvements in gear selectivity and spatial temporal closures are suggested as measures to reduce discards and mortality of target species and bycatch (Colloca et al., 2013).

The results in this paper show that the future increase in fuel cost which is the main production cost for fisheries, and overexploitation of stocks, could significantly threaten the sustainable economic yield of the sector and reduce the profitability margins, in particular in smaller fleets. These results imply that policy interventions and investments may be directed at technological advancements such as modernisation of fleet, reduced fuel consumption via use of highly efficient gears or electric engines, and measures to control overexploitation. Value creation in other parts of the fisheries supply chain are also vital and small scale fishers in particular must add value to their catch if they want to survive. For example, in a move to supplying solidarity purchasing groups, as an alternative to the standard fish distribution channels, a group of Mediterranean fishers focused on quality rather than quantity. This move also opened new market opportunities through processing food, communicating culinary practices and transmitting knowledge on neglected fish species which would help in diversifying the type of fish and the marketing channels (Prosperi et al., 2019). Moreover, in order to increase the influence of local fishermen on pricing their products new marketing and labelling initiatives such as direct sale and certification of origin schemes have emerged in the Mediterranean region. These initiatives are pragmatic strategies to deal with the diminishing fisheries resources while adding value to the catch and improving sale prices (Gomez and Maynou, 2021a,b). Improved fish marketing strategies, and storage solutions for addressing natural seasonality, as well as diversification of activities such as "pescatourism" by which the emphasis is shifted from material production to service provision (Mather et al., 2006), may also be part of the adaptive response to the serious challenges of local employment and profit levels facing the Mediterranean fisheries.

5.1. *Limitations and future research*

The Mediterranean fishing fleets are complex fisheries and have a direct impact on the regional economies and their fishing communities as well as having a long history that has influenced the coastal communities' culture. The focus of this paper is solely on the economic indicators and the optimisation model determines the total amount of catch that would be sustainable and profitable but it does not directly address the selectivity and discard problems. The impact of climate change on the future biological productivity of fish stocks is also an important issue. Unfortunately, empirical data for Mediterranean fish stocks that could help relate changes in sea temperature to, e.g., growth, natural mortality or stock/recruitment parameters are lacking. Regardless of our inability to forecast the evolution of Mediterranean fishery resources accurately under climate change, fishing fleets will have to adapt to a likely scenario of diminishing traditional resources (such as hake or red mullet) and move to target new and emerging species. It is expected that cephalopods will benefit from environmental conditions in the next few decades and, at least in the Eastern Mediterranean, non-indigenous marine resources are already becoming important. In the short term, fishers will have to adapt their behaviour (choice of fishing location, modification of fishing gear), while in the mid and long term, decisions on investment/disinvestment, adoption of new technology (for instance, more fuel-efficient engines) and new marketing strategies will have to be adopted.

Therefore future research may include these factors as well as other cultural and environmental aspects in the models. Consequently, for the successful implementation of any management measures, socio-economic, cultural and environmental attributes as well as improved scientific stock data has to be taken into account for developing strategies for tackling the challenges in the case study region.

Credit author statement

Negar Akbari: Conceptualization, Investigation, Methodology, Data curations, Formal Analysis, Writing-Original draft and editing. **Francesc Maynou:** Conceptualization, Investigation, Methodology, Data curations, Formal Analysis, Writing-Original draft and editing, Funding Acquisition, Project Administration. **Trond Bjørndal:** Conceptualization, review and editing, funding acquisition, project management administration. **Pierre Failler**: Conceptualization, review and editing, funding acquisition, project management and administration. **Benjamin Drakeford**: review and editing, funding acquisition, project administration. **Andy Forse**: Review and editing.

Declaration of competing interest

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

Acknowledgements

The EU provided funding for this research through project "Paradigm for Novel Dynamic Oceanic Resource Assessments" (Horizon 2020 research and innovation programme under the grant agreement No. 773713).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jenvman.2021.113794.

References

Adeogun, O.A., et al., 2009. Economic viability of small-scale marine capture fisheries in the Bonny rea, Rivers State, Nigeria. Mar. Resour. Econ. 24, 195–203.

Baki, B., Yucel, S., 2017. Feed COST/PRODUCTION income analysis OF seabass (Dicentrarchus labrax) aquaculture. International Journal of Ecosystems and Ecology Sciences (IJEES) 7 (4), 859–864.

Cardinale, M., Osio, G.C., Scarcella, G., 2017. Mediterranean sea: a failure of the European fisheries management system. Frontiers in Marine Science 4 (72).

Colloca, F., et al., 2013. Rebuilding Mediterranean fisheries: a new paradigm for ecological sustainability. Fish Fish. 89–109.

FAO, 2020. The State of Mediterranean and Black Sea Fisheries 2020. General Fisheries Commission for the Mediterranean, Rome.

Franquesa, R., Oliver, P., Basurco, B., 2008. The Mediterannean fishersies sector: a review of facts and figures. Options méditerranéennes, Série B: Études et Recherches 62, 9–41.

Garcia, D., et al., 2017a. Bioeconomic multistock reference points as a tool for overcoming the drawbacks of the landing obligation. ICES (Int. Counc. Explor. Sea) J. Mar. Sci. 74 (2), 511–524.

Garcia, D., et al., 2017b. Technical Manual for FLBEIA, A R Package to Conduct Bio-Economic Impact Assessments Using FLR (Version 1.15). [Online] Available at: https://flbeia.azti.es/how-to-get-started/.

Garcia, D., et al., 2017c. FLBEIA: a simulation model to conduct Bio-Economic evaluation of fisheries management strategies. Software 6, 141–147.

Gomez, S., Maynou, F., 2020. Economic, sociocultural and ecological dimensions of fishing capacity in NW Mediterranean fisheries. Ocean Coast Manag. 197.

Gomez, S., Maynou, F., 2021a. Alternative seafood marketing systems foster transformative processes in. Mar. Pol. 127, 104432.

Gomez, S., Maynou, F., 2021b. Balancing ecology, economy and culture in fisheries policy: participatory research in the Western Mediterranean demersal fisheries management plan. J. Environ. Manag. 2021, 112728.

Hamon, K.G., et al., 2021. Future socio-political scenarios for aquatic resources in europe: an operationalized framework for marine fisheries projections. Frontieris in Marine Research 8.

Kleitou, P., Crocetta, F., Giakoumi, S., Giovos, I., 2021. Fishery reforms for the management of non-indigenous species. J. Environ. Manag. 280, 111690.

Lleonart, J., Maynou, F., 2003. Fish stock assessments in the Mediterranean: state of the art. Sci. Mar. 67, 37–49.

Mather, A.S., Hill, G., Nijnik, M., 2006. Post-productivism and rural land use: cul de sac or challenge for theorization? J. Rural Stud. 441–455.

Prellezo, R., et al., 2017. Bioeconomic assessment of a change in fishing gear selectivity: the case of a single-species fleet affected by the landing obligation. Sci. Mar. 17, 371–380.

Prosperi, P., et al., 2019. Adaptation strategies of small-scale fisheries within changing market and regulatory conditions in the EU. Mar. Pol. 100, 316–323.

Punt, A., et al., 2016. Management strategy evaluation: best practices. Fish Fish. 17, 330–334.

Sanchez, l., et al., 2020. A new management framework for western Mediterranean demersal fisheries. Mar. Pol. 112.

STECF, 2017. Mediterranean Assessments 2016- Part 2 (STECF-17-06). Publications Office of the European Union, Luxembourg.

STECF, 2019. The 2019 Annual Economic Report on the EU Fishing Fleet (Scientific Technical and Economic Committee for Fisheries 19-06). Publications Office of the European Union, Luxembourg.

Symes, D., Phillipson, J., Salmi, P., 2015. Europe's coastal fisheries: instability and the impacts of fisheries policy. Sociol. Rural. 55 (3), 245–257.

Woltier, G., Kuiper, M.H., 2014. *The MAGNET Model: Module Description,* s.L. LEI Wageningen UR, Wageningen.