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Sustainability now or later? Estimating the benefits of pathways to maximum sustainable yield for EU Northeast Atlantic fisheries[☆]

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1. Introduction

Most countries have the goal to manage their fisheries to achieve a combination of biological, economic, social, and political objectives [1,2]. This is also the case for the EU's Common Fisheries Policy (CFP). According to Article 2 of the CFP [3]: "*The CFP shall ensure that fishing and aquaculture activities are environmentally sustainable in the long-term and are managed in a way that is consistent with the objectives of achieving economic, social and employment benefits, and of contributing to the availability of food supplies*".

Furthermore, and in accordance with the resolutions of the World Summit on Sustainable Development, the CFP establishes the objective of restoring and maintaining populations of fish stocks above the biomass levels capable of producing the maximum sustainable yield (MSY).[1] In order to reach the objective of progressively restoring and maintaining populations of fish stocks above biomass levels capable of producing maximum sustainable yield, the maximum sustainable yield exploitation rate shall be achieved by 2015 where possible and, on a progressive, incremental basis at the latest by 2020 for all stocks [3].

However, despite the general improvement in the status of many fish stocks that are exploited by the EU fishing fleet [4,5], approximately half (48%) are still exploited at rates greater than F_{MSY} [6]. Reducing fishing mortality on fish stocks to $F_{MSY,}$ generally means that in the medium- to long-term, catches from such stocks would be higher than at present, implying that the EU fishing fleet could improve on their current economic performance. In other words, the EU fishing fleet is currently losing potential economic rents because many fish stocks are being exploited at rates that are not capable of delivering the MSY.

In this context, Willman et al. [7] show that by improving the management of world marine fisheries (through a significant reduction of fishing effort), the potential (operating) profit of global fisheries could increase by $50 billion per year.[2] Similarly, Srinivasan et al. [11]

[☆] **CAVEAT:** The opinions expressed in this paper are those of the authors and do not necessarily reflect the European Commission's positions or policy.

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[1] Article 14 of the CFP defines MSY as the highest theoretical equilibrium yield that can be continuously taken on average from a stock under existing average environmental conditions without significantly affecting the reproduction process.

[2] In order to compare the results from the different available studies, it is used the following simplified classification of the economic performance indicators:

- Gross profit = turnover (i.e., value of landings) – direct (variable) costs.
- Operating cash flow = gross profit – fixed costs.
- Operating profit = Operating cash flow – depreciation.
- EBIT (Earnings Before Interest and Taxes)= operating profit + non fishing income (not belonging to the fishing activity, e.g. subsidies, fishing tourism) – non fishing costs.
- Net profit =EBIT – taxes – financial costs.

Economic (or extraordinary) profits are estimated when the opportunity cost of capital is deduced to the (normal) profits.

Full equity profit means that the profitability is estimated assuming that the boat owner has no debts.

Economic (or resource) rents can only be equal to the economic profits when: (i) salaries are equal to the opportunity cost of labour and so no labour rents are generated [8], (ii) vessels are homogeneous and consequently no intra-marginal rents are created [9,10], and (iii) the administration is not extracting rents through taxes (e.g. fuel taxes) or other tools.

In our study, it is estimated the operating profit assuming full equity profit.

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estimated that the potential contribution to food security of rebuilding stocks globally is between 83 and 99 million tonnes annually and consequently by not fishing at MSY, the foregone yield to global fisheries was between 7% and 36% of the reported landings in 2000, which equates to a potential landed value between $93 to $116 billion, compared to the reported $87.7 billion in 2000 [12].

Based on the results of Srinivasan et al. [11], Sumaila et al. [12] estimated that by rebuilding fish stocks to the levels that can deliver MSY, operating profit of the global fleet would increase by $49.2 billion per year. The estimated increase in economic performance is to a large extent due to a reduction in fishing costs from $73 billion in the year 2000 to $37 billion per year arising as a result of higher stock biomasses and lower fishing effort. Sumaila et al. [12] also estimate that the costs of rebuilding global fish stocks (which may include payments for vessel buyback programs and alternative employment training initiatives for fishers) to be about $203 billion, resulting in a net present value of $769 billion (discounted over a 50-year period assuming a 3% annual discount rate).

The estimates from Willman et al. [7] and Srinivasan et al. [11] relate to the long-term equilibrium situation and consequently do not address the economic performance during the transition period to stock rebuilding nor the rebuilding costs. Sumaila et al. [12] assumed a rebuilding period for fish stocks of 10 years, and estimated that it would take 12 years after rebuilding begins for the gains to exceed the costs (including buybacks).

Merino et al. [13] estimate that to achieve maximum economic yield (MEY), fish stock biomass in the North Atlantic would need to be 2.4 times greater than at present, which implies that fishing effort would need to be reduced by 53% compared to the current level. They also estimate that the potential economic earnings before interest and taxes (EBIT) at MEY for North Atlantic fish stocks to be about €12.85 billion, which corresponds with a MSY of approximately 12.66 million t. In other words, when considering the current estimated economic EBIT of €0.63 billion, North Atlantic fisheries are only generating 5% of their economic potential, largely as a result of ineffective fisheries management.

For the Northeast Atlantic, Crilly and Esteban [14] estimate that restoring 49 overfished stocks (out of 54 stocks with available information) to their full MSY potential could deliver up to €16.58 billion per year in value of landings (2.4 times the current value of landings). If in order to restore stocks to levels that will deliver MSY through the cessation of all fishing, then compensation payments of around €12 billion (€10.56 billion in present value using a 3.5% discount rate) over the transition period (9.4 years) would need to be invested. However, the operating profit over the transition period alone would be €5.10 billion. Thus, restoring these overfished stocks would lead to a net present value of €138.56 billion over a 40-year period (2013–2052) [14].

Guillen et al. [15] investigated the long-term potential yields that the French demersal fleets fishing in the Bay of Biscay could obtain from the three main target species; hake (*Merluccius merluccius*), *Nephrops* (*Nephrops norvegicus*) and sole (*Solea solea*). They estimated that under 2009 economic conditions and fishing effort, the fleet generated €24 million in operating cash flow. To maximise the aggregated catch from the three main target species (multiple maximum sustainable yield, MMSY), fishing effort would need to be reduced to 48% of the 2009 level. While, if all three stocks were to be exploited at or below F_{MSY}, fishing effort would have to be reduced to 46% of the 2009 level. In addition, in order to maximise operating cash flow at €85 million, fishing effort would need to be reduced to 39% of current effort. Similarly, the Bay of Biscay French *Nephrops* fishery could generate an economic operating profit of €31.6 million if it was exploited at MSY level, with fishing effort at 62% of the 2010 effort level, instead of the €1.8 million that would be achieved at the reported level of effort for 2010 [8]. Furthermore, MEY would be obtained when fishing effort is reduced to 30% of the 2010 level, leading to €47.2 million in economic operating profit.

Merino et al. [16] investigated the long-term potential yields that the trawler fleet from Mallorca could obtain from the four main target species; i.e., red mullet (*Mullus surmuletus*), hake (*Merluccius merluccius*), *Nephrops* (*Nephrops norvegicus*) and red shrimp (*Aristeus antennatus*). They estimated that under 2001–2011 economic conditions and fishing effort, the fleet generates €1.29 million in economic operating profit. The aggregated catch from the four species is maximised (MMSY) when fishing effort is reduced to 43% of the 2001–2011 level. If all four stocks were to be exploited at or below F_{MSY}, fishing effort would have to be reduced to 29% of the 2001–2011 level. While, in order to maximise total economic operating profit at €1.9 million, fishing effort would need to be reduced to 52% of 2001–2011 effort level.

According to the data reported in FAO [17], Northeast Atlantic waters correspond to the main EU fishing grounds and account for more than 72% of the total EU marine catches. In the present study, a surplus production model (SPM) is used to estimate the potential operating profit for the EU fleet fishing in the Northeast Atlantic waters (area FAO 27) assuming that the MSY can be simultaneously achieved for all of the fish stocks exploited by the fleet. Where available, estimates for MSY are based on multispecies assessments, although single-species estimates are used for stocks for which no multispecies estimates are available. It is also investigated the potential effects of achieving F_{MSY} over different timescales as follows: (i) achieving F_{MSY} in 2016 (t+1), (ii) achieving F_{MSY} in 2020 (t+5), and (iii) progressively moving towards F_{MSY} from 2016 to 2020. For each timescale scenario, three different cost assumptions are made (see Section 2).

2. Methodology

2.1. Model

The growth of a fish stock can be expressed in the continuous version of the logistic model described by the differential equation used in the Verhulst/Pearl surplus production model [18]. Changes in biomass of an exploited population can then be expressed as:

$$\frac{dB}{dt} = r\ B\left(1 - \frac{B}{K}\right) - H \tag{1}$$

Where B is biomass, dB/dt is the temporal change in B, r is the intrinsic rate of natural population growth, K is the environmental carrying capacity for the population, and H is the biomass extracted in the form of catch (harvest).

The short-run harvest function follows the common Schaefer harvest function [19], where the harvest is proportional to the fishing effort and the stock level:

$$H = q{\cdot}E{\cdot}B \tag{2}$$

Where q is the catchability coefficient and E is the fishing effort. The catchability coefficient (q) expresses how effective the fishing effort is in relation to the stock level by a given fishing fleet. In this study q is assumed to be constant and consequently does not change over time (i.e., no technical change), while changes in E can take place.

The proportional factor F is the instantaneous rate of fishing mortality, which is partitioned into two factors: fishing effort (E) and catchability (q), hence:

$$H = F{\cdot}B \tag{3}$$

This means that the harvest is proportional to the biomass, F being the proportionality factor.

While in the steady state (i.e. dB/dt =0) the sustainable harvest level is derived as:

$$H = qKE - \frac{q^2K}{r}E^2 \tag{4}$$

This implies that harvest follows a parabolic curve as a function of E, with a maximum harvest called the Maximum Sustainable Yield (MSY) at a value of E_{MSY}. The biomass that enables a fish stock to deliver the MSY (B_{MSY}) is K/2.

Following the sustainable harvest curve as defined by Eq. (4), it is not until the biomass recovers that harvests can achieve the sustainable level expressed in the curve. However, in the steady state the harvest does not change (i.e. the system is in equilibrium). The general case (dB/dt‡0) is obtained integrating Eq. (1), giving the equation of the dynamics [20–22].

$$H_t = qE_tK\frac{\ln \alpha_t}{r} \tag{5}$$

being

$$\alpha_t = \left[1 - \frac{rB_t(1 - e^{r-qE_t})}{K(r - qE_t)}\right] \tag{6}$$

H_t and E_t are respectively the yield obtained and effort exerted, with respect to time t, while B_t is the biomass at the beginning of the period t. H_t, as a function of E_t and B_t, gives a monotonic growth curve which is asymptotic at B_t. Thus the mean biomass ($\bar{B}$) during the period t is:

$$\bar{B}_t = K\frac{\ln \alpha_t}{r} \tag{7}$$

Eq. (5) can also be expressed as:

$$H_t = q{\cdot}E_t{\cdot}\bar{B}_t \tag{8}$$

In order to compute successive years it is estimated the biomass at the end of the period t (start of period $t+1$) according to:

$$B_{t+1} = B_t\frac{e^{r-qE_t}}{\alpha_t} \tag{9}$$

The gross revenue of a fishery is equivalent to the value of landings (VL), and so equals the quantity harvested multiplied by the price of fish. It is assumed the price of fish (p) to be constant across time and quantity.[3]

$$VL_t = p\ H_t \tag{10}$$

For this study, three different cost assumptions were made:

(1) Proportional costs: fishing costs (TC_1) are assumed proportional to effort, implying a constant marginal cost of effort. This is based on the homogeneous vessel assumption, where a vessel is added to (or taken out of) the fishery at the same cost as the previous one. The cost function is proportional (linear) to effort at a constant cost per unit of effort (c).

$$TC_{1t} = c\ E_t \tag{11}$$

(2) Corrected costs: when considering the costs of changes to fishing effort, because fishing capacity is often non-malleable (i.e. cannot be converted to other uses easily), some of the costs may prevail when effort is reduced (scrapping of vessels or otherwise) and even if no fishing takes place. There are some costs that will still need to be borne, for example, depreciation and capital costs, as well as any unemployment payments to redundant crew. Here it is assumed that labour and capital costs correspond to 60% of the total fishing costs incurred by the existing fleet with current effort (E_0). Hence the corrected costs for a reduction in the size of the fleet (reduction in effort) are the labour and capital costs plus the cost of deploying the effort for the reduced fleet (E_t):

$$TC_{2t} = 60\%{*}c{*}E_0 + 40\%{*}c{*}E_t \tag{12}$$

Transforming Eq. (12) it is obtained:

$$TC_{2t} = c\ E_t + 0.6\ c\left(E_0 - E_t\right) \tag{13}$$

and hence, corrected costs (TC_{2t}) are estimated to be proportional to effort deployed (E_t) and 60% proportional to the effort reduction ($E_0 - E_t$).

(3) Buy-back programme: the third assumption analysed considers that a buy-back programme (i.e., scrapping and permanent removal of vessels from the fleet) is implemented in year 1, with an initial lump sum payment to reduce effort to that required to achieve F_{MSY}. The buy-back costs are estimated by multiplying the number of vessels that need to be removed from the fleet (proportional to the required effort reduction) by the historical average cost of decommissioning a vessel obtained from Calvo *et al.* [25]. Subsequently, fishing costs are considered proportional to effort. Thus, the third cost assumption works as the first assumption while also accounting for the buy-back costs in the first year.

Operating profit can therefore be estimated by the difference between the revenues generated (value of landings) and the total costs, at any given effort level.

$$\text{Profits} = \text{VL–TC} \tag{13}$$

where TC is obtained from summing the crew wage cost (crew), estimates of unpaid labour (unpaid), energy cost (energy), other variable cost (othervar), other non variable cost (othernonvar) and depreciation (depreciation).

$$\text{Profits} = \text{VL} - \text{crew} - \text{unpaid} - \text{energy} - \text{othervar} - \text{othernonvar} - \text{depreciation} \tag{14}$$

So the cost per unit of effort (c) is obtained from estimating the TC at the initial period and assuming the effort at the initial period to be 1.

The operating profit is calculated as full equity profit, which means the profit that the boat owner would receive if the owner had no debts.

To estimate the potential gains from rebuilding Northeast Atlantic stocks to the level that is capable of delivering MSY, it is estimated the difference between current value of landings and the value of landings that would be obtained if all stocks were at MSY.

Estimates of MSY in the Northeast Atlantic waters are only available for a limited number of assessed species (s) and areas (z), as reported in the Appendix. In order to estimate the potential value of landings that the EU fleet could obtain when all stocks are at MSY, it is multiplied the potential EU landings at MSY for the stocks with available information ($MSY_{S,Z}$) by the species price ($P_{TACs,z}$) and raise it by a factor that relates the total EU value of

[3] The use of constant fish prices is justified as:

- EU landings in the Northeast Atlantic are a small fraction of landings worldwide (4%; according to FAO [17]), so variations in EU landings would have only a minor effect on global production and are unlikely to have a significant influence on fish prices in international markets.
- EU seafood production covers 44% of the EU consumption [23]. So, more than half of the EU seafood products consumed need to be imported, and consequently prices are largely determined by the international market. Seafood is one of the most traded food commodities. Therefore, we expect just a substitution of origin effect, especially when forecasts estimate overall increases in the seafood demand [24].
- And last, but not least, we did not wish to add more (noise) uncertainty to the results. This way, results (costs and revenues) are directly related to the stock recovery and the accompanying reduction in effort.

Table 1
Summary of the data used in the analysis (2013).Source: own elaboration from FAO [17], STECF [6] and Calvo et al. [23] data.

	Value
Total EU landings in Northeast Atlantic (million tonnes)	3.64
TAC information available (million tonnes)	2.34
TAC uptake landings (%)	80
Number of EU vessels in the Northeast Atlantic (FAO Area 27)	27,081
Yields at MSY for available TACs (million tonnes)	5.91
Mean price (€/kg)	1.24
Average buy-back cost per vessel (€ thousand)	218.5

Table 2
Summary of the AER data (in millions) used in the analysis (2013).[a]Source: own elaboration from STECF [6] data.

	STECF (2015) data	Raised data
Landings weight (tonnes)	**3.28**	**3.64**
Landings value (€)	**4064.8**	**4512.7**
Crew wage costs (€)	1213.8	1347.5
Unpaid labour (€)	163.2	181.2
Energy costs (€)	860.8	955.7
Repair costs (€)	349.0	387.5
Other variable costs (€)	524.1	581.9
Other non-variable costs (€)	358.8	398.3
Annual depreciation (€)	502.6	558.0
Total costs (€)	**3972.3**	**4410.1**
Operating profit (€)	**92.4**	**102.6**

[a] AER data are multiplied by 1.11 in order to raise cost data from the 3.2 million tonnes reported in STECF [6], to the EU landings reported by FAO for Area 27 (3.64 million tonnes).

landings of all species in the area by the value of EU landings of the available total allowable catch (TAC).

$$\text{Potential Landings Value} = \sum \left(MSY_{S,Z} \times P_{TAC_{S,Z}}\right) \times \frac{\text{Total EU landings value}}{\text{Value of EU TAC landings}} \quad (15)$$

The logistic production function (Eq. (4)) that relates harvest in value (H) with fishing effort (E) can be delineated when it is estimated 3 of its points: the value of landings at the current effort level (assumed to be 1), the point (0,0) and it is known that the maximum point in the curve is the Potential Landings Value.

This allows us to estimate r, k, q and B_{MSY}, in order to mimic the behaviour of the aggregated Northeast Atlantic production. In this way, it is possible to investigate how stocks are rebuilt when fishing mortality is reduced since changes in fishing mortality lead to changes in the harvest and total biomass levels (following (Eqs. (5)–9)).

2.2. Data

Total EU landings in the Northeast Atlantic (area 27) were obtained from FAO statistics [17] (see Table 1). TACs were obtained from the European Commission (2013b). Yields at MSY for the species and areas were obtained from different literature sources [13,15,26–28] (see Table A1 in the Appendix). Where no multi-species or single species estimates were available MSY estimates were generated by assuming a similar exploitation pattern on stocks and change in level at MSY.

Average price for the EU landings in the Northeast Atlantic was estimated from the 2015 Annual Economic report [6], by dividing the value of landings by the landings weight for the Northeast Atlantic.[4] Similarly, cost per unit of effort (Table 1) was estimated

[4] Northeast Atlantic includes Northeast Atlantic, North Sea and Baltic Sea areas in the 2015 Annual Economic report [6].

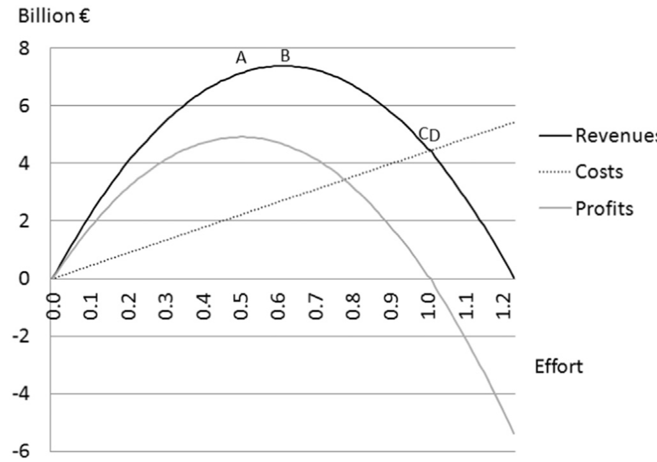

Fig. 1. Long-term equilibrium value of landings (revenues), costs and operating profit (€ billion) at different relative levels of fishing effort (current level of effort = 1.0) for the EU fleet in the Northeast Atlantic.

from the 2015 Annual Economic report [6] data on total fishing costs for the EU landings in the Northeast Atlantic (Table 2). Average buy-back cost per vessel is derived from Calvo et al. [25] and estimated as the total public expenditure on the permanent cessation of fishing activities, divided by the total number of vessels that have received such payments.

2.3. Scenarios analysed

There are carried out two sets of projections:

1) Long-term equilibrium projections of revenues, costs, gross value added (GVA) and operating profit for four different management objectives:

- Maximise profit (MEY)
- Maximise production (MSY)
- Status quo (fishing effort = 1)
- Bioeconomic equilibrium[5] (profits = 0)

2) Medium term projections to 2035 of three alternative management scenarios to achieve F_{MSY}

- Reduce current fishing mortality to F_{MSY} in 2016 (t+1);
- Reduce current fishing mortality to F_{MSY} in 2020 (t+5);
- Reduce current fishing mortality progressively from 2016 to reach FMSY at 2020.

Each of the above scenarios under option 2 was undertaken using the three different cost assumptions detailed above (see sub-Section 2.1): (a) proportional costs, (b) corrected costs, and (c) buy-back programme.

3. Results

3.1. Long-term equilibrium projections

The long-term equilibrium relationship for the EU fleet in North-east Atlantic waters between effort and yield, expressed in monetary terms as value of landings, costs and profits is shown in Fig. 1.

[5] Bioeconomic equilibrium or Open Access corresponds to maximum effort level, and consequently employment that the fishery could sustain in a non-loss making fishery [29].

Table 3
Long-term equilibrium estimates of value of landings, total costs, gross value added and operating profit (€ billion) and the associated relative level of effort for 3 different management objectives and for the status quo.

Management objective	Representation in Fig. 1	Relative effort level	Value of landings	Costs	GVA	Operating profit
Max profits (MEY)	A	0.50	7.12	2.21	5.76	4.91
MSY	B	0.62	7.38	2.73	5.70	4.64
Status quo	C	1.00	4. 51	4.41	1.80	0.10
Bioeconomic eq.	D	1.005	4.43	4.43	1.71	0.00

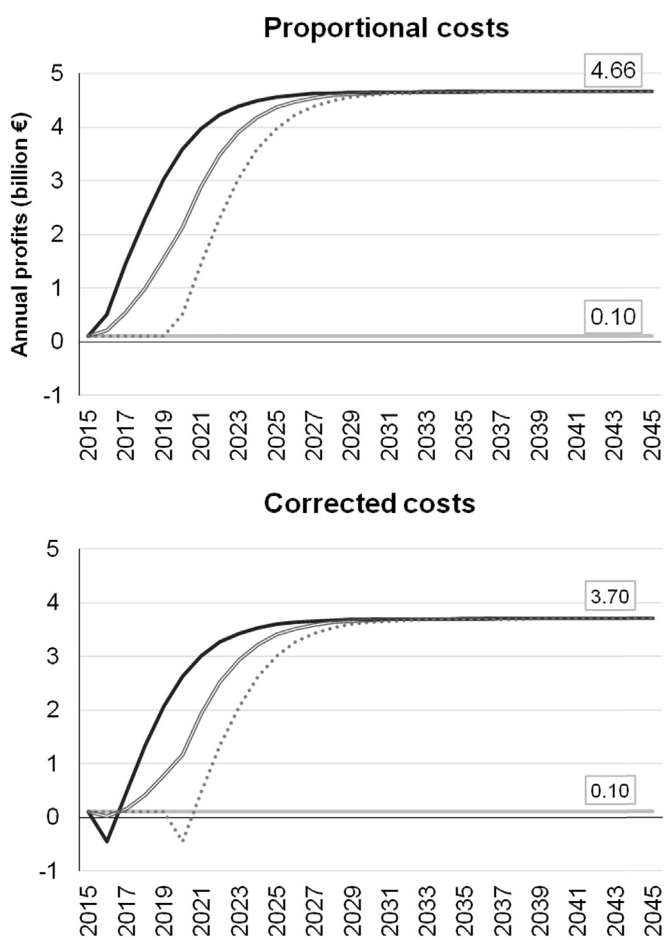

Fig. 2. Operating profit (in € billion) of the EU fleet in the Northeast Atlantic under three MSY scenarios (FMSY 2016 [solid black line], FMSY 2020 [double grey line], FMSY incremental [dotted grey line]) compared to the status quo [solid grey line] for the period 2015–2045. The MSY projections are calculated and illustrated here using two different cost assumptions.

Fig. 1 indicates that current exploitation level (point C; effort =1.0) is close to the bioeconomic equilibrium (point D; fishing effort level 1.005). Furthermore, the difference between estimated value of landings at MSY (point B; fishing effort level 0.62) and value of landings at MEY (point A; fishing effort level 0.50) is minor. This is also true for profits (Table 3).

Therefore, if Northeast Atlantic waters were exploited at rates that on average would deliver MSY, the EU fishing fleets could expect to receive €4.64 billion more in operating profit per year, or €4.91 billion if exploited at the MEY level, instead of the €0.10 billion at current exploitation rates. Detailed results are presented in the Appendix (Table A2).

3.2. Medium-term projections

To undertake medium term projections for each of the three alternative management scenarios to achieve F_{MSY} (represented as F_{MSY} 2016, F_{MSY} incremental, F_{MSY} 2020 in Fig. 2), three different costs assumptions were made (see 2.1 above):

1. Proportional costs: fishing costs are proportional to effort.
2. Corrected costs: fishing costs are proportional to effort with a 60% correction.
3. Buy-back programme Fishing costs are proportional to effort, with buy-back costs applied in the first year of the projections (t+1).

In order to achieve MSY for all Northeast Atlantic stocks, fishing effort must be reduced by 38%. If it is considered that there are 27,081 EU vessels in the Northeast Atlantic [6], then the optimal fleet size to achieve MSY would be 16,790 vessels, implying that fleet capacity in the area would need to be reduced by 10,291 vessels.

The results indicate that under the first and third cost assumptions, operating profit declines below current operating profit once the fishing mortality is reduced to F_{MSY}, and is not until year three in the projections that operating profit is higher than current operating profit (€0.1 billion). Under the second cost assumption (corrected costs), operating profit is predicted to fall below current operating profit for only one year (see Fig. 2 and Table A3 in the Appendix).

The third cost assumption (buy-back programme) operates similarly to the first cost assumption while also accounting for the buy-back costs in the first year. In order to achieve MSY for all Northeast Atlantic stocks, fishing effort must be reduced by 38%. Given that in 2013, there were 27,081 EU vessels actively engaged in the Northeast Atlantic [6], and assuming a direct relationship between fishing effort and number of vessels, the optimal fleet size to achieve MSY would be 16,790 vessels, implying that fleet capacity in the area would need to be reduced by 10,291 vessels. Assuming that such a reduction would be achieved through buy-back programs and that the cost to buy-back one vessel is €218.5

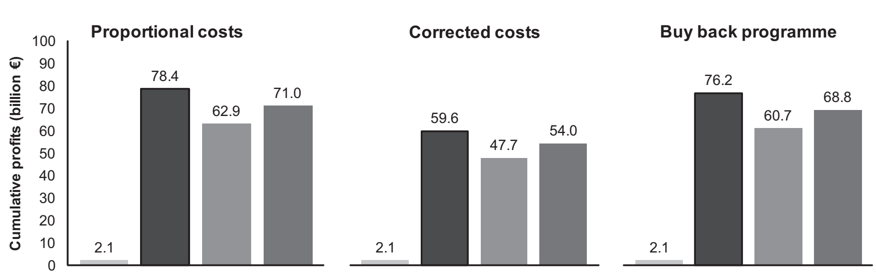

Fig. 3. Net present value of the EU fleet in the Northeast Atlantic under three MSY scenarios (F_{MSY} 2016 [black], F_{MSY} 2020 [light-medium grey], F_{MSY} incremental [dark-medium grey]) compared to the status quo (no action) [light grey] for the period (2016–2045). The MSY projections are calculated and illustrated here using three different cost assumptions.

thousand [25], the equivalent cost would be €2.25 billion. (Fig. 3).

When analysing the net present value for the period 2016–2045 (see Table 3), assuming an annual discount rate of 3%, our results indicate that under any of the three cost assumptions, all of the three alternative management scenarios to achieve F_{MSY} generate operating profit at least 22 times greater than the operating profit obtained if no action is taken. Moreover, by delaying the reduction in fishing mortality to F_{MSY} until 2020 instead of 2016, more than 31% of the potential operating profit is lost.

The third management scenario considered is to reduce fishing mortality progressively from 2016 so as to reach F_{MSY} in 2020. In this scenario, the estimated reduction in operating profit in the first year is lower than in management scenarios 1 and 2, but the subsequent increase above status quo operating profit does not occur until the third year (see Table A3 in the Appendix). Furthermore, the estimated net present value (in operating profit) for the period 2016–2035 is between 9% and 10% lower compared to the scenario in which F_{MSY} is achieved in 2016.

When the buy-back programme costs of €2.25 billion are taken into account, losses are expected in the first year that the programme is applied, but the benefits exceed the costs from the second year onwards (see Table A3 in the Appendix).

4. Discussion

Exploiting fish stocks at rates that will restore and maintain stock biomasses at levels capable of delivering MSY is a long-term goal of the CFP. Indeed, the Green paper on the CFP reform recommends achieving the goal of restoring fisheries to levels capable of producing MSY by 2015 [30]; while, the 2012 reform to the CFP (EU 2013a) requires all stocks to be fished at F_{MSY} by 2020. However, this goal has not been achieved for all stocks, and may in part be due to the annual TAC decision process for which 7 out of every 10 TACs were set above advice between 2001 and 2015. However, trends indicate that the level by which TACs are set above scientific advice is falling and that TACs are being brought more in line with scientific recommendations-a positive trend occurring alongside signs of stock recovery in some EU waters [31–33].

North Atlantic fisheries are currently producing less fish than in recent decades despite some yield improvements in recent years [4,5]. Nevertheless, for many fish stocks in EU waters, stock biomasses are less than those required to deliver MSY and many stocks are fished at a rate that is not consistent with achieving MSY.

Aggregated fisheries production functions are not new and have been used to assess the economic efficiency of global fisheries as a single exploited unit [9], at ecosystem level [14,34,35] and at species-EEZ level [11]. Alternatively, SPMs have been used to produce simple representations of the key ecological processes underlying fisheries [35]. For example, SPMs can be used to estimate biological reference points such as the biomass level and the rate of exploitation required to achieve the MSY of single fish stocks or marine ecosystems. SPMs allow the extension of fisheries assessment into other disciplines beyond ecology. It is used an aggregated form of a SPM to estimate the economic potential of European Northeast Atlantic fisheries under the assumption that the MSY from all stocks exploited by such fisheries can be achieved.

Outcomes from this study, despite the high uncertainty, confirm that effort and capacity of the EU fleet fishing in Northeast Atlantic waters need to be significantly reduced in order to achieve MSY and MEY management objectives. Moreover, results indicate that the EU fishing fleet could generate a high profitability if the biomass of all exploited stocks were to recover to B_{MSY} or B_{MEY} levels. Our estimates suggest that about €4.64 billion in operating profit per year (€7.38 billion in revenue minus €2.73 billion in costs) could be obtained from the Northeast Atlantic fisheries if the biomass of all exploited stocks were to recover to B_{MSY} and the EU fleet harvested the MSY. If Northeast Atlantic fisheries were managed at MEY, the EU fishing fleet could obtain €4.91 billion in operating profit. Even if these estimates may be imprecise, we consider that they are indicative of the relative magnitude of potential improvement in profits. Note however, the above results assume that catchability remains constant (no change in technical efficiency). However, if increases in technical efficiency were considered, the MSY could be achieved with a further reduction in fishing effort or number of vessels.

Profits are obtained from an increase in revenues and a decrease in costs. It is well-known that if stock biomasses were at levels supporting MSY or MEY they would be providing increased revenues. In addition, because of the important effort reductions that are required to deliver FMSY, total fishing costs would decrease significantly (about 35–50%). Even if the increase in profits only comes from the cost reduction side (a less uncertain result), it is still a significantly high value (about €2 billion), especially when compared to current profit of €0.10 billion. Anyway, similar estimates for managing the whole North Atlantic fisheries at MEY were obtained by Merino et al. [13], who estimated profit measured as economic EBIT to be €12.85 billion. These results are also in keeping with Crilly and Esteban [14] and Sumaila et al. [12] who confirm that investing to restore overexploited stocks is economically profitable. It should be noted that there is a trade-off between social (employment), biological and economic objectives; reductions in effort and capacity are needed to achieve maximum production or profits and assuming no major changes in fleet structure, will consequently be at the expense of employment levels.

Potential economic benefits from the sustainable exploitation of living marine resources, exceed the reported profit for the fishing sector [7]. Indeed, our operating profit estimates exclude benefits from related activities such as recreational fisheries, marine tourism, illegal fishing, the economic contribution of dependent activities such as fish processing, distribution, and consumption. It also excludes the value of biodiversity losses, pollution, greenhouse gas emissions and food security.

In this study there are employed three different cost assumptions to investigate the sensitivity of the economic performance of the EU fishing fleet operating in Northeast Atlantic waters when stocks are rebuilt to the levels capable of delivering MSY. In assumption 1, fishing costs are estimated as proportional to fishing effort and consequently reducing fishing effort to achieve a decrease in fishing mortality will lead to a proportional decrease in costs. In assumptions 2 and 3, rebuilding costs are assumed, as in Sumaila et al., [12] and Crilly and Esteban [14]. In assumption 2, it is assumed that costs are proportional to fishing effort (as for assumption 1), but in addition, it is continued to compensate the fishing effort that has been reduced with a 60% of the initial costs (e.g. compensation is paid to capital investments and crew). In the third assumption, it is assumed that costs are proportional to existing fishing effort as in assumption 1, with a buy back (scrapping) programme in the first year that purchases and removes all excess fishing vessels.

There is considerable debate among fisheries scientists on the utility of single-species MSY estimates as fishery management reference points. Such estimates have been criticised because it is ecologically and technically impossible to simultaneously fish all species at MSY level in a multiple species fishery [36]. Consequently, the multiple maximum sustainable yield (MMSY) of marine ecosystems is expected to be lower than predicted by the sum of single stocks' MSYs [15,35]. On the other hand, using current catch statistics to estimate MSY may underestimate the full potential of stocks after centuries of exploitation. In Table A1 in the Appendix there are reported the MSY estimates used in this study.

It is also important to take into consideration that MSY is a moving target. An improvement in exploitation pattern (an increase in the size and age of fish caught) gives rise to medium- to long-term increases in stock biomass and yields and consequently MSY also increases [37–40]. Similarly, if a stock is exploited by different fleets, yields can change when fishing patterns (relative fishing effort deployed by such fleets on different age- or size-groups of fish) change, so the MSY could increase by changing the allocation of effort between fleets so that the exploitation pattern improves [15]. For a given level of fishing effort, improvements in fishing pattern give rise to increased potential benefits in terms of landings weight and stock biomasses. However, improvements in fishing pattern also give rise to changes in MEY, *a priori* it is unclear whether such improvements would lead to improvements in economic performance and employment, as they could favour fleets that are less cost-effective or less labour intensive. Similarly the reallocation of quotas between fleets could lead to changes in the fishing pattern and consequently on the economic performance of the fleets and associated employment [41].

The sooner fishing mortality rates are reduced to F_{MSY}, the greater the profits' net present value from EU fisheries in the Northeast Atlantic. Even if time paths for stock recovery may be uncertain, economic benefits will be evident, also in the short-term. This is because the effort reductions alone lead to cost reductions and consequently to overall profitability increases by about €2 billion, Furthermore, even higher revenues can be obtained by fishing when biomasses are capable of delivering MSY. Note however that profitability increases from effort reductions are much more certain than those coming from biomass recoveries. Hence, if effort reductions are effected 5 years earlier, (significant) profits are also going to be achieved 5 years earlier. This 5-year lag has an important effect on the net present value.

Outcomes from our projections (see Table A3 in the Appendix) imply that during the first years of implementation, most of the improvements in economic performance come from the reduced costs associated with a reduction in the size of the fleet. But in the long-term, recovery of the stocks to levels capable of delivering MSY is the major source of increases in profitability, since results from this study suggest that it represents 63% of the profitability increase when considering the proportional cost assumption and 80% when considering the corrected cost assumption.

For the realization of this study it has been assumed all stocks (i.e., species) as one entity, behaving as the average of all individual stocks. Likewise, due to data limitations, it has also been assumed that all fleets and vessels behave identically. Despite the above, it is expected that the economic performance of all fleet segments will improve when fish stocks are rebuilt, but the extent of these improvements will vary by fleet segment and by country [6]. Such improvements will depend on the species composition of the catches by the different fleets because not all stocks are overexploited to the same degree. Furthermore, the potential for stock biomass to increase and the speed of stock rebuilding will vary depending on their life-history characteristics of the stock in question.

Stock recovery is highly species-dependent, with short-lived species having the ability to recover more rapidly than long-lived species. Costello et al. [42], found that under an optimal rebuilding strategy, fish stock recovery requires between 4 years and 26 years (with a mean of 11 years), depending on the species. Sumaila et al. [12] assume a rebuilding period of 10 years (as in the Magnuson–Stevens Fishery Conservation and Management Act of the USA). Our study is in line with these rebuilding timelines and suggests that with current exploitation patterns, once F_{MSY} is reached, it takes about 20 years to fully recover stocks and take the MSY (at 99.99%), but after the 6th year yields are over 90% of their full potential at MSY.

While the present study relates to the EU fisheries in the Northeast Atlantic, similar potential economic benefits can be expected in other areas if fish stocks can also be restored to MSY or MEY levels. In addition, the establishment of a discard ban in EU fisheries could help to recover fish stocks faster if it can decrease the fishing mortality levels.

5. Conclusions

The 2012 CFP reform [3] establishes the objective of restoring and maintaining populations of fish stocks above the biomass levels capable of producing the maximum sustainable yield (MSY) and in order to achieve this objective, the maximum sustainable yield exploitation rate is to be achieved by 2015 where possible and, on a progressive, incremental basis at the latest by 2020 for all stocks [3]. This implies that TACs should be set in accordance with F_{MSY}. Achieving such policy would result in great economic benefits and our results suggest that the EU fishing fleet could gain an extra €4.54 billion operating profit per year if all fish stocks in the Northeast Atlantic could be exploited at MSY. Alternatively, setting TACs that are not consistent with catches at F_{MSY} (i.e., postponing exploitation at F_{MSY}) could result in significant foregone profits in the medium- and long-term for the EU fleets operating in the Northeast Atlantic.

Reducing fishing mortality to F_{MSY} is estimated to produce, in the medium- and long-term, fisheries rents significantly higher than those obtained at current exploitation rates. The increase in medium- and long-term fisheries rents compensates the initial rebuilding costs just after few years. Moreover, the sooner fishing mortality rates are reduced to F_{MSY}, the greater the profits' net present value from EU fisheries in the Northeast Atlantic.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.marpol.2016.06.015.

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