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Bioeconomic multistock reference points as a tool for overcoming the drawbacks of the landing obligation

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The landing obligation policy was one of the major innovations introduced in the last Common Fisheries Policy reform in Europe. It is foreseen that the policy will affect the use of fishing opportunities and hence the economic performance of the fleets. The problem with fishing opportunities could be solved if single-stock total allowable catches (TACs) could be achieved simultaneously for all the stocks. In this study, we evaluate the economic impact of the landing obligation policy on the Spanish demersal fleet operating in the Iberian Sea region. To generate TAC advice, we used two sets of maximum sustainable yield (MSY) reference points, the single-stock MSY reference points defined by ICES and a set of multistock reference points calculated simultaneously using a bioeconomic optimization model. We found that the impact of the landing obligation is time and fleet dependent and highly influenced by assumptions about fleet dynamics. At fishery level, multistock reference points mitigate the decrease in the net present value generated by the implementation of the landing obligation. However at fleet level, the effect depends on the fleet itself and the period. To ensure the optimum use of fishing opportunities, the landing obligation should be accompanied by a management system that guarantees consistency between single-stock TACs. In this regard, multistock reference points represent an improvement over those currently in use. However, further investigation is necessary to enhance performance both at fleet level and in the long term.

Keywords: bioeconomic, fleet dynamics, landing obligation, management strategy evaluation, reference points.

Introduction

Fisheries management in Europe comes under the Common Fishery Policy (CFP). The CFP is revised every few years, with the latest reform having been made in late 2013. The main innovations were the landing obligation of all catches and a governance shift towards regions (Salomon *et al.*, 2014). The landing obligation policy will be introduced gradually, for some fleets the rule was implemented in January 2015 and for others it will not be brought in until 2019 (Salomon *et al.*, 2014). Although maximum sustainable yield (MSY) has been the management target in Europe for years, it was not until the last reform when it was introduced explicitly in the CFP.

The landing obligation is expected to have a huge impact on the performance of the fishing fleets, especially in the so-called mixed fisheries where a variety of stocks are caught simultaneously and they cannot discriminate among the stocks they catch. These fleets will be obliged to stop fishing when the quota of any one of the stocks they catch is reached. To reduce the impact of the landing obligation policy, the fleets could employ more selective gear or direct their effort to areas where the bycatch of unwanted stocks is lower. However, these measures are not always feasible or economically profitable. The major causes of discard in Europe are the minimum landing size, the total allowable catch (TAC) and quota limitations, and the low or null economic value of catches (Borges, 2015).

TAC advice in Europe has traditionally been given on a single-stock basis without taking into consideration the interactions among stocks at fleet level. Inconsistencies between single-stock TAC advice in a mixed fisheries context is an important reason for over-quota discards (Ulrich *et al.*, 2011). For this reason and in the wake of the closure of the cod fisheries in the North Sea in 2002, European fisheries scientists started working on reconciling single-stock TACs in a mixed fisheries context (Vinther *et al.*, 2004). Currently, the Fcube method (Ulrich *et al.*, 2011; Iriondo *et al.*, 2012) is routinely used to provide mixed fisheries advice in the North Sea (ICES, 2014a). Outside the framework of ICES, Da Rocha *et al.* (2012) have developed a bioeconomic model for calculating reference points in a mixed fisheries context. Fcube and the bioeconomic model of Da Rocha *et al.* (2012) can be used to produce consistent single-stock TACs, i.e. catch levels that in theory will be exhausted simultaneously for all stocks. While the Fcube method could be used to harmonize single-stock TACs produced independently at stock level, the fishing mortality targets obtained with the model of Da Rocha *et al.* (2012) could be used directly to produce consistent single-stock TACs.

Since its announcement in 2013, the landing obligation policy has provoked great expectations among local administrations, fishers, and scientists. During this time, several studies have been published dealing with discarding practices and the landing obligation policy. Batsleer *et al.* (2013), Condie *et al.* (2013, 2014), and Hatcher (2014) focused on incentives to fishers to comply with the landing obligation in various European fleets. Using different economic approaches, they all conclude that the landing obligation needs to be accompanied by strong controls and enforcement to reduce discards. Simons *et al.* (2015) used a bioeconomic model to evaluate the performance of two alternative discard-prevention strategies in the North Sea saithe fishery. They found that the negative effects of the landing obligation could be reduced by allowing a quota increase for the most restrictive stock at the expense of the quota for the least restrictive stock. For Iberian Waters, Fernandes *et al.* (2015) characterized the discards of trawler fleets and Wise *et al.* (2015) analysed the long-term bioeconomic effect of selectivity changes in Portuguese crustacean trawler fleets. The first found that the minimum landing size for hake and blue whiting high grading are the major reasons for discard in this fishery and Wise *et al.* (2015) concluded that improvements in selectivity have little effect on the revenue of the fleets, a positive effect on the biomass of some target species and reduced fish bycatch.

In this work, we focused on the Spanish demersal fishery operating in Atlantic Iberian waters and the main stocks they catch. The results in Fernandes *et al.* (2015) suggest that the landing obligation will significantly impact the performance of trawler fleets in this area. Apart from trawlers the fishery also comprises gillnetters and vessels using hooks and lines. In Iberian waters, the landing obligation is currently being implemented on a fishery-by-fishery basis, following the discard plans for Southwestern Waters (EU, 2014, 2015). From 1 January, 2015, the landing obligation was introduced for pelagic stocks. However, otter trawlers operating in Iberian Waters, which target pelagic stocks over several months, were not affected. From 2016 onwards, the discard plan for demersal species (EU, 2015) will affect fisheries targeting hake, nephrops, plaice and sole, which include the Spanish demersal fleets. The implementation date for megrim and anglerfish has not yet been set; hence, the fleets will be able to continue discarding their catches of these stocks. Fishers and the fishing industry recognize that discards are an unacceptable waste of natural resources that must be addressed. However, they consider that there is a lack of definition in the implementation of the landing obligation and they fear that there will be a big discrepancy between intended incentives and operational ones (De Vos *et al.*, 2016). They also think that this measure could give rise to a black market for juveniles, neutralizing all the efforts made so far by the administration to address this problem. In this regard, they agree to increased control and enforcement actions at the port (De Vos *et al.*, 2016).

At this time, Simons *et al.* (2015) are the only authors who have quantitatively forecast the effect of the landing obligation policy in European fleets using an integrated bioeconomic model. Their work focused on certain fleets operating in the North Sea, as well as the existing technical interaction between the saithe and cod stocks. However, the results obtained cannot be extrapolated to the Iberian demersal fishery system, where several stocks are caught simultaneously and fleets are segmented with different target and bycatch species.

Here, we used a bioeconomic management strategy evaluation (MSE) approach (Punt *et al.*, 2014) to analyse the impact of the landing obligation on the Iberian waters fishery system. Furthermore, we investigated whether the drawback of the landing obligation could be overcome using multistock reference points to produce TAC advice. To do this, we compared the bioeconomic performance of the system in eight scenarios, which differed in the reference points used, the implementation, or not, of the landing obligation and the model used to describe fleet dynamics. The work has stand-alone relevance, but also provides a tool that can be used to evaluate regional management plans for Iberian waters. The model has been conditioned following a participatory modelling process (Voinov and Bousquet, 2010) in the framework of the MyFish project (http://www.myfishproject.eu/). The stakeholders validated the tool qualitatively, gave us insight into the conditioning of the model and proposed management scenarios of their own that were later tested and presented to them.

Material and methods

The case study

Iberian waters comprise the northwestern waters of the Iberian Peninsula, corresponding to the ICES Divisions VIIIc and IXa (Figure 1). Portugal and Spain are the main countries operating in this area with France making a small contribution to the catch of some stocks. The demersal fleet catch comprises a great number of stocks, most of which have not an analytical assessment.

The fishery was made up of 2524 vessels grouped into seven fleet segments. Although our focus was the economic performance of the Spanish demersal fleets, the Portuguese fleets were also included because they account for the remainder of the catch of the majority of the stocks included in the simulation. The Spanish fishery comprises four fleet segments, gillnetters, demersal trawlers, vessels using hooks and lines, and purse-seiners. In turn the Portuguese fleet is composed of three segments, demersal trawlers, polyvalent artisanal fishing boats and purse-seiners. Purse-seiners are pelagic, but were included in the analysis because they account for the

Figure 1. Case study area.

entire catch of southern horse mackerel (*Trachurus trachurus*) not caught by the demersal fleets.

Eight stocks were explicitly included in the model, hake (*Merluccius merluccius*), megrim (*Lepidorhombus whiffiagonis*), four spot megrim (*L. boscii*), white anglerfish (*Lophius piscatorius*), mackerel (*Scomber scombrus*), southern horse mackerel (*T. trachurus*), western horse mackerel (*T. trachurus*) and blue whiting (*Micromesistius poutassou*). All these stocks are assessed analytically by ICES. The first four are demersal stocks whose distribution coincides with the area of interest. The rest are pelagic stocks and only the distribution of southern horse mackerel coincides with the study area. Mackerel and blue whiting are widely distributed and their range extends from Iberian waters in the south to the northern Norwegian Sea in the north. In turn, horse mackerel in the northeastern Atlantic is divided into three stocks, the two considered in this study correspond to the southern stock distributed throughout Iberian waters and the Western stock, which is found along the northeast continental shelf of Europe from the Bay of Biscay to Norway.

The contribution of the Iberian waters demersal fleets to the total catch of mackerel, blue whiting, and western horse mackerel is ∼3% for the first two stocks and ∼16% for the third. Moreover, these only contribute significantly to the catch and income of trawlers. However, these stocks could play a crucial role under the new European landing obligation policy (Salomon *et al*., 2014) if the low quotas combined with a high abundance of stocks convert them into choke species [a species whose quota corresponds to the lowest effort in a mixed fishery 'chokes' the opportunity of catching the quotas of the other species (Schrope, 2010)] for the fleets. The eight stocks included account for 34, 40, and 53% of the income of the gillnetters, longliners, and trawlers, respectively (Table 1). The majority of the remaining stocks caught by the fleets are not assessed by ICES and for those which are, the data necessary to condition the simulation model is not available. Hence, to account for the income from the stocks not considered in the study, an artificial stock was introduced into the model (denoted as OTH).

Table 1. Contribution of the stocks included in the model to the income of the Spanish Demersal fleets.

Fleet	Stock	Contribution to income (%)
Gillnetters	H.Mack (S)	1
	Hake	25
	Mackerel	5
	Anglerfish	3
	Total	34
Vessels using hooks and lines	Hake	26
	Mackerel	13
	Anglerfish	1
	Total	40
Trawlers	4S Megrim	5
	B.Whiting	3
	H.Mack (S)	1
	H.Mack (W)	4
	Hake	32
	Mackerel	5
	Megrim	1
	Anglerfish	2
	Total	53

All the stocks considered are subject to annual TAC and quotas. Technical measures such as limits on gear specifications, minimum landing sizes, and spatio-temporal closures are also in place. Although technical measures were not explicitly modelled, minimum landing size of hake and megrims were implicitly introduced in the model. In the projection discards-at-age were calculated using retention ogives. These ogives represented the proportion of catch-at-age that was landed and were calculated using historical landing and discard data at age. In historical data, undersized individuals were always discarded and hence this was the case in the projection.

In addition, a recovery plan for hake and Norway lobster (Council Regulation, CE 2166/2005) has been enforced in the area since 2006.

Data

Stock data used to condition the model were taken from ICES assessment reports: hake, the two megrims and anglerfish from ICES (2013b); southern horse mackerel from ICES (2013a); blue whiting, western horse mackerel and mackerel from ICES (2013c).

All the stocks, except hake and anglerfish, are assessed using annual-age-structured models and the outputs of the assessments were directly used to condition the simulation model. Hake and anglerfish are assessed using quarterly-length-structured assessment models, Gadget (Begley and Howell, 2004) and SS3 (Methot and Wetzel, 2013), respectively. For hake, quarterly length-based results were converted to annual age ones based on individual growth and mortality and for anglerfish the annual-age-based outputs of SS3 were used to condition the model.

Catch (landings and discards) and effort data by fleet and métier was compiled by national institutes, the IEO in Spain and the IPMA in Portugal, within the framework of the GEPETO project (Atlantic Area, 2011/1-159). Catch data included discard data for hake, megrims, and mackerel and it was equal to landings for the other stocks. The landings and effort data were based on official statistics (logbooks, sales notes, and fleet censuses) provided by the national administrations and discards were estimated using on-board sampling programmes of IEO and IPMA. The data were disaggregated by technical fleet groups as established by the European Data

Collection Framework (DCF; EC, 2008). The fleet segment was defined as a group of vessels using the same predominant fishing gear throughout the year. In turn, métiers were identified by cluster analyses of catch profiles per trip (Castro *et al.*, 2010; Punzón *et al.*, 2010). The list of métiers by fleet is given in Table 2.

Monthly fish price data from 2001 to 2012 for all the stocks were obtained from the regional government of Galicia (www.pescadegalicia.com). The data showed seasonal patterns and a weighted mean of the price over months was used to calculate the average annual price. The prices did not show any clear trend throughout the years and the average price for 2010 to 2012 was used to condition the model in the projection. Prices were only available at the regional level and the same price was used for all the fleets, métiers, and age groups. As the catch composition of the stocks included in OTH varied by métier, the mean price of OTH stock was calculated at métier level. Catch and price data for the stocks included in OTH, at métier level, were only available for 2011; hence, the mean price per ton at métier level in that year was used to condition the price of OTH stock in the projection. Fishing costs were obtained from the Annual Economic Report on the EU Fishing Fleet (STECF, 2014). The costs in the report were given by gear and vessel length and a weighted mean, using effort as weighting factor, was used to calculate them by gear. Fixed costs were calculated per vessel and by definition were assigned at fleet level. Variable costs were calculated by unit of effort and were only available at fleet level; hence, they were equal for all the métiers within the same fleet. Both costs were assumed to be constant throughout the simulation.

Simulation model, FLBEIA

The simulations were run using the bioeconomic integrated model FLBEIA (Garcia *et al.*, 2013; Jardim *et al.*, 2013; http://flbeia.azti.es/). This simulation framework follows the MSE approach (Punt *et al.*, 2014) and is built on FLR libraries (Kell *et al.*, 2007). In MSE approach, the models are divided into two main components the operating model (OM) and the management procedure (MP). The former describes the real system which includes the stocks and the fleets and the last the MP which includes the observed data, the estimated stocks and the management advice. FLBEIA provides different functions for modelling the processes that build-up the fishery system (stock dynamics, effort allocation, harvest control rules (HCRs), etc.) and the specific functions used in this work are described in the following sections.

Stocks

The five stocks distributed throughout Iberian waters were simulated using an age-structured exponential survival model together with a stock–recruitment model to generate the new cohorts. The recruitment of hake was modelled using the Bayesian Ricker model estimated in Cerviño *et al.* (2013). In each of the iterations of the model, a set of stock–recruitment parameters were randomly drawn from the joint posterior probability distribution. For the other stocks, a deterministic segmented regression model was adjusted to the historical recruitment and spawning-stock biomass (SSB) data. Recruitment uncertainty in the projection was introduced using a multiplicative lognormal error around recruitment point estimates. The median of the error was equal to one and the coefficient of variation was equal to the historical one obtained in the model fit. Thus, hake's recruitment had two sources of uncertainty, one coming from the random Bayesian parameters and a second one arising from the uncertainty around the model curve.

In the projection, the abundance of widely distributed stocks, blue whiting, western horse mackerel and mackerel, was maintained constant and equal to the 2010–2012 mean level. The biomass of OTH stock was also constant and equal to one thousand billion (1e12) tons throughout the simulation. The biomass level was set sufficiently high to ensure that it would not restrict the catch of OTH stock in the projection.

The biological parameters, natural mortality-, weight-, and maturity-at-age were considered constant and equal to the average of last 3 data years for all the stocks. In the case of widely distributed stocks, as population size was constant in the simulation, only weight-at-age was used.

Fleet dynamics

The catch was generated using a Cobb-Douglas production function (Cobb and Douglas, 1928) with constant return to scale (elasticity parameters equal to 1). Historical catchability (2010–2012) was calculated using historical biomass and effort data in the Cobb-Douglas function, i.e. catchability was equal to catch divided by the product of biomass and effort. In the projection, catchability was assumed to be constant and equal to the 2010–2012 average. Effort share between métiers was constant and equal to the average of the last 3 years in the traditional fleet dynamics approach and was a model variable in the profit maximization approach. Selectivity-at-age was implicitly included in catchability, assuming catchability is the product of selectivity, vulnerability and availability (Arreguín-Sánchez, 1996). Hence, it was constant and equal to the average of the last three data years. In turn, the catch was divided into landings and discards using a retention ogive that was calculated as a ratio of landings- and catch-at-age data. In the projection, the average of last three years' retention ogives was used. The only fleets with discards were the trawlers, which discarded hake, megrims and mackerel.

Table 2. List of métiers by fleet with the notation used along the text and figures and a short description.

Fleet(s)	Métier	Description
Trawlers	OTB_DEF	Bottom otter trawl targeting hake, anglerfish and megrim using "Baka" nets
	OTB_MPD	Bottom otter trawl targeting mixed pelagic and demersal fish using "Baka" nets
	PTB_MPD	Bottom pair trawl targeting mixed pelagic and demersal fish
Vessels using hooks and lines and gillnetters	GTR_DEF	Trammel-net targeting demersal fish with mesh size range 60–79
	LHM_DEF	Handline targeting demersal fish
	LLS_DEF	Longline targeting demersal fish
	GNS_DEF_≥100	Set gillnet targeting demersal fish with mesh size ≥100
	GNS_DEF_60–79	Set gillnet targeting demersal fish with mesh size range 60–79
	GNS_DEF_80–99	Set gillnet targeting demersal fish with mesh size range 80–99

The métiers in vessels using hooks and lines and gillnetters are the same.

The short-term dynamics of Spanish demersal fleets were simulated using two different approaches, one based on tradition and another on profit maximization. For the Portuguese fleets and Spanish purse-seine fleet only the traditional approach was used because no economic data were available.

The traditional fleet dynamics approach was based on the Fcube method (Ulrich *et al.*, 2011). The effort share between métiers in the projection was constant and equal to the last 3 years' average. Total effort was calculated in each step based on the quota share of the stocks caught by the fleet. First, the total effort that corresponded to the catch quota of each of the stocks ($E_{st,y}$) was calculated. Then, assuming no landing obligation, the effort that was closest to that of the previous year was selected, mathematically:

$$E_y = E_{st_0,y}, \quad \text{where} \quad \left|1-\frac{E_{st_0,y}}{E_{y-1}}\right| = \min_{st}\left(\left|1-\frac{E_{st,y}}{E_{y-1}}\right|\right) \tag{1}$$

where y and st are the subscripts for year and stock, respectively, and E_y is the total effort in year y. Under the landing obligation policy, as over-quota discards were not allowed, total effort was equal to the lowest effort, mathematically:

$$E_y = \min_{st}(E_{st,y}) \tag{2}$$

In the profit maximization approach, the effort share between métiers and the total effort to maximize profits were calculated using an optimization algorithm. The optimization was restricted by the capacity of the fleet and the hake quota, assuming no landing obligation and by all the quotas subject to the landing obligation. Mathematically:

$$\max_{E_y,\gamma_1,\ldots,\gamma_{N_{\text{met}}}}\left(\sum_{m=1}^{N_{\text{met}}}\left(\sum_{st\in\Delta_m} C_{y,st,m}\cdot \mathrm{Pr}_{st} - \gamma_{y,m}\cdot E_y\cdot VC_m\right) - FxC\cdot N_{ves,y}\right) \tag{3}$$

with the following restrictions:

$$\begin{aligned}
&C_{HKE} \le TS_{HKE} \quad \text{or} \quad C_{st} \le TS_{st} \ \text{for} \ \forall \ \text{st} \in \Delta \\
&0 \le \gamma_1,\ldots,\gamma_{N_{\text{met}}} \le 1 \\
&\sum_{m=1}^{N_{\text{met}}} \gamma_m = 1 \\
&E \le K
\end{aligned} \tag{4}$$

where m is the subscript for métier, C denotes catch in weight, Pr is stock price, γ_m is the proportion of effort that the fleet exerts in métier m, VC are the variable costs per unit of effort, FxC are the fixed costs per vessel, N_{met} and N_{ves} are the number of métiers and number of vessels, respectively, Δ_m and Δ represents the set of stocks caught by the métier m and the fleet respectively and TS_{st} denotes the fleet's TAC share of stock st. Finally, K is the capacity of the fleet, defined as the maximum effort that a fleet can exert annually. While the restrictions in equation (4) are fulfilled, according to equation (3) the system has full flexibility to expend the effort in any of the métiers. On the other hand, it should be noted that with this model, the overall selection pattern of the fleet alters with the change of effort distribution between métiers. All the variables used in equations (1)–(4), except price, are fleet specific, but fleet subscripts have been omitted for simplicity.

The long-term dynamics of the fishery, i.e. the entry and exit of vessels in the fishery, were modelled using the model described by Salz *et al.* (2011). Here, the (dis)investment in vessels depends on the difference between revenue and the amount of revenue needed to cover both fixed and variable costs. If the difference is positive and the fleet is operating at full capacity, the number of vessels is increased. On the contrary, if the difference is negative the number of vessels is decreased. The annual variation was restricted to 3% because historically the decrease in capacity has always been <3%. Furthermore, no more than 20% of the profits could be used to buy new vessels. The investment data from different Basque fleet segments (purse-seiners, hookers, and trawlers) was compared with their profits. There was enormous interannual variability in the resulting percentages and the average between segments (20%) was used to condition the model. The model was only applied to the Spanish demersal fleets, for the rest of the fleets the number of vessels was kept constant.

The management procedure

Within the MP the focus of this study was in the performance of the HCR. Hence, it was assumed that the data (landings- and discards-at-age) and the stock status were known without error. The difference between the real system in the OM and the data used to generate management advice in the MP arose from the 2 year time-lag between the data used to calculate and to implement the TAC. As it happens in reality where the TAC for certain year y, is calculated the year before, $y-1$, using data and stock estimates up to previous year, $y-2$. Hence, when the fleets caught the TAC in year y, the stocks in the real system could be different from the estimated stocks used to calculate the TAC.

From 2013 to 2015, historical TACs were utilized instead of using an HCR to produce them. From 2016 onwards, the ICES MSY framework HCR (ICES, 2012) was used to generate annual TAC advice. The objective of this HCR is to maintain stock exploitation at levels in accordance with MSY. The HCR uses three reference points, a fishing mortality target, F_{msy}, and two SSB reference points, B_{trigger} and B_{lim}. When the SSB of the stock is above B_{trigger} the TAC advice corresponds to F_{msy} and when it is between B_{trigger} and B_{lim}, the fishing mortality is decreased linearly. Below B_{lim} ICES has not defined a universal rule and in this study we used zero TAC advice. The fishing mortality was translated into TAC using the Baranov catch equation. Biomass reference points were not available either for the demersal stocks or the southern horse mackerel. For these stocks, the biomass references points were computed using a common ICES approach where B_{lim} is set as the lowest biomass observed in the historical time-series and B_{trigger} is equal to B_{lim}*1.4 (Hauge *et al.*, 2007).

Single-stock fishing mortality targets (F_{msy}) for demersal stocks and southern horse mackerel were taken from ICES assessment reports (ICES, 2013a, b). Multistock fishing mortality reference points were calculated using the bioeconomic optimization model developed in Da Rocha *et al.* (2012). The reference points corresponded to those that maximize the net present value (NPV) of the whole fishery using a discount factor of 5%. The model returns a multiplier that applied to the *statu quo* reference fishing mortalities of the stocks result in a fishing mortality that could produce the highest NPV in the long term while maintaining biomasses above given reference points. The discount factor was selected based on macroeconomic literature (Prescott, 1998) which considers 5% an adequate value for calibration. The *statu quo* reference fishing mortality for each stock was calculated as the average over the last 3 data years (2010–2012) and the reference age range. The reference age ranges were taken from assessment reports (ICES, 2013a, b). For widely distributed stocks, instead of an HCR, a constant catch quota equal to the mean catch quota of last 3 years was used.

The landing obligation was implemented in 2018. Although the fishing mortality targets in the HCR were the same prior and after that year, up to 2017 the TAC was given in terms of landings and after 2017 in terms of catch. To calculate the TAC in terms of landings, the retention ogive resulting from dividing landings- by catch-at-age was used.

Scenarios

Eight scenarios were run which depended on:

- The fishing mortality target used in the HCR: single-stock reference points used by ICES (denoted as "ices"), or multistock reference points calculated using the bioeconomic model (denoted as "msmsy").
- Fleet dynamic model using either a traditional approach (denoted as "trad") or profit maximization approach (denoted as "mpro").
- Implementation, or not, of the landing obligation (denoted as "lo").

The eight scenarios resulted from a combination of the two options in each of the three points above. As the objective of the study was to evaluate whether multistock reference points overcome the drawbacks of the landing obligation, we had to compare the current management scenario, i.e. ICES reference points and no landing obligation, with the scenarios including the landing obligation and both sets of reference points. Additionally, we combined these scenarios with two contrasting hypotheses on fleet dynamics because there was a high uncertainty related to their real dynamics and this could have a high impact on the results. Table 3 lists the notation used for each scenario with the options used. Each scenario was projected from 2013 to 2025 using 250 independent iterations run in parallel.

Table 3. List of scenarios with the modelling options used in each.

Scenario	Reference points	Fleet dynamics	Landing obligation
ices_trad	ices	Traditional	No
ices_mpro		Profit maximization	
msmsy_trad	msmsy	Traditional	
msmsy_mpro		Profit maximization	
ices_trad_lo	ices	Traditional	Yes
ices_mpro_lo		Profit maximization	
msmsy_trad_lo	msmsy	Traditional	
msmsy_mpro_lo		Profit maximization	

Indicators

The performance of the system was analysed using a set of indicators, at stock, fleet, and fishery levels to analyse the biological sustainability and economic performance of the system:

-$p(SSB < B_{\mathrm{lim}})$ and $p(SSB < B_{\mathrm{trigger}})$: for each stock and year, the probability of being below B_{lim} and B_{trigger}, respectively, calculated as the ratio between the number of iterations where SSB was below the reference biomass and the total number of iterations. This indicator measures the sustainability of the management strategies in biological terms.

-*Quota uptake:* for each stock, fleet, and year, the ratio between the catch and the quota advice minus one. It shows the use of quotas at fleet level. With no landing obligation a value >0 indicates the existence of discards. Under the landing obligation, it is always $< = 0$. The stocks with quota uptake equal to zero are the stocks that limit the fleet's activity, which in cases where the quota is very small may act as choke species, severely constraining the possibility of the fleet to catch its fishing opportunities. Stocks with values close to -1 indicate wastage of fishing opportunities.

-Profits: the profits for each fleet and year, calculated as the revenue minus total costs. Total costs were calculated as the sum of fixed costs and variable costs. In turn, fixed costs were equal to $Nves{\cdot}FxC$ and variable costs to $E{\cdot}VC$. This indicator measures the annual economic performance of the fleets.

-Effort share: the proportion of effort exerted by each fleet in each métier and year. In the traditional approach scenario, this indicator is constant by definition. In the profit maximization scenario, it shows the métier combination resulting in the highest profits under the given restrictions.

-NPV: the NPV of the Spanish fleet in the projection period using a discount factor of 5%, mathematically:

$$NPV = \sum_{y=2016}^{2025} \frac{Pr\,f_y}{1.05^{y-2015}}$$

where PrF_y denotes profits in year y. This indicator measures the profitability of the whole Spanish fishery over the entire projection period taking into account the fact that 1 euro today is more valuable than 1 euro will be in 15 years time.

Results

The results were analysed at stock level for the stocks distributed exclusively in Iberian waters and at fleet level for Spanish demersal fleets.

Stock level

Reference points

Multistock and ICES fishing mortality targets and biomass reference points per stock are shown in Table 4. Multistock reference points implied a 30% reduction in *statu quo* fishing mortalities. The multistock reference points were lower than the ICES single-stock estimates except for hake, which showed an ~80% higher estimate.

The biomass reference points were well below the SSB in the most recent historical years for all the stocks except horse mackerel. The SSB in the initial year of the simulation was well above B_{lim} for all the stocks except horse mackerel, where the SSB was only 4% higher.

Table 4. ICES and multi-stock fishing mortality targets and biomass reference points, in thousands of tons, for the stocks distributed along Iberian Waters exclusively.

Hake	H.Mackerel	Megrim	Four spot megrim	Anglerfish
0.24	0.11	0.17	0.18	0.19
0.43	0.07	0.11	0.16	0.11
8 836	215 571	605	3205	1925
12 371	301 799	846	4487	2695

Spawning-stock biomass

The probability of SSB being below B_{lim} was positive only for southern horse mackerel in the last 2 years of the two "ices" scenarios with no landing obligation (Table 5). However, the probability was low (<3%).

The probability of being below B_{trigger} was positive, in at least 1 year, for southern horse mackerel in all the scenarios, as well as for the megrims in the "msmsy_mpro" scenario (Table 5). The probability for the megrims was always <4%. For southern horse mackerel, the probability of being below B_{trigger} in the scenarios with no landing obligation and "ices" reference points was >20% for all the years from 2019 onwards. On the other hand, the probability in the scenarios with the landing obligation and "msmsy" reference points was always <3%. In the "ices_mpro_lo" scenario, the probability from 2018 to 2021 decreased from 18 to 11%. In the other cases, the probability was always <10%.

Fishing mortality

In the scenarios with the landing obligation, fishing mortality decreased significantly when it was introduced in 2018. Beginning in that year, the fishing mortality time-series became fairly stable throughout the projection in all the scenarios. In 2025, under the landing obligation, fishing mortality for all the stocks was well below the target (Figure 2). Under the current management framework and "ices" reference points, fishing mortality was above the target only for hake (Figure 2). In contrast, using "msmsy" reference points the fishing mortality of hake was the only one below the target. For the other stocks, the fishing mortality was around the target, except anglerfish and four spot megrim in the profit maximization scenario, where the target was exceeded. In general, the uncertainty was low and under the landing obligation it was even lower. The scenarios with the highest uncertainty corresponded to profit maximization scenarios.

Fleet level

Profits

The profits were highly affected by the fleet dynamics model. In the short term, there was an adjustment period with high interannual variability, but in the long term the time-series were fairly stable. Under both fleet dynamics models, the effect of the landing obligation and reference points was fleet dependent.

In the traditional fleet dynamics scenario, vessels using hooks and lines obtained higher profits when the landing obligation policy was in place, both in the short and long term (Figure 3). Furthermore, the increase in profits was enhanced by the use of "msmsy" reference points. On the contrary, the profits of trawlers were lower, although the difference was somewhat reduced in the long term (Figure 3). In the short term, the profits obtained in the "msmsy_trad_lo" scenario were almost the same as those obtained in the "ices_trad" scenario. However, in the long term, the profits in "msmsy_trad_lo" scenario were significantly lower. The landing obligation caused a decrease in the profits of the gillnetters in the first years of implementation and an increase in the final year of simulation (Figure 3). As with trawlers, the use of "msmsy" reference points cushioned the impact of the landing obligation in the short term, but it generated a loss in profits in the long term.

In the profit maximization dynamics scenario, the landing obligation produced a decrease in the profits of vessels using hooks and lines and trawlers in the short term (Figure 3). For gillnetters, the profits were slightly higher. Using "msmsy" reference points under the landing obligation resulted in higher profits than "ices" reference points for all the fleets. However, in the short term, they did not cover the losses seen in trawlers and vessels using hooks and lines. In the long term, profits were covered for the vessels using hooks and lines, but not for trawlers. In general, the loss in profits derived from the landing obligation under profit maximization dynamics was lower than that seen for traditional fleet dynamics.

Quota-share utilization

By definition, under the landing obligation policy, the quota was not exceeded for any of the stocks.

In the traditional fleet dynamics scenario, quota uptakes in 2025 were low in general and even lower under the landing obligation (Figure 4). The effect of "msmsy" reference points was slight and stock dependent. For gillnetters and trawlers, the utilization under the landing obligation was lower than under the current management framework and for vessels using hooks and lines it was higher (Figure 4). Southern horse mackerel and hake were the limiting stocks for gillnetters (Figure 4). Furthermore, the former was a choke stock which produced a decrease of 23% in profits (Figure 3). In the scenarios with no landing obligation and when these stocks were not limiting the effort, their quota was exceeded.

Table 5. Probability of SSB being below B_{lim} and B_{trigger} from 2013 to 2025.

Scenario	Stock	Indicator	2013 (%)	2014 (%)	2015 (%)	2016 (%)	2017 (%)	2018 (%)	2019 (%)	2020 (%)	2021 (%)	2022 (%)	2023 (%)	2024 (%)	2025 (%)
ices_trad	Southern	$p(SSB < B_{\mathrm{trigger}})$	100	0	0	0	0	10	26	36	42	38	35	50	62
msmsy_trad	Horse		100	0	0	0	0	2	7	12	12	6	3	6	11
ices_trad_lo	Mackerel		100	0	0	0	0	10	9	9	6	3	1	1	2
msmsy_tradlo			100	0	0	0	0	2	1	2	1	0	0	0	0
ices_mpro			100	0	0	0	2	18	35	44	51	52	48	65	74
msmsy_mpro			100	0	0	0	0	0	3	6	6	4	1	4	6
ices_mpro_lo			100	0	0	0	2	18	18	15	11	4	1	2	2
msmsy_mpro_lo			100	0	0	0	0	0	1	1	0	0	0	0	0
ices_trad	Southern	$p(SSB < B_{\mathrm{lim}})$	0	0	0	0	0	0	0	0	0	0	0	0	1
ices_mpro	H. Mackerel		0	0	0	0	0	0	0	0	0	0	0	1	2
msmsy_mpro	4S Megrim	$p(SSB < B_{\mathrm{trigger}})$	0	0	0	0	0	0	2	2	2	2	2	2	3
msmsy_mpro	Megrim		0	0	0	0	0	0	1	0	0	0	0	0	0

Only the stocks and scenarios for which the probability is positive for any of the years is shown. Dark grey indicates probabilities >15%, grey indicates probabilities between 6 and 15%, and light grey indicates probabilities between 1 and 5%.

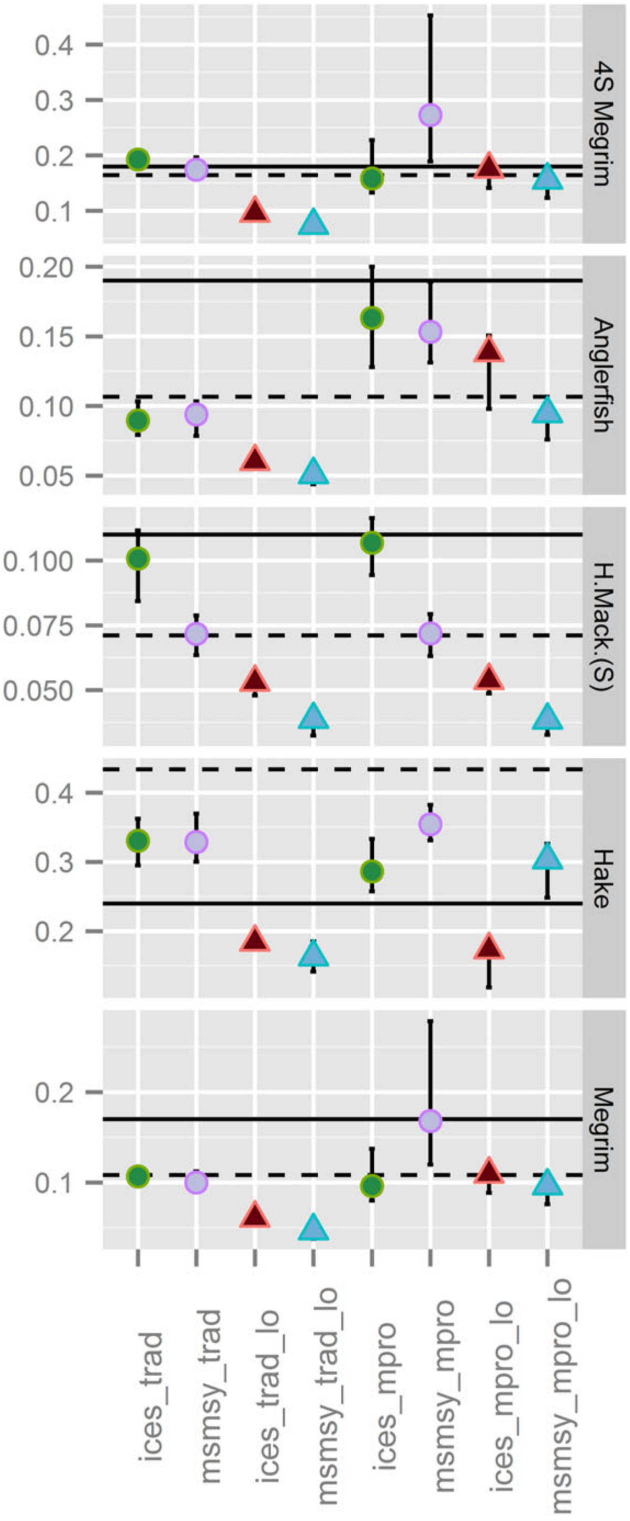

Figure 2. Fishing mortality in 2025. The points indicate the median value and the vertical lines the 5 and 95% confidence intervals. Circles correspond to scenarios without landing obligation and triangles to scenarios with landing obligation. Horizontal lines correspond to fishing mortality targets, solid one correspond to "ices" reference points and dashed one with "msmsy" ones. This figure is available in black and white in print and in colour at *ICES Journal of Marine Science* online.

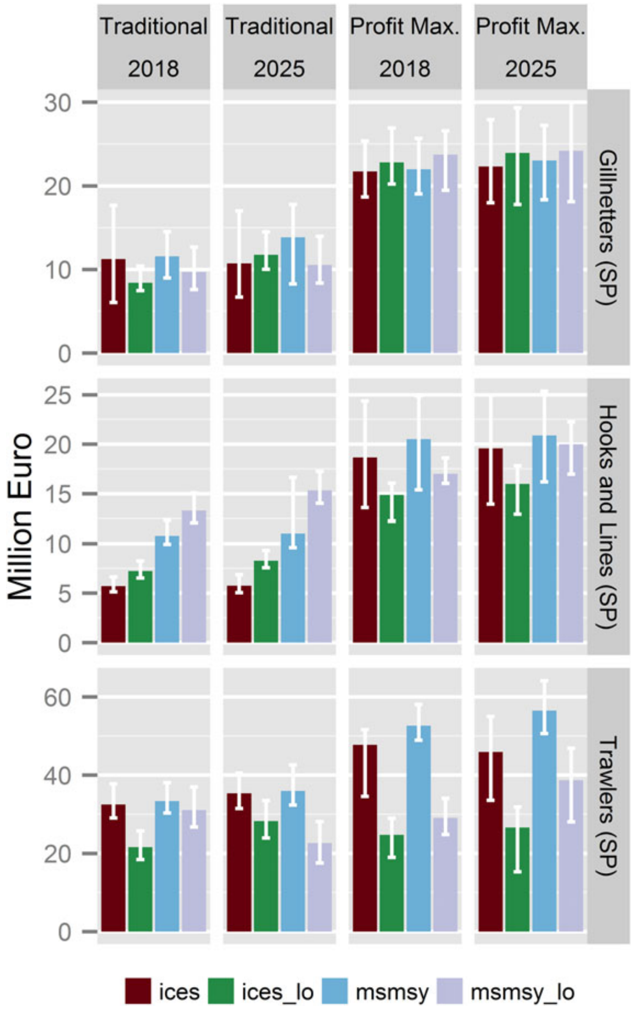

Figure 3. Spanish demersal fleets' profits in 2018 and 2025 by fleet dynamics model scenario. Bars correspond to median values along iterations and vertical lines to 5 and 95% confidence intervals. This figure is available in black and white in print and in colour at *ICES Journal of Marine Science* online.

The quota uptake of anglerfish was significantly higher in the scenarios with "msmsy" reference points. The quota uptake of mackerel and OTH catch was slightly affected by the landing obligation. Hake was always the limiting stock for vessels using hooks and lines and the quota was not exceeded for any of the stocks (Figure 4). The quota uptake of non-hake stocks was >20% higher when "msmsy" reference points were used. The effort of trawlers was restricted by the western horse mackerel quota when there was no landing obligation. With the landing obligation southern horse mackerel and hake became the choke stocks in the "ices" and "msmsy" reference point scenarios causing a loss of 20 and 36% in profits, respectively (Figures 3 and 4).

Using profit maximization fleet dynamics, the quota uptake and over-quota in 2025 was significantly higher than under traditional fleet dynamics (Figure 4). The gillnetters' quota of southern horse mackerel was highly underutilized in all the scenarios except in the "mpro_msmsy" scenario (Figure 4). In contrast, the quotas of hake, mackerel and anglerfish were almost fully consumed in all the scenarios. The catch of OTH stock was always above the historical catch particularly in “msmsy” scenarios. Vessels using hooks and lines fully consumed their quota of hake and mackerel in all the scenarios (Figure 4). The over-quota of some stocks in vessels using hooks and lines and trawlers was very high and it was even higher when “msmsy” reference points were used (Figure 4). The catch of OTH stock was higher than historical catch only when the landing obligation was not in place (Figure 4). The quota of blue whiting was highly underutilized in all the scenarios. For trawlers, the quota utilization under the landing obligation was significantly higher when using “msmsy” reference points.

Effort share

In vessels using hooks and lines, almost all the effort concentrated in a métier that was minor in the past (GTR_DEF); on the other hand,

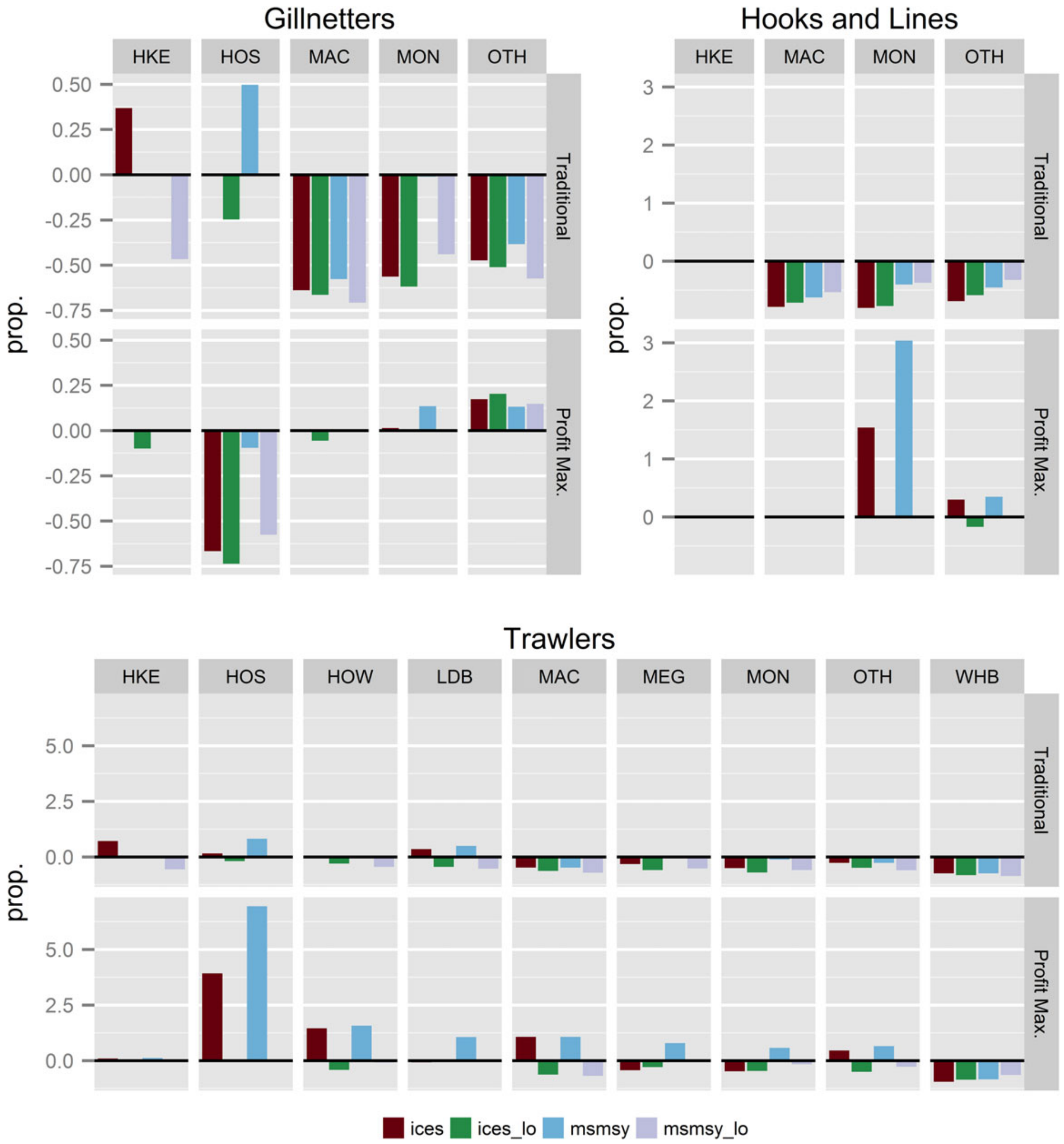

Figure 4. Spanish demersal fleets’ quota uptake in 2025 by fleet dynamics model scenario. Bars correspond to median values. For OTH stock, the bar corresponds to the ratio between catch in 2025 and historical catch instead of quota uptake. The labels in the columns correspond to stock names, HKE to hake, HOW to western horse mackerel, HOS to southern horse mackerel, LDB to four spot megrim, MAC to mackerel, MEG to megrim, MON to monkfish, OTH to other stocks and WHB to blue whiting. This figure is available in black and white in print and in colour at *ICES Journal of Marine Science* online.

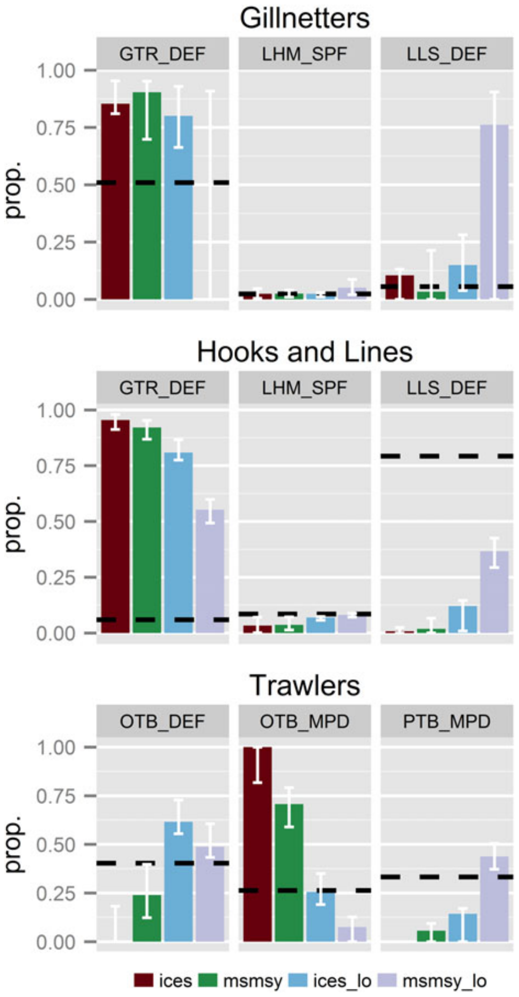

Figure 5. Spanish demersal fleets' effort share in 2025 in profit maximization fleet dynamics scenarios for the most important métiers. Bars correspond to median values, vertical lines with 5 and 95% confidence intervals and dashed horizontal lines to the average historical effort share in each of the métiers. This figure is available in black and white in print and in colour at *ICES Journal of Marine Science* online.

the effort in the principal métier (LLS_DEF) was low in general (Figure 5). The effort distribution of gillnetters was concentrated in the métier with the highest effort in the historical period, except in the "msmsy_mpro_lo" scenario (Figure 5). In this scenario, the uncertainty was very high and although in median 75% of the effort concentrated in one métier (LLS_DEF) the 90% probability interval covered almost the whole domain. The effort share per scenario in trawlers was more variable than in the rest of the fleets (Figure 5). With no landing obligation, the effort concentrated in the OTB_MPD métier, especially for "ices" reference points where, in median, all the effort was exerted in this métier. Under the landing obligation, the effort distribution was more heterogeneous and closer to the historical effort distribution. Except in the "msmsy_mpro_lo" scenario for gillnetters, the uncertainty was low.

Net present value

The "msmsy" reference points were designed to maximize NPV, as such these scenarios performed better with relation to NPV than the homologous "ices" scenario.

Table 6. Net present value of demersal Spanish fleets in each scenario.

Scenario	Euros	Difference with current management (%)
ices_trad	556	–
msmsy_trad	597	107
ices_trad_lo	517	93
msmsy_trad_lo	558	100
ices_mpro	888	–
msmsy_mpro	969	109
ices_mpro_lo	778	88
msmsy_mpro_lo	870	98

Current management refers to "ices_trad" and "ices_mpro" scenarios (ices reference points and no landing obligation).

The highest NPV was obtained when no landing obligation was combined with "msmsy" reference points and the lowest was obtained under the landing obligation and "ices" stock reference points, independently of the fleet dynamic model used (Table 6). The loss in profits under the landing obligation was reduced when "msmsy" reference points were used. The NPV under traditional fleet dynamics, landing obligation and "msmsy" reference points (msmsy_trad_lo scenario), was slightly higher than the NPV under current management framework ("ices_trad" scenario), (Table 6). Using profit maximization dynamics, the NPV in"msmsy_mpro_lo" scenario was lower than under the current management framework ("ices_mpro" scenario), but was significantly higher (12%) than using single-stock reference points with the landing obligation (ices_mpro_lo scenario) (Table 6).

Discussion

This study analysed the bioeconomic performance of the Iberian waters demersal fishery system under different management scenarios. They are distinguished by the reference points used and the implementation, or not, of the landing obligation policy. Moreover, two different fleet dynamic models were used to describe the fleet behaviour, one based on tradition and another on profit maximization. Various indicators at stock, fleet, and fishery level were analysed to evaluate the sustainability of the management strategies and investigate whether the loss in the profits of the fleets caused by the landing obligation can be overcome using multistock reference points.

Performance of multistock reference points

This is the first time that multistock reference points, as proposed by Da Rocha *et al.* (2012), have been tested at fleet level. Their implementation in practice has been proved to partially overcome the loss in profits under the landing obligation. At the fishery level, "msmsy" reference points compensated the losses derived from the landing obligation using current "ices" reference points, independent of the fleet dynamics employed. The lower profits seen in "msmsy_mpro_lo" and "msmsy_trad_lo" scenarios compared with those in "ices_mpro" and "ices_trad" scenarios in some fleets were compensated for by higher profits in other fleets. At fleet level, this depended on the fleet itself and the period. Under profit maximization, "msmsy" reference points always compensated, to some extent, the losses of the landing obligation, independent of the period and fleet. Under traditional fleet dynamics, "msmsy" reference points compensated for the losses in all the fleets in the short term, although in the long term, under the landing obligation, the profits of trawlers and gillnetters were lower in "msmsy_lo" scenarios.

Multistock reference points were estimated by multiplying the *statu quo* fishing mortalities by a common factor. Therefore, as *statu quo* fishing mortalities were, in percentage, at the same distance from the targets, a simultaneous depletion of the catch quotas of these stocks was expected. However, this did not occur in any of the "msmsy" scenarios. There were two differences between the real system and the MP which precluded the simultaneous exhausting of quotas. First, in the real system, the catch was calculated using the Cobb-Douglas function and in the MP the TAC was calculated using Baranov catch equation. Cobb-Douglas function assumes a non-linear relationship between the two inputs (fishing effort and biomass) and the produced catch and is widely used in bioeconomic fleet dynamic models. On the contrary, in age-structured stock assessment models, Baranov catch equation is the most common relationship used to generate catch as a function of fishing mortality. Second, as the TAC is calculated the year before its implementation using data up to 2 years before, there was a 2-year time-lag between the calculation of the TAC in the MP and its implementation in the real system. Moreover, in the profit maximization scenarios, there was a third difference: the overall selection pattern varied between the real system and the MP.

Stock sustainability

Both sets of reference points, single- and multistock, were precautionary in the sense defined by ICES (ICES, 2014b), i.e. the probability of being below B_{lim} was $<5\%$ for all the stocks and scenarios. For hake, where the multistock reference point was almost double than the ICES reference point, the biological risk for the stock was not increased. This was not surprising given that the hake multistock reference point is between Beverton–Holt (0.23) and Ricker (0.56) MSY fishing mortalities estimated by Cerviño *et al.* (2013) and the stock–recruitment model used to simulate recruitment was the Ricker model proposed in that study. This suggests that current hake fishing mortality target could be increased without increasing the risk for the stock. However, to propose this as a new management target, at least its robustness to different stock–recruitment dynamics should be evaluated.

Impact of the landing obligation at fleet level

The impact of the landing obligation depended on the fleet, the fleet dynamic used and the period (short or long term). The landing obligation rewarded the most selective fleets, namely vessels using hooks and lines and gillnetters, as observed in Condie *et al.* (2014). The catch quota utilization of these fleets was higher and therefore so were their benefits. Moreover, these fleets do not have undersize discarding like trawlers, hence the quota uplift derived from generating the TAC in terms of catch instead of landings since the implementation of landing obligation fully contributed to their landings. However, the trawlers had to use this increment to cover the undersize discards that counted towards the quota and did not produce any revenue. Here, the quota uplift was divided among fleets in the same percentages as the TAC quotas. In reality, it will be distributed per country using relative stability and, thereafter, member states could use it to compensate the fleets most affected by the landing obligation. Which will beneficiate the corresponding fleets but reduce the CFP objective of improving selectivity by reducing catches of small individuals.

The catch quota uptake by vessels using hooks and lines and gillnetters depended on fleet dynamics. Under traditional dynamics, quota utilization was higher for hookers and lower for gillnetters, while this was reversed in a profit maximization scenario (Figure 4). When the landing obligation was implemented, that resulted in an increase in the profits of vessels using hooks and lines under traditional fleet dynamics and those of gillnetters under profit maximization dynamics. In trawlers, the quota utilization was always lower under the landing obligation and thus the profits were always lower regardless of the fleet dynamics employed.

Jardim *et al.* (2010) analysed the recovery plan of southern hake using alternative fishing mortality targets combined with different discard scenarios. They concluded that $F_{\max} = 0.25$ combined with a total discard ban would be the best strategy in terms of sustainability and total yield. Furthermore, they suggested that the fishery would be more profitable under a discard ban scenario, in contrast to the results obtained in this study. They analysed the problem from a single-stock and single-fleet point of view and linked the discard ban to a hypothetical change in selection pattern leading to a very different conclusion about the effect at fishery level. This difference highlights the importance of using multifleet approaches and including all the stocks caught by the fleets when analysing the economic performance of any management strategy. This is especially relevant for selectivity scenarios where the benefits forecasted from a single-stock perspective could not compensate for the losses derived from the decrease in the catch of other stocks.

The importance of selectivity under the landing obligation

The métier definition uses data from the European DCF that groups trip data with common gear, vessel size, target ecological group, and mesh size. This level of aggregation may underestimate the ability of vessels to discriminate between species. On the one hand, this is because ecological groups do not distinguish the stocks within a group and on the other, because the trip category may not be fine enough to capture the selectivity of the fleet. Trawlers, characterized for being unselective, make several hauls in the same trip. The catch composition of the hauls varies depending on the target species and in the same trip the skipper may change the target species from haul to haul. Moreover, under the landing obligation it is expected that skippers will try to be more selective to be able to consume all their quotas without exceeding any of them (Batsleer *et al.*, 2013; Condie *et al.*, 2013). In this sense, the traditional approach could underestimate the interspecies selectivity of the fleets and in reality quota-share utilization could be higher than estimated. Under a profit maximization scenario, the movement between métiers improves the quota-utilization in relation to the traditional approach; nevertheless, it could also underestimate the real utilization capacity. In some mixed fisheries, to understand the real interspecies selectivity of vessels, especially in mixed fisheries, units of measurement finer than "trip" and ecological group are necessary to define the métiers.

When subjected to the landing obligation, if selective fishing is not possible, the quotas of limiting stocks become an input management factor, i.e. they determine the amount of effort that the fleets are able to execute. In this regard, the loss in profits generated by the implementation of the landing obligation in some fleets is not only generated by the loss in the landing of stocks subject to quota system but from the loss in the landing of other valuable stocks for which there is no catch restriction. In fact, for demersal fleets in Iberian waters the chance to catch OTH stock marked to a large degree the economic performance of the fleets. Although pelagic stocks are not the target stocks of the fleets considered in this study, under the landing obligation their quota in some cases became an input management measure that allowed fishing for the target stocks.

Implementation of landing obligation in practice

In practice, the implementation of the landing obligation will be more complex than simulated here. On the one hand, the fleets will try to improve their selectivity to make the best use of fishing opportunities by changing their gear configuration (Bayse *et al.*, 2016) and/or altering their behaviour (Batsleer *et al.*, 2016). On the other hand, the landing obligation policy includes several exemptions (Salomon *et al.*, 2014) that provide flexibility and which have not been simulated in this study. In turn, the change in selectivity will generate a change in F_{msy} and the reference points will have to be recalculated to manage the fishery optimally. Therefore, the version of the landing obligation implemented here is the most restrictive possible and the impact on the fleets could be less than that forecasted.

Fleet dynamic models

Fleet dynamics are a key element in the simulation of fishery systems (Fulton *et al.*, 2011). In this study, instead of looking for the model that best describes the dynamics of the fishery, we have used the scenario approach ("what if"). Fishers may not behave exactly as in the past and may not be able to execute the exact effort distribution that maximizes their profits but we expect that the real dynamics are somewhere in between. Other approaches to approximating fleet dynamics exist and have been applied elsewhere, for example Andersen *et al.* (2010) used a discrete choice model to predict effort allocation and Marchal and Vermard (2013) combined tradition with anticipated economic opportunities in the same model. A review of fishers tactical behaviour can be found in van Putten *et al.* (2012). They concluded that although economic drivers are the key components of fleet dynamics models, "hybrid" models that included explanatory variables related to tradition are required to improve their predictability. For FLBEIA this would imply, for example, combining the tradition and profit maximization models into a single, inclusive model. The pivotal question would be how to weight both approaches in practical implementations. Nøstbakken *et al.* (2011) carried out a literature review on economic models of strategic behaviour. They found that although there is a large amount of literature on the measurement of capacity, there is little work on investment modelling and most of this is theoretical. They encourage the incorporation of this type of models into bioeconomic models to improve the medium- and long-term predictability of a fishery's response to management strategies.

Limitation of profit maximization dynamics

The profit maximization approach provides information on the gains that could be obtained from the fishery changing only the effort allocation. FLBEIA allows full flexibility to move from métier to métier as in FcubeEcon (Hoff *et al.*, 2010). In practice, this flexibility resulted in an effort distribution far from the historical distribution, so much so that in some cases the historically more important métiers almost disappeared. Under the landing obligation a big change was expected as the fishers reacted to the new situation. However, for vessels using hooks and lines and trawlers, the change was greater under the current management framework. The effort share in these fleets under no landing obligation was concentrated mainly in one métier which did not match the historically more important métier. Under the landing obligation, the flexibility of the model was restricted by the discard ban. Hence, the fleets were forced to diversify their effort among métiers to make the best use of their quotas without exceeding any of them. Uncertainty in the gillnetters' effort share was very high in the "msmsy_mpro_lo" scenario. However, the uncertainty was not translated into profits, meaning that the optimization surface was quite flat and different combinations of effort share produced similar profits.

In practice, the mobility between métiers could be restricted by different factors. For trawlers, the seasonality of the OTB_MPD métier restricts the amount of effort that the vessels can expend in this, as pelagic stocks only approach the Iberian coast in the spring months. As in this case FLBEIA implementation is annual, an additional restriction in the profit maximization function would be needed to limit the effort in this métier. For gillnetters and vessels using hooks and lines, the movement between métiers is restricted by the administrative permissions needed to change métier, which could be denied or delayed in time. However, we have no information to assess the importance of this restriction or to allow it to be included in the model. Furthermore, tradition and risk aversion are important factors that preclude the fishers changing their behaviour from year to year, as pointed out by various authors (van Putten *et al.*, 2012; Marchal and Vermard, 2013).

On the other hand, variable costs were equal for all the métiers within the same fleet and stock prices were equal for all the métiers and fleets. Hence, the difference in the profitability of the métiers was only driven by the difference in the catch profile and the catchability of the stocks. If the differences in costs and prices among métiers were high, distribution of effort obtained would differ significantly from that obtained here. The effort share in métiers with lower variable costs and/or higher prices would be underestimated and overestimated otherwise.

Need for a different approach to mixed fisheries management

Under the landing obligation, fishing mortalities were, in general, well below the targets independently of the reference point used. Each fleet had a limiting stock that prevented it from reaching the quotas for the rest of the stocks. Hence, the overall TACs were never reached and fishing opportunities were lost for all of them. To assure a better use of fishing opportunities, the landing obligation should be accompanied by a management system that ensures consistency between single-stock TACs.

The inconsistency of TACs and quotas is a problem in mixed fisheries (Ulrich *et al.*, 2011) that could be exacerbated with the implementation of the landing obligation, as proven here. In the North Sea, single-stock advice is already harmonized, taking into account the mixed fisheries nature of the fishery using the Fcube method (Ulrich *et al.*, 2011; ICES, 2014a). However, the multistock reference points proposed here are independent of the traditional single-stock advice provided by ICES and their fit within current ICES management framework is complicated. The EC is planning to introduce fishing mortality ranges around the current ICES targets (STECF, 2015). These ranges will provide flexibility to the current European TAC and quota system, which in turn will allow single-stock TACs to be harmonized. Within this new framework, multistock reference points have a natural fit. They could be used as management targets in a multistock HCR to automatically produce multistock TAC advice. But before this, the algorithm used to calculate multistock reference points will have to be slightly constrained to ensure the values fall inside the predefined ranges.

One of the drawbacks of the multistock reference points used here is that they depend on the relative exploitation levels of stocks and hence need to be periodically updated to account for changes in the relative exploitation patterns of the fleets. In the framework of fishing mortality ranges, an alternative for overcoming this problem could be to annually apply a common factor to the *statu quo* fishing mortalities, which give fishing mortalities within the ranges, to produce single-stock TACs.

At present, Simons *et al.* (2015) are the only authors that have analysed the landing obligation policy using a quantitative multistock and multifleet bioeconomic model. They found that the landing obligation with no exemptions would produce a decrease in the biomass of saithe stock and in the profits of all the fleets. They studied the combination of the landing obligation with exchange rates between cod and saithe quotas and found that the exchange would be beneficial for both fleets and stocks. The different results obtained in both studies highlight the importance of evaluating the impact of the landing obligation at a regional level to pinpoint case-specific corrective measures to overcome the possible negative effects of the policy.

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