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# Managing mixed fisheries in the European Western Waters: Application of Fcube methodology

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ABSTRACT

Fisheries management is moving towards ecosystem based management instead of traditional single species based advice. To progress towards an ecosystem approach, a new methodology called "Fleet and Fisheries Forecast" (Fcube) has been proposed. In the application of the method, a precise initial fleet and metier segmentation used is important to get representative results in the analysis. Once they were defined, different data aggregations for fleets and metiers were tested with the objective of getting the best aggregation level to get equilibrium between detailed results and real management. Results showed that the difference in the forecast catches in different aggregation levels was low. Finally, hindcasting analyses were carried out to evaluate how sensitive forecasts are to different parameters. Stock indicators and catchability show the highest source of error and the effort share the lowest. In this analysis, Western Waters fleet management results show consistency between stocks and their respective TACs. The study highlights that it is possible to deliver advice within the context of mixed fisheries using the Fcube method.



## 1. Introduction

Most European demersal fisheries are mixed fisheries, meaning that more than one species are caught simultaneously by fishing gears. When managing mixed fisheries, conflicts between ecological and economic objectives arise (Greenstreet and Hall, 1996; Jennings et al., 1999; Pope et al., 2000). The problems these conflicts cause arise due to the different stock status, conservation needs and their value.

The currently used Total Allowable Catch (TAC) management system in European waters is based on single-stock status assessments. But it has failed to support a sustainable exploitation of some demersal species and no sign of recovery for some stocks already depleted (Khalilian et al., 2010). Mixed fisheries are characterised by high levels of discarding (Pastoors et al., 2000; Cotter et al., 2002) mainly caused by the continuation of fishing when the quota for one or more species is exhausted. The implications for single-species quota allocations may lead to an increase in discarding at the end of the year.

In an attempt to solve these problems, the 2002 reform of the European Common Fisheries Policy moved from TAC control to TAC and effort control in a mixed-fisheries approach. In TAC and effort control, TAC manages the output, the quantity of fish that is extracted from the sea, meanwhile effort control is managing the input, the level of harvesting capacity. In recent years, ICES has consistently indicated that setting a TAC is not enough to limit fishing mortality on many stocks and has recommended that effort management be applied in those cases (CEC, 2002; Penas, 2007). In 2009, a Green Paper from the European Commission was published (EC, 2009) for the Reform of the Common Fisheries Policy. The reform tries to go a step ahead towards an ecosystem based approach to fisheries management, by including a regional approach for management. However, the main concern still remains on how to integrate these changes, at all stages, starting from stock assessment and scientific advice towards sustainable fishery management.

Here is a method to manage mixed fisheries, given that the Total Allowable Catch (TAC) management system in Europe is currently based on single-stock status assessments. However, other

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researches show that, alternatives to the currently Total Allowable Catch (TAC) management system exist. There are limited methods were well-defined targets for the management of mixed fisheries are set. Two of these limited methods are described by Gröger et al. (2007) and Da Rocha et al. (2012). Both use maximization methods to define multitarget objectives for mixed-fishery management. Gröger et al. determine targets for five stocks assessed and managed by the National Marine Fisheries Service (NMFS). Da Rocha et al. (2012) define targets for the European northern hake stock (*Merluccius merluccius*), where fleets also capture northern megrim (*Lepidorhombus whiffiagonis*) and northern anglerfish (*Lophius piscatorius* and *Lophius budegassa*).

In the short term, management measures to be applied on mixed-species multi-fleet management must consider fleet- or fishery-based advice rather than just stock-based advice (STECF, 2003; Vinther et al., 2004; Gascuel et al., 2012). These approaches should attempt to reconcile conflicting management advice for different species within the same fishery, and to generate catch/effort advice that accounts for the mixed-species nature of the fishery in a multi-fleet structure.

A fleet and fisheries approach has been implemented recently for providing mixed-fisheries advice in Europe, the "Fleet and Fisheries Forecast" method known as Fcube (Ulrich et al., 2008, 2009; ICES, 2006, 2009a,b; Hoff et al., 2010). This method was initially developed within the multifleet, multi-species simulation framework TEMAS (fleet-based bio-economic simulation software to evaluate management strategies accounting for fleet behaviour) (Ulrich et al., 2007). Fcube was selected within an ICES workshop (ICES, 2006) as the most suitable candidate approach as replacement of the MTAC (Mixed species TAC evaluation) method (Vinther et al., 2004). MTAC represented an initial attempt to use fleet catch information to give TAC advice for mixed fisheries. However this was unsuccessful for a number of reasons, the main was that catch data used to parameterise the model made no distinction between the fleets and their activity (Ulrich et al., 2008).

In this study the definitions of fleets and metiers used are consistent with the Data Collection Framework of European Commission (EC, 2008) and they have been used in some analysis concerning mixed-fisheries (Marchal, 2008). A fleet segment is defined as "a group of vessels with the same length class (LOA) and predominant fishing gear during the year. Vessels may have different fishing activities during the reference period, but might be classified in only one fleet segment". A metier is "a group of fishing operations targeting a similar (assemblage of) species, using similar gear, during the same period of the year and/or within the same area and which are characterised by a similar exploitation pattern". So, in the same fleet segment different metiers could be identified.

The conceptual basis of the Fcube approach is that a fleet can exploit a number of different metiers during the year, hence the partial fishing mortality it exerts on a given species can be estimated from the amount of effort allocated to a given metier multiplied by the catchability of that species in that metier to that fleet, summed across all metiers exploited during the year (Ulrich et al., 2009; ICES, 2009a,b).

Finally, as in any model, the results are subjected to uncertainties due to parameters estimates and particularly the inability to predict future values of annually variable parameters (Charles, 1998). The impact of assumptions made for their estimation should thus be evaluated.

Using example of mixed fisheries in Western EU waters, the aim of this article is to evaluate the utility of Fcube for predicting how the effort should be allocated in managing mixed fisheries, and how sensitive these predictions and any resulting advice might be to assumptions regarding how fleets are specified and information on stocks and catchability.

## 2. Material and methods

### 2.1. Fcube method and strategies

The Fcube method is described in detail in Ulrich et al. (2008, 2009) and ICES (2006, 2009a,b), and the main features are summarised below.

Fcube method forecasts the effort level by fleet corresponding to each single stock TAC, i.e. the effort that fleets use to catch their quota share of each stock. It relies on two assumptions, firstly fishing mortality within a metier is proportional to effort and catchability by stock within the metiers and their effort share within the fleets are known. Secondly the TAC share of the fleets is equal to the average observed share of catches.

The input parameters to the method are, single stock TACs, $TAC_s$, together with their respective fishing mortality, $F_s$, effort share of the metiers within the fleets, $\alpha_{fm}$, defined as the proportion of the effort that is exerted by fleet, $f$, in each metier $m$ and catchability of the stock, $s$, for each metier, $q_{fms}$. If $\beta_{sf}$ is the TAC share of the stock $s$ and fleet, $f$, first marginal fishing mortalities of fleets for each stock are calculated:

$$F_{sf} = F \cdot \beta_{sf}$$

Then, the effort corresponding to each fleet and stock, $E_{fs}$, is calculated solving the following equation:

$$F_{sf} = \sum_{m \in M_f} E_{fs} \cdot \alpha_{fm} \cdot q_{fms} = E_{fs} \cdot \sum_{m \in M_f} \alpha_{fm} \cdot q_{fms}$$

where $M_f$ represents the set of metiers of fleet $f$.

After calculating these efforts, catch by metier for each stock is calculated according to different effort rules applied to all fleets and using stock number estimates obtained from single stock assessments.

The effort rules currently available form the basis of developing strategies, these are:

- Maximum of the efforts corresponding to single stock TACs, $E_f = \max_s(E_{sf})$ (max rule).
- Minimum of the efforts corresponding to single stock TACs, $E_f = \min_s(E_{sf})$ (min rule).
- The effort corresponding to the TAC of a specific stock, $s_0$, $E_f = E_{s_0 f}$ (stock rule).

Weighted mean of effort corresponding to single stock TACs, where weight is defined as $\delta_{sf} = TAC_s \cdot \beta_{sf} \cdot \nu_{sf}$ and $\nu_{sf}$ is the mean value of stock $s$ in fleet $f$, $E_f = \sum_s \delta_f \cdot \nu_{sf}$. This is represented as a very simple proxy computed with respect to value (value rule). Based on the effort rules described above, total international catch forecast for each stock are calculated and can be presented under different management strategies. The strategies are the possible effort rules defined for management. The strategies defined are described below. The species chosen for those strategies are considered the most important ones for the European Western Water mixed fisheries case study as described later.

- 'Max': fishing continues until all the proposed TACs are exhausted.
- 'Min': fishing stops when the first proposed TAC is exhausted.
- 'Val': fleet-specific fishing effort is adjusted to the species that give the maximum value of the catch.
- HKE: fishing stops when the hake TAC is exhausted.
- MEG: fishing stops when the megrim TAC is exhausted.
- ANK: fishing stops when the black anglerfish TAC is exhausted.
- MON: fishing stops when the monkfish TAC is exhausted.

These strategies of Fcube method try to provide advice in terms of coherence among single stock TACs. The appropriate strategies should be used as management advice: "max" for non-conservative management, "min" for conservative one, or the output of one specific stock scenario if the conservation of a specific stock is the main objective.

### 2.2. Case study data exploration

The main input data needed to run the Fcube method are from single stocks assessment, fishing mortality and catch forecast or TAC. Otherwise, observed effort and landings by fleet, metier and stock are needed.

Landings and fishing effort data from log-books were available for the French, Spanish and English fleets and metiers operating in Western Waters from the year 2003 to 2006. French and English data were available for all vessels above 10 m. Spanish data were compiled from the official logbooks of the whole Spanish fleet operating in non-Spanish Atlantic Community waters. Data from Denmark, Ireland and Belgium were provided aggregated without fleet or metier disaggregation of either landings or effort, so these country data were considered at country level. Landings from remaining countries with no fleet and metier information were aggregated in "others".

Landings data in weight (tonnes) were aggregated at country level, by year, stock, fleet and metier. Fishing effort information by country was disaggregated by fleet and metier in fishing days. Fleet segmentation was based on main target species, main fishing area, main gear and vessel length.

The demersal species (assessed and) exploited in the Western Waters are hake, sole, cod, plaice, megrim, anglerfish and *Nephrops* and are caught by a large variety of gears either as target species or as by-catch. The areas within the analysis are typically mixed demersal fisheries. However, it is possible to associate specific target species with particular fleets and sea areas.

The most important four stocks in terms of landings were chosen to be analysed: Northern stock of Hake (*M. merluccius*) from Divisions IIIa, Subarea IV, VI and VII, and Divisions VIIIa,b,d. Monkfish or white anglerfish (*L. piscatorius*) and black anglerfish (*L. budegassa*) from Divisions VIIb–k and VIIIa,b,d and megrim (*L. whiffiagonis*) from Divisions VIIb–k and VIIIa,b,d. All these stocks are caught in the Northeast Atlantic fisheries and all of them are assessed by the ICES Working Group on the Assessment of Southern Shelf Stocks of Hake, Monk and megrim (WGHMM). From these assessment results, stock biomass and fishing mortality were used as input data for Fcube method.

Various quantities of hake, anglerfish, megrim and *Nephrops* are taken together, depending on gear type and fishing area. The most important fleets in terms of number of vessels include trawls (otter or beam trawl) named as FL3, FL4, FL5, gillnets FL13 and FL14 and longlines FL9 (see Tables 1 and 2).

In Fig. 1 catch proportion for each of the considered stocks by each of the main fleets and country are presented. In the case of black anglerfish (ANK), hake (HKE) and megrim (MEG) Spanish FL5 fleets had the highest proportion of catches and in the case of white anglerfish (MON) French FL4 was the highest one.

For consistency between data sources, stock catch from logbook data had to be equal to the stock catch data used in the stock assessment Working Group (WG) data. To achieve this consistency, a raise from logbook data to WG data available by country was done.

The only species price information available came from sales slips provided by ship-owners of Basque Country harbours. It was given in euro and calculated as a mean value for all years, without taking into account differences in prices between marketable categories, fleet, metier or years.

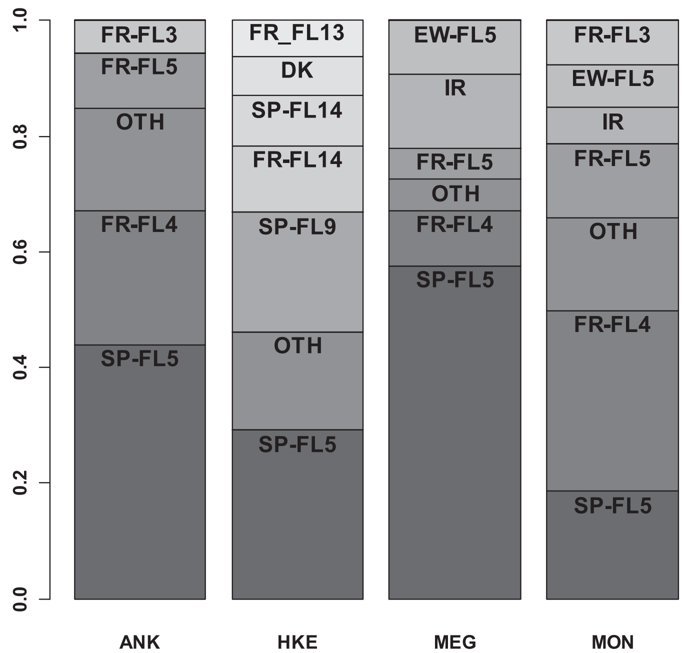


**Fig. 1.** Catch proportion of each stock in the main fleets studied. ANK: black anglerfish, HKE: hake, MEG: megrim, and MON: white anglerfish.

Historical stock catchabilities exploited by metiers were calculated dividing their partial fishing mortality by their effort and the average catchability of years 2004–2006 was used for the forecast. In Fig. S1 for the period 2003–2006, standardized catchabilities (catchabilities divided by their mean) of the main Spanish, French and English metiers by fleet are presented.

The main Spanish metiers catching the four assessed species are Bottom otter trawl-demersal fish and Bottom otter trawl-Mixed cephalopods and demersal fish (MT3 and MT5, respectively) included in the demersal trawl fleet (FL5). MT3 metier showed opposite trends in catchabilities between two groups of species: MEG-MON vs. HKE-ANK, when the catchabilities of the two first go up the others go down (Fig. S1). The catchabilities for the four stocks in the MT5 metier showed a decreasing trend from 2004, which suggest that using average catchability in the forecasts could not be a good approximation for projecting this metier.

Two French metiers stand out against others because of their large effort share (bottom trawlers targeting demersal fish (OTB-demersal fish) and intermediate multi-rig otter trawlers (OTT-demersal fish) catching anglerfish and monkfish (Fig. 2). The catchability of this last metier showed also a decreasing trend from 2003.

Most English and Welsh landings of megrim were made by beam-trawlers (TBB-demersal) (MT10) fishing in ICES Divisions VIIe,f,g,h and the remainder by demersal otter trawlers, OTB-demersal (MT3) and otter trawlers targeting crustacean and demersal fish (MT4). Megrim catchabilities showed a decreasing trend from 2004 in metier MT10 an increasing trend in metier MT4 from 2003 (Fig. 2).

The efforts share in the forecast of Fcube was considered equal to that calculated for the average of years 2004–2006. In general, the effort share of the fleets in different metiers remained relatively stable in the historical time series, thus using an average for the forecast was considered appropriate.

### 2.3. Data aggregation

Spain has the simplest segmentation in terms of number of fleets and metiers and has the highest catches of all the countries

**Table 1**
Western area case study. Main fleets characteristics and codes.

| Main target species | Main area | Main gear | Length (m) | Code |
|---|---|---|---|---|
| Demersal | Celtic Sea and Bay of Biscay | Demersal trawl | <10 | FL1 |
| | | | 10–11.99 | FL2 |
| | | | 12–17.99 | FL3 |
| | | | 18–23.99 | FL4 |
| | | | 24–39.99 | FL5 |
| | | | 40+ | FL6 |
| | | Longlines | <10 | FL7 |
| | | | 12–17.99 | FL8 |
| | | | 24–39.99 | FL9 |
| | | Drift and fixed nets | <10 | FL10 |
| | | | 10–11.99 | FL11 |
| | | | 12–17.99 | FL12 |
| | | | 18–23.99 | FL13 |
| | | | 24–39.99 | FL14 |
| | | | 40+ | FL15 |

**Table 2**
Western area case study. Main metiers characteristics and codes.

| EU level | | Celtic Sea and Bay of Biscay | |
|---|---|---|---|
| Gear | Code | Fishing activity | Code |
| Multi-rig otter trawl | OTT | Demersal | MT1 |
| Bottom otter trawl | OTB | Crustaceans | MT2 |
| | | Demersal fish | MT3 |
| | | Mixed crustaceans and demersal fish | MT4 |
| | | Mixed cephalopods and demersal fish | MT5 |
| | | Small pelagic fish | MT6 |
| | | Deep-water species | MT7 |
| | | Mixed demersal and deep-water species | MT8 |
| Bottom pair trawl | PTB | Demersal fish | MT9 |
| Beam trawl | TBB | Demersal fish | MT10 |
| | | Mixed demersal and cephalopods | MT11 |
| Set longlines | LLS | Demersal fish | MT12 |
| Set gillnet | GNS | Demersal fish | MT13 |
| Driftnet | GND | Demersal fish | MT14 |
| Others | ZZZ | Others | ZZZ |

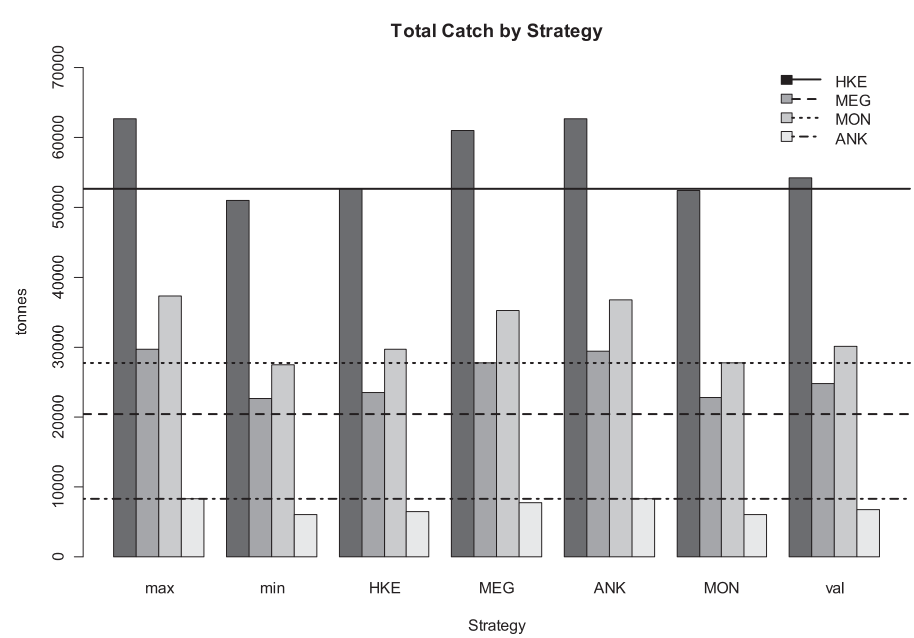


**Fig. 2.** Total international catch forecast for 2007 for each stock in the Base Case Scenario under each strategy. The horizontal lines represent the TAC for each stock.

considered. On the contrary, England and Wales with only the 7% of the total catch have twice and a half the number of fleets and metiers of Spain. The reason of this difference could be that Spain is the only country without small-scale fleets in the analysed area.

The aim of this procedure of aggregation is to have an automatic way to discriminate the fleets and metiers with incidental catches in order to centre the analysis in the most important fleets and metiers to reduce complexity in management. Also, robustness of the Fcube results are compared under different aggregations.

With the aim of reducing the number of fleets and metiers, less significant fleets in terms of their contribution to the international catch, were aggregated in a single fleet. The same procedure was followed to aggregate metiers within fleets but in this case it was done in respect to total fleet catches. Different proportions of catch thresholds were used to aggregate fleets and metiers. These thresholds could vary from 1% to 10% of the total international catch (for fleet aggregation) or total fleet catch (for metier aggregation).

Thus, a number of steps were conducted in order to aggregate less important fleets and metiers in a so called ‘BAG’ fleet and/or metier and reduce the total number of fleets or metiers. First, occasional catches that appear in a metier are included in ‘BAG fleet’. Then the aggregation of “small” metiers within each fleet segment into a “BAG” metier within this fleet segment. A small metier is defined as landing less than a given threshold for all of the four species in all the years. The effort of the new ‘BAG’ metier is set equal to the sum of the efforts of the metiers moved to ‘BAG’. Different thresholds were tested $\alpha = 0.001$, 0.01, 0.05, and 0.1. Using mathematical notation, if for a given country $c$, fleet $f$ and metier $m$:

$$\text{if} \quad \frac{C_{sycfm}}{C_{sycf}} < \alpha, \quad \forall \; s \text{ and } y \text{ then } m \in \text{‘BAG’}$$

Finally, the aggregation of “small” fleets into a “BAG” fleet was done. A small fleet is defined as landing less than a given threshold for the four selected species in all the years. In this case the effort is set equal to 1 as the fleets aggregated in ‘BAG’ could be of very different nature. Different thresholds were tested, $\beta = 0.001$, 0.01, 0.05, and 0.1. Using mathematical notation, if for a given country $c$, fleet $f$:

$$\frac{C_{sycf}}{C_{sy}} < \beta, \quad \text{for all } s \text{ and } y \rightarrow f = \text{‘BAG’}$$

Then each fleet can engage in a number of defined metiers plus the BAG metier, whose effort and catches is the sum of effort and catches of all small metiers within that fleet. As such, the national fleets retained in the database are those with at least one explicit metier defined, catching a significant proportion (depending on $\alpha$ and $\beta$, chosen) in at least one year of at least one species considered in the study.

In Fig. S2, the number of fleets or metiers and the proportion of catch included in the “BAG” fleet and metier are presented for each value chosen for $\alpha$ and $\beta$. This figure provides information about the number of fleets or metiers that could be reduced with a minimum loss of catches in the BAG variable.

The scenario with $\alpha$ and $\beta$ equal to zero, corresponds to the scenario in which intermittent catches are moved to ‘BAG’. The number of fleet or metier combinations varies from 116 to 33 depending on $\alpha$ and $\beta$ values, and catch proportion in ‘BAG’ from 0.01 to 0.15. So if one fleet or metier segment does not catch certain stock routinely and when it does it, catch is small, the catchability estimates obtained for this stock will not be credible. As the amount of catch in BAG fleets in this case is very small and the reduction in number of fleets and metiers eases the interpretation of the results and lightens the computation runtime, it was decided to use this data scenario ($\alpha = 0$ and $\beta = 0$) as the Base Case Scenario.

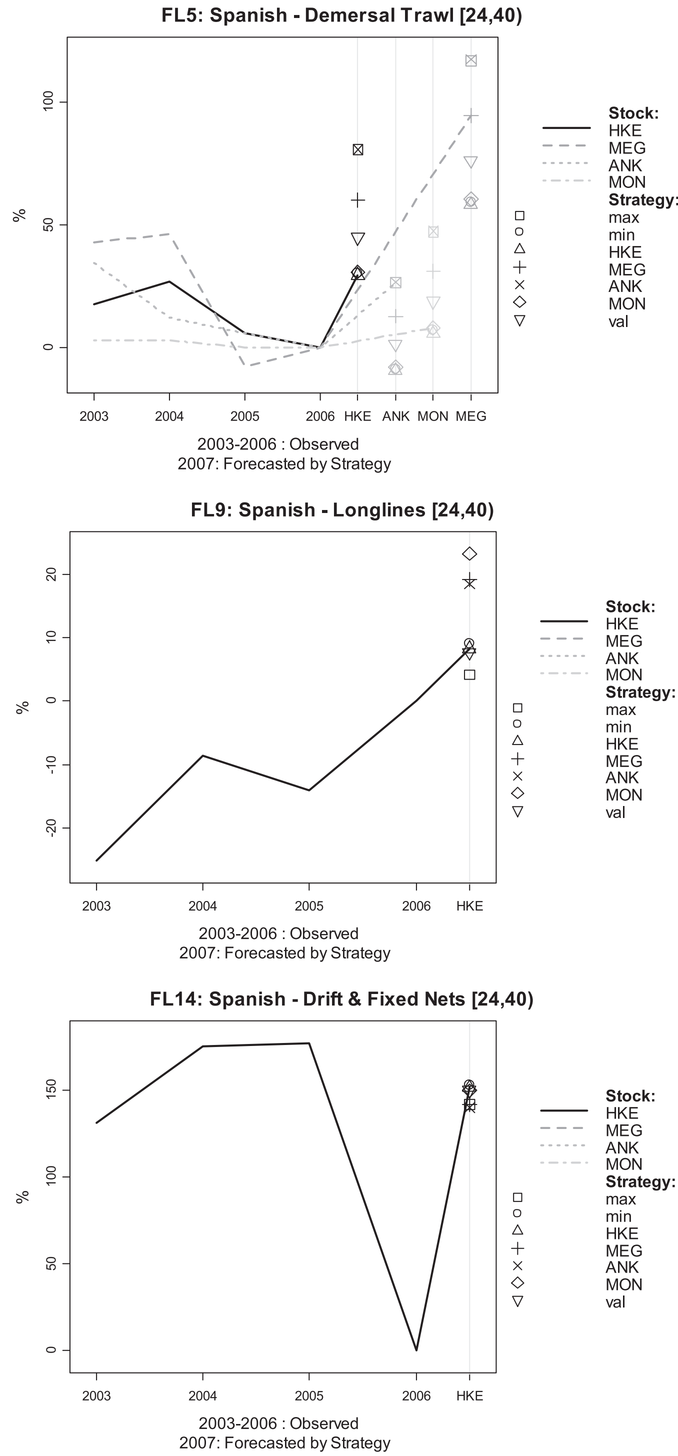


**Fig. 3.** Observed and forecast percentage of variation in catch for main Spanish fleets taking year 2006 as reference point. Lines represent observed values and points forecast values for 2007 under each management strategy.

Three scenarios were defined to analyse the effects of data aggregation on final effort forecasts:

- Base Case Scenario where only intermittent catches are moved to BAG fleet and no fleets and metiers aggregation ($\alpha$ and $\beta$ equal to zero) was done.
- Low Aggregation Scenario (Low Agg.) ($\alpha$ and $\beta$ equal to 0.01) where fleets or metiers that contributed less than 1% to the total

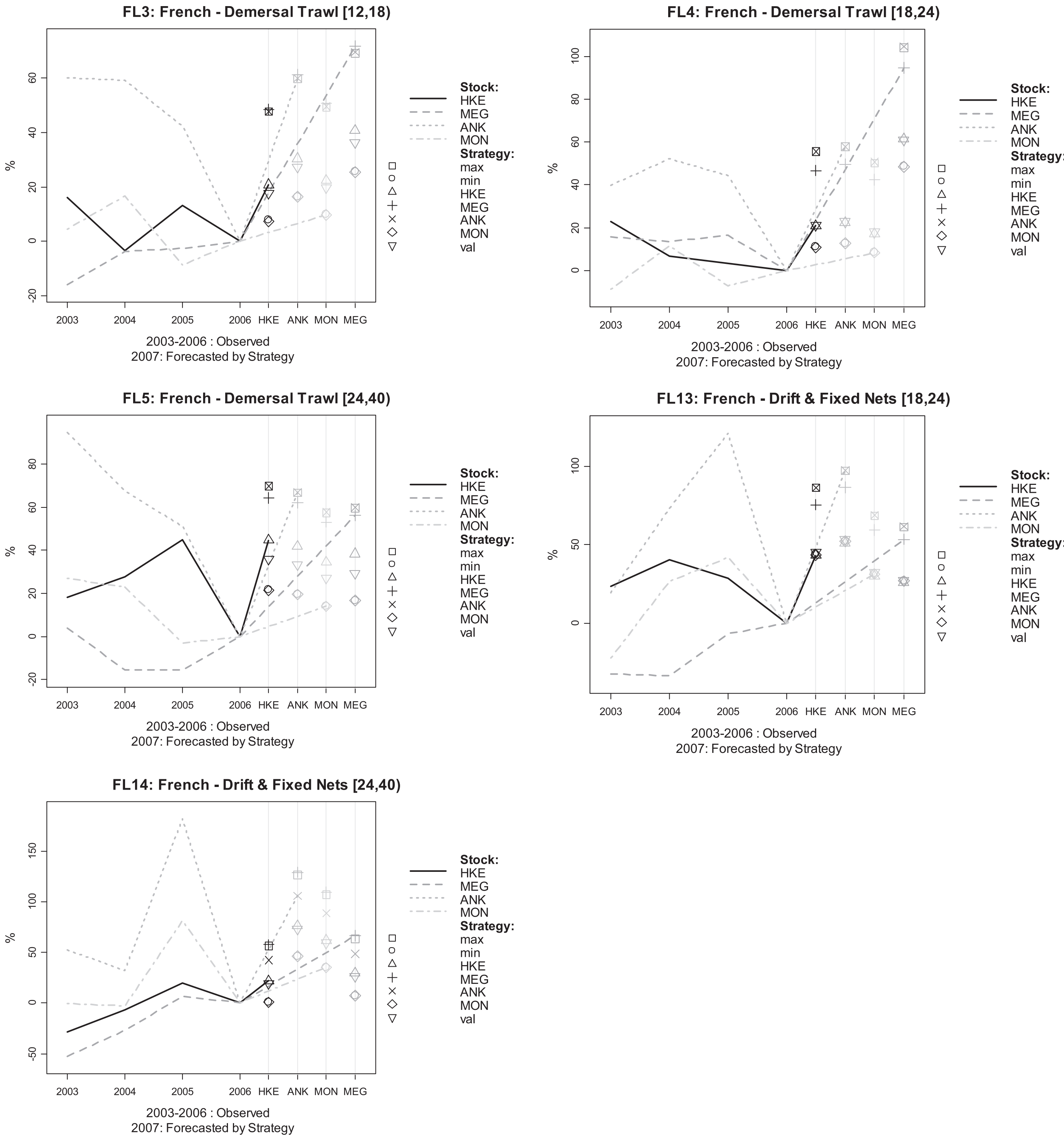


**Fig. 4.** Observed and forecast percentage of variation in catch for main French fleets taking year 2006 as reference point. Lines represent observed values and points forecast values for 2007 under each management strategy.

international catches (for fleet aggregation) or to the total fleet catches (for metier aggregation) were aggregated.

- High Aggregation Scenario (High Agg.) ($\alpha$ and $\beta$ equal to 0.1) where fleets or metiers that contributed less than 10% of the total international catches or the total fleet catches were aggregated.

### 2.4. Hindcasting

Fcube method uses several parameters that need to be estimated based on historical data. TAC and fishing mortalities used in the analysis were derived from single-species stock assessments and also Fcube catch forecasts were obtained using this information.

Thus Fcube results were subject to the same range of uncertainties as those underlying single-species stock assessments. Besides, additional fleet-based parameters are used as inputs in the Fcube, i.e. (i) effort share by metier for each fleet, (ii) landings share by fleet and stock and (iii) catchability by fleet, metier and stock. As shown above, some of these parameters showed strong variability from year to year, in particular catchability (Fig. S1).

The propagation of errors in input parameters was evaluated by running a number of hindcasting scenarios. The model was run back in time combining known (observed) input parameters with estimated ones and then comparing predicted and observed values. The analysis was conducted for year 2006. The observed 2006 landings were used as the proxy for TAC and the model was run as in the Base Case scenario. The following hindcasting scenarios were run for some strategies like ANK, HKE, MEG and MON.

- "**all ok**": all 2006 parameters are known without error(*). Stock numbers at age, weight at age and selectivity data are estimated for 2006; fleet-based parameters are those from the database.
- "**effort share**": (*), except for effort share by fleet and metier, calculated as 3-year average 2003–2005.
- "**catch share**": (*), except for landings share by fleet and stock, calculated as a 3-year average 2003–2005.
- "**catchability**": (*), except for catchability by fleet, metier and stock, calculated as a 3 years average 2003–2005.
- "**stock indicators**": all 2006 fleet-based parameters are known without error, but stock-based parameters are calculated using a standard short-term forecast procedure. Selectivity and weight at age are calculated as a 3 years average 2003–2005.
- "**all**": all of the above. All input parameters are calculated using the 3-year average as would be the case in a forecast procedure.

## 3. Results

### 3.1. Base Case Scenario

In Fig. 2 total international catch forecast for 2007 for each stock under each strategy is shown. Under a certain stock strategy, the total catch of the stock driving the strategy corresponded exactly with its TAC for all the stocks except for megrim. Megrim was the only stock analysed in which discards were included in the assessment. Within the Fcube, as the assumption is that the discarding rate will be equal to the observed average discarding rate, the total forecast catch did not correspond with the TAC.

Differences among strategies were not high. MON strategy was the most restrictive strategy and very similar to the "val" (species that give the maximum value) and HKE strategies. On the contrary ANK strategy was the one which gave higher catches and it was very similar to MEG strategy. The MAX strategy gave slightly higher catches than ANK strategy and MIN strategy was the lower.

In Table 3, variation in effort by fleet from 2004 to 2006 in relation to 2007 and effort under each strategy, in the right side, are shown. Variation was largely different from fleet to fleet and from strategy to strategy. For instance in Spanish trawlers, FL5, the strategy which gave smallest variation in effort was 'MEG' with a 4% decrease, followed by ANK strategy which gave an 8% increase and finally HKE and MON strategies resulted in a decrease in effort of a 25%. For the English fleet FL5, the lowest increase in effort is for MON strategy with a 6% increase. Among all French fleets and strategies, the smallest variation in effort was obtained for FL4 with HKE strategy (3% decrease), whereas ANK strategy gave the largest decrease (17%) for FL3. For French small demersal trawlers (FL3), all strategies led to a decrease in effort in 2007, changing the effort trend in relation to previous years.

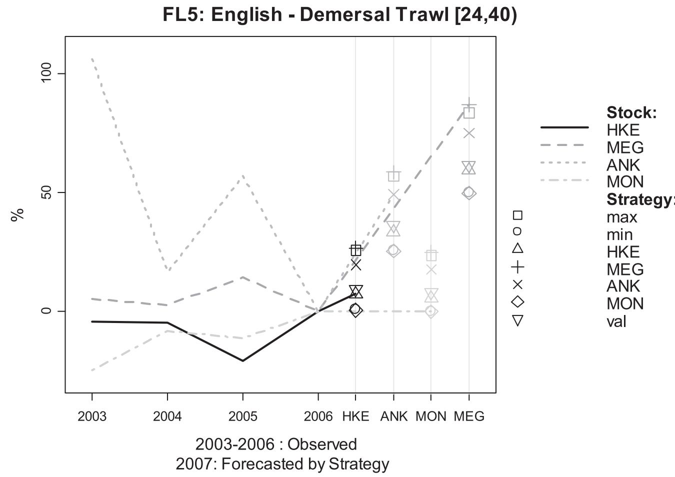


**Fig. 5.** Observed and forecast percentage of variation in catch for main English and Welsh fleets taking year 2006 as reference point. Lines represent observed values and points forecast values for 2007 under each management strategy.

In Fig. 3 the observed and forecast percentage of variation in catch for main Spanish fleets is shown taking year 2006 as reference point. As the effort in demersal trawlers among strategies was very different, consequently catch by strategy was also different. Hake catches, the only species caught by Spanish drift and fixed netters, was very similar for all the strategies because effort average was similar to historical effort average.

In Fig. 4 French observed and forecast catch are shown. For the three French fleets 18–24, 24–40 m demersal trawlers, and 18–24 m netters, the 2003–2006 period was characterised by a strong decrease in effort and stable catches for all species. Whatever the management scenario, predicted catches were larger in 2007 than in 2006. For 18–24 m demersal trawlers fleet, all strategies showed the same increase in catch for the main targeted species (monkfish). On average, effort increased from 2003 to 2006 for small vessels belonging to the French demersal trawlers fleet (12–18 m) and for the largest netters (24–40 m). The decrease in trawlers effort was mainly induced by the decrease in effort for multi-rig otter trawlers targeting crustaceans and demersal fish.

In Fig. 5 English observed and forecast catch are shown. In English demersal trawling fleet, forecast catches showed similar trends for all the strategies. Overall English fishing effort over 2004–2006 showed a steady decrease. The effort scenarios implied by the 2007 TACs ranged from the minimum due to the monkfish TAC, which implied total effort similar to that in 2006, to a maximum, due to the megrim TAC, which implied effort similar to that observed in 2004.

### 3.2. Data aggregation

A comparison of the difference in the forecast catch among different aggregation scenarios was done. Base Case Scenario where no fleets and metiers aggregation were done, was compared with Low Aggregation Scenario (Low Agg.) and High Aggregation Scenario (High Agg.) where fleets or metiers contributed less than 1% and 10% to the international catches or fleet catches respectively were aggregated.

The difference in the forecast catch between Base Case Scenario and different aggregation levels was very low. In Fig. 6 the difference in percentage in the total catch forecast among Original Data and Base Case Scenario, Low Aggregation and High Aggregation Scenarios are shown. The difference ranges between −1% and 3% for all the scenarios and depends on the strategy and the stock considered. For megrim the difference is negligible in all the

**Table 3**
Effort variation year by year in Base Case Scenario. In 2007 the effort forecast under each strategy is compared with the observed effort in 2006. The strategy under which the effort variation is the smaller is written in bold characters.

| % Effort variation | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Country | Fleet | 2004 | 2005 | 2006 | 2007 | | | | | | |
| | | | | | MON | ANK | HKE | MEG | Max | Min | Val |
| SP | FL5 | 113 | 106 | 103 | 75 | 108 | 75 | 96 | 108 | 75 | 84 |
| SP | FL9 | 112 | 114 | 114 | 88 | 88 | 78 | 88 | 78 | 78 | 78 |
| SP | FL14 | 110 | 81 | 73 | 134 | 134 | 135 | 134 | 135 | 135 | 135 |
| EW | FL5 | 91 | 90 | 87 | **106** | 132 | 114 | 139 | 139 | 106 | 117 |
| FR | FL3 | 93 | 86 | 168 | 58 | **83** | 65 | 83 | **83** | 58 | 64 |
| FR | FL4 | 101 | 95 | 95 | 89 | 129 | **97** | 121 | 129 | 89 | 98 |
| FR | FL5 | 82 | 97 | 90 | **92** | 134 | 110 | 129 | 134 | **92** | 104 |
| FR | FL13 | 99 | 52 | 104 | **127** | 171 | **127** | 160 | 171 | 127 | 129 |
| FR | FL14 | 175 | 106 | 92 | 79 | 115 | **95** | 127 | 127 | 79 | 94 |

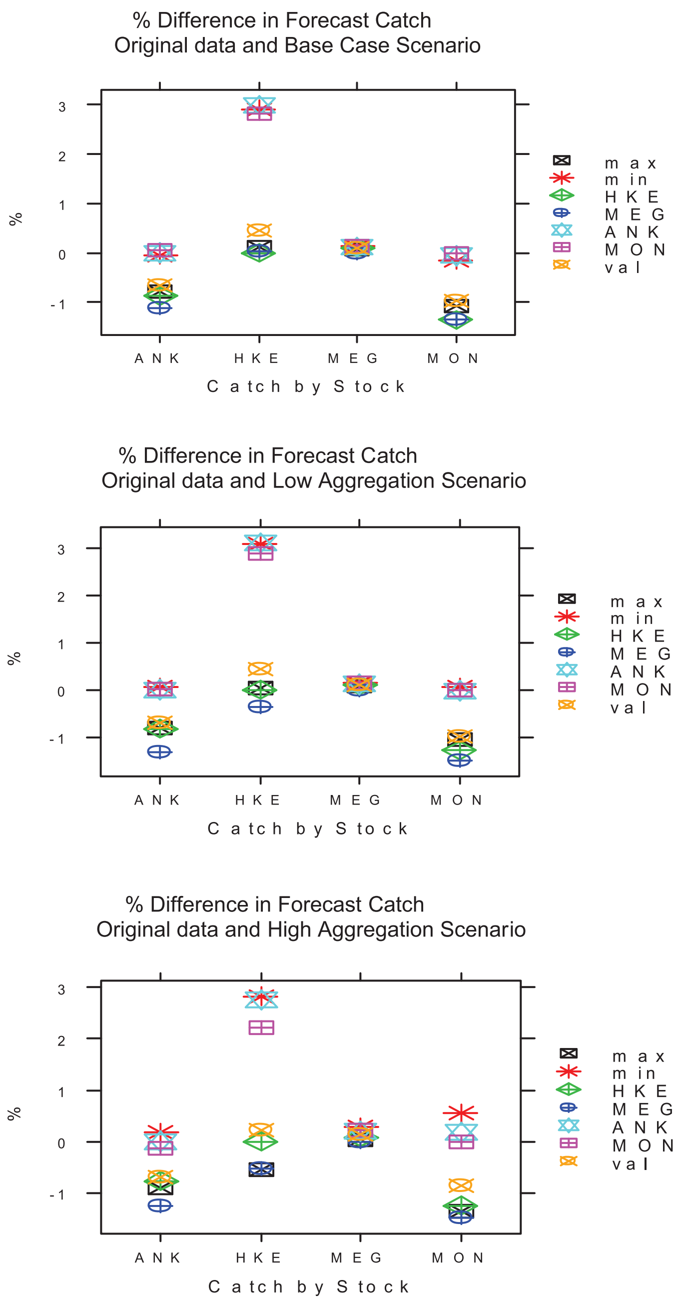


**Fig. 6.** Difference between forecast of international catch in Original Data and Base Case Scenario, Low Aggregation Scenario and High Aggregation Scenario.

scenarios and strategies and for both anglerfish the difference is around −1% for all the strategies except for the strategies driven by them in which no differences are detected. The main difference is in the catch of hake under both anglerfish strategies where the difference in catch forecast is a 3% higher under all aggregation scenarios, except for the MON strategy in High Aggregation (2%). So, the difference in the forecast catch between Base Case Scenario and different aggregation levels was very small.

### 3.3. Hindcasting

In Fig. 7 ratio between catch forecast and catch observed in 2006 by country by strategy and by hindcasting scenarios are shown. The ratios are shown for total international catch and also for countries' total catch. As it was expected from the exploratory data analysis, the parameter that introduces less error was effort share which ranges from −10% to 7%, followed by catch share with an error range from −11% to 20%, then catchability from −20% to 40% and

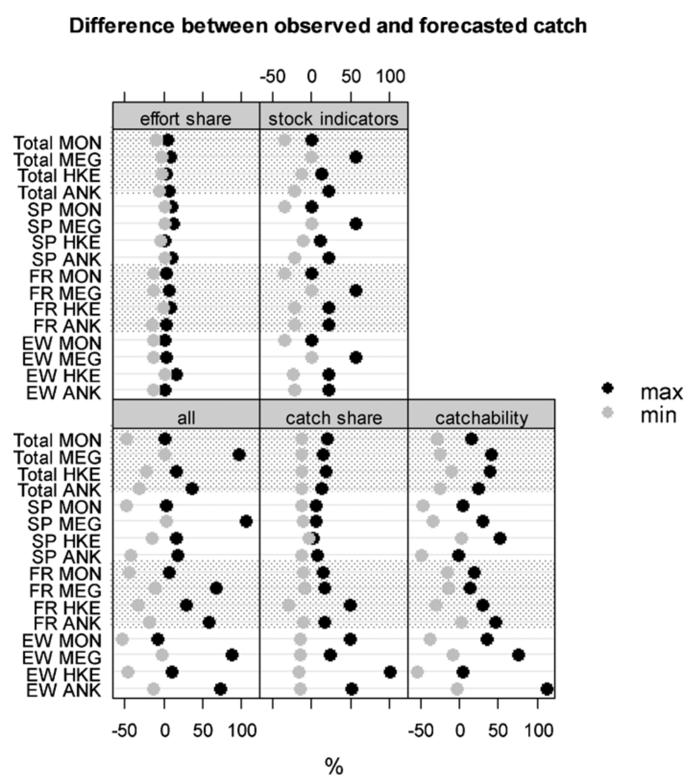


**Fig. 7.** Ratio between total international catch forecast and catch observed in 2006 by country, strategy and scenario.

the highest source of error came from assessment and short term forecast ("stock indicators") with a range from −40% to 60%. When all parameters were used in the forecast ("all" panel) an error range from −50% to 100% was obtained. Error in effort share and stock indicators had similar magnitude for the three countries. However the error produced by catch share and catchability was country dependent. While Spain was less affected than France by the error in catch share, France was less affected by the error in catchability. On the other hand, England and Wales had the highest error in both cases, catch share and catchability. In "all" scenario were estimates were used for all parameters, depending on the stock error range was different by country. MON's catch forecast error was similar for the three countries, the highest error in MEG catch forecast was obtained by Spain. France and England and Wales had the highest error range in HAKE's catch forecast and finally the highest error in ANK's catch forecast was represented by England.

## 4. Discussion

Delivering advice within the context of mixed fisheries appears to be possible using the Fcube method. It is about to be the case for the North Sea. ICES WKMIXFISH (ICES, 2009a) and later ICES AGMIXNS (ICES, 2009b) are the accepted form for mixed-fisheries advice which will be included as part of the advice from 2010 onwards. Although management currently used is based on individual stock assessment, these assessments can in turn be integrated within Fcube application and can help towards providing mixed fisheries advice. Mixed fisheries advice could be used to ensure no TAC is overshot and safeguard most vulnerable stock.

Thus, in mixed-fisheries context once a coherent TAC is decided, the challenge is to predict the future level of effort by fleet in agreement with the TACs of the other target species for management purposes. Western Waters fleet management results show consistency between stocks and their respective TACs.

The characteristics of basic data to be used in the model, single stock assessment results, observed fishing effort and landings are very important to understand some results. For instance, some unexpected Fcube results can be explained by the lack of information available to feed into the model. This is especially important at the maximum effort scenario where the limiting species for most of the fleets is anglerfish *L. budegassa* and for the rest of stocks TACs are highly overfished. Otherwise, for the minimum scenario, the limiting species is monkfish *Lophius piscatorious*. These results are not understandable when considering that both *Lophius* species are caught in the same fisheries. These contradictory results could be probably related to a problem in the species identification instead of a real difference among strategies. So a good sampling of landings is an important issue in relation to the management of these *Lophius* stocks. TAC advice of these two stocks is given in an aggregated manner although the assessment is carried out separately. In order to be able to include both stocks in the Fcube calculations, TAC advice is divided by species using historical catch ratios.

Hake strategy is similar to 'val' strategy, although hake is not the most expensive species, it has higher catches than the others. The weighted mean of the effort used in 'val' strategy for the effort corresponding to hake had the highest weight. Other drawbacks identified are prices, they were calculated as a mean value for all years without taking into account differences in prices between fish sizes, season or even exploitation fleet. As an example, hake price is completely dependent on marketable size, time of the year and gear used. In Spain, hake caught with longliners reaches much higher prices than those coming from trawling, because fish from longliners in general is bigger and of better quality. In the case of anglerfish in Fcube method both species have the same price, however in Spain, black anglerfish (ANK) is more expensive than monkfish (MON).

The results from the demersal trawlers targeting an assemblage of species allow comparing different scenarios. For example the black anglerfish strategy corresponds to the maximum effort scenario, while monkfish corresponds with the minimum effort scenario. Both groups of scenarios present a large difference between the efforts and possibilities of resulting catches. It appears reasonable that the strategy to be chosen for these fleets is the megrim strategy, as the level of effort predicted is the average of the effort series. Besides, this is one of the most important species caught in otter trawlers targeting demersal species which is the most important (in terms of number of trips) metier in that fleet.

From a management perspective based on the fleets, this is important to have a moderate number of fleets to manage. The Fcube results in relation to strategies used appear to be robust to different aggregations proposed. Having a large number of fleets in the segmentation would complicate the management. Thus, choosing the adequate level of aggregation is a balance exercise between the catch which is aggregated when aggregating metiers, and the number of fleets and metiers to be managed. The smallest the catch aggregation and the highest the number of fleet and metiers reduced should be the criteria to choose different aggregation levels. Robustness of the results of the Fcube methods to the aggregation procedure is important when feasible management of fleets and metiers is proposed.

It has to be considered that more disaggregated fleet data could give a different picture of the fishery. As an example, Spanish trawlers fleet between 24 and 40 m are split into 5 different metiers. These consist of pair trawlers targeting hake (with more than 90% of hake in catches) that contribute in a small amount to fleet effort. Otherwise, otter trawlers targeting demersal fish, in which hake rarely reaches more than 10–15% of catches in weight, contribute more than 90% to fleet effort. At the same time Spanish metier targeting demersal species is composed of vessels from different harbours and different target species, some target exclusively megrim while other target hake. The trends detected in catchability of this fleet and metiers are the result of the aggregation of different gears and assemblage of target species included in this fleet. So a precise segmentation of metiers used is considered very important to have coherent and sensible results. The limitation of the study is that some data aggregation and raising procedures needs to be done a priori. Depending on how these are performed, results are expected to be different. As an example, when landing by species is raised to the total country landings of that species, the assumption is that all the fleets misreport in the same degree (amount and sizes). However, raising species to the total landing by fleet and metier appears to be more in line with the actual reality of the metiers than the straight raise to country level.

The hindcasting analysis showed that catchability and stock indicators are the most important parameters for a good Fcube forecast. The improvement of stock indicators parameters are somehow outside the scope of the Fcube, as this is linked to single-stock assessment and forecast procedures. So excluding stock indicators, fleet segmentation and effort measures used are the two factors that affect catchability estimates. Effort measures for gillnetters and longliners appear not to be adequate (days at sea) whilst using a more adequate effort unit (like number of hauls or number of nets) would result in a more suitable catchability result. But as this information was not available for many fleets, it could not be used. France has a highly disaggregated fleet and metier segmentation and it has lower error in catchability than Spain that has a less disaggregated segmentation. However England and Wales has the most disaggregated segmentation and it is the most affected country by catchability, thus a more disaggregated segmentation does not always lead to a better catchability parameterisation. Using average historical effort share and specially catch share seems to be especially suitable for Spain and especially unsuitable for England and Wales. This could be related to the level of segmentation in both countries, the level of disaggregation in Spanish segmentation is low while it is very high in English and Welsh one. Thus, to get an adequate fleet segmentation it is not enough to disaggregate it to a very fine level, the key issue is to have a segmentation which adequately describes the nature of the fishing activities.

Furthermore, a compromise should be taken between the number of segments and the detail in describing the fishing activity, because an improvement in catchability estimates could imply impairment in other parameter estimates such as catch share or effort share.

The hindcasting procedure used in this study can be used to analyse the 'goodness' of data sets regarding the power of Fcube method to forecast catches at fleet level. A low error in catch forecast in hindcasting procedure suggests that the parameter estimates obtained from the fleet segmentation used are adequate.

In the last four years, from 2007 onwards, due to severe deficiencies in data quality for megrim, anglerfish and monkfish in relation to age reading, data availability and other discrepancies, there is not analytical assessment deployed for these stocks. Given that Fcube relies on biomass and fishing mortality estimates this is an important issue for the reliability of the results, so at least it should be interesting to have an idea of the uncertainty around the results. Furthermore, fleets considered in this study are characterised by catching a great variety of species of which most of them have no analytical assessment, and from those, some are managed using TACs but most of them are not managed at all. In some fleets the proportion of species without analytical assessment is high so in order to manage them from a mixed-fisheries perspective it would be necessary to consider them in some way. The unmanaged species do not represent a problem as they do not constrain the effort of the fleets but progress should be done in relation to the species without analytical assessment but managed with TACs to be incorporated in the method. The simplest approach would be to analyse, fleet by fleet, the correlation between the effort and the catch of no assessed stocks or between the catch of the assessed stocks and the catch of no assessed stocks and afterwards forecast the effort necessary to catch the quota share based on these correlations.

For some fleets and management strategies the forecast effort did not follow the historical trend observed. This could be related to the catch share and catchability used in the forecast which did not follow the trends of the observed values. Longer effort time series information available would improve the effort forecast. For some fleets which have the same effort under different strategies the predicted catches are slightly different due to the behaviour of the rest of the fleets under each strategy, the more the rest of the fleets catch, the lower is the catch of a certain fleet.

The original Fcube framework does not include any evaluations of the economic outcomes of the different effort scenarios, although economic assessment of such scenarios is important, seeing that fisheries management has a significant impact on both human behaviour and ecosystem development. Therefore, the original Fcube framework has been extended to contain an economic assessment module described by Hoff et al. (2010).

To summarise, future research on mixed fisheries management using Fcube would require further investigation into fleet behaviour, especially in relation to effort share and catchability. The inclusion of other species with and without TAC and quotas could be analysed; the incorporation of fleet and metier based approaches into a management strategy evaluation framework would be implemented; and finally some more years should be included in the data series in order to be able to analyse trends in the time series.

In conclusion, this is one of the first methods has been deployed and tested in the framework of integrated management of stocks being jointly exploited. Therefore Fcube could be considered as a tool to give management advice on ICES in the context of mixed fisheries. It is coherent with assessment and relatively easy to implement in an annual basis.

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## Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.fishres.2012.07.019.

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