Bio-economic Impact Assessment of the multi-annual management plan (MAP) for the Celtic Sea (ICES divisions VII bc, e-k) fisheries

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Introduction

Simulations of the impact of the multi-annual management plan on Celtic Sea fisheries were undertaken using the bio-economic management strategy evaluation tool FLBEIA. Stocks included as age-structured population models were cod VIIe-k, haddock VIIb-k, whiting VIIb-k, plaice VIIfg, sole VIIfg. Nephrops in Functional Unit 22 ('the smalls') was included using a Biomass-dynamic population model) and anglerfishes (both *Lophius piscatorius* and *Lophius budegassa* combined) as a fixed population (i.e. constant abundance). Fleets included all those that were all those landings a minimum of 2% of the landings of any one stock , leading to 13 fleets in total, with an additional 'other catches' fleet. Métiers were defined according to at least one of five gear-mesh combinations, in addition to delineating activity in divisions VIIfg from the rest (VII bc,e,h-k). Economic information on fixed and variable costs as well as landed value (price per tonne) were included, where available.

Four management scenarios were evaluated, i) according to the implementation of the basic CFP provisions introduced from 2018 (Fmsy target for all stocks, with a landings obligation), ii) MAP implementation from 2018 (Fmsy target for all stocks, with a landings obligation and a biomass safeguard to rebuild B > Bpa within 5 years), iii) MAP implementation from 2018 (Fmsy upper limit target for all stocks, with a landings obligation and a biomass safeguard to rebuild B > Bpa within 5 years), iv) MAP implementation from 2018 (Fmsy lower target for all stocks, with a landings obligation and a biomass safeguard to rebuild B > Bpa within 5 years). Fleet dynamics were assumed to be a fixed share of effort by fleets across métiers (based on historical data), where a fleet stops fishing when it reaches its first quota (lowest quota).

Case study

The case study made use of work progressed under the EU project DAMARA (DemersAl Mixed fishery Analysis Tool for Regional Advice; MARE/2012/22). The DAMARA project aims to provide a framework that can be used to compare different options to achieving these specific targets e.g. F_{msy} and to assess what the biological and economic implications are of choosing different approaches or paths and thus provide an enabling tool for stakeholders. The Celtic Seas comprise the shelf area west of Scotland (ICES Subarea VIa), the Irish Sea (VIIa), west of Ireland (VIIb), as well as the Celtic Sea proper (VIIf-k) and western Channel (VIIe). However, the geographical bounds of the model, and hence the case study, are ICES divisions VIIbc, e-k (Figure 1).

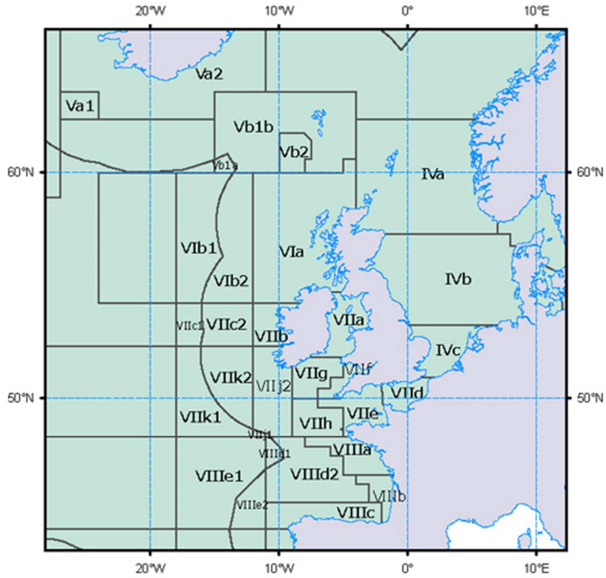

Figure 1. Map of case study area: The “Celtic Sea” (ICES divisions VIIbc, e-k).

The project runs until December 2015, and the model is currently in a *beta* development stage, hence results should be considered indicative rather than absolute. At present the following stocks are included in the model and simulations undertaken for NWWMAP:

Species	**Stock boundaries**
Anglerfishes (combined spp.)	ICES divisions VIIb-k and VIIIa,b,d
Cod	ICES divisions VIIe-k
Haddock	ICES divisions VIIb-k
Nephrops	Functional Unit 22 (ICES statistical rectangles)
Plaice	ICES divisions VIIfg
Sole	ICES divisions VIIfg
Whiting	ICES divisions VIIbc,e-k

The variety of habitats in the Celtic Sea accommodates a diverse and abundant range of fish, crustaceans and cephalopods species that enables a wide variety of fisheries targeting different species assemblages. The ecoregion has important commercial fisheries for cod, haddock, whiting and a number of flatfish species. Hake (Merluccius merluccius) and anglerfish (Lophius spp) are also fished across the whole area. The major commercial invertebrate species is the Norway lobster (Nephrops norvegicus), targeted by trawl fisheries throughout the Celtic Sea. Common cuttlefish (Sepia officinalis) are also exploited in the Celtic Sea, whilst there is dredging for scallops and smaller bivalves in the western English Channel, Irish Sea and west of Scotland. Pot fisheries take place for lobster (Homarus gammarus) and edible crab (Cancer pagurus) in coastal areas of this region. The main gear types used in the Celtic Sea are otter trawls, beam trawls, netters, dredges and pots.

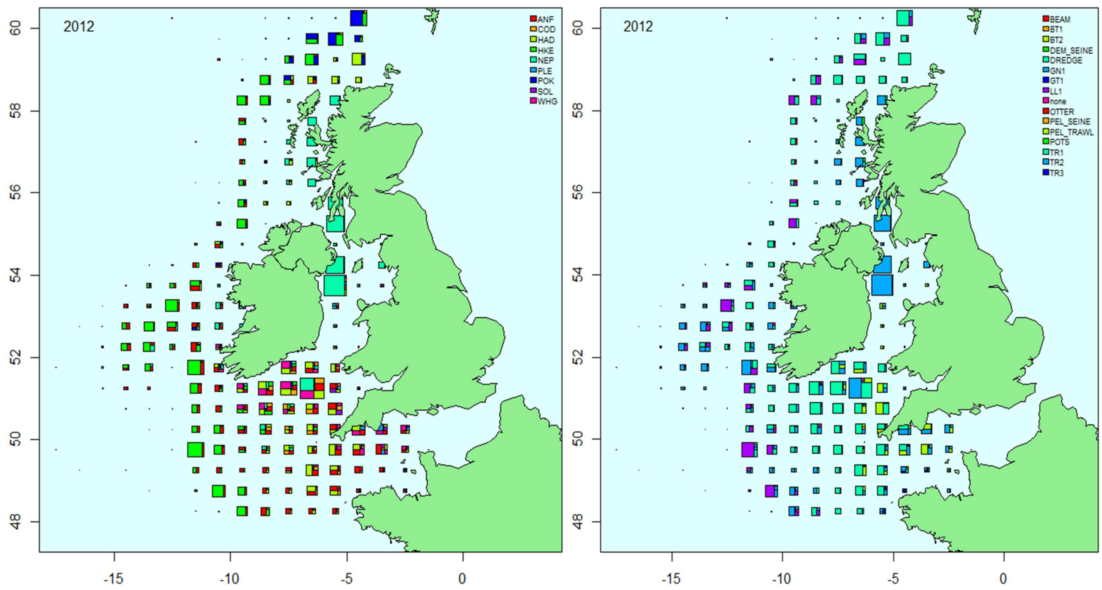

Figure 2. Maps illustrating the spatial distribution of the catches of main targets species included in the model (left) and the catches per gear in the Celtic Seas all species included (right), based on STECF catch data. Each statistical rectangle is split depending on the proportion of each species/gear catches and their size are proportional to the total amount of catches.

The otter trawlers with codend mesh size over 100mm (TR1) are the predominant fishery in the Celtic Sea (Figure 2), with the highest fishing effort, accounting for 23% of the total effort (STECF, 2013). It has a widespread distribution in the whole area, but most of the effort is exerted in ICES VII e, g and h. The countries that contributed with most effort were France, Spain, Ireland and England. The TR1 fishery is characterized to be a mixed fishery, mainly targeting 'gadoid' species, such as haddock (Melanogrammus aeglefinus), cod (Gadus morhua) and whiting (Merlangus merlangus) as well as anglerfishes and megrims (Figure 2). There is an important TR1 mixed fishery in ICES VIIj-k, mainly operated by Irish and Spanish vessels and targeting anglerfishes (Lophius spp), megrims (Lepidorhombus whiffiagonis), hake (Merluccius merluccius), haddock and whiting.

The trawlers with a codend mesh size range 70-100mm (TR2) is the fishery with second highest effort in Celtic Sea, accounting for 18% of the total effort (STECF, 2013). It is less widespread than the TR1, and the main 13 fishing areas are localized in ICES VIIe, close to the English and French shores and in VIIg, close to the Irish shore. The TR2 fishery in the Celtic Sea is mainly characterized by: 1) fishery for Norway lobster (termed 'Nephrops') operated mainly by Irish trawlers. There are significant Nephrops fisheries in the Smalls, Labidie and Porcupine bank that are not shown in the effort maps; 2) mixed fishery targeting anglerfish, gadoid species and non-quota species (cuttlefish and squid), taking place in VIIe close to the English and French shore; 3) Spanish-mixed fishery (otter trawl with codend mesh size 70-99mm) targeting flatfish, principally megrims and anglerfish, with hake as one of the main bycatches. Effort is distributed on shallow waters of Grand Sole and Porcupine Bank fishing mainly in Division VIIj. According with the STECF data (STECF, 2013), most of the TR2 effort is mainly operated by English and French vessels, however most of the Spanish effort in the Celtic Sea are TR2 and is likely to be underestimated due to a lack of data.

The effort of small meshed (16-32 mm) TR3 fishery is relatively little compared with TR1 and TR2 fisheries in the Celtic Sea , contributing with just 1% of the total effort. The TR3 effort is mainly localized in ICES VIIe and h and to a lesser extent in VIIb. In ICES VIIe this fishery targets mainly sprat (Sprattus sprattus) and is predominantly operated by English vessels. In ICES VIIh and b, the main target species is the boarfish (Capros aper), by the Scottish and Irish vessels, respectively.

Only one beam-trawl category operates in the Celtic Sea, the beam trawlers with 80-120mm codend mesh size (BT2). The BT1 (mesh size >120mm) have a negligible effort in this area. The BT2 effort accounts for 10% of the total effort in the Celtic Sea and is mainly carried out by English, Belgium and Irish vessels and is confined to ICES VIIe, f, g and h. This fishery is characterized by flatfish species including plaice (Pleuronectes platessa) and sole (Solea solea), as well as anglerfish and cuttlefish.

Dredging and potting fisheries are mainly carried out by England, France and Ireland and are usually confined to the coastal areas. The main target species for these fisheries are shellfish species - crabs for potting and scallops for dredges. Long line and gillnet fisheries are carried out by Spain mainly in Divisions VIIh, j.

The model

The simulations were undertaken using FLBEIA (FL Bio-Economic Impact Assessment (Garcia *et al.*, 2012, 2013), implemented in R (R.Core.Team, 2008) and FLR (Kell *et al.*, 2007). FLBEIA was developed to provide a flexible and generic simulation model to conduct Bio-Economic Impact Assessments of harvest control rule based management strategies (TAC setting strategies; capacity limitation; area and seasonal closures; technical measures) for multi-fleet, multi-stock fisheries.

FLBEIA is divided into two main blocks, the operating model (OM) and the management procedure model (MPM) (Figure 3), simulating the stock dynamics, fleet dynamics and management procedure. More details on the FLBEIA model are provided in Annex/Section XX.

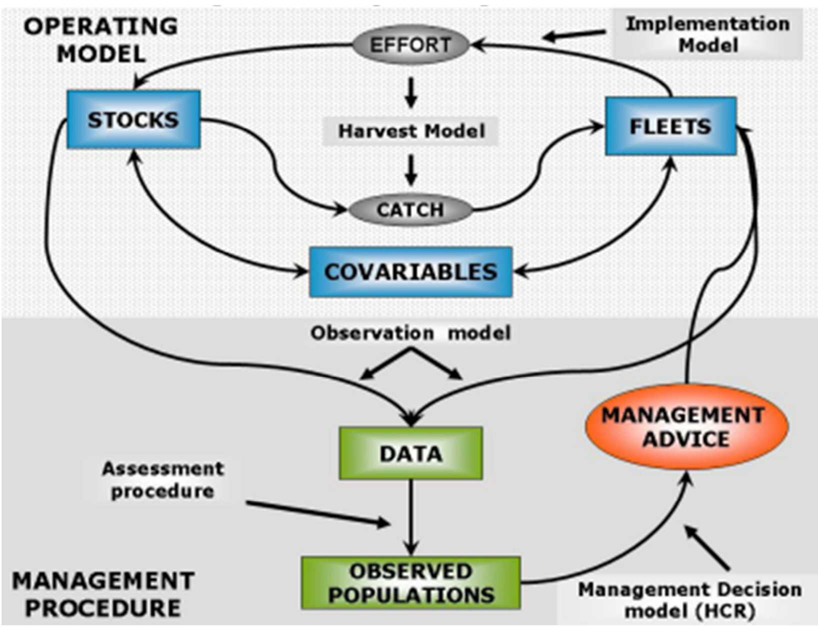

Figure 3. Conceptual diagram of FLBEIA

Multiplicative uncertainty can be incorporated in the simulations through almost any parameter in the model. Uncertainty around the stock-recruitment fits were programmed assuming log-normal error from the residuals of the stock-recruitment fit, but could not be implemented due to the limited time available in preparation for and during the meeting. As such, results presented are based on a deterministic run (single draw from the uncertainty surrounding the stock-recruitment fits).

Conditioning

Stocks

The stocks included in the model were treated differently depending on the information available. Four age-structured stocks were included based on the latest numbers, weights, maturity and natural mortality at-age coming from the ICES assessment data available. For cod, haddock, whiting and sole this was from the assessments undertaken in May 2015 (WGCSE, 2015). For plaice the latest information available was from the assessment undertaken in 2013 (WGCSE, 2013). In order to provide consistency between stocks, all data was truncated to an end year of 2012, and simulated from this point.

For the age-structured stocks, harvest control rules were based on the objective to reach FMSY within the stipulated timeframe, taking account of any safeguards to rebuild the stock above its precautionary biomass reference point within the stipulated timeframe. As such, biological reference points for fishing mortality and biomass targets and limits were collated or estimated where unavailable (Table 1.). Cod and Had reference points FMSY and FMSY ranges were estimated during the WGCSE May 2015 meeting. For sole and whiting, only FMSY point estimates were available. FMSY ranges were calculated using a linear relation with the Fmsy estimates (WD. Fmsy ranges for EWG 15 09). No references points were available for plaice. Provisional estimates for FMSY and FMSY ranges were derived using Eqsim software (ICES-WKMSYREF3, 2014). Bpa was used as the biomass safeguard for the stocks.

Table 1: Biological Reference points used in the simulations

	Flim	**Fpa**	**Fmsy**	**Fup**	**Flo**	**Blim**	**Bpa**	**Btrigger**	**Source**
COD	0.78	0.56	0.32	0.45	0.2	7.300	10.300	10.300	Estimated by ICES (WGCSE 2015)
HAD	1.41	0.74	0.4	0.6	0.26	6.700	10.000	10.000	Estimated by ICES (WGCSE 2015)
PLE			0.3	0.43	0.21	1.275	1.785	1.785	STECF (2015)
SOL	0.52	0.37	0.31	0.43	0.21	1.571	2.200	2.200	ICES (2015) ; STECF (2015)
WHG	0.5		0.32	0.44	0.21	25.000	40.000	40.000	ICES (2015); STECF (2015)

Stock-recruitment models were fit to the available time series of estimates of R and SSB for the stocks to generate recruitment estimates in the simulations. All Stock-Recruitment fits were based on a ‘hockey-stick’ segmented-regression formulation (Table 2)with the break point estimated through maximum likelihood using FLR FLSR() function (Kell *et al.*, 2007).

Two stocks included in the simulation do not have age-structure population models: anglerfishes and *Nephrops* Functional Unit 22. These were treated as follows:

Anglerfishes: No accepted analytical assessments are available for the two anglerfish stocks (*L. piscatorius* and *L. budegassa*) in area VII. However, as they are economically important stocks for the fisheries it was decided to include them in the simulations as a single stock with a fixed population. As a consequence, catches of these stocks are based on an effort multiplier where catches scale directly with the effort required to catch the other stocks.

Nephrops (FU22): Underwater-TV abundance estimates are available for this stock, but no population dynamics model is currently used to provide advice for the stock. In order to incorporate the population dynamics, a biomass-dynamic model was fit to the time-series of abundance.

Table 2: Stock-Recruitment relationships used in the simulations

	Stock-recruitment relationship
ANF	Not applicable
COD	Segmented Regression
HAD	Segmented Regression
NEP22	K, r params ?? Cóilín
PLE	Segmented Regression
SOL	Segmented Regression
WHG	Segmented Regression

All stock parameters (weights-at-age, selectivity) were based on the average of the past three years.

Fleets

Landings, discards, fishing effort and economic data

The DAMARA prototype fleet and metier definitions were based on readily available and accessible information from STECF (STECF, 2013). In the model, the following approach was used:

- Fleet, defined by:
    - country (including if available region within country)
    - main gear used
    - length (or size) group
- Metier, i.e. combination of fleet, area fished and mesh size range, defined by:
    - Gear and mesh size range (e.g. TR1, for large mesh > 100 mm otter trawlers)
    - Area (e.g. VII fg, VIIbc,e,h-k)

The data on fleet *activity* (catch and effort) was generated by aggregating country and vessel length disaggregated metier-based (i.e. activity) data used for evaluation of the cod plan into consistent fleet segments based on an assumption that there is no switching of gear type (e.g. otter trawlers do not beam trawl, netters do not trawl etc.). These were then matched to *economic* information from the AER to provide costs and earnings information for each of the fleets, where available.

The activity of these fleets segments in terms of mesh-size used (e.g. TR1 or TR2) was then split into two spatial units (VIIfg, VIIbce-k) to provide metier-based catches which have the characteristics required to allow the range of different management options being considered to be explored with the prototype (e.g. selectivity measures, area closures, effort allocation, quotas etc..).

The end results was a number of fleet units based on country, gear type and vessel length (e.g. IRL_OTB_>10m) that operate in a number of mesh and spatially separated metiers (e.g. TR1_VIIfg, TR2_VIIbc,e-k). Table 5 and Table 6 show the fleet segmentation used, catches and effort.

It should be noted that no effort was expended on ensuring data quality at this stage, as this was not considered a priority for the prototype. Instead, the data was taken "as was" and excluded if it failed to load (e.g., fleet segments without data). Clearly this is an important consideration in the final conclusion of the fleet and metier segmentation to be used in the model.

Briefly, the following steps were followed to generate the fleet component:

- Landings and discards numbers-at-age for o10m vessels were used to apportion volumes for u10m vessels according to the same age-pattern, and then the combined dataset was standardized to ICES assessed data on total catch-at-age (to ensure consistency with assessment removals).
- Fishing effort and capacity was taken from the STECF database according to the same fleet and metier definitions as for catch-at-age.
- Landings and discards weights at age were taken from the relevant stock assessment data (same landings weights and discards weights as the stock weights, and consistent across all fleets and metiers).
- Historic landings selectivity and discards selectivity were calculated at-age according to relative proportion of the total catch-at-age of that stock by that metier.
- There were many fleets and métiers that were excluded from the final FLFleetExts object either due to i. effort but no catch of the 3 stocks, ii. Catch but no effort (i.e. poor data), or iii. No catch-at-age data. No attempt was made to address these data issues due to time constraints, and the relevant fleet or métier was combined in the 'others' fleet and metier.
- In the final object, there were 13 fleets (plus one "others" fleet), fishing in up to five métiers each and up to seven stocks per metier.

The economic data used in the prototype model is presented in Table 7. Note that variable costs, and fuel costs, in the prototype are specified by metier but have not been calibrated to indicate differences in trip distances; they will be in the full model.

A summary of the input data feeding into the model for the economics module, all by fleet and metier are:

- Landings volume

- Landings value
- Discards volume
- Effort, days at sea
- Prices
- Fuel prices
- Costs (by fleet only): crew, fuel, variable, fixed, capital, and investment.

All fleet parameters (quota share, selectivity etc...) in the model runs were based on the past year (2012) due to the missing Spanish data in earlier years.

Inclusion of hake and megrim

Catch at age data was used as input data for the model. Data used in STECF EWG 15 09 are mostly from the database compiled for the STECF Effort meeting Data Call in 2013 (Ref. Ares (2013)222443 - 20/02/2013). However, catch at age data for hake and megrim are not available in the STECF data set as hake growth is in revision in recent years, while megrims data are provided aggregated for the two species together in the STECF Call in accordance with the TAC aggregation level.

To overcome this, STECF EWG15 09 used available ICES WGBIE hake and megrim catch at age data, but such data were not divided by VIIfg ICES divisions and the rest of the VII Subarea divisions as in the FLBEIA model. In order to provide this spatial resolution, WGBIE hake and megrim age data were split according to the data on weight of landings from the STECF Data Call data, in order to have this separation.

ICES WGBIE metiers and fleets were matched to those in the STECF data set. In order to do that it was assumed that hake landings in the ICES WGBIE UK VII *Nephrops* trawler fleet were associated with the STECF trawler fleet with mesh size range 70-99 mm (TR2) and in the case of megrim, ICES WGBIE French VII *Nephrops* trawler fleet landings were associated with the STECF trawler fleet with mesh size over 100 mm (TR1).

Unfortunately, due to time limitations hake and megrim could not be incorporated in the simulation runs.

Model simulations

The simulations are split into two periods: 2013 – 2017, when we simulate the intermediate period between the data and the implementation of the scenarios and 2018 +, from when we simulate the multiannual plan (MAP) scenarios. For the intermediate period, the simulation settings are the same for all four scenarios.

Intermediate years (2013 – 2017) assumptions

Fleet dynamics:

<u>*SMFB Previous*</u> – fleet dynamics follow a Simple Mixed Fisheries Behaviour where production (in terms of catch by a fleet) is concurrent with all stocks exploiting simultaneously, and the assumption that effort for each fleet (and by extension, each métier) is set to the effort for the stock that is most

similar to effort in the previous year. This constant effort is intended to simulate no mixed fisheries management in the period between the data and th implementation of the MAP.

Stock management rules:

Fmsy - Target fishing mortality is set to be Fmsy for the age-structured stocks, and fixed advice for the non-age structured stocks. However, implementation error (over-quota catches) arise from the mismatch between the effort (set as constant) and the effort required to catch each of the quotas.

Scenario years (2018 +) settings

Fleet dynamics:

'SMFB minimum'- fleet dynamics follow a Simple Mixed Fisheries Behaviour but a fleet's effort is set to be consistent with catch for the first quota reached in its portfolio (i.e. all fishing stops when a fleet reaches its lowest quota). This is consistent with a full implementation of the landings obligation for all stocks.

Stock management rules:

This depends on the scenario, see Tables 3 and 4 below. Scenarios were:

1. CFP_no constraint: This is the baseline scenario where the Fmsy point estimate is targeted, with no biomass safeguards or flexibilities (use of upper or lower Fmsy bounds) (Table 3).
2. LO_Fmsy_5yrs: This is the MAP scenario where the Fmsy point estimate is targeted, with biomass safeguards where the stock must rebuild to > Bpa within 5 years, if it falls below this level. No landings obligation flexibilities (de minimis, inter-species flexibilities or survival assumptions) were able to be simulated in the time available.
3. LO_Fup_5yrs: This is the MAP scenario where the Fmsy upper range is targeted, with biomass safeguards where the stock must rebuild to > Bpa within 5 years, if it falls below this level. No landings obligation flexibilities (de minimis, inter-species flexibilities or survival assumptions) were able to be simulated in the time available.
4. LO_Flo_5yrs: This is the MAP scenario where the Fmsy lower range is targeted, with biomass safeguards where the stock must rebuild to > Bpa within 5 years, if it falls below this level. No landings obligation flexibilities (de minimis, inter-species flexibilities or survival assumptions) were able to be simulated in the time available.

SCENARIO SETTINGS:

BASELINE

Table 3. Baseline

	Historical		CFP

Stocks	2014-2015		2013-2016	2017	2018	2019	2020+
Cod Haddock Whiting Plaice Sole	TAC	Advice	Fmsy	Fmsy	Fmsy	Fmsy	Fmsy
		TAC Constraints	NO	NO	NO	NO	NO
		Safeguards	NO	NO	NO	NO	NO
		LO	NO	NO	YES	YES	YES
		Banking, Borrowing Swaps	IMPLIED	IMPLIED	IMPLIED	IMPLIED	IMPLIED
		Inter species Flexibility	NO	NO	NO	NO	NO
		De minimis	NO	NO	NO	NO	NO
Nep 22	TAC	Advice	FIXED	FIXED	FIXED	FIXED	FIXED
		TAC Constraints	NO	NO	NO	NO	NO
		Safeguards	NO	NO	NO	NO	NO
		LO	NO	NO	YES	YES	YES
		Banking, Borrowing Swaps	IMPLIED	IMPLIED	IMPLIED	IMPLIED	IMPLIED
		Inter species Flexibility	NO	NO	NO	NO	NO
		De minimis	NO	NO	NO	NO	NO
Anglerfishes	TAC	Advice	FIXED	FIXED	FIXED	FIXED	FIXED
		TAC Constraints	NO	NO	NO	NO	NO
		Safeguards	NO	NO	NO	NO	NO
		LO	NO	NO	YES	YES	YES
		Banking, Borrowing Swaps	IMPLIED	IMPLIED	IMPLIED	IMPLIED	IMPLIED
		Inter species Flexibility	NO	NO	NO	NO	NO

		De minimis	NO	NO	NO	NO	NO

MAP scenarios

Table 4. MAP. Fmsy, Fup or F Down for 5 year recovery (3 scenarios)

	Historical		CFP	MAP			
Stocks	2014-2015		2013-2016	2017	2018	2019	2020+
Cod Haddock Whiting Plaice Sole	TAC	Advice	Fmsy	MAPHCR (Fmsy-high/low) ?	MAPHCR (Fmsy-high/low)	MAPHCR (Fmsy-high/low)	MAPHCR (Fmsy-high/low)
		TAC Constraints	NO	NO	NO	NO	NO
		Safeguards	NO	NO	YES (5yr)	YES (5yr)	YES (5yr)
		LO	NO	NO	YES	YES	YES
		Banking, Borrowing Swaps	IMPLIED	IMPLIED	IMPLIED	IMPLIED	IMPLIED
		Inter species Flexibility	NO	NO	IF WORKING	IF WORKING	IF WORKING
		De minimis	NO	NO	IF WORKING	IF WORKING	IF WORKING
Nep 22	TAC	Advice	FIXED	FIXED	FIXED	FIXED	FIXED
		TAC Constraints	NO	NO	NO	NO	NO
		Safeguards	NO	NO	NO	NO	NO
		LO	NO	NO	YES	NO	YES
		Banking, Borrowing Swaps	IMPLIED	IMPLIED	IMPLIED	IMPLIED	IMPLIED
		Inter species Flexibility	NO	NO	IF WORKING	NO ? IF WORKING	IF WORKING
		De minimis	NO	NO	IF WORKING	NO? IF WORKING	IF WORKING
Anglerfishes	TAC	Advice	FIXED	FIXED	FIXED	FIXED	FIXED

		TAC Constraints	NO	NO	NO	NO	NO
		Safeguards	NO	NO	NO	NO	NO
		LO	NO	NO	YES	NO	YES
		Banking, Borrowing Swaps	IMPLIED	IMPLIED	IMPLIED	IMPLIED	IMPLIED
		Inter species Flexibility	NO	NO	IF WORKING	NO? IF WORKING	IF WORKING
		De minimis	NO	NO	IF WORKING	NO? IF WORKING	IF WORKING

$F[TAC[y+1]\ ] < F_{Down}$ for the case of the lower range of the F_{MSY}.

Results

Intermediate years (2013 – 2017)

Fishing mortality rates are forecasted to remain constant (in relation to the last data year, 2012) during the intermediate period under a constant effort assumption (with, implementation error),highlighting implementation issues in mixed fisheries. While TAC management rules aimed at achieving Fmsy are implemented F fails to reduce as fleets continue to fish beyond the single-stock exploitation limits in pursuit of other fishing opportunities. As a result, F for cod remains higher than Fmsy at just below Fpa, for haddock F remains at around Fmsy (it had been fluctuating between Fmsy and Fpa in the earlier years), while F on plaice remains very high and sole somewhat below Fpa but above Fmsy. For whiting, F remains below Fmsy reflecting the relatively low exploitation rate on this stock (Figure 3).

During this period, catches of cod remain at 5 – 10 thousand tonnes, fluctuating with recruitment (Figure 4) and SSB. Similarly, haddock catches decline rapidly with SSB before recovering to > 20 thousand tonnes on the back of a strong recruitment. Plaice, sole and whiting catches remain relatively stable over this period while anglerfish and *Nephrops* catches are also stable. SSB for cod and whiting increase slightly, while haddock declines before increasing again following strong recruitment (Figure 4). Plaice and sole SSB are relatively stable (Figure 3). The figures illustrate that the dynamics of the gadoid stocks in the Celtic sea are strongly recruitment driven.

Quota uptake is forecast to be high, well above 1 (1 indicating 100% uptake, >1 indicating catches above those consistent with the single stock exploitation target) for cod and for haddock in some years, except for whiting and *Nephrops* where it is < 1, indicating that current effort would be insufficient to catch these quotas. Higher uptake than 1 can be interpreted as there currently being higher effort than the target for the relevant management scenario (Fmsy, Fup or Flo). TACs are higher for Fup, Flo and in between for Fmsy, as you would expect reflecting the differences in F target.

Catch variability is similar under all scenarios, +-~45% for cod, but much higher for haddock (+-150%) potentially reflecting the much stronger inter-annual variability in recruitment for haddock – requiring sharp changes in catch to take account of the varying productivity of the stock. Variability for the other stocks was relatively low.

For some fleets profits are lower under the Flo scenario than the Fmsy or Fup reflecting the fact that they are unable to land fish caught with the same amount of fishing effort and (fixed and variable) costs (Figure. 7). While for other fleets, the profits and effort remain the same.

Management years (2018+)

Under all the scenarios, following full implementation of the landings obligation F sharply declines in 2018 to stabilise below Fmsy for all stocks (Figure 3). This reflects the large drop required to meet all the Fmsy targets simultaneously and the effect of technical interactions ‘choking’ the fisheries before the quotas can be taken. This is somewhat alleviated by the use of an upper Fmsy bound (Fup scenario) but even here only plaice is close to its Fmsy point estimate, remaining well below for the other stocks. It should be noted that this is based on an assumption of no changes to the dynamics of the fisheries (constant effort share across métiers, same exploitation patterns as previously) and without the flexibilities of de minimis and inter-species flexibilities. Nonetheless, it illustrates the challenges in trying to achieve Fmsy for all stocks simultaneously given current exploitation and fishery patterns.

The first years after the implementation of the LO, catches drop in response to decrease in F and increases again in response to quick increase in SBB. Catches of anglerfishes and nephrohs are stable in time as a result of model speciation. Catches of anglerfishes are lower than the time series and a consequence of lower effort trying to fulfil the other quotas and a constant catch-rate assumption for these stocks. *Nephrops* catches also remain at a lower level. Despite an increase in SSB, catches of whiting remain around 10 000t (corresponding to their level in 2010) and catches of sole do not overpass 500 tones, due to very low F compare to FMSY and previous F regime. Catches of cod remain highly variable and relatively similar to before, fluctuating between 5 and 15 thousand tonnes, while haddock catches fluctuate around 10 thousand tonnes (Figure 3). Given catches are relatively similar under all scenarios, it indicates that implementation of the landings obligation and the reaction of fleets to it are more important than the variation in quotas allowed by the Fmsy ranges. Under current fishing patterns the Fmsy ranges are insufficient in themselves to allow fishing at Fmsy, and other measures are required to allow this, such as flexibilities, quota swaps and changes in fishing patterns.

SSB for cod, plaice and sole and whiting rebuild rapidly to a high level, never observed in the time series. Haddock SSB remains in the previous observation ranges. SBB fluctuates reflecting the recruitment dynamics, expect for sole (Figure 3, Figure 4).

Available fishing opportunities for most stocks are higher than prior to the implementation of the MAP but quota uptake for all stocks is <1 (i.e. below 100%, Figure 5) reflecting the fact that different quotas are ‘choking’ different fisheries, resulting in a net under-exploitation of all stocks with the benefits of the increased SSB for catches being negated by the limitations of technical interactions. Such an effect may be mitigated somewhat by switching of métiers and quota swaps, but these were not modelled here. The impact of target (FMSY upper, lower bounds) can have variable effects on available fishing opportunities depending on the species (little differences for plaice and high differences between scenarios for whiting). It is noteworthy that inter-annual variability of TAC is low to high depending on the species and fleet dynamics (low for sole, plaice, and haddock; medium for and whiting and high for cod). Generally, setting the target at Fup allows for higher quotas and catches without any risk to the stocks due to the lower realised fishing mortality. However, this could not be fully tested without simulations including stochastic recruitment where probabilities and risks to the safeguard references points could be tested. Fishing at the upper bound may though be considered a risky strategy, as if the fisheries were able to change fishing patterns to exploit the upper end of the Fmsy range this may lead to some risk for the stock. Further testing would be required to establish this effect.

For fleets, profits are generally higher than the baseline at Fup and lower than the baseline at Flo (with few exception such as GBR and IRL TBB), reflecting the increased quota allowed to be fished (e.g. increased landings of anglerfishes) (Figure 7). On effort and catch by fleet the main effect is produced by the implementation of LO in 2018 (Figure 6) and decrases are more or less pronounced depending on the fleet .Little differences are generally observed between scenarios (FMSY ranges). However, care should be taken in interpreting these results, without more completely taking into account the population dynamics of the stocks and additional revenues from other species for the fisheries.

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Table 5. Fleets and effort ('000 KWdays)

fleet	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
BEL_DTS_o10m	22	119	189	425	465	467	469	425	290	465
BEL_TBB_o10m	2915	4569	3997	3246	3352	2287	1971	2463	2374	3256
ESP_DTS_o10m	0	0	0	0	0	0	0	0	0	3747
FRA_DFN_o10m	1784	2085	2144	1948	2176	2240	2240	2234	2043	2287
FRA_DTS_o10m	18551	19082	19456	19052	18465	13763	13693	16604	16330	16075
FRA_PG_o10m	762	972	1202	1372	1530	1044	1043	993	1000	937
GBR_DFN_o10m	2540	2853	2182	1160	1177	1080	1079	1112	1083	1112
GBR_DTS_o10m	6037	6119	6178	5610	5584	4991	4869	5611	5015	4648
GBR_DTS_u10m	90	82	91	419	667	653	515	490	350	420
GBR_TBB_o10m	6327	6117	5903	5291	5022	4325	3866	3743	3888	3730
IRL_DFN_o10m	1062	887	679	531	562	533	550	523	451	495
IRL_DTS_o10m	11658	11781	11542	9691	10101	8535	7685	8626	8245	8167
IRL_TBB_o10m	4015	3032	2975	2079	1767	1020	916	948	880	1085

Table 6. Aggregated landings (t) by fleets and metiers included in the model. Showing 2010 – 2012. Note, no data on Spanish fleets available except for 2012.

fleet	**metier**	**2010**	**2011**	**2012**
BEL_DTS_o10m	TR2_VIIbcehjk	6	17	22
	TR2_VIIfg	319	277	354
	Total	**325**	**294**	**375**
BEL_TBB_o10m	BT2_VIIbcehjk	231	228	305
	BT2_VIIfg	1730	2037	3020
	Total	**1961**	**2265**	**3325**
ESP_DTS_o10m	TR1_VIIbcehjk	0	0	2567
	TR1_VIIfg	0	0	92
	TR2_VIIbcehjk	0	0	2145
	TR2_VIIfg	0	0	5
	Total	**0**	**0**	**4809**
FRA_DFN_o10m	GN1_VIIbcehjk	656	1081	1267
	GN1_VIIfg	0	2	4
	Total	**657**	**1083**	**1271**
FRA_DTS_o10m	TR1_VIIbcehjk	4046	11945	13930
	TR1_VIIfg	3969	4763	7765
	TR2_VIIbcehjk	2106	3204	4350
	TR2_VIIfg	68	26	43
	Total	**10188**	**19939**	**26088**
FRA_PG_o10m	GT1_VIIbcehjk	376	958	1278
	GT1_VIIfg	1	18	10
	Total	**377**	**976**	**1288**
GBR_DFN_o10m	GN1_VIIbcehjk	2427	1480	1643
	GN1_VIIfg	205	209	224
	Total	**2632**	**1688**	**1867**

GBR_DTS_o10m	TR1_VIIbcehjk	3715	3793	3324
	TR1_VIIfg	372	279	645
	TR2_VIIbcehjk	1460	924	821
	TR2_VIIfg	442	94	109
	Total	**5989**	**5090**	**4900**
GBR_DTS_u10m	TR1_VIIbcehjk	26	43	45
	TR1_VIIfg	3	12	12
	TR2_VIIbcehjk	184	113	138
	TR2_VIIfg	35	22	40
	Total	**249**	**190**	**235**
GBR_TBB_o10m	BT2_VIIbcehjk	4605	3662	3048
	BT2_VIIfg	565	397	864
	Total	**5171**	**4060**	**3912**
IRL_DFN_o10m	GN1_VIIbcehjk	41	78	111
	GN1_VIIfg	190	209	338
	Total	**231**	**286**	**448**
IRL_DTS_o10m	TR1_VIIbcehjk	4546	2519	2263
	TR1_VIIfg	2451	2895	3532
	TR2_VIIbcehjk	1541	1134	1267
	TR2_VIIfg	3651	2625	3620
	Total	**12189**	**9172**	**10682**
IRL_TBB_o10m	BT2_VIIbcehjk	0	3	40
	BT2_VIIfg	1127	867	1331
	Total	**1127**	**870**	**1370**
OTHER_Fleets	OTHER_Metiers	1517	1120	2092
	Total	**1517**	**1120**	**2092**

Table 7. Economic data developed from AER and STECF effort databases used in the prototype model (Note: not all fleet segments came within the >2% landings threshold, and those that did not were not included in the model).

	€/Day	% over revenue	€/Day	€/vessel and year	€/vessel	Days	Number of vessels	FTE per vessel	Max Kwdays per vessel
Fleet	**Fuel Cost**	**Crew Cost**	**Variable Cost - Fuel cost**	**Fixed Cost**	**Capital Cost**	**Max days**	**Number of vessels**	**Employment per vessel**	**Max KWdays**
BEL_DTS_o10m	1,321	34%	816	100,767	67,638	55	6	5	92,913
BEL_TBB_o10m	369	32%	151	59,199	107,833	16	37	5	105,597
ESP_DFN_o10m	-	44%	-	-	-	69	3	-	10,176
ESP_DTS_o10m	-	30%	-	-	-	225	22	-	204,379
ESP_HOK_o10m	-	28%	-	-	-	225	83	-	36,946
FRA_DFN_o10m	48	45%	48	16,443	59,759	165	47	4	58,402
FRA_DFN_u10m	14	48%	15	4,338	18,757	141	33	1	12,937
FRA_DTS_o10m	60	33%	27	56,942	57,691	225	161	6	119,810
FRA_DTS_u10m	82	48%	37	6,229	23,438	103	16	1	10,422
FRA_HOK_o10m	58	46%	44	14,074	40,732	67	30	3	30,220
FRA_HOK_u10m	6	46%	7	4,831	20,723	60	122	1	6,332
FRA_PG_o10m	14	51%	12	5,575	2,403	115	44	2	25,548
FRA_PG_u10m	18	53%	18	827	3,228	166	17	0	16,461
FRA_TBB_o10m	314	40%	109	19,508	29,806	112	6	3	26,387
FRA_TBB_u10m	-	0%	-	-	-	3	1	-	379
GBR_DFN_o10m	347	28%	355	63,194	14,370	85	12	6	67,088
GBR_DFN_u10m	4	28%	1	1,856	580	76	126	1	7,663
GBR_DTS_o10m	246	24%	137	52,501	32,950	180	46	5	84,291
GBR_DTS_u10m	17	27%	7	6,823	6,798	48	73	3	6,903
GBR_HOK_o10m	1,463	40%	674	51,231	17,693	21	7	12	6,197
GBR_HOK_u10m	2	25%	1	1,026	4,880	24	283	2	2,109
GBR_PG_o10m	-	0%	-	-	-	19	6	-	23,447
GBR_PG_u10m	-	0%	-	-	-	3	1	-	700
GBR_TBB_o10m	205	23%	50	95,343	43,795	171	43	6	104,090
GBR_TBB_u10m	-	0%	-	-	-	-	-	-	-
IRL_DFN_o10m	2,386	40%	1,656	234,772	155,043	10	21	41	28,313
IRL_DTS_o10m	140	26%	72	76,990	132,689	13	60	8	163,336
IRL_HOK_o10m	-	0%	-	-	-	6	17	-	4,573
IRL_PG_o10m	-	0%	-	-	-	107	6	-	15,320
IRL_TBB_o10m	615	21%	229	118,145	165,474	40	12	10	108,502
NLD_DTS_o10m	942	24%	375	104,213	144,835	40	8	8	23,181
NLD_DTS_u10m	266	3%	74	2,608	1,177	1	1	1	36

Table 8. Price data used in the simulations

	Subarea VII. All countries, all gears aggregated
Species	Average 2010-12 Price (€/kg)
COD	2.57
HAD	1.20
HKE	2.27
NEP	3.47
PLE	1.40
SOL	10.77
WHG	1.27
Anglerfishes	4.06
Megrims	3.10
Source: STECF. 2014. Annual Economic Report	

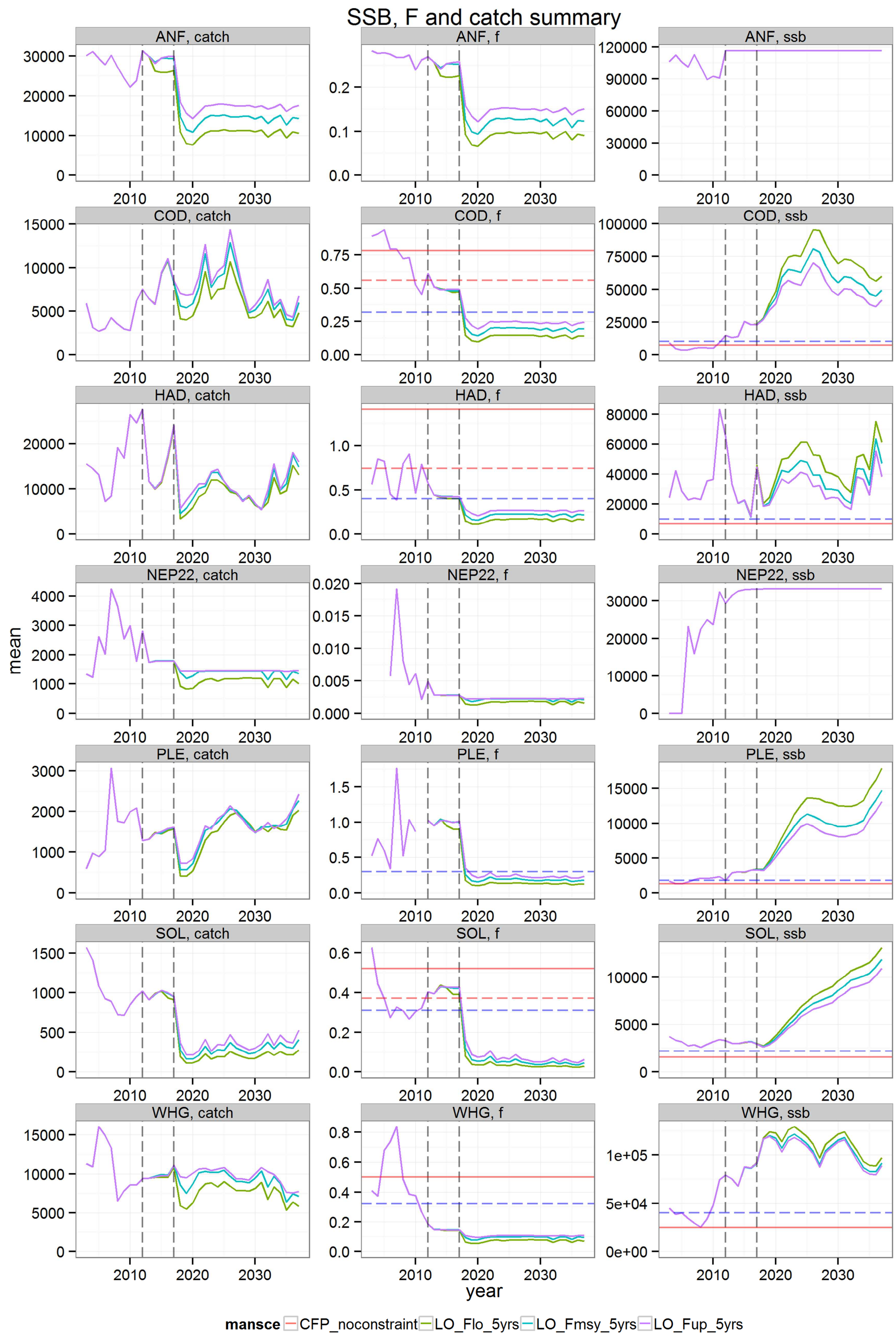

Figure 3. Catch, fishing mortality and SSB for the simulated stocks under each scenario. Note: the baseline (CFP no constraint) and LO_Fmsy_5years are the same due to the safeguard levels of biomass not being reached. Blue dashed line indicates Fmsy or Bpa/Btrigger, red solid line Flim or Blim. Dashed vertical lines delineate the data, intermediate and management rule years.

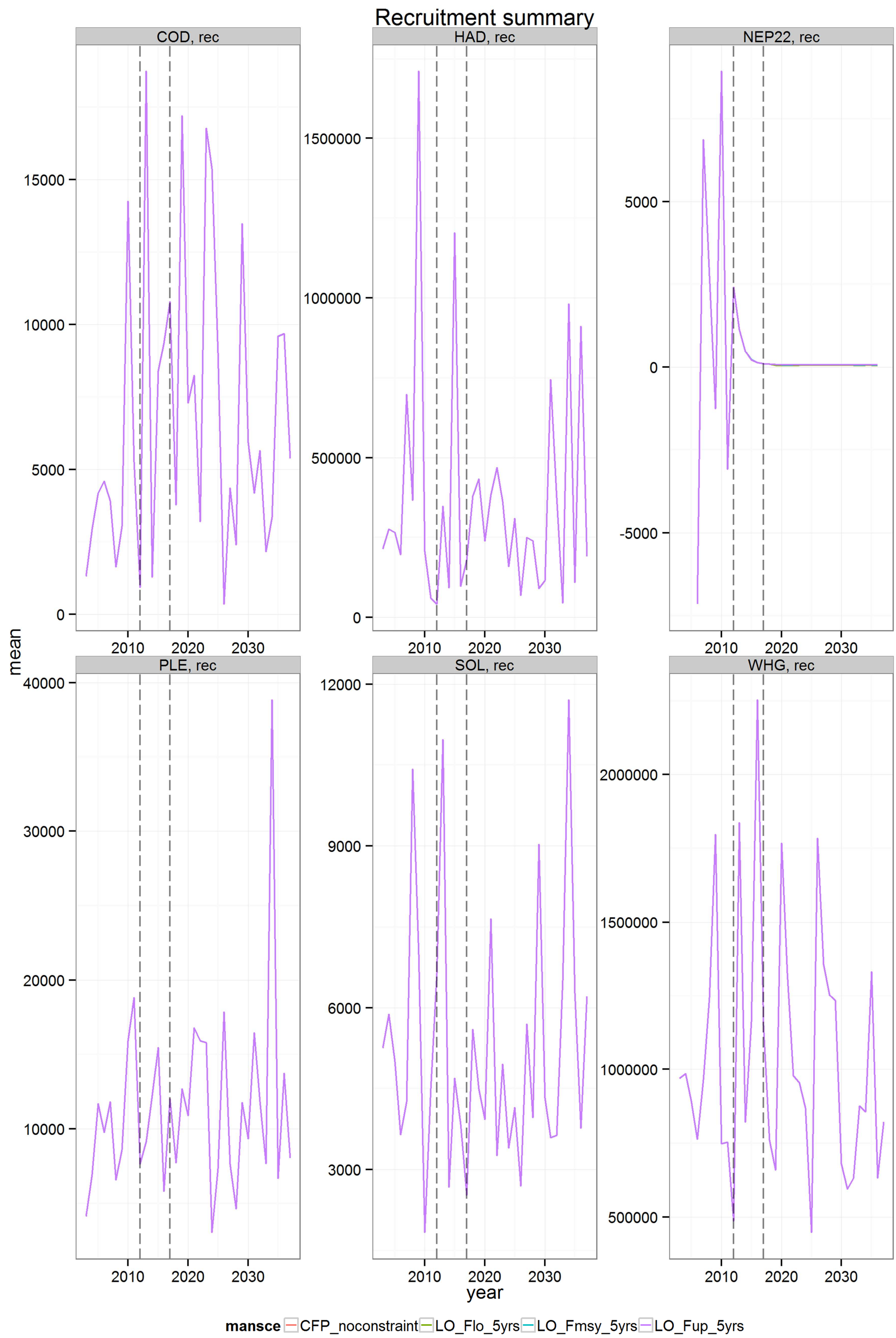

Figure 4. Recruitment assumptions under the scenarios (same for each scenario), illustrating the large variation in recruitment for the stocks. Runs based on stochastic simulations with detailed modelling of stock recruit dynamics were not possible in the time available.

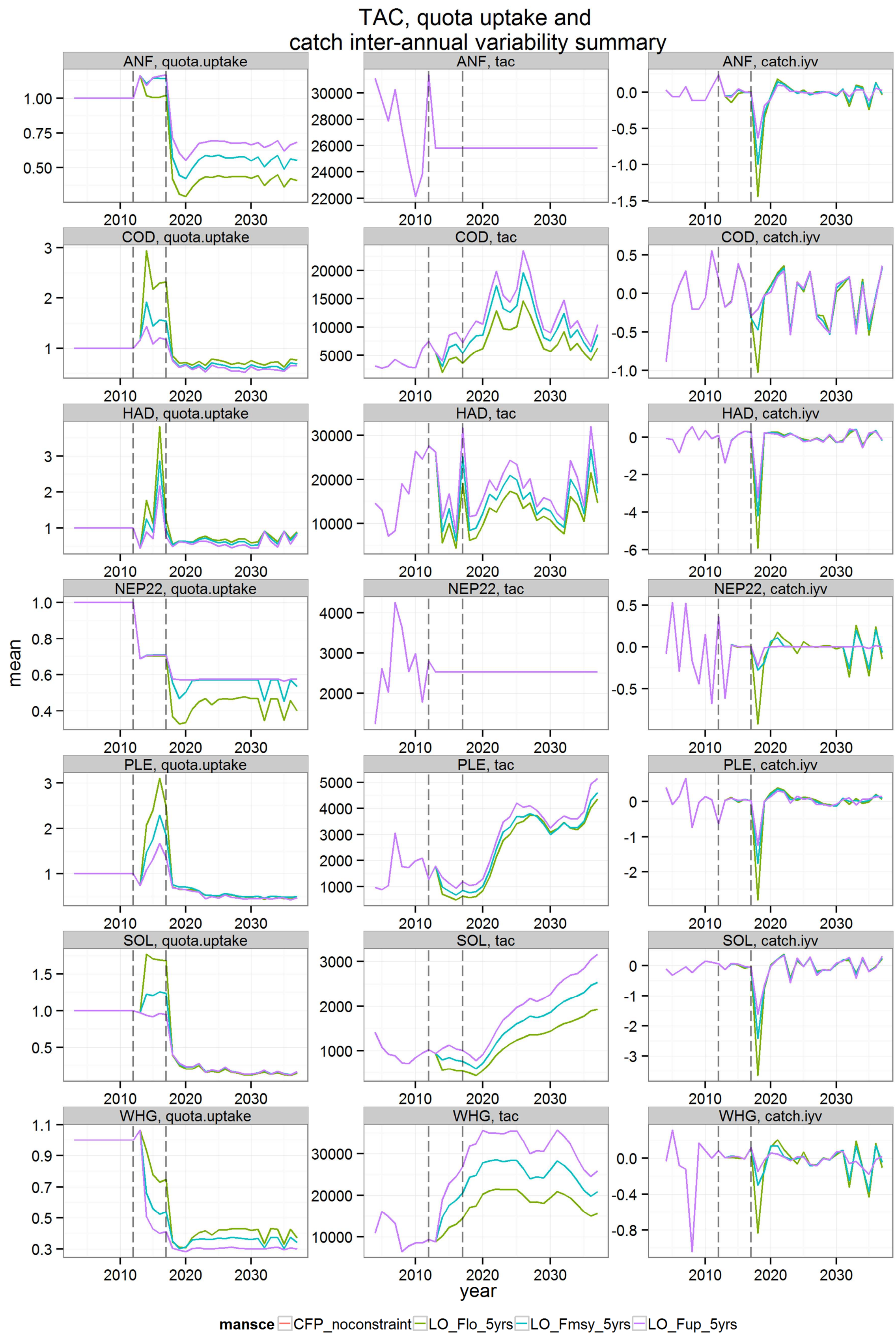

Figure 5. Quota uptake, TAC and catch inter-annual variability for the simulated stocks under each scenario. Note: the baseline (CFP no constraint) and LO_Fmsy_5years are the same due to the safeguard levels of biomass not being reached. Dashed vertical lines delineate the data, intermediate and management rule years.

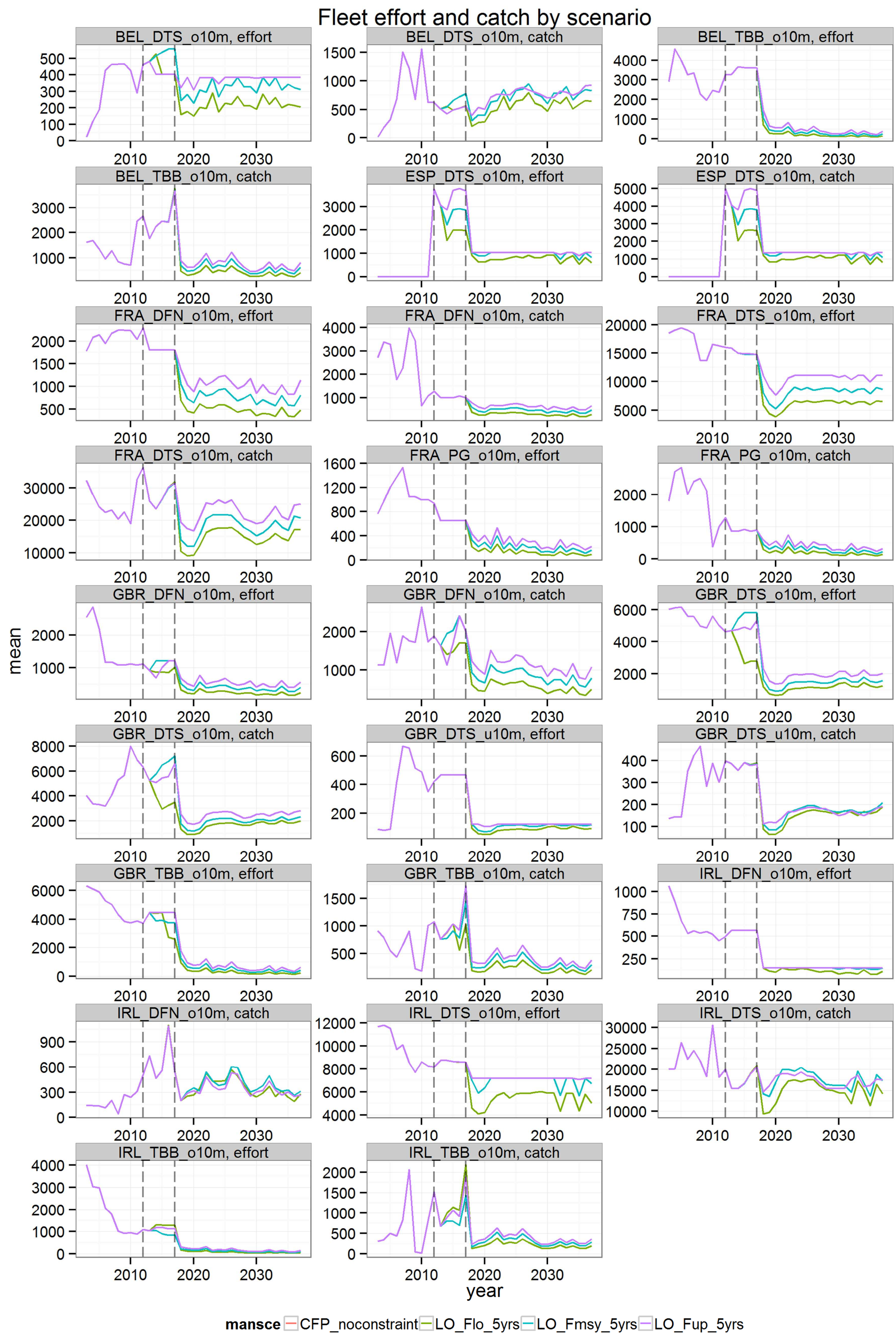

Figure 6. Effort and catch by fleet under each scenario. Note: the baseline (CFP no constraint) and LO_Fmsy_5years are the same due to the safeguard levels of biomass not being reached. Dashed vertical lines delineate the data, intermediate and management rule years.

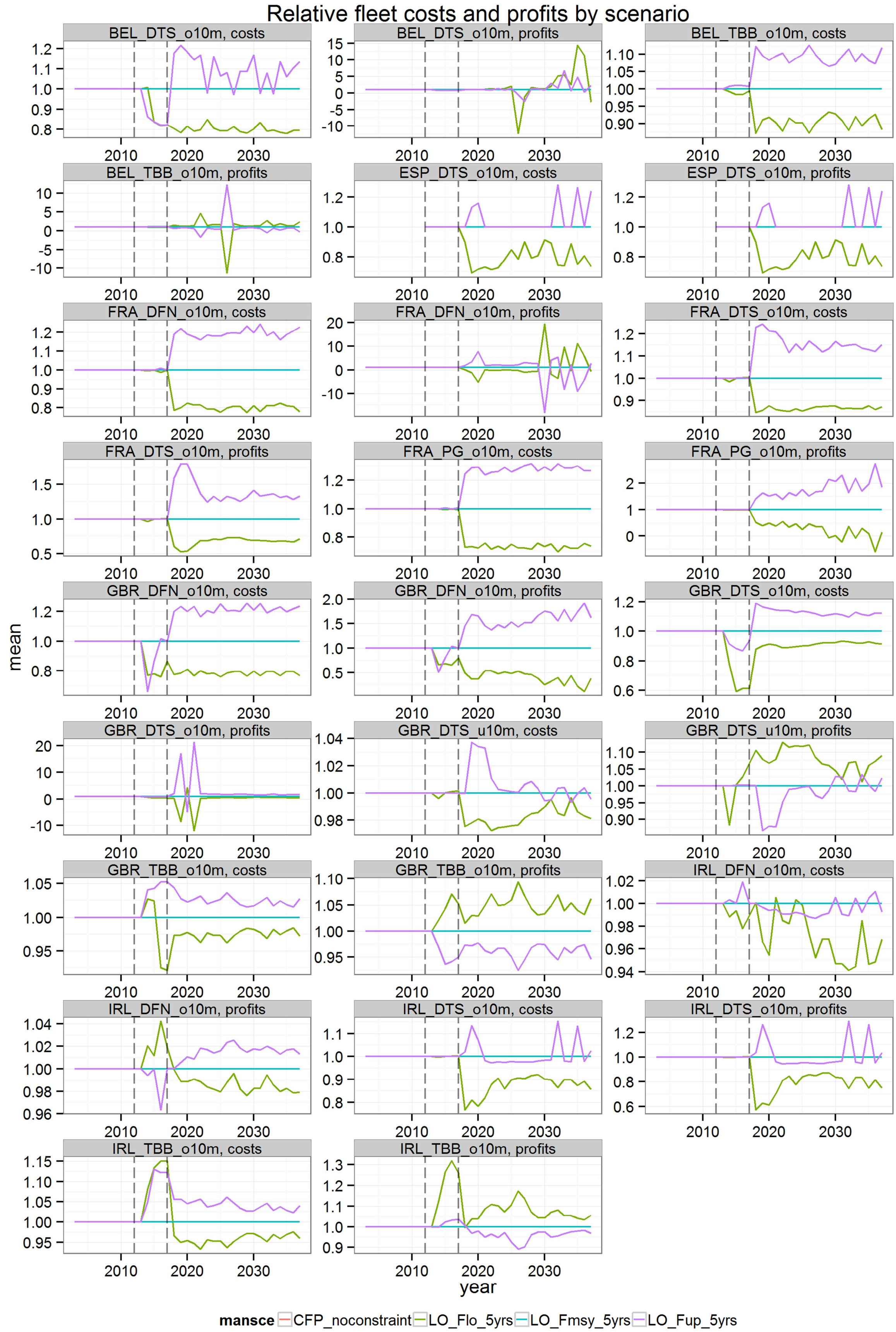

Figure 7. Change in costs and profits relative to the baseline for the management scenarios. Dashed vertical lines delineate the data, intermediate and management rule years.