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Deliverable No. 2.3

DiscardLess

Strategies for the gradual elimination of discards in European fisheries

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Deliverable 2.3

Final fishery scale models and results of scenarios (baseline, alternative management scenarios and DMS scenarios)

(Month 42)

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[1] PU: Public, PP: Restricted to other programme participants (including the Commission Services), RE: Restricted to a group specified by the consortium (including the Commission Services), CO: Confidential, only for members of the consortium (including the Commission Services)

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Revision Control

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Executive summary

This deliverable presents the results of the bio-economic modelling assessments carried out under tasks 2.3 and 2.4.

Task 2.3 covered the choice and initial parametrisation of relevant bio-economic models for the included case studies, and formulation of scenarios to be analysed. Models were chosen on the basis that they were already operational (i.e. had been used in other applications previously to Discardless) and as such thoroughly tested and documented in peer-reviewed journals, to secure a high scientific standard of the models and the expected assessment results. The selected scenarios firstly included, for all considered case studies, two benchmark scenarios; (i) 'Business as usual', i.e. how the economic outcome of the fishery would evolve if the Landing Obligation (LO) was not implemented, and (ii) 'Full implementation', i.e. what the predicted economic consequences for the fishery will be given a full implementation of the LO with no exemptions or mitigation measures implemented. Secondly a number of relevant scenarios were defined for each case study based on either expectations on or direct knowledge about how the LO, and possible exemptions and mitigation strategies will be implemented in the specific case study. And finally, each case study has assessed and applied outputs from Work Packages (WPs) 3-7, to the extend possible given the bio-economic model in use.

Task 2.4 has firstly throughout the project updated the parametrisation of the chosen bio-economic models given the newest knowledge about the fisheries in question. Secondly task 2.4 has covered the running of the models, given the scenarios identified in task 2.3, and documentation of the resulting outputs.

The following case studies have been analysed (parenthesis displaying the bio-economic model used):

- The Danish North Sea Demersal fishery (Fishrent)
- The UK mixed demersal fisheries in the North Sea, West of Scotland and Area 7 (SEAFISH model)
- The French mixed demersal fishery in the Eastern English Channel (ISIS-Fish)
- The Spanish mixed demersal fishery in the Bay of Biscay (FLBeia)
- The Icelandic mixed demersal fishery (Model for various use of unwanted catches)
- The Spanish demersal fishery in the Western Mediterranean (MEFISTO)
- The Greek demersal and small-scale fishery in the Thermaikos gulf (MEFISTO)

The outcomes of the simulations are mixed and indicate that the economic effects of the LO for affected fishing fleets depends on both the fishery in question, on the management system on which the LO is superimposed, and on applied exemptions and mitigation strategies. A full implementation of the LO with no quota-uplifts and no exemptions or mitigation strategies applied will in the long run lead to on the average (average over all fleet segments considered in a given case study) reduced or at best similar economic outcomes, compared to the situation with no LO, for the considered fisheries. Application of mitigation strategies and exemptions improves this result for most considered cases, but has in few cases been predicted to make the economic situation worse given redistributional effects, i.e. that the applied mitigation strategy or exemption will have further consequences for the

stocks and other fleets, and thus indirectly make the economic situation worse for the considered fleet. When individual fleet segments are considered the picture becomes even more complex as it is in most case studies predicted that some fleet segments will profit while others will loose out given the LO, both without and with added exemptions and/or mitigation strategies.

Thus, in all it is concluded that the economic effects of the LO for affected fisheries are, according to model predictions, very varied, going from losses to actual gains. And that the effects to a high degree depends on (i) the management system on which the LO is superimposed, and (ii) on which and how exemptions and mitigation strategies are implemented.

Finally, it must be emphasized that the work performed in tasks 2.3 and 2.4 has built up a valuable model library that can be used for ongoing assessments of the economic outcomes of introducing exemptions and mitigation strategies in relation to the LO in the case studies covered. Understanding the consequences of various approaches to the implementation of the LO, and possible mitigation strategies, on economic performance of affected fishing fleets (using these models) is of broad interest for fishers, policy makers and stakeholders, as well as for anybody interested in sustainable fisheries and life in the oceans.

The Deliverable report consists of two sections. Section 1 presents a synthesis of the work performed in the seven case studies, and as such gives a short introduction to each case study, to the applied models, to the scenarios analysed and a final synthesis and discussion of the results. Section 2 includes individual case study chapters, that present in-depth information about the case study, the applied model, the reasoning behind the chosen scenarios, discussion on interaction with WP3-7, and detailed outline and discussion of the assessment results.

Box 1: Highlights from the bio-economic model assessments

The in-depth analysis of the effects of the landing obligation on the economy of the case study fishing fleets has been conducted in the project using complex bio-economic models. The results of these simulations indicate:

- In Denmark, the ITQ management system applied is predicted to mitigate the economic effects of the LO in the long run and use of exemptions and improved selectivity may reduce possible economic losses further.
- In UK, the LO will mean losses in revenue due to choke in the medium long run after full implementation of the policy in 2019. However, application of various mitigation strategies, including quota adjustments, catch allowances for zero TAC stocks, TAC deletions, vessel movements between metiers, quota swaps (both nationally and internationally) and selectivity measures, all to some degree mitigate these negative economic consequences.
- In West Mediterranean, a full implementation of the LO will lead to reduced profitability, but other measures such as reduced fishing mortality and improved selectivity, may lead to increased profitability in the long term due to increased SSB and Yield.
- In E. Mediterranean, a full implementation of the LO and partial implementations with reduced fishing mortality will lead to slightly reduced profitability, but improved selectivity may lead to increased SSB that will in turn increase catches and profitability in the long term.
- In Bay of Biscay, the Basque trawler fleet is better off with a fully implemented LO than without in terms of Gross value added (remuneration of labour and capital), as long-term gains outweigh short term losses. Inter-species year-to year flexibility and *de minimis* reduces this result and makes the fishery worse off than without the LO. On the other hand, application of improved selectivity makes the fishery significantly better off than without the LO.
- In the Eastern English Channel ISIS-Fish runs suggest that full implementation of the LO induces a slight increase in long-run gross revenues at about 2.5% relative to the no-LO case. Introducing *de minimis* increases this to about 12.5% relative to the no-LO case. However, fleet opportunism, i.e. how flexible the fishers are in their choice of metiers, may affect these results both negatively (low flexibility) and positively (high flexibility). Closures of fishing grounds to protect whiting and sole has a negative effect for the economic outcome but allows delaying TAC exhaustion.
- For Iceland the model works opposite to the other models in the WP2 modelling, as the baseline is a fishery under LO. This case is used to contrast the results of the other case studies and reflect the possible value of landing UUC. It is found that the combined yearly value of products produced from these UUC is around 12.5 M Euros.

Box 2: The Methods/Approaches followed
- Existing numerical bio-economic models have been applied with focus on assessment of the effects of the LO on the economic performance of European fishing fleets affected by the LO, and to test the economic effects of possible discard mitigation strategies. - Analysed scenarios have been designed based on the problems faced, given the LO, by the specific case study and the management system on which the LO is superimposed. These problems may differ depending on whether the case study fishery is managed primarily through quotas or through Minimum Conservation Reference Size (MCRS) regulation. - Analysed scenarios have been designed based on current knowledge on how the LO will be implemented and on mitigation strategies expected to be introduced in the given case study. - Interaction with Discardless Work Packages 3-7 and implementation of results from these have been performed where possible in the different case study models.

Box 3: How these results can be used and by whom
Understanding the consequences of various approaches to the implementation of the LO, and possible mitigation strategies, on economic performance of affected fishing fleets (using bio-economic models) is of very broad interest for fishermen, policy makers and stakeholders, as well as for anybody interested in sustainable fisheries and life in the oceans.

Contents

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1 Synthesis of Discardless bio-economic model assessment work

1.1 Introduction

Commercial fisheries of the EU are diverse, with fish ranging from high-value species for human consumption to fish used for fishmeal and fish oil. Technological and biological interactions make it difficult to catch target species completely selectively. For almost a century, landings of immature fish have been prohibited by regulations. Discarding fish below a minimum conservation reference size (MCRS) has been mandatory in European waters since the adoption of the Common Fishery Policy (CFP) in 1983. The CFP Landings Obligation (LO) of 2013, requires fish under the MCRS to be landed, with implementation being phased in from 2015-2019. Similarly, before 2013, it was forbidden to land species for which quota was exhausted and discarding was therefore a required, logical practice in mixed species fisheries.

Many businesses expect significant short-term negative economic repercussions of the LO due to increased operating costs, decreased income from landings and under-utilisation of quotas. However, the actual outcomes of the LO will depend on several factors, including; i) the management system in place, ii) application of exemptions (e.g. de minimis allowance of discards up to 5%), iii) inter-annual transfers, iv) catch allowances of stocks without TACs, v) quota adjustments and quota swaps/movements, vi) application of selectivity measures, vii) costs of landing unwanted catch, viii) price obtained for unwanted fish and (ix) compliance of the sector. It is hoped that short-term losses could be mitigated by longer run gains, given the expected reduced pressure on fish stocks and anticipated increases in quota and catch rates.

This deliverable outlines predicted economic outcomes, based on bio-economic model projections, for the fishing fleets in the majority of the Discardless Case Studies[2], comprising (i) UK and Danish North Sea demersal fisheries, (ii) the French demersal trawl fishery in the Eastern English Channel, (iii) The Icelandic mixed demersal fishery within the Icelandic EEZ, (iv) the Spanish trawl fishery in the Bay of Biscay, (v) the Greek trawl and small-scale coastal fishery the in the Thermaikos Gulf (East Mediterranean), and (vi) the Spanish demersal trawl fishery in the Western Mediterranean. Analysed scenarios comprise (i) ‘business as usual‘, i.e. how the economy of the given case study fishery would have evolved without the LO in place , (ii) ‘full implementation‘, i.e. how the economy of the case study fishery would evolve under the LO if no mitigation strategies were in place, (iii) economic effects of expected mitigation strategies, and (iv) implementation of selected outcomes of Discardless Work Packages 3-7. The Deliverable report consistes of two sections. Section 1 presents a synthesis of the work performed in the seven case studies, while Section 2 includes individual case study chapters, that presents in-depth information about the case study, the applied model, the reasoning behind the chosen scenarios, discussion on interaction with WP3-7 and detailed outline and discussion of the assessment results.

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[2] It was the agreement in the outline of Discardless that only Case Studies for which bioeconomic models already existed would be included in economic assessment framework covered in tasks 2.3 and 2.4 of Discardless. This excludes the Azores, Celtic Sea, and Barents Sea case studies.

1.2 Material and methods

1.2.1 The Case study fisheries

Possible economic implications of the LO are presented for seven Discardless case study fisheries. Characteristics of each case are summarised in Table 1.1. Cases are divided into two groups: (i) demersal fisheries in the Atlantic, comprising the North Sea, West of Scotland, English Channel, Bay of Biscay and Icelandic EEZ, represented by Danish, UK, French, Basque and Icelandic fisheris, and (ii) Mediterranean fisheries represented by the two mixed demersal trawl fisheries from the Balearic Islands (Spain, Western Mediterranean) and the Greek trawl and small scale coastal fishery in the Thermaikos gulf (Eastern Mediterranean). Of these the Icelandic case has already had a LO implemeted for over four decades, and as such this case study diverges from the others in that this case reflects the possible value of landing unwanted fish.

The analysed fisheries have different management systems on top of which the LO is imposed. However, all have a certain degree of MCRS regulation, and before the LO it was compulsory to discard fish below MCRS, with a few derogations within certain pelagic fisheries. After the LO it has become obligatory to land these fish, but they cannot be sold at the price for human consumption. On top of MCRS regulation, the North Sea, West of Scotland and English Channel fisheries are regulated by quotas, in some cases combined with effort regulation and technical conservation measures. National quotas are managed as ITQs in Denmark, are distributed between Producer Organisations (POs) and vessel owners in the UK in a system that is essentially a quasi-ITQ system, and between POs in France. Swaps and quota exchanges are allowed between organisations in the UK and France. The Icelandic demersal fishery is managed through a an ITQ system, with 12-15% of the quotas reserved for the coastal sector and additional 2.5% for a voluntary „Olympic“ coastal fishery scheme. The Atlantic Basque fishery are regulated with Total Allowable Effort (Prellezo *et al*. 2016) and TACs. The Mediterranean fisheries are regulated through technical gear specifications and MCRS for the main target species, temporal and spatial closures and effort control (Stergiou et al. 2016).

Table 1.1. Base characteristics of the Discardless case study fisheries for which socioeconomic consequences of the LO have been analysed.

	Fishery	Target species	Fleet	Management system	Reasons for discard
Atlantic	**Danish North Sea Demersal Fishery**	Cod, plaice, hake, haddock, sole and nephrops.	Netters and trawlers, with length groups from 12 to 40 meters.	ITQ	- Quota utilisation optimisation - Fish below MCRS - High-grading
	UK mixed demersal fisheries in the North Sea, West of Scotland and area 7	73 main UK stocks targeted by different fleets in different areas. Pelagic species and non-quota species representing around 58% of value and 75% of weight landed by UK fleet are excluded.	All* UK active vessels grouped in 99 Producer Organisation fleet segments.	Fixed Quota Allocation units that can be pooled within a PO, traded by vessel owners, or can be leased by other vessels in the same or other PO.	- Quota utilisation optimisation - Fish below MCRS - High-grading
	French demersal fishery in the Eastern English Channel	Sole, scallops, whiting, cephalopods, cod, red mullet, sea bass and plaice.	Bottom trawlers, mixed trawlers and trawl-dredgers, with length groups from 12 to 40 meters.	Quotas, minimum landing sizes, seasonal closures for scallops, and effort limitation.	- Quota utilization optimisation - Fish below MCRS - High-grading
	Spanish mixed demersal trawl fishery in the Bay of Biscay	Pair trawlers: mainly hake. Otter trawlers: hake, megrims, horse mackerel, blue whiting, mackerel, rays red mullet, seabass, squids, and cuttlefish.	Pair and otter trawlers using different métiers	The fleet is managed with fishing rights, TACs, Total allowable Effort, together with mesh and MCRS limitations.	- Quota utilisation optimisation Fish below MCRS
	Icelandic mixed demersal fishery	Cod, haddock, Saithe and Redfish	Mixed demersal fleet (trawlers, Danish seiners, longliners, gillnetters, jiggers)	ITQ (scenarios explored include various levels of discard mitigating measures within the ITQ)	High-grading Choke-species
Mediterranean	**Spanish demersal fishery in the Western Mediterranean**	Four different fishing tactics are used, depending on the main target species (Palmer et al 2009): 1) shallow shelf (striped red mullet); 2) deep shelf (European hake); 3) upper slope (Norway lobster); and 4) middle slope (red shrimp).	Mixed demersal trawl	MCRS and other technical measures.	- Hake below MCRS - High-grading - Discard of low value species
	Greek demersal trawl and small scale fishery in the Thermaikos Gulf	Mainly hake and red mullet (also surmulle+t and deep-water rose shrimp)	Bottom trawlers and small scale coastal vessels using gill nets and trammel nets.	Spatial and temporal restrictions, MCRS, other technical measures (e.g. mesh size and effort control)	- Hake and red mullet below MCRS - High-grading

Demersal fishing activities in the North Sea, West of Scotland and in the English Channel have highly mixed species catches and therefore it is not possible to fully catch all quotas at the same time in the year, leading to either underutilisation of quota or discarding of fish for which the quotas are exhausted first. Under the LO, the risk of a choke situation, i.e. having to stop fishing when the quota of a low quota stock is exhausted, is a great concern to managers and vessel operators alike (Ulrich et al. 2011). This is especially expected to be a problem for French vessels, operating with fixed quota shares within producer/fishery organisations, while this problem may be less severe for UK and Danish fleets, where quota trade may mitigate the problem to some extent. For Spanish demersal fisheries in the Bay of Biscay, mackerel and horse mackerel are discarded because of low quota allocation, i.e. to optimize quota utilization of other species, while hake is primarily discarded because of being below MCRS. Thus, in these fisheries choke situations may also be an issue. In the Mediterranean fisheries, discarding is primarily due to fish below MCRS, and to high-grading. As such all cases[3] face lower revenues under the LO given that previously discarded fish of low value and below MCRS must now be landed, combined with increased handling costs of unwanted catches.

1.2.2 Analysed mitigation strategies

Given the different challenges that the selected fishing fleets face under the LO, different scenarios have been analysed, addressing: (i) how fleets will respond given the LO, and (ii) how possible economic losses, given the LO, can be reduced through mitigation strategies most relevant for that fleet. Table 1.2 gives an outline of the scenarios analysed for each case study.

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[3] Excepting the Icelandic case where the LO has been in place for more than four decades.

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Table 1.2. Scenarios analysed in the case study fisheries.

	Atlantic					Mediterranean fisheries	
	Iceland	**DK**	**UK**	**France**	**Basque**	**W. Med**	**E.Med**
Business as usual (no LO)	■	■	■	■	■	■	■
Full implementation of LO, no exemptions		■	■	■	■	■	■
De minimis	■	■		■	■		
Year Transfer					■		
Allowed landings exceeding quotas	■						
Selectivity (mesh size)		■			■	■	■
Flexibility (effort reallocation)		**(2)**		**(2)**			
Quota uplift/adjustment			■	**(1)**	**(1)**		
Decrease minimum landings size		■					
Catch allowances zero Tac stocks			■				
TAC deletion			■				
Vessel movements between metiers			■	■			
Quota movement (swaps)			■				
Discard of high survival species		■	■				
Avoidance strategies		■		■			
Increased landings costs		■					

Notes: (1) Quota adjustments assumed in all LO scenarios for the Bay of Biscay and the E. English Channel cases. (2) Effort reallocation can be seasonal and between fleets (the Danish case) and spatially (the French case.

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1.2.3 The Full Implementation scenarios

In all case studies the economic situation was analysed for the fleet, given the current management system (cf. Table 1.1), i.e. if the LO had not been implemented (named 'Business as usual'). In all case studies, except the Icelandic case, full implementation of the LO with no exemptions was also analysed, i.e. the economic situation for the fleets given their current management system with the LO superimposed. Application of full implementation in the case study models was based on different assumptions for each case study:

- In the Danish North Sea demersal case, fish below MCRS must be landed, with gradual implementation from 2016 to 2019 depending on species

- In the UK mixed demersal fleets, each vessel in a PO has its initial quota available and by 2019 no demersal species below MCRS can be discarded. The LO is implemented gradually towards 2019 depending on the fish stock.

- In the French mixed demersal case, vessels in métiers are forbidden to continue fishing as soon as the quota of one of their target stocks is reached and fishing effort is then allocated between the remaining métiers. Fish under MCRS are landed but cannot be sold (price set to zero).

- In the Bay of Biscay Basque mixed demersal trawl case, the fishing activity of a given métier is stopped when the most binding quota share is reached.

- In both Mediterranean cases, a 10% increase in daily variable costs and one more crew member on-board are assumed to reflect the extra effort needed to bring ashore unwanted catches. Three full implementation scenarios were examined for the Greek case (E. Mediterranean) based on varying discard rates: (iv) 5% increase of daily costs, no extra crew member, (v) 10% increase of daily costs, 10% extra crew (the original full implementation scenario), (vi) 20% increase of daily costs, 20% extra crew (based on the discard rates reported in the literature). The reason for the extra full implementation scenarios was that, according to official reports (DCF 2016), the percentage of hake and red mullet discards in Greece had dropped to less than 5% since 2013; thus, this case differs substantially from initial estimates that were based on the literature (e.g. Tsagarakis et al. 2014).

For the Icelandic case there is no full implementation with no excemptions scenario. The reason being that in the Icelandic mixed demersal case, the current situation is, and has been for more than 40 years, a full discard ban with a number of mitigating measures already in place. Assumptions of the use of unwanted fish landed under these mitigation strategies is then compared to the 'no LO' case, where it is assumed that the same fish are discarded.

1.2.4 Analysed mitigation strategies

The analysed mitigation strategies (see Table 1.2) are different for each case, reflecting the specific challenges each fleet faces when the LO is introduced.

In the UK, Danish and French cases, the focus is on maximizing quota utilisation. For the Danish demersal fishery, the effect of introducing a 5% *de minimis* exemption is analysed. Moreover, economic effects of lowering the MCRS for cod (making it possible to sell some fraction of cod below the previous MCRS) are analysed. And finally, the effect of introducing increasing selectivity for the large trawlers for human consumption, and allowing discard of Norwegian lobster, assuming high survival rate for this species, is analysed. For the UK North Sea and West of Scotland mixed demersal fleets a number of mitigation strategies are analysed: (i) allowance for catching and landing species with zero TAC; (ii) as scenario (i) but with quota adjustment to all TAC species; (iii) as scenario (ii) but with the possibility to reallocate effort to other areas of operation to better utilise Producer Organisation (PO) quota; (iv) as scenario (iii) but with quota reallocation allowed within the UK to maximize use of quotas; and (v) as scenario (iv) but with international and national swaps at the level of the baseline year incorporated, and UK end of year quota reallocated to PO fleets in need of quota. On top of this a number of high survival, TAC deletion and selectivity assumptions are superimposed. The French mixed demersal fishery in the English Channel case focused on (i) implementation of a *de minimis* exemption, (ii) assuming that fishers can to some degree be opportunistic, i.e. shift metiers in time and space to reduce unwanted catch, and (iii) avoidance strategies for sole and whiting. In this case quota adjustments for sole, plaice, cod and whiting are assumed in all LO scenarios

The choke situation and having to land fish below MCRS are also issues in the Spanish Atlantic cases. Thus, focus is on quota utilisation optimisation and on fishing gear selectivity. For the Basque Bay of Biscay mixed demersal fishery, focus is on investigating the economic effects of implementing (i) 5% *de minimis* exemption, (ii) inter-year quota flexibility, (iii) combining *de minimis* and inter-year flexibility and (iv) selectivity changes for the pair trawlers, given the single species nature of their catches (90% hake), assuming a change in minimum mesh (MMS) size from 100mm to 120mm. In this case quota adjustment of target species is assumed in all scenarios.

The two Mediterranean cases focus predominantly on selectivity issues, given their high catches of unwanted species and fish below MCRS. For the Spanish demersal trawl fishery around the Balearic Islands (Western Mediterranean) several selectivity possibilities for hake are analysed, (i) no fishing mortality for hake at age 0, (ii) no fishing mortality of hake below MCRS (by decreasing the fishing mortality of age 1 individuals by 10%), and (iii) no fishing mortality of immature individuals (through modification of age-selectivity parameters).

For the Greek demersal trawl and small-scale coastal fishery in the Thermaikos gulf (Eastern Mediterranean), three selectivity scenarios are applied to both hake and red mullet: (i) no fishing mortality at age 0, (ii) no fishing mortality below MCRS (by additionally decreasing the fishing mortality of age 1 individuals by 10%), and (iii) no fishing mortality for hake and red mullet at ages 0 and 1 through modification of age-selectivity parameters.

The Icelandic mixed demersal case differs from the other case studies, as the fishery is already operating under a discard ban. The discard ban has been in effect for four decades and has been gradually amended in order to facilitate success of the ban. These amendments include a number of mitigating measures that have the aim of creating incentives to land unwanted catches. The mitigating measures include an (almost) fully individual transferable quota system that allows for quota swaps, leasing and permanent acquisition of quota shares, flexibility with yearly transfers, the possibility of landing catches exceeding quota (choke species in particular) without deducting from quota given that landing value is forfeited. The current situation also includes the fact that there are no limits on the use of undersized (MCSR) catches. The model explores the economic efficiency of these mitigating measures, compared to a system where discards are permitted/obligatory.

1.2.5 Scenarios based on interactions with WP3-7

It must be emphasized that all scenarios included in the analyses presented in this deliverable, i.e. all scenarios presented in table 1.2, are based on expected reactions to the LO in the different case studies. I.e. to expected management mitigation strategies in the respective countries (including application of *de minimis*, quota adjustments, decreased MLS, etc., plus expectations regarding possible physical mitigation strategies, e.g. selectivity changes). As such all scenarios are in accordance with the work performed in WPs 3-7, even though some of the analysed scenarios do not directly simulate the actual outcomes of these WPs.

A number of the analysed scenarios are more directly based on interactions with WP3-7. This either directly, transferring the findings in WP3-7 in a given case study, to the bio-economic case study model applied in WP2. Or more generically basing scenarios on general findings from WP3-7, when results from these work packages are not directly applicable.

As such the following scenarios are based directly or generically on findings from WP3-7[4]:

- In the Danish North Sea demersal fishery, (i) a selectivity scenario has been constructed, assuming that the large human consumption trawlers 24-40 meters can reduce the catch of undersized gadoids (cod, haddock, hake, whiting, saithe and pollack) with 30 respectively 50%, and (ii) a scenario in which discards of undersized nephrops is allowed for all fleet segments. Scenario (i) has been implemented, given that in the Danish case the only fleet segment seriously affected by the LO is the large trawlers for human consumption, as that these can not buy enough quota (under the Danish ITQ system) to not choke on especially hake given the LO. The assumption of possible reduction in catch of undersized fish is based generically on the Challenge experiment reported in WP4 (Reid et al. 2017b), where a number of Danish demersal trawlers ere challenged to reduce their discard of Cod, Whiting, Saithe, Plaice, Haddock, Hake and Norway lobster. Scenario (ii) is based on the fact that Nephrops is assumed a high survival species and as such is exempt from the LO, given expected or already implemented policy changes listed through WP7.
- In the Spanish mixed demersal trawl fishery in the Bay of Biscay a scenario is run in which the Minimum Mesh Size (MMS) is increased for the Pair trawlers from 100mm to

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[4] Mitigation measures based on WP3-7 has not been included for the Icelandic case, as a LO has been implemented for this fishery for more than 40 years. As such the Icelandic model is constructed with the aim of illustrating the economic effects of various uses unwanted catches, more than test various mitigation strategies.

120mm to reduce catches on undersized hake. This is in accordance with analyses performed in WP3.

- In the case of the Greek demersal trawl and small-scale fishery in the Thermaikos gulf perceptions of the Greek fishers on how the LO will affect wages are based on findings in WP4, together with applied discard rates. Furthermore, the included selectivity scenarios have been based on previous research on mesh selectivity of Greek trawlers and netters.
- In the Spanish demersal fishery in the Western Mediterranean, attempts have been made to include selectivity improvements for the bottom trawl fleets. However, the attempt was not pursued as it was concluded that the theoretical foundation for performing this analysis was too weak. This is discussed in the country chapter in detail, together with why a spatio-temporal approach to mitigation measures (based on WP4 findings) was not pursued.
- In the UK mixed demersal fishery in the North Sea, scenarios have been included in which it is allowed that undersized nephrops may be discarded given assumed high survival of this species. Moreover, TAC deletion scenarios have been tested, assuming deletion of the TACs for Cod in 6A West of Scotland, whiting in 7A and Boarfish in area 6, 7 and 8. These scenarios are based on expected or already implemented policy changes listed through WP7. Moreover, a number of selectivity scenarios have been run, based on a STECF Economic Working Group meeting. As such the latter is not directly related to WP3, but still generically applies the foundation for WP3, i.e. that gear changes may mitigate the effects of the LO.
- In the French demersal fishery in the Eastern English Channel an avoidance strategy tool has been designed in cooperation with WP4, based on discussions with fishermen. The tool helps identify areas and seasons of interest, i.e. areas and seasons that should be avoided by fishers. The tool has been used in the case study to draw up three avoidance scenarios for sole and whiting. Ongoing interaction with fishers regarding model setup and results furthermore ensures that the model is continuously updated with the newest data and information.

As such it has in each case study been analysed if it is possible to apply outputs from Work Packages 3-7 in a way that is relevant for the fishery in question. Implementation of the selectivity measures identified in WP3 are relevant for all case studies, given that landings of previously discarded fish below MCRS may choke in the fisheries managed with quotas, and generally increase the costs (wages and landings costs) for all fleets. Given the structure of the bio-economic models, analysis of the effects of implementing selectivity measures is possible to some degree in all applied models (again excepting the Icelandic model). 'To some degree' refers to that not all applied bio-economic models include age-structured stock projections or fleet segments subdivided in métiers, both of which makes it possible to simulate selectivity measures more realistically. MEFISTO (E. and W. Mediterranean case studies), FLBeia (Bay of Biscay case study) and ISIS-Fish (French eastern English Channel fishery) all include age-structured stocks. FLBeia, ISIS-Fish and the SEAFISH model moreover include métiers division of the included fishing fleets. These models are as such able to simulate possible selectivity measures at a level of detail that includes age- and métier-differentiated catch possibilities. In models that do not include detailed age-structured stocks and/or métiers, simulation of selectivity measures are more akin to sensitivity analyses of the possible average outcomes, given possible selectivity scenarios (which has e.g. been done in the Danish case). However, it is still possible to base these considerations on the selectivity possibilities revealed in WP3, as long as it is remembered that the applications are not a direct simulation of the WP3 results.

With regards to spatial measures, e.g. spatially changing fishing grounds or fishing patterns, MEFISTO (Mediterranean) and ISIS-fish (E. English Channel) have spatial components. However, the Mediterranean cases lacked sufficient data to set up working models for investigating spatial mitigation measures as proposed in WP4. On the other hand, ISIS-fish distributes effort on métiers, defined according to area of operation, season, gear and search intensity, according to two parameters: historical fishing patterns and assumptions regarding opportunism, where the latter depends on recent experience regarding landed value per landed weight. In this case it has been possible to analyse a number of avoidance scenarios based on the outcomes of WP4

1.2.6 Model tools

The analyses were carried out using different bio-economic models constructed for the geographical areas of the case study fleets (Table 1.3). The models are described in more detail in the individual case study chapters. All but the Icelandic models are dynamic, evaluating the development of fleet capacity, economic performance and effort, together with stock dynamics, over a pre-set period. For most cases this period is set to 2015-2025, with the exception of the UK case where the period is 2015-2019. The Icelandic model, which is static, estimates the outcome for the Icelandic fishery given different usages of unwanted catches, compared to an assumed case of no LO in place.

Table 1.3 Model tools applied to evaluate the consequences of the LO for European case fisheries.

	Fishery	Model
Atlantic	Danish North Sea Demersal Fishery	Fishrent: A bio-economic profit maximization model integrating, and allowing feedback between, the economy and the biology of the fishery (Frost et al. 2013).
	UK mixed demersal fisheries in the North Sea – West of Scotland and area 7	SEAFISH: Based on the Fishrent structure, the SEAFISH simulation model is developed to analyse the activity of the total UK fleet (Mardle et al. 2017).
	French demersal fishery in the Eastern English Channel	ISIS-Fish: A spatialised operational simulation model which simulates the dynamics of fish populations and fleets of the mixed fisheries in the Eastern Channel. (Pelletier et al. 2009, Lehuta et al. 2015).
	Spanish mixed demersal trawl fishery in the Bay of Biscay	FLBeia: A management strategy evaluation model coupling economic, biological and social dimensions, shares economic structure with Fishrent but with an age structured biological component. (Garcia et al, 2017)
	Icelandic mixed demersal fishery	Excel based model that enables the user to explore the product value (export value) of "unwanted" catches that are landed due to the mitigating measures that have been built into the Icelandic ITQ system to incentivise lading of unwanted catches.
Mediterranean	Spanish demersal fishery in the Western Mediterranean	MEFISTO (Mediterranean Fisheries Simulation Tool): A bio-economic fisheries simulation model with an age structured biological component (Lleonart et al., 2003b, https://mefisto2017.wordpress.com/).
	Greek demersal fishery in the Thermaikos Gulf (Eastern Mediterranean)	

1.3 Results

This section presents a synthesis of the long-term results of the case study model studies. As such a single year view of the economic outcome of the LO for the considered fisheries in 2025 (2019 for the UK case) is presented in this synthesis. Detailed results are presented in the individual case study chapters in Section 2 of this report.

Whether 2025 corresponds to a long term will, to some degree, depend on the specific case study, i.e. on whether adjustments are ongoing in the given fleet, or whether equilibrium is reached. Theoretically, a better measure of impacts would have been the net present value (NPV) covering the whole period from 2015-2025. However, not all models included in the present synthesis are able to provide NPVs over that period, and it has therefore been chosen to present the outcomes for 2025 alone in this synthesis. Referring to the individual model chapters, more detailed results are given, where possible presenting profit or NPV.

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The synthesis includes two parts, firstly the economic outcome under the LO benchmarked against the outcome if the LO had not been introduced (table 1.4), and secondly the LO mitigation scenarios benchmarked against the LO scenario with no exemptions or other mitigation strategies included (Table 1.5). The Icelandic results are left out of these overall considerations, as this case works "opposite" to the other cases, given that the baseline is a fishery under LO. This case is used to contrast the results of the other case studies and reflect the possible value of landing UUC. The results of this case will be discussed separately at the end of this section.

1.3.1 Economic consequences of the LO relative to the case with no LO

In 2025 (2019 in the UK case) two of the seven case studies, i.e. the UK and W. Mediterranean cases, are expected to be severely negatively affected by the LO, when no exemptions are assumed (see Table 1.4). The reasons for these expected economic losses are increased daily and crew costs (Western Mediterranean case) and the industry being unable to process the previously discarded fish, and lost landings value due to cessation of fishing after choke situations (the UK case).

For the remaining case studies the economic outcome in 2025 when the LO is introduced with no exemptions is within +/- 5% of the economic outcome that could be expected had the LO not been implemented. For the Danish case, where choking on low quota stocks is the greatest concern, possible negative economic consequences of the LO are reduced through (i) quota trade under the ITQ system in place, and (ii) seasonal effort flexibility. In the French demersal fishery in the Eastern English Channel the long-term benefits mainly arise from higher sole revenues, since landed values for other target species show no or negative change. In the Spanish mixed demersal fleet in the Bay of Biscay, possible economic losses are reduced by the effects of choke situations reducing mortality and increasing stock size, i.e. under full implementation of the LO, other fleets face choke situations and cease fishing before catching quotas of other stocks, such that the target species stock size increases in the long term, thus increasing catch possibilities (Prellezo et al. 2016). In the Greek Eastern Mediterranean case study, the percentage of discards for hake and red mullet that are officially reported is below 5% for trawlers and even lower for netters (DCF 2016). For that reason, the full LO implementation scenario will result in very low increase (<5%) in the daily costs and will not necessarily require an extra crew member to handle the extra catch.

Compared with how the case study fisheries would have evolved without the LO, the LO implemented with mitigation measures is, in some cases, expected to make the fisheries equally or better off in 2025. This is so for the Danish North Sea demersal fishery, as the ITQ management system makes it possible for the fleets involved to avoid choke situations through quota trade and seasonal effort flexibility. Likewise implementation of *de minimis* and application of improved selectivity measures for the large trawlers for human consumption makes the fishery equally or better off in the Danish case, compared to the situation in 2025 if the LO had not been implemented. However, if landings costs are increased the Danish fishery is predicted to be worse off in 2025 compared to the case with no LO.

Table 1.4 This table displays the economic outcomes in 2025 (2019 in the UK case) for the LO scenarios relative to the scenario assuming no LO (business as usual). For most scenarios the economic outcome is measured as the total profit (P) in 2025 for the included fleets, while for the UK and French cases the economic outcome is measured in total revenue (R) for the included fleets.

	Atlantic				**Mediterranean fisheries**	
	DK	**UK**	**France**	**Basque**	**W. Med**	**E.Med**
Full implementation of LO, no exemptions	🟨 **P**	🟥 **R**	🟨 **R**	🟨 **P**	🟥 **P**	🟨 **P**
De minimis	🟨 **P**		🟩 **R**	🟥 **P**		
Year Transfer				🟨 **P**		
Allowed landings exceeding quotas						
Selectivity (mesh size)	🟨 **P**			🟨 **P**	🟩 **P**	🟩 **P**
Flexibility (effort reallocation[1])	🟨 **P**		🟨 **R**			
Flexibility + de minimis			🟩 **R**			
Quota uplift/adjustment		🟥 **R**				
Decrease minimum landings size	🟨 **P**					
Catch allowances zero Tac stocks		🟥 **R**				
TAC deletion		🟥 **R**				
Vessel movements between metiers		🟥 **R**				
Quota movement (swaps)		🟥 **R**				
Discard of high survival species	🟨 **P**					
Avoidance strategies			🟥 **R**			
Increased landings costs	🟥 **P**					

Note: [1] Effort reallocation can be seasonal and between fleets (the Danish case) and spatially (the French case.
[2]Yellow indicates less than 5% change, red indicates more than 5% decrease and green indicates more than 5% increase.

For the Spanish demersal fishery in the Bay of Biscay, inter-annual quota flexibility (with a limit of 10% of the initial quota) and increased selectivity (assuming an increase in minimum mesh size from 100mm to 120mm) also limit the possible negative economic effects of the LO. However, the application of the *de minimis* exemption has a negative effect in the long term. The application of *de minimis* increase the fishing mortalities compared to the case with no LO, and the harvest control rule will then reduce the advised TAC for the next year (which then happens every year). Thus, the penalty imposed, given increased fishing mortalities, is higher than the flexibility gained by the exemption itself.

Increased selectivity also makes the fishery better off for the Spanish fishery around the Balearic Islands (W. Mediterranean) and for the Greek trawl and small-scale coastal fishery in the Thermaikos gulf, especially if the catch of immature hake individuals is totally avoided, which raises the profit in 2025 above what could be expected without the LO.

Contrary to these cases, implementation of various mitigation measures and policy changes is not predicted to make the UK mixed demersal fishery better off in 2019 compared to if the LO had not been implemented. The reason for this being severe choke problems for this fishery.

1.3.2 Economic effects of mitigation measures and policy changes

Under the LO, a key question is to what degree the overall negative economic outcome can be avoided through appropriate mitigation measures. Table 1.5 shows the economic outcome in 2025 (2019 in the UK case) in the mitigation strategy scenarios for each of the analysed fisheries, relative to the expected situation in 2025 (2019 in the UK case) assuming full implementation of the LO with no exemptions.

Table 1.5 shows that approximately half of the mitigation strategies analysed do not significantly improve the economic outcome relative to full implementation of the LO with no exemptions. This is the case for the Spanish trawl fishery in the Bay of Biscay when inter-year quota transfers and increased mesh size selectivity are introduced. Moreover, applying the *de minimis* exemption leads to a reduced economic result for the Spanish demersal fishery in the Bay of Biscay, because increased fishing pressure leads to higher mortality and reduced hake and megrim stocks and thus reduced fishing possibilities. Likewise, for the French fishery in the Eastern English Channel, applying avoidance strategies, i.e. avoiding certain fishing grounds at certain times of the year, leads to a decreased economic result compared to the LO with no mitigation strategies. In the Danish case, implementing the mitigation strategies does not significantly alter the results relative to the LO with no mitigation strategies, the reason being, as discussed above, that the ITQ management system in place in Denmark generally mitigates possible overall negative economic effects of the LO.

Mitigation strategies that do increase the economic outcome relative to the full implementation of the LO with no exemptions are (i) *de minimis* in the French demersal fishery in the Eastern English Channel, (ii) increased selectivity in the Spanish fishery around the Balearic Islands (W. Mediterranean), (Iii) increased selectivity in the Greek fishery in the Thermaikos gulf (E. Mediterranean) and (iv) all mitigation strategies (quota adjustment, catch allowance for zero TAC stocks, vessel movements between metiers and quota swaps), policy changes and Tac deletions considered for the UK fishing fleets.

In all cases it must be emphasized that the changes discussed here are overall for the entire case study fishery, and that individual fleet variations may exist, which are discussed in the individual case study chapters in section 2 below.

Table 1.5. Results at a glance: Total economic result (Profit='P', Revenue='R') in 2025 (2019 in the UK case) with mitigations relative to full implementation of the LO with no mitigations. For most scenarios the economic outcome is measured as the total profit (P) in 2025 for the included fleets, while for the UK and French cases the economic outcome is measured in total revenue (R) for the included fleets.

	Atlantic					Mediterranean fisheries	
	Iceland[3]	DK	UK	France	Basque	W. Med	E.Med
De minimis		🟨 P		🟩 R	🟥 P		
Year Transfer					🟨 P		
Allowed landings exceeding quotas							
Selectivity (mesh size)		🟨 P			🟨 P	🟩 P	🟩 P
Flexibility (effort reallocation)[1]		🟨 P		🟨 R			
Flexibility + de minimis				🟨 R			
Quota uplift/adjustment			🟩 R				
Decrease minimum landings size		🟨 P					
Catch allowances zero Tac stocks			🟩 R				
TAC deletion			🟩 R				
Vessel movements between metiers			🟩 R				
Quota movement (swaps)			🟩 R				
Discard of high survival species		🟨 P					
Avoidance strategies				🟥 R			
Increased landings costs		🟨 P					

Note: [1] Effort reallocation can be seasonal and between fleets (the Danish case) and spatially (the French case). [2]Yellow indicates less than 5% change, red indicates more than 5% decrease and green indicates more than 5% increase.

1.3.3 The Icelandic case

As discussed above, the Icelandic case study diverges from the other case studies in that respect that it works "opposite" to the other cases, given that the baseline is a fishery under LO. This case especially considers the benefit of various uses of unwanted catches and compares this to a (theoretical) scenario where it is assumed that the unwanted catches had been discarded. The case provides valuable information that supplements the remaining case studies, as it shows how use of landed unwanted catches can add to the overall income of the fishers and in this way mitigate possible negative consequences of the LO.

The case study calculations indicate that much can be gained from utilizing landed overquota catches and fish below MCRS. Estimated revenues generated between the years 2004 and 2015 were in the vicinity of 150 million Euros, when utilizing overquota catch for filleting and export of dried heads and the catch under MCRS as frozen, whole products (which is the most common utilisation method in Iceland). The model moreover indicates that silage production would produce lower values compard to the former alternatives. However, in some cases, silage production might be the only viable option.

1.4 Discussion

To assess the likely fleet economic repercussions of the LO, bio-economic models covering seven European fisheries have been applied to estimate the economic performance of fishing fleets before and after implementing the LO. The selected fisheries cover different species compositions and fishing technologies and different management systems ranging from the North East Atlantic to the Mediterranean.

When the four groups of factors that encourage discarding, i.e. institutional, biological, technological and economical, are combined, the main issues to address are i) that certain stocks cause a choke species situation for some fleets, ii) landings of small or damaged fish, which have low market values, and iii) illegal high-grading as a consequence of the two former issues when vessel operators seek to maximise their profits. Consequently, it is important to improve catch selectivity through gear changes, changes to fishing patterns and effort reallocation and to apply management measures that decrease effects of choke situations, such as enabling quotas to be traded or reallocated. Finally, the use of price measures (deemed value) that consider the differences between market prices and the social value of the fish should be considered to reduce the relative benefits of high-grading (Pascoe 1997).

The economic consequences of the LO are expected to differ depending on whether they are evaluated in the short or long term. Short term is defined as a period in which only variable inputs can change (e.g. fuel and crew) but not fixed inputs such as vessels, equipment and gear, while in the long term, all inputs can change. Generally, some short-term negative economic effects of the LO can be expected. The main reasons for this are (i) the choke species issue for fisheries regulated with quotas whereby catch of some species is constrained once catch of another species has reached its total quota, (ii) that landing of unwanted fish below MCRS and of low market value will replace landings above MCRS and of high value, and (iii) the higher costs created by landing instead of discarding. The scale of these short-term losses is case-specific. In the long term, choke situations and displacement of vessels to other areas are expected to reduce fishing pressure, leading to biomass increases and thus improved fishing possibilities. However, ensuing economic improvements is predicted to differ for individual fleet segments and vessel businesses, depending on catch composition, and on whether TACs increase proportionally when biomasses increase. If the latter is not the case, the choke situation may be enhanced.

In the long term, economic repercussions will differ as the four factors mentioned above interact in different ways for each fishery and the type of management affects the options for businesses to adjust. In the Mediterranean, which is managed with MCRS and has a wide variety of species, the main anticipated issue is the cost of dealing with undersized fish which cannot be sold for human consumption and for which there is a lack of processing facilities to make into fishmeal or other non-food products. This issue also applies to the northern fisheries, but here the choke issue also plays a role. Countries that have tradable quota systems, such as Denmark and UK, can, to some degree, avoid or delay choke situations though quota trade. While trading is possible however, there are no mechanisms to ensure or require trading of quota units to mitigate choke situations. The choke issue could be more severe for stocks managed by non-transferable quota shares such as in France and Spain. Although total long-term profits are expected to increase, some individual vessel businesses may not have the financial resources to overcome the severe economic losses predicted during the first years of implementation. Some governments might find it appropriate to implement measures to ensure that businesses do not fail as a result of short-term impacts of a fully implemented LO.

Mitigation strategies such as selectivity changes, *de minimis* exemptions and quota adjustments equal to previous discarded quantities, could enable fishing businesses to increase profits with the implementation of the LO. But for the fisheries analysed in this chapter, the profits are generally lower than or equal to profit with no LO. For the North East Atlantic fisheries, regulated with TACs and quotas, a useful policy could be to further develop a system to mitigate the problem of choke stocks. Such a policy is already in place in the EU (cf. Frost 2010) through the annual setting of TACs, when single species assessments show recommended total removals that are adjusted to take account of multispecies interactions and fleets' technological characteristics. Reducing differences between stock TACs and fleets' catch compositions could mitigate the choke problem and allow individuals, producer organizations, or fleet segments to land and sell fish and decrease the inherent incentive to discard. However, this approach would also to some extent negate the purpose of the LO, which is to encourage more selective fishing by creating incentives to avoid catching species with lower quotas. To create incentives to avoid catching fish below MCRS, price measures could be used to correct the difference between the sale price and the estimated social value of the fish. The difference must be sufficient to cover handling costs of landing the fish, and thus create an incentive to do so, but not high enough to incentivise targeting the fish beyond the quota, and vice-versa to reduce prices for fish species with unused quotas.

Finally it must be emphasized that the work performed in tasks 2.3 and 2.4 have build up a valuable model library that can be used for ongoing assessments of the economic outcomes of introducing exemptions and mitigation strategies in relation to the LO in the case studies covered. Understanding the consequences of various approaches to the implementation of the LO, and possible mitigation trategies, on economic performance of affected fishing fleets (using these models) is of very broad interest for fishermen, policy makers and stakeholders, as well as for anybody interested in sustainable fisheries and life in the oceans.

2 Case Study Chapters

2.1 Danish North Sea demersal fishery

2.1.1 Introduction

The Danish North Sea (NS) fishery constitutes a major part of the total Danish fishery; In 2012-2014 this fishery harvested 68% of the total value produced by the Danish fishery. The landings of demersal species constituted 25% of the total landed value from the NS in the same period. The Danish NS fleet constitutes vessels primarily fishing for pelagic species, vessels primarily fishing for demersal species, and vessels targeting both types including fish for fishmeal and fishoil. However, pelagic species plus a number of species used for fishmeal and fishoil are not discarded, even though slipping may occur for catches of mackerel and herring. Therefore, the NS demersa fishery has been the focus of this case study.

2.1.2 Analysed scenarios

Table 2.1.1 presents the scenarios analysed for the Danish NS case. Only one scenario, the Base case, allows discards, i.e. projects how the fishery would have evolved without the LO. The remaining scenarios all assume that the landings obligation (LO) has been implemented.

**Table 2.1.1. Scenarios analysed for the NS case study.*

Scenario	Name	Description
Base	Business as usual	Landings obligation not implemented, i.e. discards allowed.
Sc-1	Landings obligation, no exemptions.	Landings obligation implemented. No extra costs of landing unwanted species that are sold at 0.2 EUR/kg (the price of species for fishmeal and fishoil).
Sc-2	Landings obligation, *de minimis* exemption.	As Sc-1 but with a 5% *de minimis* implemented, i.e. fishermen are allowed to discard undersized fish of species that constitute less than 5% of their total catch.
Sc-3	Landings obligation, costs of landing unwanted species.	As Sc-1, but with an added cost of 0.34 EUR/kg of landing unwanted undersized fish.
Sc-4	Landings obligation, new minimum size for cod.	As Sc-1 but with the minimum size reduced for cod, for which the fish that were previously undersized are now sold at the lowest price for fish above minimum landings size.
Sc-5a **Sc-5b**	Reduced catch of undersized gadoids for the large human consumption trawlers	As Sc-1, but with reduction of catch of undersized gadoids (cod, hake, haddock, whiting, saithe, pollack) for the large human consumption trawlers 24-40 meters. Reduction in undersized gadoids catches of 30% (Scen-5a) and 50% (Scen-5b) analyzed.
Sc-6	High Survival Nephrops	As Sc-1, but with discards of Nephrops allowed in all years, given that high survival is assumed for this species.

Sc-1 is the full implementation of the LO all else equal, i.e. how the fishery, as it operates today, will evolve given the LO. In Sc-2 it is assumed that a *de minimis* exemption is implemented. In Sc-3 it is investigated what the consequence will be given extra costs of having to land undersized fish. In Sc-4 it is assumed that the MCRS for cod is reduced and thus that a proportion of previously undersized cod can be sold at the lowest price for cod above MCRS.

Sc-5 represents a situation where the large trawlers 24-40meters for human consumption reduce their catch of gadoids given use of selectivity improving implements. This is based on the Challenge experiment reported in WP4 (Reid et al. 2017b), where a number of Danish demersal trawlers, including 6 operating mainly in the North Sea, participated in an 'unrestricted gear' trial during a 6-month period, in which the fishers were challenged to reduce their discard of Cod, Whithing, Saithe, Plaice, Haddock, Hake and Norway lobster. Of the 6 vessels, 3 reduced their discard ratio, 2 increased their discard ratio and 1 did not display any difference to the control fisheries with no gear changes. Moreover, the test fishery (with gear changes) on the average landed a higher proportion of large cod, haddock, hake and whiting, while a higher, but not significant, proportion of small plaice and saithe was landed. Thus indicating that the gears to a large degree selected against small size gadoids. Based on this two sensitivity analyses have been performed where the catches of undersized gadoids are assumed to be reduced by 30% (Sc-5a) and 50% (Sc-5b).

Finally Sc-6 is based on Nephrops being declared to fall under the high-survival exemption in the NS for all gears from 2016 and on[5].

As such Sc-1 to Sc-4 concerns what can be expected for the Danish fishery under the LO, given assumped exemptions and changes in cost and prices. Sc-5 builds on the output from WP3 and WP4 and Sc-6 on knowledge gained in WP7. It has been chosen in the present context not to pursue further discard mitigation strategies or management alterations/proposals examined in WP3-7. The main reason for this is that the effect of the LO for the Danish demersal fishery is, as will be seen below, estimated to be low, with the exception of the large trawlers 24-40 meters for human consumption. Given that the model assumes a fully functioning ITQ system with no restrictions in quota trade, the proposed mitigation strategy of 'lease of quotas via the Danish ITQ system' (Reid, 2017a) is already a basic part of the analysis. The model is not spatial and thus it has not been possible to implement avoidance of certain fishing patches, also proposed by Danish fishers in Reid (2017a). However, the monthly disaggregation of the model (see below) to some degree makes up for this as effort can be reallocated between months to avoid potential choke issues. Finally, a TAC on dab has been used in the present context in spite of the TAC on dab having been deleted from 2017. However, dab does not choke in the Danish case, and thus the results would not be changed by removing the dab TAC. As such it is belived that Sc-5 and Sc-6 are relevant mitigation scenarios to implement based on the findings from WP3-7 in the Danish NS demersal case.

It must be noticed that the analyses for the Danish case are carried out without quota adjustments. This makes it possible to investigate what happens in the most restrictive case. If

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[5] Lisa Borges, personal communication.

quota adjustments were included in the calculations, most of the scenario results would not have differed from the current ones or the result would have become better from an economic point of view. Only an inclusion of further, illegal, discard may have entailed different result. But there is no scientific basis for inclusion of such an assumption.

2.1.3 The Fishrent model

The Danish NS demersal fishery has been analysed using Fishrent, a bio-economic model that integrates the economy and the biology of a fishery. The structure of Fishrent is described in Salz *et al.* (2011) and Frost *et al.* (2013). Fishrent integrates the following components: (i) recruitment of fish-stocks (through mass balance modelling), (ii) fishing technology, (iii) economic behaviour of fishers, (iv) management that can be both input (effort) and output (landings/catch) driven, and (vi) price formation. In the Danish NS demersal fishery case Fishrent operates at a monthly basis over a period of 10 years (2016-2025). The objective function, that is maximised over this period is the total net present value (NPV) of the fishery:

$$max_{E_{y,m,f}} NPV = max_{E_{y,m,f}} \sum\nolimits_{y,m,f} P_{y,m,f} \cdot (1+\rho)^{-y} \qquad (2.1.1)$$

where $P_{y,m,f}$ is the profit of fleet f in month m of year y, ρ is the discount rate, and $p_{f,s}$ is the corresponding price.. The variables in the maximisation are the efforts $E_{y,m,f}$ applied by fleet segment f in month m of year y. These are the product $V_{y,f} \cdot d_{y,m,f}$ of the number of vessels $V_{y,f}$ in in fleet segment f in year y, and the Days at Sea (DAS) $d_{y,m,f}$ applied by fleet segment f in month m of year y.

The original Fishrent model (Salz *et al.* 2011, Frost *et al.* 2013) has in the present context been adjusted to cover the specific problem of the LO. The landings $L_{y,m,s,f}$ are thus given by the function:

$$L_{y,m,f,s} = \begin{cases} Ca_{y,m,f,s}\,; & \text{no LO} \\ C_{y,m,f,s}\,; & \text{LO, no } \textit{de minimis} \\ Ca_{y,m,f,s}\,; & \text{LO, } \textit{de minimis}\text{, } \textit{de minimis} \text{ species} \\ C_{y,m,f,s}\,; & \text{LO, } \textit{de minimis}\text{, not } \textit{de minimis} \text{ species} \end{cases} \qquad (2.1.2)$$

where $Ca_{y,m,s,f}$ is the catch above minimum landings size (MCRS) and $C_{y,m,s,f}$ is the total catch of species s taken by fleet segment f in month m of year y. Equation (2.1.2) shows that it is assumed that only catches above MCRS are landed in the case where the LO is not implemented. When the LO is implemented without any exemptions all caught fish, both below and above the MCRS, is landed. In the case where it is assumed that *de minimis* is implemente only fish above MCRS is landed for species that fall under *de minimis* , while all caught fish must be landed for fish that do not fall under *de minimis*. $Ca_{y,m,s,f}$ is evaluated using a Cobb-Douglas (CD) function:

$$Ca_{y,m,s,f} = q_{m,s,f}\left(d_{y,m,f} \cdot V_{y,f}\right)^{\alpha_{s,f}} \cdot X_{y,s}^{\beta_{s,f}} \qquad (2.1.3)$$

where $q_{m,s,f}$, $\alpha_{s,f}$ and $\beta_{s,f}$ are CD parameters, for which is assumed that the effort and biomass elasticities $\alpha_{s,f}$ and $\beta_{s,f}$ are constant over the year, while the catchability factors $q_{m,s,f}$ varies between months. $X_{y,s}$ is the stock of species s in year y. The total catch $C_{y,m,s,f}$ of species s taken by fleet f in month m of year y is given by the catch above MCRS times a discard correction factor $\eta_{s,f}$, correcting for catch below MCRS ($Cb_{y,m,s,f}$):

$$C_{y,m,s,f} = \eta_{s,f} \cdot Ca_{y,m,s,f} = Ca_{y,m,s,f} + Cb_{y,m,s,f} \tag{2.1.4}$$

Finally total Danish landings (equation 2.1.2) are constrained below the total Danish quota allocated to the investigated fleets segments:

$$\sum_{m,f} L_{y,m,f,s} \leq Qdk_{y,s} \tag{2.1.5}$$

Where $Qdk_{y,s}$ is the Danish quota of species s in year y. Thus redistribution of effort, to maximize NPV (cf. Equation 2.1.1) can take place through trade of quotas between fleet segments, as long as the total catches are below the total quota. On top of this redistribution of effort can take place through monthly reallocation of effort, given that the model is disaggregated at the monthly level.

The NPV maximizations have been performed given the following constraints: (i) an upper limit, equal to the maximum observed values, for the DAS of a vessel for each fleet segment in each month (with an overall upper maximum of 26 DAS per month), and (ii) the number of vessels cannot vary by more than +/- 4% per year. The latter assumption is derived from the historically observed average yearly change in number of vessels in the Danish fishery. It must be noted that the estimated NPV is a "first best" solution that cannot be obtained in practice because of lack of divisibility and transparency and occurrence of transaction costs.

2.1.4 Data

The model covers the period 2015-2025. The base year of the analysis is 2015, in which all variables are kept constant and equal to the observed 2015 values. The parametrisation of the Danish demersal NS fleet is based on data from (i) the Danish Fisheries Analytical Database (DFAD) provided by the Danish Agrifish Agency, which comprises individual vessel information on landings weight and value, and effort data at trip level, and (ii) fleet cost data from Statistics Denmark's Account Statistics for Fisheries. The model is parametrisation based on averages for the period 2012-2014.

Vessels that have a turnover of more than 275 000 Danish kroner (37 000 EUR) are included from the DFAD. This mainly excludes small vessels owned by part time fishers, the turnover of which constitutes less than 2% of the total Danish turnover. Ten fleet segments are included in the analysis, for which the landings value of demersal NS species constituted more than 20% of their total landed value in 2012-2014. It is expected that the implementation of the LO will significantly influence these segments' economy. The cost data for the 10 segments are presented in table 2.1.2.

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Eleven species are included in the analysis (table 2.1.3), that are of importance to Danish demersal NS fishery. Spawning stock biomass (SSB) is projected individually (assuming no species interaction) in the analysis for seven of the eleven species, for which the International Council for the Exploration of the Sea's (ICES) stock database comprises time-series of absolute measures of the stocks. For these seven species, table 2.1.3 displays the 2015 SSB (based on ICES 2017 assessment), that has been used as initial values in the analysis. For the last four species, the SSBs are held constant and equal to 1 in the analyses, and the landings functions for the fleet segments (equation 2.1.2) normalised accordingly. Table 2.1.3 moreover displays the TACs and F_{MSY}s in 2015 for the species under management.

Table 2.1.2. Number of vessels and cost data for the Danish fleet segments operating mainly in the NS. Numbers are averages over 2012-2014.

Fleet segment	**No vessels**	**Fuel costs (1000 €/DAS)**	**Crew costs (fraction of revenue)**	**Var costs (fraction of revenue)**	**Fixed costs (1000 €/ vessel)**	**Capital costs (1000 €/ vessel)**
Net1215_NS	18	0.18	0.38	0.27	43	35
Tra1215_NS	5	0.50	0.40	0.13	49	32
Net1518	13	0.33	0.45	0.18	108	137
Tra1518_NS	12	0.63	0.36	0.14	80	70
Net1824	6	0.38	0.42	0.15	137	116
Tra1824_NS	19	0.80	0.30	0.14	132	139
Tra2440mCon	28	1.28	0.25	0.12	237	391
Net12_NS	28	0.21	0.49	0.18	27	16
Sein1518	7	0.19	0.37	0.35	41	21
Sein1824	13	0.32	0.38	0.23	92	106

Note: Net_1215_NS=Netters 12-15 meters fishing primarily in the NS, Net1518=Netters 15-18 meters, Tra1518_NS=Trawlers 15-18 meters fishing primarily in the NS, Net1824=Netters 18-24 meters, Tra1824_NS=Trawlers 18-24 meters fishing primarily in the NS, Tra2440mCon= human consumption Trawlers 24-40 meter, Net12_NS=Netters under 12 meters fishing primarily in the NS, Sein1518=Danish Seine 15-18 meters, Seine1824=Danish Seine 18-24 meters.

Table 2.1.3. Species included in the model for the Danish demersal fishery in ICES area IV. SSB, TAC and F_{MSY} in 2015 for these species, together with Parameters of the surplus growth functions (β_1 and β_2) for the species included in the NS model.

Name (Species code)	**SSB 2015 (tonnes)**	**TAC 2015 (tonnes)**	**F_{MSY}**	β_1	β_2 (tonnes^{-1})
Nephrops (NEP)	-	17843	-	-	-
N. Prawn (PRA)	-	3270	-	-	-
Whiting (WHG)	246295	13678	0.15	0.3804	1.05E-6
Common Dab (DAB)	-	18434	-	-	-
E. Hake (HKE)	272795	90849	0.28	1.7034	5.23E-6
Haddock (HAD)	142921	40711	0.194	1.0313	3.09E-6
Pollack (POL)	-	-	-	-	-
Saithe (SAI)	220918	66006	0.36	1.1340	2.67E-6
Plaice (PLE)	770556	128376	0.21	0.8647	8.94E-7
Sole (SOL)	45650	11900	0.2	1.2002	1.91E-5
Cod (COD)	134323	29189	0.31	1.3733	7.32E-6

Source for SSB, TAC and F_{MSY}: ICES Stock Assessment data 2017, http://standardgraphs.ices.dk/stockList.aspx

Surplus growth functions have been estimated for the seven species for which the model performs dynamic stock projections. The surplus growth is approximated by a second order polynomial, for which the parameters β_1 and β_2 (presented in table 2.1.3) have been estimated using ordinary least squares regression[6] from ICES assessment time series over the period 1995-2014 of stocks and recorded catch:

$$R_y = \beta_1 \cdot SSB_y - \beta_2 \cdot SSB_y^2 \tag{2.1.6}$$

Table 2.1.4 displays average discard rates, i.e. the fraction discard constitutes of the total catch in the NS, for the fleets and species included in the model. The rates are based on Larsen *et al.* (2013) and Ravensbeck *et al.* (2015).

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[6] It is included in the estimation of the surplus function that the stock must not exceed the maximum stock observed in the period 1995-2014.

Table 2.1.4. Average discard rates in the NS for the fleet and species included in the model.

	NEP	PRA	WHG	DAB	HKE	HAD	POL	SAI	PLE	SOL	COD^b
Net1215_NS	0.00	0.00	0.31^a	0.21	0.00	0.26	0.00	0.06	0.01	0.00	0.07
Net1518	0.00	0.00	0.31^a	0.21	0.00	0.26	0.00	0.06	0.01	0.00	0.07
Net1824	0.00	0.00	0.31^a	0.21	0.00	0.26	0.00	0.06	0.01	0.00	0.07
Net12_NS	0.00	0.00	0.31^a	0.21	0.00	0.26	0.00	0.06	0.01	0.00	0.07
Tra1215_NS	0.16	0.00	0.22	0.21	0.09	0.03	0.00	0.01	0.05	0.00	0.09
Tra1518_NS	0.16	0.00	0.22	0.21	0.09	0.03	0.00	0.01	0.05	0.00	0.09
Tra1824_NS	0.16	0.00	0.22	0.21	0.09	0.03	0.00	0.01	0.05	0.00	0.09
Tra2440mCON	0.16	0.00	0.22	0.21	0.09	0.03	0.00	0.01	0.05	0.00	0.09
Sein1518	0.00	0.00	0.40	0.21	0.09	0.03	0.00	0.01	0.05	0.00	0.09
Sein1824	0.00	0.00	0.40	0.21	0.09	0.03	0.00	0.01	0.05	0.00	0.09

Notes: ^{a}The discard rates of Whiting for netters have been set equal to the average of the rates for Trawlers and Danish Seine, as no discard rates or Whiting are reported for netters. ^{b}For cod in the NS is used the same discard rates as for cod in the Western Baltic (cf. Ravensbeck et al. 2015).

Average prices (table 2.1.5) for each fleet segment and species have been determined using the average yearly landings weight and value over the period 2012-2014. It is assumed in the model that prices are independent of volume and season.

Constant returns to scale (CRS) is assumed as default for the Cobb-Douglas equation (2.1.3), i.e. $\alpha_{s,f}+\beta_{s,f} = 1$. Few estimations of fisheries production functions exists in the literature. In a study of the Iberian-Atlantic hake fishery the catch-effort and catch-stock coefficients in a Cobb-Douglas function are estimated at 0.59 and 0.24, respectively, for the trawl fleet and 0.14 and 0.74 for the gill net fleet (Garza-Gil et al. 2003). Others find increasing returns to scale (IRS). Eide et al (2003) estimate α and β to be 1.23 and 0.42, respectively, for the Norwegian bottom trawlers targeting cod in a model with technical progress, and Kronbak (2005) estimates α and β to be 0.75 and 0.64, respectively, for bottom trawlers in the Baltic Sea. It is reasonable to expect that the catch-effort elasticity is higher for trawlers, which use mobile gear, than for netters, which use stationary gear, and *vice versa* for the catch-stock elasticity. Thus, in the present context it has been chosen, based on the above numbers, to set $\alpha_{s,f}=0.4$ and $\beta_{s,f}=0.6$ for the netters while $\alpha_{s,f}=0.6$ and $\beta_{s,f}=0.4$ for the trawlers. The catchability factor, $q_{m,s,f}$, has for each month, fleet and species been estimated using historical landings, effort and biomass values for the period 2012-2014, together with the given $\alpha_{s,f}$ and $\beta_{s,f}$ values. Yearly averages of the catchability coefficients are presented in table 2.1.6.

Table 2.1.5. Average prices (EUR/kg) for the fleets and species included in the model.

	NEP	PRA	WHG	DAB	HKE	HAD	POL	SAI	PLE	SOL	COD[b]
Net1215_NS	5.55	-	1.50	0.74	2.26	1.75	2.90	1.60	1.31	8.06	*3.07*
Net1518	6.90	-	1.01	0.77	2.10	1.63	3.02	1.28	1.35	8.29	*3.44*
Net1824	10.74	-	1.01	0.91	2.12	1.51	3.08	1.13	1.37	8.63	3.65
Net12_NS	-	-	1.10	0.83	1.91	2.00	2.99	1.42	1.18	11.47	2.97
Tra1215_NS	-	-	1.03	0.95	2.03	1.48	3.29	-	1.27	14.65	2.66
Tra1518_NS	6.90	9.22	0.90	0.87	1.54	1.19	2.43	1.37	1.14	7.83	2.82
Tra1824_NS	6.95	-	1.15	0.95	1.63	1.33	2.90	1.20	1.18	12.83	2.91
Tra2440mCON	7.99	8.12	1.04	0.98	1.91	1.31	2.90	1.36	1.32	9.31	2.85
Sein1518	-	-	-	1.09	1.86	1.56	2.76	2.24	1.34	21.69	3.38
Sein1824	6.54	-	1.15	0.91	1.55	1.39	3.23	1.37	1.40	8.40	3.22

Note: '-' indicates that the species has not been caught by the given fleet segment during the period 2012-2014.

Table 2.1.6. Yearly average of the catchability factors for the fleets and species included in the model.

	NEP	PRA	WHG	DAB	HKE	HAD	POL	SAI	PLE	SOL	COD
Net1215_NS	2.2E-4	-	6.4E-7	2.4E-1	2.5E-4	4.7E-5	1.0E-1	2.6E-5	1.6E-3	1.3E-3	4.5E-3
Net1518	4.0E-4	-	1.5E-7	6.6E-1	1.4E-3	1.3E-4	1.5E-1	1.2E-4	5.5E-3	3.2E-3	4.0E-3
Net1824	4.3E-4	-	5.7E-7	3.7E-1	9.8E-5	3.8E-5	1.9E-2	2.0E-4	5.6E-3	1.7E-3	2.3E-3
Net12_NS	-	-	2.1E-8	7.0E-1	1.4E-4	1.4E-4	6.8E-2	6.0E-6	2.6E-3	9.7E-5	3.2E-3
Tra1215_NS	-	-	7.3E-7	1.4E-1	6.0E-5	4.9E-4	1.1E-3	-	9.4E-3	5.5E-5	2.4E-3
Tra1518_NS	4.9E-1	8.9E-1	1.9E-5	1.4E-1	7.3E-4	5.6E-4	4.7E-3	3.1E-3	1.8E-2	1.8E-4	3.0E-3
Tra1824_NS	2.2E-1	-	7.4E-6	3.3E-1	6.2E-4	1.1E-3	8.2E-3	7.3E-4	6.5E-2	9.9E-5	1.1E-2
Tra2440mCON	8.4E-1	1.6E-1	1.5E-3	2.2E-1	3.6E-2	1.7E-2	2.0E-1	6.8E-2	5.1E-2	1.2E-3	5.9E-2
Sein1518	-	-	-	4.2E-1	3.2E-5	1.3E-4	6.3E-4	3.9E-7	1.8E-3	3.0E-7	2.4E-3
Sein1824	3.7E-4	-	9.3E-7	4.2E-1	1.1E-4	2.3E-4	3.0E-2	2.3E-4	6.3E-3	2.6E-3	5.5E-3

Note. '-' indicates that the species has not been caught by the given fleet segment during the period 2012-2014.

The fleet segments included in the model catch other species than the eleven included species. Together the ten segments catch 75 different species in the NS. However, it would be difficult, and increase output uncertainty, to parametrise the model with respect to all 75 species. The species listed in table 2.1.3 are the major species with regards to the LO and also for most segments constitute the major part of their landings. The revenues for each fleet segment are scaled up with a fraction representing the historical (over 201-2014) difference between the catch value of the species included in the model and all species caught by the segment.

2.1.5 Results

Table 2.1.7 displays a summary of outcomes of the analyses. The table displays total net present value (NPV) aggregated over the period 2016-2025, yearly mean effort aggregated over all fleets, and total landings and total discards, aggregated over all fleets and all species over the period 2016-2025. The table shows that the overall NPV of the Danish fishery is expected to be reduced, but only marginally so, when the LO is introduced. It is seen that the total NPV decreases with ~2% when the LO is introduced without any exemptions or flexibility (Sc-1). Applying the *de minimis* expemptions (Sc-2) reduced this loss, but only marginally so. Assuming increased costs connected with landing unwanted catches (Sc-3) leads to a NPV reduction of ~5%, while lowering the MCRS for cod (Sc-4) reduces the loss to ~1%. When it is assumed that the large huma consumption trawlers 24-40meters increase their selectivity (Sc-5a, Sc-5b) the NPV will decrease with less than 1% relative to the case with no LO. And finally if it is allowed for all segments to discard undersized nephrops (sc-6) the reduction in NPV is again ~2% copared to the base case, and this reduction is even higher than in the case of the LO with no exemptions (Sc-1). This because undersized nephrops is not sold in this scenario.

Table 2.1.7. Summary of main results of analysing the influence of implementing the LO in the Danish Demersal NS fishery, given ITQ or FQS management. Totals are over the period 2016-2025. Numbers in parenthesis shows the percentage change of the values in scenarios 1-4 relative to the values in the base scenario.

	NPV (mill €)	Mean Effort (1000 DAS)	Total landings (1000 tonnes)	Total Discards (tonnes)
Base	99	17.43	243	13377
Sc-1	97 (-2.01%)	17.27 (-0.92%)	250 (3.0%)	1314 (-90%)
Sc-2	97 (-1.98%)	17.32 (-0.63%)	249 (2.5%)	3005 (-78%)
Sc-3	94 (-5.33%)	17.21 (-1.26%)	250 (2.9%)	1314 (-90%)
Sc-4	98 (-1.06%)	17.29 (-0.76%)	250 (3.1%)	1314 (-90%)
Sc-5a	98 (-0.85%)	17.32 (-0.61%)	251 (3.2%)	1061 (-92%)
Sc-5b	99 (-0.04%)	17.35 (-0.42%)	251 (3.3%)	890 (-93%)
Sc-6	97 (-2.20%)	17.27 (-0.92%)	249 (2.7%)	2166 (-83%)

Table 2.1.7 further shows that the effort applied is only reduced marginally in all scenarios relative to the case with no LO. The largest reduction is seen in Sc-3 where it must be assumed that effort is reallocated between fleets to reduce fuel and variable costs, given the increased landings cost. Landings are increased in all LO scenarios, given that undersized, previously discarded fish, must now be landed, and given that not all Danish quotas choke the fishery. Thus

additional landings of undersized fish can be taken within the quotas. This effect is smallest in the *de minimis* case (Sc-2) and the case where undersized nephrops can be discarded (Sc-6), given that in these cases some undersized fish can still be discarded. Contrary to this the highest increase in landings are seen in Sc-5a and Sc-5b where the large human consumption trawlers increase their selectivity, which reduces the choke effect for this segment and thus makes it possible for it to land more. Finally table 2.1.7 shows that the discard is reduced significantly in all scenarios, with between 78% and 93% compared to the base case with no LO. The lowest decrease in discards is seen in the *de minimis* casse (Sc-2) followed by the case where undersized Nephrops can still be discarded (Sc-6). The highest reduciton in discards are seen in the two scenarios where the large human consumption trawlers 24-40meters increase their selectivity, i.e. generally catch less undersized fish.

Fleet economy

Table 2.1.8 displays the total NPV over the period 2016-2025 for each of the included fleet segments. The table shows absolute values in the base case and percentage changes relative to the base case in each of the LO scenarios.

Table 2.1.8 firstly shows that most segments are expected to experience increasing NPV over the period when the LO is introduced (Sc-1) compared to the base case. The reason for this is that it is possible for most segments to land and sell undersized fish on top of what they have landed when the LO was not in place, given that most of the Danish quotas are not expeced to choke (see below), and thus increase their income. The exceptions are the human consumption trawlers 24-40 meters and the Danish seine 15-18 meters. For the latter the reduction in NPV is marginal and is caused by general quota trade, i.e. it is more profitable for the fishery if other segments buy quotas from this segment. On the other hand, for the large human consumption trawlers, the decrease in NPV given the introduction of the LO, is considerable. This segment takes around 40% of the total catches of all included fleet segments, and is as such a major player in the Danish demersal NS fishery. The segment catches hake and sole (that limit the fishery, cf. the discussion of quota utilisations below) in all months of the year with an especially large catch rate of hake (cf. table 2.1.6), leading to large undersized discards of this species in the base scenario. Thus the segment is to some degree locked in its catch pattern over the year and cannot reallocate effort to months where hake is not caught to avoid being limited by this species. Likewise, given that this segment takes the majority of the hake catches it is not possible for the segment to buy additional hake quotas from other segments to reduce the choke effect, as this would limit the catch possibilites of the selling segments to such a degree that it is not profitable for the entire fleet. Thus the segment must reduce its effort to comply with the LO, leading to reduced catches and thus NPV. Table 2.1.8 further shows that this loss can be remedied for this segment through incresed selectivity (Sc-5a, Sc-5b).

Table 2.1.8. Total NPV over the period 2016-2025 for each of the 10 Danish fleet. Absolute values (mill EUR) are shown for the base scenario while change relative to the base scenario is shown for Sc-1 to Sc-6.

	Base	**Sc-1**	**Sc-2**	**Sc-3**	**Sc-4**	**Sc-5a**	**Sc-5b**	**Sc-6**
	Mill €	**% relative to the base case**						
Net1215_NS	-2.6	2.0	1.8	0.2	4.0	2.0	2.0	2.0
Net1518	-8.6	0.7	0.5	0.1	1.1	0.7	0.6	0.7
Net1824	4.2	1.5	1.2	0.3	2.1	1.4	1.3	1.5
Net12_NS	-3.4	0.4	0.7	-0.9	1.2	0.5	0.5	0.4
Tra1215_NS	4.9	2.1	2.0	-1.1	2.7	2.0	2.0	2.1
Tra1518_NS	58.0	0.6	0.5	-0.3	0.7	0.6	0.6	0.5
Tra1824_NS	28.4	2.3	2.0	-1.2	2.8	2.3	2.3	2.2
Tra2440mKon	18.4	-18.3	-17.3	-24.9	-15.6	-12.0	-7.6	-18.6
Sein1518	-0.6	-1.9	0.1	-4.6	-0.4	-0.8	-0.2	-1.8
Sein1824	0.17	42.2	54.9	-35.1	76.9	43.3	42.9	42.3

In the *de minimis* case (Sc-2) table 2.1.8 shows that most segments would have increasing NPVs compared to the case with no LO, but that this increase is less than in Sc-1 for most fleet segments, illustrating that *de minimis* species below MCRS are now discarded and not sold. However, for the large human consumption trawlers 24-40 meters *de minimis* reduces the loss, given the LO, a small amount. When costs of landing unwanted species are increased (Sc-3) all fleet segments are worse of than without these extra costs (comparing with Sc-1), but some are still marginally better off than without the LO, again illustrating that the possiblity to land and sell undersized species may still be profitable for some segments in spite of the increassed landings costs. When the MCRS for cod is decreased, making it possible to sell previously undersized fish at lowest price for human consumption (Sc-4), all segments, as expected, have a better result than in Sc-1, i.e. than when the LO is introduced with no exemptions or changed prices. Assuming that the large human consumption trawlers 24-40 meters can change their selectivtiy (Sc-5a, Sc-5b) reduces the losses for this segment, as discussed above, but do not result in significant changes for the remaining segments compared to Sc-1. Finally, assuming that undersized Nephrops is discarded (Sc-6) has no effect on most segments compared to Sc-1, but has a negative effect on the large human consumption trawlers that looses the income from selling undersized nephrops at the price for fish for reduction.

Effort

Table 2.1.9 displays the average yearly fleet segment efforts (1000 DAS) over 2016-2025 in each of the analysed scenarios. The table 2.1.9 that most fleet segments only have marginal changes in their effort, given the LO, again reflecting that choking is not a problem for most Danish fleet segments. But that the large human consumption tralwers 24-40 meters is expected to see a reduction of its effort of 2-5%, corresponding to the above discussion of the choke issues experineced by this segment. The reduction in effort for this segment is smallest when it is assumed it uses selectivity increasing measures, and largest in Sc-3 with increased costs of landing unwanted species, where this segment will try to limit the additional losses through a decrease in effort.

Table 2.1.9. Average yearly fleet efforts over the period 2016-2025. Absolute values (1000 DAS) are shown for the base scenario while change relative to the base scenario is shown for Sc-1 to Sc-4.

	Base	**Sc-1**	**Sc-2**	**Sc-3**	**Sc-4**	**Sc-5a**	**Sc-5b**	**Sc-6**
	1000 DAS	**% relative to the base case**						
Net1215_NS	1.3	0.33	0.32	0.22	0.53	0.28	0.25	0.33
Net1518	1.2	-0.13	0.11	-0.18	-0.01	-0.09	-0.09	-0.13
Net1824	1.0	0.34	0.29	0.44	0.33	0.21	0.13	0.34
Net12_NS	1.0	-0.62	0.57	-1.72	0.11	-0.36	-0.29	-0.61
Tra1215_NS	0.7	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tra1518_NS	3.6	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tra1824_NS	3.5	0.39	0.40	-0.07	0.48	0.36	0.35	0.37
Tra2440mKon	3.7	-4.66	-4.14	-4.94	-4.56	-3.25	-2.32	-4.67
Sein1518	0.3	-0.83	0.45	-2.21	-0.12	-0.55	-0.56	-0.81
Sein1824	1.1	0.24	1.33	-1.34	0.97	0.25	0.19	0.25

Quota utilisation, landings and discards

Table 2.1.10 displays the average utilisation over the period 2016-2025 of the Danish quotas in each of the 8 scenarios. The table firstly shows that there is full quota utilisation for hake and sole in all scenarios. All fleet segments catch these species (cf. table 2.1.6) and it must thus be expected that at least one of these species limits the fishery of the individual fleet segment, even though quota trade can go some way to mitigate this problem.

Table 2.1.10 further shows that the quota utilisations increases to some degree for most other species in all scenarios except Sc-2 (*de minimis*) compared to the base, given that undersized fish are now landed and counted against the quotas. The exception is saithe for which the quota utilisation decreases in all scenarios. Saithe is caught mainly by the large human consumption trawlers that cannot buy enough hake quota to not choke on this species, and thus have reduced effort under the LO (cf. the discussion above). This leads to reduced saithe catches and landings for this segment that takes the majority of the Saithe catches. In Sc-2 (*de minimis*) only small changes compared to the base case are seen, given that now *de minimis* species for the individual fleets are not landed. The exceptions are cod and plaice for which the amount that falls under the *de minimis* exemption is negligible. In Sc-6 the quota utilisation for Nephrops falls to below the base case, given that undersized Nephrops is discarded in this scenario and that the landings of Nephrops are also reduced in this scenario (see table 2.1.11 below).

Table 2.1.10. Average utilization (Landings/Quota) over the period 2016-2025 of the Danish quotas.

	Base	Sc-1	Sc-2	Sc-3	Sc-4	Sc-5a	Sc-5b	Sc-6
NEP	0.74	0.86	0.76	0.85	0.86	0.86	0.87	0.72
PRA	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
WHG	0.49	0.59	0.48	0.59	0.59	0.56	0.54	0.59
DAB	0.21	0.25	0.22	0.25	0.25	0.25	0.25	0.25
HKE	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
HAD	0.84	0.84	0.83	0.84	0.84	0.84	0.84	0.84
POL	-	-	-	-	-	-	-	-
SAI	0.83	0.80	0.80	0.80	0.80	0.81	0.82	0.80
PLE	0.66	0.68	0.68	0.68	0.68	0.68	0.69	0.68
SOL	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
COD	0.82	0.87	0.87	0.87	0.87	0.86	0.86	0.87

Table 2.1.11. Total landings 2016-2025. Values relative to the base (1000 tonnes) are displayed for Sc-1 to Sc-6.

	Base	Sc-1	Sc-2	Sc-3	Sc-4	Sc-5a	Sc-5b	Sc-6
	1000 tonnes	**% relative to the base scenario**						
NEP	4.60	16.1	3.3	16.0	16.1	16.9	17.5	-2.5
PRA	2.84	-0.4	-0.4	-0.5	-0.4	-0.3	-0.2	-0.4
WHG	0.78	22.0	-2.9	21.8	22.0	16.2	12.2	21.9
DAB	3.54	17.8	2.5	17.6	17.9	17.2	16.7	17.8
HKE	14.83	0.9	0.8	0.9	0.9	1.0	1.0	0.9
HAD	10.28	0.9	-0.4	0.8	0.9	1.2	1.4	0.9
POL	0.87	-3.0	-2.6	-3.1	-3.0	-2.1	-1.6	-3.0
SAI	29.55	-3.1	-2.9	-3.1	-3.1	-2.1	-1.4	-3.1
PLE	130.59	2.9	3.1	2.8	3.0	3.3	3.5	2.9
SOL	3.01	0.0	0.0	0.0	0.0	0.0	0.0	0.0
COD	42.09	6.3	6.5	6.2	6.4	5.8	5.4	6.3

Table 2.1.11 displays the total Danish landings over the period 2016-2025 of the demersal species included in the analysis. The table shows that when the LO is introduced with no exemptions (Sc-1) the landings of most species increase, compared with the base case with no LO. This is the case for nephrops, whiting, dab, hake, haddock plaice, sole and cod. For the non-choke species (*nephrops*, whiting, dab, haddock plaice and cod) this is caused by landings of undersized fish within the quotas, given that the quotas are not fully utilised for these species. For the choke species (hake) the slight increase in landings (including undersized fish) relative to the base case is caused by a small TAC increase over the assessment period, given a slight increase in stocks after introduction of the LO (see the discussion of stock changes below). A similar picture is seen in Scenarios 3 and 4. In Sc-2 (*de minimis*) the changes in landings, compared to the base case with no LO, are smaller than in Sc-1 for most species. However, the catches of plaice and cod increase a small amount compared to scenario 1. This is caused by the

fact that hake falls under *de minimis* for some fleet segments, especially for the large human consumption trawlers 24-40 meters, thus making it possible to catch more of other species, and especially of plaice and cod.

Table 2.1.11 further shows an interesting picture in Sc-5a and Sc-5b where the catch of undersized gadoids (whiting, dab, hake, haddock, pollock, saithe and cod) by the large human consumption trawlers 24-40 meters is reduced by 30% and 50%. Firstly the landings of whithing, dab, and cod decreases relative to Sc-1 (full implementation of the LO), while the catches of the remaining species increase relative to Sc-1. These changes illustrate changes in the catches of the large trawlers for human consumption, and to understand these it is neccesary to delve a bit deeper into the catch patterns of this segment in Sc-1 and Sc-5. From the base case (no LO) to Sc-1 (full implementation of the LO) the total landings over the evaluation period of nephrops, whiting, dab, hake, plaice and cod increase for this segment, while the total landings of the remaining species decrease. The increase of landings of some species, in spite of the reduced effort from the base case to Sc-1 (cf. Table 2.1.9) is caused landings of fish below MCRS, that was discarded in the base case. I.e. with large enough catches of fish below MCRS it is possible for the segment to catch more of these species under the LO in spite of the reduced effort. For the remaining species, for which the landings fall in Sc-1, the landinigs of fsh below MCRS is not enough to counteract the reduced effort. As noted above the landings of whiting, dab and cod decreases from Sc-1 to Sc-5 for this segment. The undersized catch of these species is reduced in Sc-5 given the improved selectivity and thus the landings of these species fall in spite of the increased effort in this scenario. For the remaining species the increase in landings from Sc-1 to Sc-5 is caused by the increase in effort. For haddock, pollock and saithe this is enough to counteract the reduced landings of fish below MCRS caused by the increased selectivity.

Finally in Sc-6 table 2.1.11 shows that the only change compared to full implementation of the LO (Sc-1) is that the landings of Nephrops decreases and fall to below the level in the base case. This is caused by undersized neprhops now being discarded in combination with the total effort being reduced relative to the base case.

Table 2.1.12 displays the total discards (of fish below MCRS) over the evaluation period for each species. The table shows that the discards generally decrease significantly for all species in all scenarios, with the execption of Sc-2 and Sc-6. The reason discards are not reduced by 100% for all species in the remaining scenarios is that the LO is phased in over the period 2016-2019 in the evaluations. In Sc-2 (*de minimis*) it is seen that the discards of especailly nephrops, whithing and dab increase realtive to full implementation of the LO (Sc-1), indicating that these species are major *de minimis* species. In Sc-6 it is seen that the discards of nephrops is almost equal to the base case with no LO, given that all undersized nephrops is discarded in this scenario. In Sc-5 (a and b) it is seen that discards of whiting, dab, hake, saithe and cod is reduced relative to Sc-1 (full implementation of the LO) which is to be expected given that the selectivity of the large human consumption trawlers has been increased.

Table 2.1.12. Total discards 2016-2025. Values relative to the base (tonnes) are displayed for Sc-1 to Sc-6.

	Base	**Sc-1**	**Sc-2**	**Sc-3**	**Sc-4**	**Sc-5a**	**Sc-5b**	**Sc-6**
	tonnes	**% relative to the base scenario**						
NEP	874	-100	-31	-100	-100	-100	-100	-2
PRA	0	0	0	0	0	0	0	0
WHG	226	-90	-3	-90	-90	-93	-95	-90
DAB	955	-70	-12	-70	-70	-71	-72	-70
HKE	1461	-68	-64	-68	-68	-77	-83	-68
HAD	438	-100	-60	-100	-100	-100	-100	-100
POL	0	0	0	0	0	0	0	0
SAI	317	-69	-59	-69	-69	-77	-82	-69
PLE	5131	-100	-100	-100	-100	-100	-100	-100
SOL	0	0	0	0	0	0	0	0
COD	3976	-89	-87	-89	-89	-91	-92	-89

Fish stock development

Table 2.1.13 displays the spawning stock biomasses in 2025 for each of the stock included in the analysis that are assessed yearly by ICES (cf. table 2.1.3). Comparison with table 2.1.3 firstly shows that the SSBs are expected to increase over the analysed period in the bases case for all stocks except plaice and cod that are expected to decrease a bit compared to the 2015 value. For plaice the reason is that the plaice stock was the highest observed in 20 years in 2014/2015, and thus increased TACs and decreasing surplus production leads to decreasing stocks. For cod the decrease towards 2025 is small but is again caused by the stock being realtively high in 2015 leading to increased TACs and decreased surplus production.

Table 2.1.13. Spawning stock biomass in year 2025 of each of the assessed species included in the analysis. Absolute values (1000 tonnes) are given for the base scenario, while values relative to the base scenario are displayed for Sc-1 to Sc-6.

	Base	**Sc-1**	**Sc-2**	**Sc-3**	**Sc-4**	**Sc-5a**	**Sc-5b**	**Sc-6**
	1000 tonnes	**% relative to the base scenario**						
WHG	380	0.7%	0.7%	0.7%	0.7%	1.7%	2.3%	0.7%
HKE	298	1.5%	1.4%	1.5%	1.5%	1.5%	1.5%	1.5%
HAD	364	0.9%	0.8%	0.9%	0.9%	0.8%	0.7%	0.9%
SAI	244	0.5%	0.5%	0.5%	0.5%	0.4%	0.3%	0.5%
PLE	701	0.2%	0.2%	0.3%	0.2%	0.1%	0.1%	0.2%
SOL	54	0%	0%	0%	0%	0%	0%	0%
COD	133	0.2%	0.2%	0.3%	0.2%	0.3%	0.4%	0.2%

Table 2.1.13 further shows that the stocks of all species, except sole, is expected to increase in all scenarios where the LO is implemented. However, it must be kept in mind, that this is assuming

that all other fleets targeting these species acts as the Danish fleets, and these results are thus tentative. The stock improvements vary, but not to a significant degree, according to the assumptions regarding exemptions. It is e.g. seen that it is not an overall good thing for all stocks if more selective gear is used by large trawlers (Sc-5a and 5b). As discussed above, higher selectivity ensures that the fleet segments choke later on hake and thus can catch more of some species. As such the stocks of haddock and saithe are negatively affected by the higher selectivty, while the stocks of whiting and cod are positively affected.

The stock of sole is not predicted to be affected in the present context by the introduction of the LO. Sole constitues an only minor role as bycatch for the fleet segments analysed in the present context and as such the catches of sole are not affected by the LO. However, as emphasized above, these results are tentative and do not take into account the real behaviour of other fleets targeting these species.

2.1.6 Discussion/conclusion

The analysis presented in this chapter suggests that introducing the LO will not have a considerable negative effect for the Danish NS demersal fleet as a whole, and that some fleet segments may even benefit from the LO, if it is possible to sell previously discarded undersized fish at prices for fish for reduction. However, this result rely on the Danish ITQ regulation system, i.e. that fleets can trade/lease quotas in order to avoid choking. And, in spite of the ITQ system in place, the large trawlers 24-40 meters for human consumption are predicted to have a decrease of 18% in NPV over the period 2016-2025 given the LO if no exemptions or mitigation strategies are in order. This because this fleet segment takes a majority of the Danish NS demersal catches and as such can not trade/lease enough quotas from other segments, in order not to choke. However, assuming the segment can use selectivity increasing measures will reduce the potential economic loss, but this at the cost of possible reduced stocks of some of the demersal species.

These effects are also reflected in the quota utilisations, landings and efforts experienced by the fleet segments. Effort is almost not influenced by the introduction of the LO (except for the large demersal trawlers). Quota utilisation is for most species improved, landings higher, and discards reduced with the LO implemented. And the included fish stocks almost all improve given teh LO.

Thus, even though the LO is not predicted to have overall significant negative economic consequences for the Danish fishery, individual fleet segments may still experience losses, that can possibly be remedied through migigation or avoidance strategies, as proposed in WP3-7 of Discardless.

It should be noted that the economic benefits estimated in all cases must be expected to be overestimated in proportion to what could be achieved in a real fishery because it is in the present context assumed that there is full information in the fishery, no market failures and no transaction costs at the exchange of quotas. However, as these assumptions apply both to the base case and the LO scenarios, the changes shown for the scenarios compared to the base case are considered robust.

Another uncertainty is associated with the exponents (elasticities) applied in the production function. Constant returns to scale are assumed. Furthermore, it is assumed that catches of the netter fleets are more sensitive to changes in fish stock abundances compared to effort changes than is the case of the trawlers, for which the opposite applies. Generally, the estimated exponents of the production function will be uncertain due to short time series. If the exponents are changed it will impact the catch distribution between fleet segments and change the net present value but the effect on total catches will be small as these are restricted by the quotas. The impact on the results without and with the LO implemented of changes in the exponents of the production function is therefore considered small.

2.2 UK mixed demersal fishery

2.2.1 Introduction

There were 4607 active boats in UK fishing fleet in 2016. The weight of fish landed by the fleet in 2016 was around 700 thousand tonnes or 1.1 billion euros. Most of UK vessels operate around the coast within UK economic zone (ICES subarea 4, 6 and 7). UK vessels target three different groups of species: pelagic, demersal and shellfish. For this specific analysis only demersal fleets and species have been analysed to show relevant impact of choke species on UK fishing fleets.

2.2.2 Analysed scenarios

Table 2.2.1 presents a detailed outline of the scenarios analysed for the UK demersal fishery case. The model is focused on assessment of choke situations, therefore most of scenarios are assessing different level of choke mitigation measures proposed by the Commission and quota movement.

The purpose of the simulations is to understand how a highly diverse industry might be affected by different policy actions. The principle question being asked is "how will fleets be affected under various assumptions of implementing the new landing obligations". The model is designed to be able to consider "what-if" analyses to inform how key levers available to policy makers could impact on the fleets and fisheries under the landing obligation.

Levers, or a combination of levers, essentially define a simulation to be investigated. Changing availability of quota is important and includes likely quota uplift levels by stocks, the ability to swap quota (e.g. across species and fleets) and of potential exemptions (e.g. de minimis). Furthermore, key data such as discard rates or catchabilities can be investigated for sensitivity on results.

Table 2.2.2 presents a summary of the policy levers modelled and the simulations that have been run. There are four baselines developed, each of which builds on the previous baseline, to enable investigation of the effect of each "fundamental" lever in turn starting with B1 with no levers; B2 with zero-TAC stocks accounted for; B3 with quota uplift introduced; and B4 with a PO fleet segment's quota enabled to move across it's metiers, if required, to alleviate a choke. B4 is therefore the baseline presented for comparison to other simulations. There are two quota simulations developed building on B4: namely S1 which enables UK quota trade and S2 which uses end of year UK quota that incorporates international swaps. Additional quota simulation (S3) had been developed in 2017 and is based on S1 quota simulation assuming quota allocation at the level of the end of baseline year, accounting for national and international quota trade.

The first version of the model also included policy levers such as de-minimis, inter-species flexibility and survivability for investigation. At this point in the landing obligation implementation it is not clear how de-minimis and inter-species flexibility would be implemented so these were not developed further. However, survivability exemption has been tested at the later stage of the project[7].

Table 2.2.1. Scenarios analysed for the UK mixed demersal fishery case study.

Scenario	**Name**	**Description**
Baseline	Business as usual	Landings obligation not implemented, i.e. discards allowed. This situation is not modelled, however model results are compared to baseline year; several baseline years (2015, 2016 and 2017) have been analysed using model to inform management decisions in 2014-2018.
B1	Baseline without uplift	**B1** assumes that each PO fleet segment only has the initial quota allocation provided to its vessels and, by 2019, UK vessels cannot discard any demersal quota stocks. In this simulation, no mitigation measures from industry or government are assumed. The year in which stocks become subject to the landing obligation in different fleet segments and metiers prior to 2019 is informed by existing and proposed management rules defined by the North Sea and North Western Waters Regional Groups.
B2	B2, B1 + zero TAC catch allowance	In **B2** a catch allowance of 1.5% of a fleet segment's total catch (all quota stocks, all sea areas) can be applied to zero-TAC stocks. The 1.5% was informed by current bycatch percentages, as there is not yet any information on how zero-TAC stocks might be addressed under the LO. The simulation does not exempt these stocks from the LO, but significantly reduces the likelihood that these stocks will create a choke point in the model.
B3	B3, B2 + quota uplift	In **B3**, in addition to the catch allowance, fleet segments also benefit from quota adjustment, when a particular metier and stock becomes subject to the LO. The methodology for applying quota adjustment in the simulation during the transition period (2017-2019) is similar to the methodology currently recommended by STECF and used by the EU.
B4	B4, IQA + uplift, zero-TAC catch & vessel metier shift	In **simulation B4** the model actively extends fishing opportunity within a PO fleet segment by reallocating unused effort from one metier (created by a choke point) to another metier to delay a choke point. B4 as such attempts to simulate decisions that vessel owners may make.

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[7] For more information about definition of different scenarios see SEAFISH Methodology Report: http://www.seafish.org/media/Publications/Seafish_Bioeconomic_Methodology_Report_FINAL.pdf

Table 2.2.1 Continued.

Scenario	Name	Description
S1	S1, B4 + reallocation of unused UK quota	In **quota simulation S1**, in addition to the mitigation measures included in baseline simulation B4, unused quota (caused by choke points in simulation B4) is moved between PO fleet segments to enable best utilisation of UK quota stocks. This simulation assumes perfect distribution of information between PO fleets and home nations, easy quota movement and full compliance with the landing obligation. However, in reality some fleets may keep unused quota until the end of the year to minimise the risk of choke or to trade for their own purposes. The simulation is not intended to accurately reflect the decisions that individual vessel owners or PO quota managers might make, instead it is applied to indicate whether the UK has the capacity to solve its own quota challenges. This simulation uses the UK's initial quota allocation (IQA) plus quota uplift.
S2	S2, B4 with UK quota after EU swaps	In **quota simulation S2**, the IQA quota which is used to inform the baseline simulations is replaced with total UK quota held at year end after swaps with other EU Member States. The quota share that is allocated to each PO fleet segment is based on Fixed Quota Allocations (FQAs), not the PO quota at the end of baseline year. This simulation assumes that the quota which comes into the UK during the year, through quota swaps between European POs, is distributed between all POs according to FQAs as no information on how UK quota is distributed between PO fleet segments at the end of the year was available during development of scenario. The purpose of this simulation is to indicate that, if similar proportions of quota can be obtained by the UK as happened in the past, could the UK have the capacity to solve its own quota challenges.
S3	S1+S2	In **quota simulation S3**, the quota which is used to inform the baseline simulations is replaced with UK quota at year end after international swaps with other EU Member States. FQA allocations (S2) are replaced by PO allocations (S1) after international and national swaps at the end of the year. The purpose of this simulation is to indicate that, if similar proportions of quota can be obtained by the UK and traded between POs as happened in the past, could the UK have the capacity to solve its own quota challenges. However, as the EU moves towards full implementation of the landing obligation, there is no guarantee that international swaps in the future will follow a similar pattern to those in baseline year.

Table 2.2.2. Specification of simulations

Simulation	Catch allowance for Zero-TAC stocks	Quota uplift	Metier quota reallocation	UK quota trade	End of year quota (after international swaps)	De-minimis	Inter-species Flexibility	Survivability[8]
B1 Baseline without uplift	✗	✗	✗	✗	✗	✗	✗	✗
B2 Baseline without uplift excl zeroTAC	✓	✗	✗	✗	✗	✗	✗	✗
B3 Baseline with uplift excl zeroTAC	✓	✓	✗	✗	✗	✗	✗	✗
B4 Baseline, B3+Metier quota re-allocation	✓	✓	✓	✗	✗	✗	✗	✗
S1, B4+UK quota trade	✓	✓	✓	✓	✗	✗	✗	✗✓
S2, B4 + Adj Quota	✓	✓	✓	✗	✓	✗	✗	✗
S3, S1+S2	✓	✓	✓	✓	✓	✗	✗	✗✓

2.2.3 The SEAFISH model

The model consists of 3 major structural parts: Data Input Framework; Bio-economic simulations and Data Output Framework. All parts are connected through the standard data flow and developed in R and VBA programming languages, which makes data input and results updatable when new data sets are published. The main advantages of the model is utilisation of information available from administrative and other institutional data sources (e.g. STECF FDI data base, ICES stock assessment, EU FIDES database, etc.) at lowest aggregation level available and incorporation of metier approach to economic fleet segments analysis, thus allowing to link economic performance indicators with activity information and gear use by area.

The model is the most extensive for the UK fleet with regards to coverage: covering around 100 UK fleet segments (defined on the level of UK home administration, PO and fishing technique); 400-600 metiers (defined through the combination of 10 ICES fishing areas and 9 main fishing gears) and 72 stocks. The model has been updated 3 times and has 2015, 2016 and 2017 baseline year's versions.

In the bio-economic simulations part there are five modules linked together to provide a yearly analysis, these are indicated in Figure 2.2.1 including the dimensions of PO fleet segment (f), metier (m), stock (s) and year (y) as applied in the model.

The five modules (boxes) and their components are described in more detail below.

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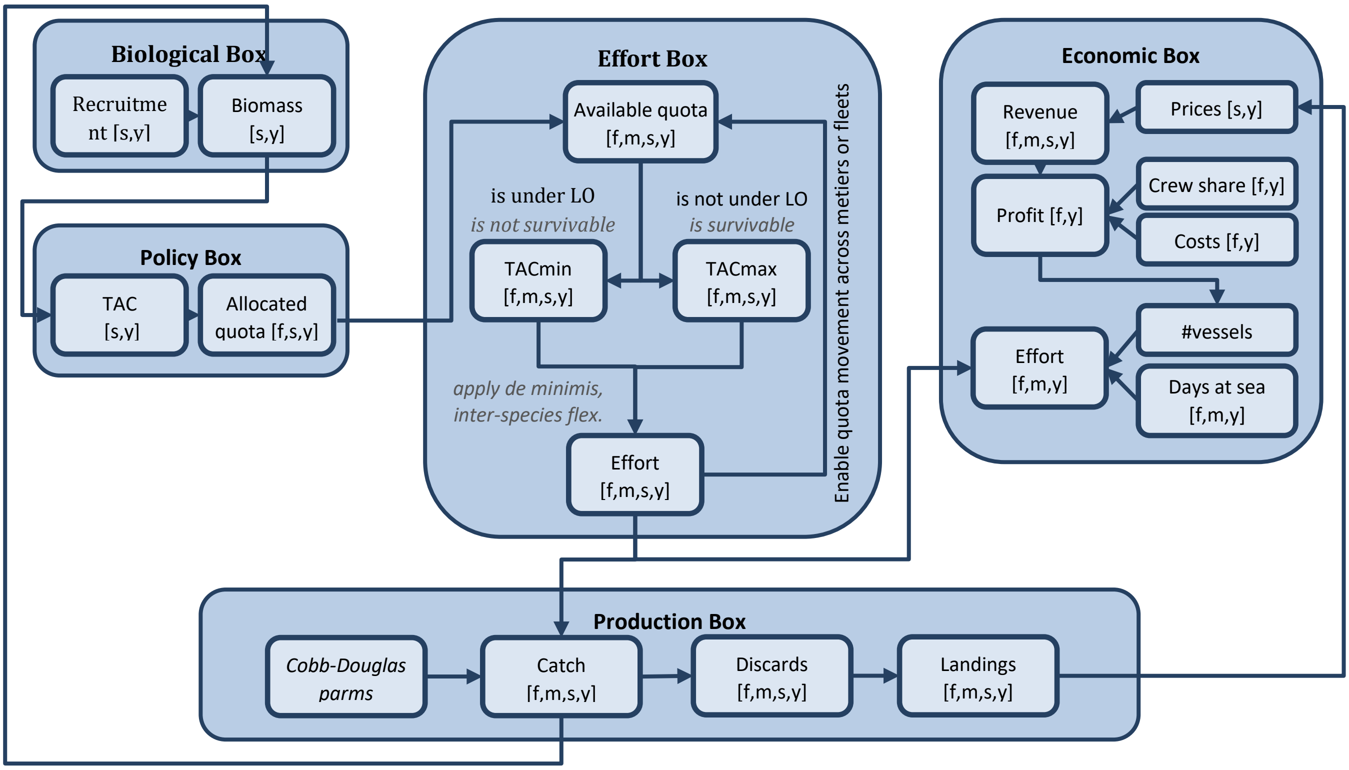
[8] Survivability is introduced through LO implementation rules in the model and is used in combination with S1 and S3 scenarios.

Figure 2.2.1. Bio-economic simulation structure



Source: Mardle et al. (2017)

Biological Box

The biological box uses a biomass dynamic model to project the assessed stocks. The biomass dynamics model is calibrated to replicate the full assessment as well as possible, while simplifying the projection greatly. A biomass dynamic model using the Schaefer Model is used to project the size of assessed stocks (see figure 2.2.2).

Figure 2.2.2. Growth and biomass equations in the biological box of the SEAFISH model

$$\text{Growth}_{[\text{stock,year}]} = \gamma 1_{[\text{stock}]} + \gamma 2_{[\text{stock}]} * \text{Biomass}_{[\text{stock,year}]} + \gamma 3_{[\text{stock}]} * \text{Biomass}_{[\text{stock,year}]}^{2}$$

$$\text{Biomass}_{[\text{stock,year}]} = \text{Biomass}_{[\text{stock,year-1}]} + \text{Growth}_{[\text{stock,year-1}]} - \text{totalCatch}_{[\text{stock,year-1}]}$$

Stock growth is of the general form of Schaefer with parameter $\gamma 1$ set to zero (i.e. zero biomass returns zero growth) with parameters $\gamma 2$ and $\gamma 3$ non-zero and biomass in the current year equals biomass plus stock growth minus total catch, from in the previous year. The gamma parameters are estimated by fitting the above growth equation to historic stock data as reported by ICES.

Policy Box

The policy box (figure 2.2.3) controls the identification of total allowable catches (TACs). The target TAC for each stock in a given year is first identified based on a calculation using the standard Baranov equation as used in stock assessments taking account of target fishing mortality (e.g. F_{MSY}) and natural mortality (i.e. M) of a stock. A limit is imposed in the model that a TAC cannot change by more than a given percentage (5% as in the formula below or 15% for some stocks) year on year. The percentage fluctuation has been set for each modelled stock depending on average yearly changes in TAC over the past 10 years. Each TAC by stock and year is then allocated across fleets modelled based on historic TAC share (i.e. TACsh) towards relative stability.

Figure 2.2.3. Equations in the policy box of the SEAFISH model

$$\text{targetTAC}_{[\text{stock,year}]} = \text{Biomass}_{[\text{stock,year}]}*(1-\exp(-\text{targetF}_{[\text{stock}]}-\text{M}_{[\text{stock}]}))*(\text{targetF}_{[\text{stock}]}/(\text{targetF}_{[\text{stock}]}+\text{M}_{[\text{stock}]}))$$

TAClimit: $95\% * \text{targetTAC}_{[\text{stock,year-1}]} <= \text{TAC}_{[\text{stock,year}]} <= 105\% * \text{targetTAC}_{[\text{stock,year-1}]}$

Or TAClimit: $85\% * \text{targetTAC}_{[\text{stock,year-1}]} <= \text{TAC}_{[\text{stock,year}]} <= 115\% * \text{targetTAC}_{[\text{stock,year-1}]}$

$\text{TAC}_{[\text{fleet,stock,year}]} = \text{TAC}_{[\text{stock,year}]} * \text{TACsh}_{[\text{fleet,stock}]}$

The equations presented in figure 2.2.3 simulate a harvest control rule that takes account of dynamic changes to stock biomass (e.g. through stock growth minus catches taken), where such stock data is available, to update quota available year on year (+/- 5% or +/- 15% depending on stock. In each simulation the biomass and TAC of a stock respond to the fishing mortality associated with that simulation.

Effort Box

With the TAC estimated, the level of effort required to catch that amount of stock (i.e. target effort) can be calculated using a re-arranged version of a Cobb-Douglas catch equation (see figure 2.2.4). There are two basic situations that the quota can be managed:

TACmin: the most restrictive TAC is used to determine the level of effort that a fleet can exert; and

TACmax: the least restrictive TAC is used to determine the level of effort that a fleet can exert.

As a result, if a stock is under the landing obligation then it follows TACmin, if not then it follows TACmax. With the level of target effort calculated, a fleet's estimated effort can be identified. A constraint is added to the effort variable to ensure that it does not exceed the maximum effort of a fleet, calculated from average fishing days per vessel and number of vessels.

For each stock in each PO fleet segment metier, the quota available in each year is combined with the calculated catch rate for the metier, to calculate the number of days at sea required to catch the available quota. If the number of days at sea required to catch the quota is estimated to be lower than the days the PO fleet segment fished in the metier in baseline year, then the stock is considered to be a potential choke stock and the choke point for the stock is the days at sea prior to choke. The primary choke stock is the stock with the earliest choke point in the metier in each simulation, i.e. fewest days at sea.

Figure 2.2.4. Equations in the effort box of the SEAFISH model

$$\mathrm{targetEffort}_{[\mathrm{fleet,stock,year}]} = [\mathrm{TAC}_{[\mathrm{fleet,stock,year}]} \;/\; (\mathrm{q}_{[\mathrm{fleet,stock}]} * \mathrm{Biomass}_{[\mathrm{stock,year}]}{}^{\beta})]^{(1/\alpha)}$$

TACmin: $\mathrm{Effort}_{[\mathrm{fleet,year}]} = \min[\mathrm{targetEffort}_{[\mathrm{fleet,stock,year}]}]$

TACmax: $\mathrm{Effort}_{[\mathrm{fleet,year}]} = \max[\mathrm{targetEffort}_{[\mathrm{fleet,stock,year}]}]$

$$\mathrm{maxEffort}_{[\mathrm{fleet,year}]} = \mathrm{seaDays}_{[\mathrm{fleet,year}]} * \mathrm{nbrVessels}_{[\mathrm{fleet,year}]}$$

$$\mathrm{propMEffort}_{[\mathrm{fleet,metier,year}]} = \mathrm{sum}_{(\mathrm{stock})}(\mathrm{Catch}_{[\mathrm{fleet,metier,stock,year-1}]} \;/\; \mathrm{totalFleetCatch}_{[\mathrm{fleet,stock,year-1}]}) \text{ OR}$$

$$= (\mathrm{seaDays}_{[\mathrm{fleet,metier,year}]} * \mathrm{nbrVessels}_{[\mathrm{fleet,year}]}) \;/\; \mathrm{maxEffort}_{[\mathrm{fleet,year}]}$$

$$\mathrm{Effort}_{[\mathrm{fleet,metier,year}]} <= \mathrm{propMEffort}_{[\mathrm{fleet,metier,year}]} * \mathrm{maxEffort}_{[\mathrm{fleet,year}]}$$

It is at this point that policy levers such as survivability, interspecies flexibility, de minimis and movement of quota can be included. For the most part, from a technical point of view, these involve a different TAC being evaluated in targetEffort (e.g. movement of quota, interspecies flexibility or de minimis) or an assumption of TACmax rather than TACmin (e.g. a "survivable" stock being exempt from the LO).

Production Box

The production box (figure 2.2.5) simulates the harvest attained from a given year's fishing effort and stock biomass with a parameterised catchability (q) by fleet, metier and stock. Catch takes a Cobb-Douglas specification with alpha and beta in the present context taking values of 1, thus making this a Schaefer catch equation.

Total catch of a stock, including that from unassessed fleets, can be calculated. Furthermore, if estimates of the stock caught below minimum landing size (i.e. d%MCRS) exist then this can also be included in total catch. Overquota discards are estimated simply by taking the difference between the catch and TAC for a given year, where it is assumed that quota discards cannot be landed for human consumption. Further, it is assumed that Overquota discards are distributed over metiers according to weighted catch in each metier. Estimated landings then follow.

Figure 2.2.5. Equations in the production box of the SEAFISH model

$$\text{Catch}_{[\text{fleet,metier,stock,year}]} = \text{q}_{[\text{fleet,metier,stock}]} * \text{Effort}_{[\text{fleet,metier,year}]}{}^{\alpha} * \text{Biomass}_{[\text{stock,year}]}{}^{\beta}$$

$$\text{totalFleetCatch}_{[\text{fleet,stock,year}]} = \text{sum}_{[\text{metier}]}(\text{Catch}_{[\text{fleet,metier,stock,year}]})$$

$$\text{totalCatch}_{[\text{stock,year}]} = \text{sum}_{[\text{fleet}]}(\text{totalFleetCatch}_{[\text{fleet,stock,year}]} \;/\; \text{TACsh}_{[\text{fleet,stock}]})$$

$$\text{Catch<mrs}_{[\text{fleet,metier,stock,year}]} = \text{d\%MCRS}_{[\text{fleet,metier,stock}]} * \text{Catch}_{[\text{fleet,metier,stock,year}]}$$

$$\text{Catch>tac}_{[\text{fleet,stock,year}]} = \max(0,\ \text{sum}_{[\text{metier}]}(\text{Catch}_{[\text{fleet,metier,stock,year}]} - \text{Catch<mrs}_{[\text{fleet,metier,stock,year}]}) - \text{TAC}_{[\text{fleet,stock,year}]})$$

$$\text{m\%TAC}_{[\text{fleet,metier,stock,year}]} = \text{Catch}_{[\text{fleet,metier,stock,year}]} \;/\; \text{totalFleetCatch}_{[\text{fleet,stock,year}]}$$

$$\text{unwantedCatch}_{[\text{fleet,metier,stock,year}]} = \text{Catch<mcrs}_{[\text{fleet,metier,stock,year}]} + (\text{m\%TAC}_{[\text{fleet,metier,stock,year}]} * \text{Catch>tac}_{\text{fleet,stock,year}]})$$

$$\text{Landings}_{[\text{fleet,metier,stock,year}]} = \text{Catch}_{[\text{fleet,metier,stock,year}]} - \text{unwantedCatch}_{[\text{fleet,metier,stock,year}]}$$

Note that for any stock where sufficient recruitment and biomass data is not available then biomass for that stock in any year will be assumed equal to one. This approach models catch using estimated catch per unit effort but enables catchability to be incorporated.

Economic Box

With landings and prices, as well as additional revenue from other species, the revenue of fleets can be calculated (figure 2.2.6). Crew costs are based on a proportion of revenue, variable costs of the number of days fished (i.e. Effort) and fixed and capital costs on the number of vessels in a fleet. Gross cash flow (or operating profit) and net profit can then be calculated directly.

Figure 2.2.6. Equations in the economic box of the SEAFISH model

$$\text{fishPrice}_{[\text{stock,year}]} = \textit{constantPrice}\ \text{OR}\ \textit{flexPrice}\ \text{OR}\ \textit{projectedPrice}\ \text{OR}\ \textit{responsePrice}$$

$$\text{Revenue}_{[\text{fleet,year}]} = \text{sum}_{[\text{metier,stock}]}(\text{Landings}_{[\text{fleet,metier,stock,year}]} * \text{fishPrice}_{[\text{stock,year}]}) + \text{otherStockRevenue}_{[\text{fleet,year}]}$$

$$\text{Revenue<mcrs}_{[\text{fleet,year}]} = \text{sum}_{[\text{metier,stock}]}(\text{Catch<mcrs}_{[\text{fleet,metier,stock,year}]} * \text{fishPrice<mcrs}_{[\text{stock}]})$$

$$\text{crewCosts}_{[\text{fleet,year}]} = \text{crewShare}_{[\text{fleet}]} * \text{Revenue}_{[\text{fleet,year}]}$$

$$\text{variableCosts}_{[\text{fleet,year}]} = \text{sum}_{(\text{metier})}(\text{Effort}_{[\text{fleet,metier,year}]}) * (\text{variableCostPerDay}_{[\text{fleet,year}]} + \text{fuelCosts}_{[\text{fleet,year}]})$$

$$\text{fixedCosts}_{[\text{fleet,year}]} = \text{numberVessels}_{[\text{fleet,year}]} * \text{fixedCostPerVessel}_{[\text{fleet,year}]}$$

$$\text{capitalCosts}_{[\text{fleet,year}]} = \text{numberVessels}_{[\text{fleet,year}]} * \text{capitalCostPerVessel}_{[\text{fleet,year}]}$$

$$\text{grossCashflow}_{[\text{fleet,year}]} = \text{Revenue}_{[\text{fleet,year}]} - \text{crewCosts}_{[\text{fleet,year}]} - \text{variableCosts}_{[\text{fleet,year}]} - \text{fixedCosts}_{[\text{fleet,year}]}$$

$$\text{netProfit}_{[\text{fleet,year}]} = \text{grossCashflow}_{[\text{fleet,year}]} - \text{capitalCosts}_{[\text{fleet,year}]}$$

2.2.4 Data

All data preparation and processing within the model are done through the Data input framework (DIF). The purpose of the DIF is to prepare data from different data sources and in different formats for input to the simulation engine. An approach using standard procedures for data processing has been developed for use with the bio-economic model.

The main data sources include UK landings logbook data (MMO), UK fleet register (MMO), Seafish fleet economic performance data (Seafish), STECF discard data (STECF), transition period (between baseline and 2019) rules (Advisory Councils), TACs and adjustments (FIDES, STECF), and stock assessment data (ICES).

The data is processed in the R statistical package and prepared for the model. All data processing, starting with attribution of the vessel to a specific PO fleet segment through to preparation of data by fleet/metier/stock, is undertaken through R scripts. These scripts are grouped by purpose to the following modules:

1. Fleet data – preparation of fleet segmentation and metiers based on individual vessel information, and preparation of fleet related data including weight and value of landings, number of vessels and days at sea;
2. TAC and quotas – preparation of all information, related to quota distribution between fleets as well as processing overall TACs from FIDES format to SEAFISH model format, including quota uplift;
3. Discards – preparation and processing of discards data by home-nation and metier;
4. Biomass – preparation and processing of biological information from ICES stock assessment;
5. Economics – preparation of economic variables for model including variable, fixed and capital costs;
6. Landing Obligation (LO) implementation – preparation of variables, defining LO implementation process during transitional period.

The processes involved in producing the above groups are described in the SEAFISH model methodology report (Mardle et al. 2017).

2.2.5 Results

Comprehensive analysis of the modelling results findings is available in Seafish Analysis of Choke Points and Problem Stocks for UK Fleet under the Landing Obligation, 2017-2019 report (Mardle et al., 2017). In addition to the analyses produced before and in order to address changes in legislation and to test some options provided in other Discardless packages, 2016 years baseline SEAFISH model have been tested with additional LO exemptions. Firstly, based on output from WP7[9], the following policy exemption scenarios have been implemented:

- High survival:
    - Nephrops in pots and creels NWW
    - Nephrops in all gears NS

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[9] Lisa Borges, personal communication.

    - Plaice in 7e,d,f,g
- TAC deletion
    - Cod 6a West of Scotland (this exemption modelled in most of scenarios through zero TAC catch allowance);
    - Whiting 7A
    - Boarfish 6,7,8

To analyse the impact of these additional policy exemptions, four main scenarios of the SEAFISH model were tested. The quota movement scenarios (S1 and S3) were updated with combined survivability exemptions and TAC deletion (and named S1S and S3S scenarios), which were compared with the same quota movement scenario without the above-mentioned policy exemptions. As such, there were 6 scenarios analysed, including B1, B4, S1 and S3 as defined in Tables 2.2.1 and 2.2.2 and S1S and S3S as defined above.

The final list of scenarios presented in this results section has been selected based on relevance for the analysis. As can be seen in table 2.2.1 all scenarios are built on top of each other and B2 as well as B3 are incorporated in B4. Therefore, consideration of zero TAC allowance and quota uplift effects separately is not as important as analysis of the combined effects of these together with effort movement between metiers (B4). Moreover, the effect of zero TAC allowance is only relevant for some specific fleets. However, it has been shown (Russel et al. 2017) that the effect of each of these measures separately also improves the economic outcome for the UK fleet relative to the full implementation with no exemptions case (B1). Furthermore, the effect of quota swaps (S1 and S3) observed in previous analyses (Russel et al, 2017, Catchpole et al, 2017) improved the economic outcome further compared to initial quota allocation without movement scenarios (B1-B4). Of the quota movement scenarios, the initial UK quota allocation scenario (S1), and end of year UK quota allocation scenario (S3), of which the latter incorporates all modelled mitigation measures, are more likely to occur in real life as UK PO actively trade within UK and internationally during the year. This is why the exemptions were tested only on quota movement scenarios (S1 and S3) and compared against these

Additional selectivity scenario of the SEAFISH model was tested at the STECF Economic Working Group Meeting 'Technical Measures Improving selectivity to reduce the risk of choke species', which was held in Dublin in March 2018. There were several selectivity devices tested (see full analysis in STECF, 2018). The results at that time showed that even with improved selectivity in nephrops trawls, whiting in area 7A will choke the Nephrops fleets in Northern Ireland (cf. Figure 2.2.7). Therefore, the removal of TAC for whiting in area 7A proposed above were expected to be beneficial for the nephrops targeting fleets in the Irish Sea. However, the results of this test show that the choke risk continues to persist in UK fishery. After whiting 7A had been removed from TAC stocks list, a second choke point for nephrops fishery in Irish Sea is cod 7A. Nevertheless, the choke effort in Northern Irish nephrops fleet were reduces from being only 12% to being 65% of the baseline effort through these two measures.

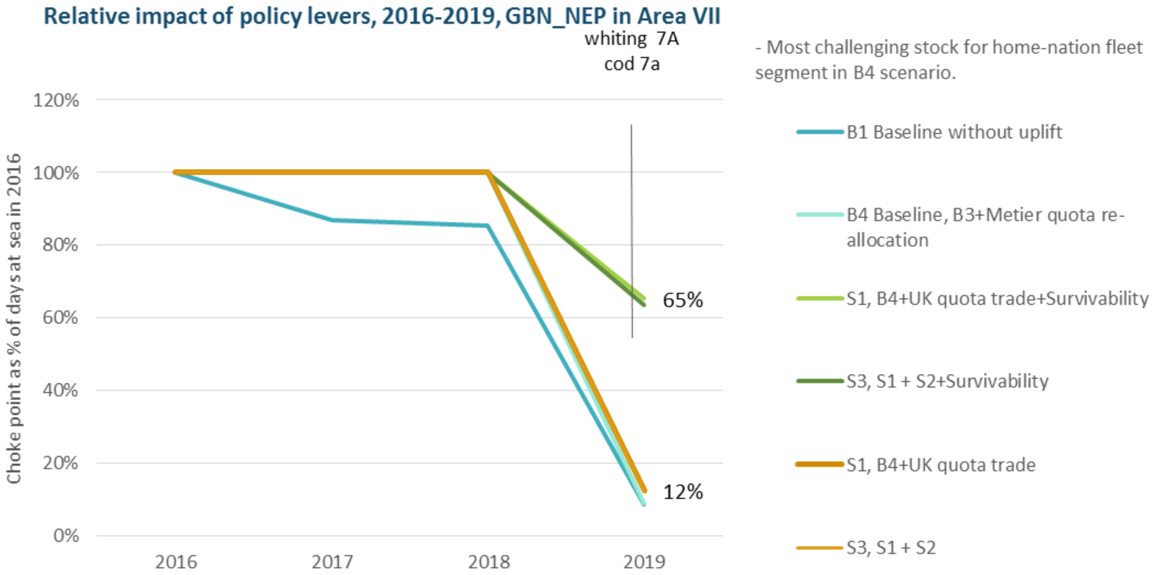


Figure 2.2.7. Modelling results for Northern Irish nephrops fleet in Area 7. Reduction in effort relative to the baseline effort, which is proportional to the reduction in revenue relative to the baseline revenue.

Survivability exemptions are also reducing choke risks to some demersal trawl fishing fleets (cf. figure 2.2.8). As we can see from the example of Scottish demersal whitefish trawl fleet there is almost no difference between B1, B4 and S1 scenarios in the case of this fleet. If choke risk is not avoided the fleet will have to stop its operation after 12% of the baseline effort utilized when the fleets available hake quota is fully utilised. This is because 11% quota uplift modelled for hake in the North Sea introduced in B4 scenario of the model can't cover fleets discards, which are on the level of 57% for TR1 gear. Internal quota trade modelled in S1 scenario also can't address the hake issue as there is no available quota in UK for hake stock in the North Sea. However, in case of S3 scenario, when international swaps are available, UK gets more than 8 times more quota, which is used to cover quota deficit in this fishery. However, in international quota trade scenario (S3) skates becomes a choke point, choking the fleet at 34% of baseline effort. This choke risk can be avoided by introduction of survivability exemption (scenario S3S). As a result, availability of tusk quota in the North Sea chokes the fleet at after utilization of 46% of baseline effort.

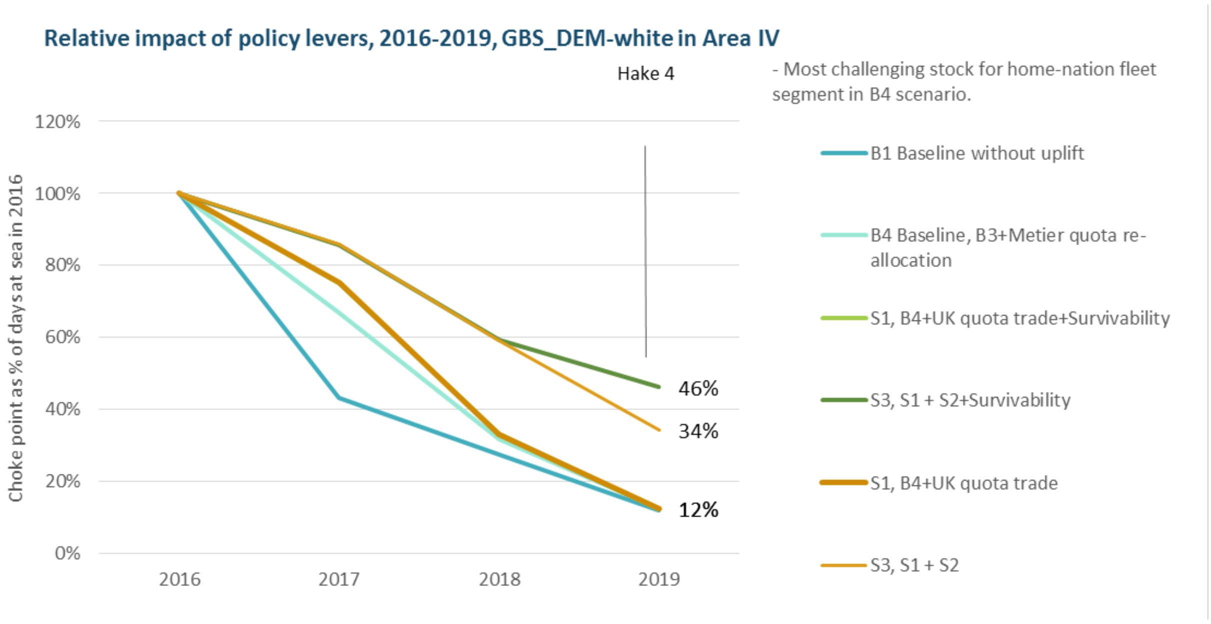
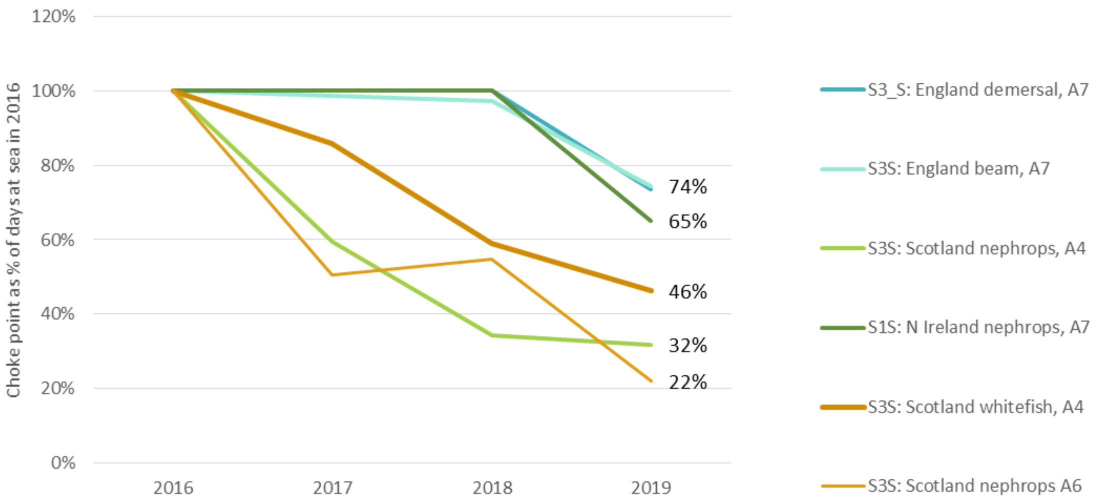


Figure 2.2.8. Modelling results for Scottish demersal whitefish fleet in Area 4. Reduction in effort relative to the baseline effort, which is proportional to the reduction in revenue relative to the baseline revenue.

When analysing all main UK fleets by fishing areas, the survivability scenario including the survivability exemptions mentioned above and removal of TACs, seems to be the best-case scenario for all main UK demersal fleets (see Figure 2.2.9). Each of these exemptions affects different fleets in a different way. Removal of the whiting quota in Area 7A will prevent nephrops fleet choking on whiting, removal of TAC for cod in the West of Scotland, will address the first choke point, i.e. cod, in case of Scottish nephrops fleet in the area 6, survivability exemption for skates and rays will reduce choke risk for the Scottish demersal whitefish fleet in the North sea and will prevent English demersal and beam trawlers choking on these specie in area 7, however these measures don‘t seem to eliminate choke risk fully. As secondary chokes appear in all analysed fleets, e.g. cod 7A becomes a problem stock for Northern Irish nephrops fleet in area 7, cod 7-k becomes a primary choke for English demersal fleets, whiting in West of Scotland becomes a choke point for Scottish nephrops fleet in area 6 and tusk becomes an issue for Scottish demersal whitefish boats.

This project has received funding from the European Union's Horizon 2020 Framework Programme for Research and Innovation under grant agreement no. 633680



2.2.9. Modelling results for Scottish demersal whitefish fleet in Area 4. Reduction in effort relative to the baseline effort, which is proportional to the reduction in revenue relative to the baseline revenue.

Overall, the quota and choke analysis (none fleet specific) results show that introduction of the additional measures discussed in this chapter reduces forgone catch (estimated relative to baseline effort) due to choke, e.g. S1 scenario with survivability show reduction of choke risk, however main marginal improvement is observed when quota is traded between fleets (S1) and internationally (S3).

2.2.6 Discussion/conclusion

The analysis presented in this chapter suggest that there will be certain choke risks for the UK demersal fishery due to difference between quota level available through national quota allocations, historical TAC allocations and catch compositions of individual fleets. All work done using the SEAFISH model showed that choke risks are significant for by catch species, which are not targeted by fleets and therefore the UK does not always have enough quota.

Some choke risk mitigation measures might help to reduce these choke problems; however, the scale of change should be extended to other not modelled measures, e.g. real time closures, avoidance, seasonal closures and other. Only combination of all different measures might help to avoid fishing closure before the end of the year.

Economic consequences were not fully analysed in this paper, as main driver of negative economic results is lack of quota for choke species. However, in case of fleets activity adaptation (e.g. use of seasonal area closures, avoidance) and removal of choke risks through combination of mitigation measures (e.g. selectivity in combination with quota trade and avoidance) there might be positive biological and economic results, which could lead to improvement of economic performance in a long term.

2.3 French demersal fishery in the Eastern English Channel

2.3.1 Short introduction

In the Eastern English Channel case study, the participatory approach implemented within DiscardLess allowed engaging in dialogue with fishers regarding the impact of the Landing Obligation (LO), the strategies for mitigating discards and the data and models used by scientists to evaluate management strategies. In the Eastern English Channel (EEC) (ICES Division VIId), a diversity of fleets targets a large variety of species with various gears. While netters seasonally rely on sole and dredgers on scallops, cod, plaice, whiting and cephalopods occupy the rest of the year. Trawlers are more diverse in their catch along the year and also target red mullet. Together the netters, dredges and trawl fleets averaged 448 vessels over the period 2008-2014. The application of the LO is complicated for these fleets by the mixed nature of the fisheries and a regulatory system (cod plan, technical measures, licenses and quotas) that limits fleet adaptability. These aspects were explicitly taken into account in the simulations presented in this section, using the spatialized simulation framework ISIS-Fish.

2.3.2 Describing the model used

2.3.2.1 ISIS-Fish

ISIS-Fish is a deterministic fisheries dynamic simulation model designed to investigate the consequences of alternative policies on the dynamics of resources and fleets for fisheries with mixed-species harvests (Mahevas and Pelletier, 2004; Pelletier *et al.*, 2009). It allows quantitative policy screening of combined management options, such as total allowable catch (TAC), effort control, licenses, gear restrictions, Marine Protected Areas (MPAs), etc. Fishing mortality is the result of the interaction between the spatial distribution of population abundance resulting from the population sub-model and the spatial distribution of fishing effort provided by the exploitation and management sub-models at a monthly time-step (Figure 2.3.1). Fishing effort is standardized per métier and fleet according to gear selectivity and efficiency, ability to specifically target a species and technical efficiency. The effect of management measures can therefore be explicitly modelled either through modifications of the standardization parameters for technical measures (e.g. change in the selectivity curve) or through modification of the level and spatio-temporal distribution of fishing time for seasonal closures or effort control for instance.

Fisher's response to management may be accounted for by means of decision rules conditioned on the population and exploitation variables, or explicitly implemented in the dynamic model via endogenous (e.g. fish prices and variable costs) or exogenous variables. Discarding behaviour is implemented through decision rules (by defaultbeing the consequence of catches under legal size or of quotas being reached). The model is flexible in its spatial resolution and level of complexity to accommodate the complexities of mixed fisheries. It has been applied to the Bay of Biscay hake fishery (Drouineau *et al.*, 2006) and pelagic fishery (Lehuta *et al.*, 2010, 2013), the European deep sea fishery (Marchal and Vermard, 2013), the New Zealand Hoki fishery (Marchal *et al.*, 2009), the Tasmanian costal mixed fishery, the cod fishery in the Baltic sea (Kraus *et al.*, 2008), and Mediterranean fisheries (Hussein et al 2011a, 2011b).

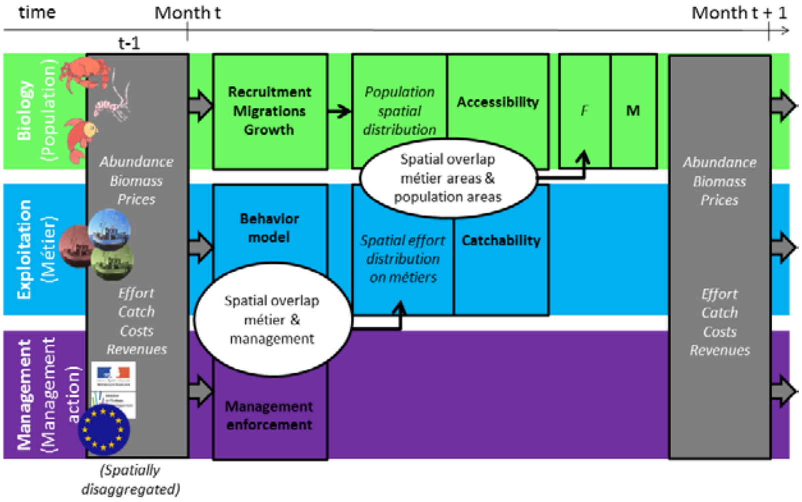


Figure 2.3.1: Conceptual diagram of ISIS-Fish model functioning highlighting the exchanges of information between the management, fishing activity and population modules within a time step.

2.3.2.2 Application to the French demersal fishery in the Eastern English Channel

The Eastern Channel application focuses on the French fleets operating in ICES area VIId and on the most valuable species landed by French fleets: sole (*Solea solea*) and scallops (*Pectens maximus*). The majority of sole landings comes from netters and, to a more limited extend, bottom trawlers and mixed trawlers. Scallops are mainly landed by dredgers. The model therefore focuses on these four fleets, consisting of a total of 448 boats in average over 2008-2010. The fleet segmentation used is the segmentation created by the French Fishery Information System (Ifremer, SIH), which groups French vessels based on the main, or two main, gears used during the year. We further segmented these SIH-fleets according to length class of the vessel and home region, which results in 17 fleet segments. The other boats operating in the EEC (including international fleets) are pooled into an inexplicit fleet "OTHER", the impact of which is modelled through a fishing mortality adjusted to management constraints. The rest of the value landed by the selected fleets mainly consists in cephalopods, sea bass, whiting, red mullet, cod and plaice. The model currently describes the dynamics of scallops (2 populations), sole, plaice, red mullet and cephalopods (2 populations of squids, a population of cuttlefish). The biological models build on the structure and parameters of the assessment models and parameters in use within ICES when available and on scientific survey data and literature otherwise. It accounts for spatial distribution and migration of populations in course of the year.

Population zones in the ISIS-Fish model of the Eastern Channel are based on the habitat structure identified by Girardin *et al.*, (2018) for the Atlantis model of the same region (Figure 2.3.2). Regarding métier zones, logbooks helped identifying the main ICES rectangles of practice for each gear and fleet. One métier per main rectangle is consequently created (e.g. OTB-27E9) while ICES rectangles with low effort for a given gear and fleet are pooled together in a unique métier (e.g. OTB-left). The structuring hypothesis of ISIS-Fish is the homogeneity of any variable

This project has received funding from the European Union's Horizon 2020 Framework Programme for Research and Innovation under grant agreement no. 633680

(effort, abundance, etc.) within a zone. Fleet behavior is modeled through the dynamical modification of effort allocation on métiers in course of the simulation. A gravity model accounts for the mix of tradition and opportunist behavior of fishers when they choose which métier to practice. More details about the EEC application can be found in Lehuta et al. (2015) and below.

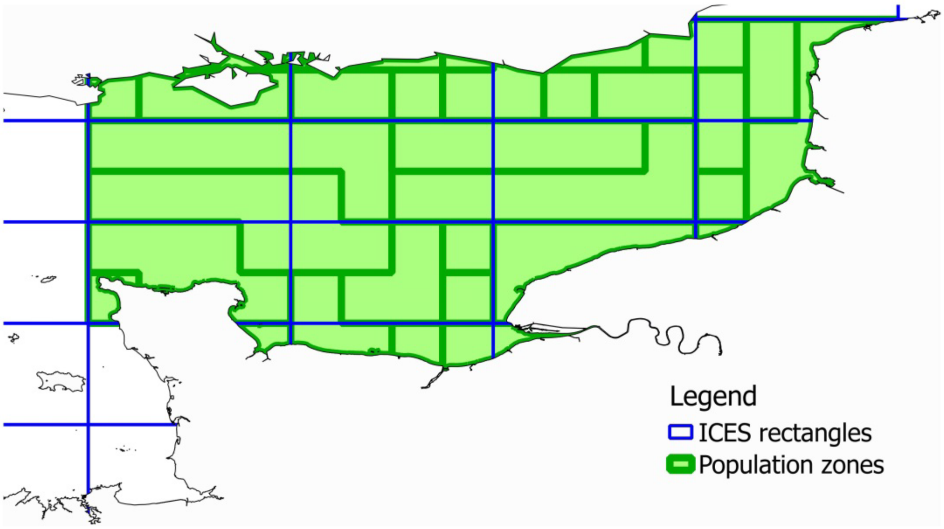


Figure 2.3.2: Spatial structure of the ISIS-Fish model of the EEC showing the overlap between population zones and métier zones (ICES rectangles).

2.3.2.3 Modeling effort distribution in ISIS-Fish

In ISIS-Fish, catches result from the distribution of fishing effort by several fleets on a variety of métiers which differ in the area of operation, the season, the gear and intensity of search on the different species. Monthly effort is constant but the distribution of effort on métiers is modified dynamically in course of the simulation to reflect the opportunist behaviour of fishers according to a gravity model. The gravity model allows balancing the level of traditional vs. opportunist behavior using a weighting factor α. For a given fleet, the proportion ($P_{\text{métier } i,t}$) of total effort of month t spent on a given métier i, is proportional for a part α to fisher's habits, which is approximated by the percentage of effort on métier in the year before (t-12), cf. equation 1, and for the rest (1- α), to the current (t-1) attractiveness of métier i, as reflected by the net value landed per unit of effort (PUE) and kg of catch (cf. equation 2). If α = 1, fishers'behavior is completely dictated by their habits and reproduces identically from one year to the other. Inversely, if α=0, fishers are completely driven by the current conditions and allocate their effort on métiers proportionally to their attractiveness. In the following, alpha is referred to as "level of tradition", while (1-α) is referred to as "level of opportunism".

$$Habits_{métier\ i,t} = \frac{Effort_{métier\ i,t-12}}{\sum_i Effort_{métier\ i,t-12}} \tag{1}$$

$$Attractiveness_{\ métier\ i,t} = \left(\frac{\text{Landed value PUE – Fuel costs PUE}}{\text{Landed quantity PUE}}\right)_{métier\ i,t-1} \tag{2}$$

Then the proportion $P_{\text{métier } i,t}$ of total effort of month t spent on a given métier i, is given by:

$$P_{métier\ i,t} = \alpha * Habits_{métier\ i,t} + (1 - \alpha) * \frac{Attractiveness_{\ métier\ i,t}}{\sum_i\ Attractiveness_{\ métier\ i,t}} \tag{3}$$

Opportunism was approximated by a function proportional to the landed value minus fuel costs per unit of effort and inversely proportional to landed quantity. This last term was introduced to account for the fact that for the same profit per unit of effort, fishers are expected to favor métiers minimizing unwanted i.e. unmarketable catches (under legal size fish, over-quota or non-commercial species). It compensates also for the lack of explicit account of ship's hold capacity in the model.

2.3.2.4 Modelling discards

In ISIS-Fish, catch results from an age/length-, fleet-, area- specific fishing mortality. The separation of the catch between landings and discards is realized afterward according to flexible decision rules. Only the landed quantities are considered for the computation of revenues. In the **status quo** simulations, discards occur if:

1- **Quota** for a species is reached: Catches cumulate monthly in course of the year until the quota of a species is reached. Thereafter the métier can still be practiced but the species for which their quotas are exhausted are discarded. If the revenues of the métiers concerned are significantly impaired, the gravity model that drives fishermen behavior will redirect fishermen toward more profitable métiers.
2- **Discarding behavior**: The analysis of data from onboard observers allowed the computation of discard rates per quarter, métier, species and fish age. It evidences that high-grading behaviors are common in the trawler fleets for species like whiting and plaice, with a large proportion of individuals above the minimum landing size discarded. The observed discard rates are applied to the catch in the Discard As Usual scenarios.

Under **LO** the assumptions are changed:

1- When **quota** is reached, the attractiveness of all métiers catching the species is set to zero reflecting the fact that vessels are no longer allowed to practice the métier. Exemptions can take place here, depending on the fleet or the métier or as a function of internal variables.
2- If fish under **minimum conservation size** are caught they are landed but their price is set to zero to reflect the absence of commercialization opportunities. The gravity model as implemented, accounts for these extra non-commercial landings, and decreases the attractiveness of the métier in consequence.

A (age-dependent) survival rate for discarded fish is possibly applied, when available (for now, the model assumes no survival of discarded fish for all species but scallops for which the survival rate is 1). Given that there is no trophic relationship in the model, the dead part of the discards is not considered in the dynamic any longer.

2.3.3 Data description

The model is parameterised and calibrated over the period 2008-2014. The population module is based on assessment model data when available (ICES, WGNSSK) and survey data for the spatial distribution and life history traits (CGFS survey, Ifremer and UK BTS survey, CEFAS). Parameters of the fishing activity module are estimated based on declarative data (Ifremer, SIH) and assessment data (ICES, 2015b). The database of model parameters can be freely downloaded at http://isis-fish.org/download.html and further details on the parameterisation are available in Lehuta *et al.*, (2015).

2.3.4 Scenarios

The simulation settings and design were discussed with fishers in the course of two meetings in order to ensure that scenarios will be relevant and acceptable by the fleets. The meetings helped also define the outputs of interest. Last, the assumptions regarding fleet flexibility were debated, resulting in additional scenarios for fishing behavior.

2.3.4.1 Fishing behavior

According to fishers, the flexibility of fleets (that is, their ability to change their behavior from one year to another) is limited due to boat characteristics (smaller boats are not able to expand their area of practice) and strategies (loss of skill to practice various métiers) and to regulatory constraints (quota availability and licenses limit their possibility to report their effort on other species). This was explored by testing three alternative values for α: 0.9 (very traditional), 0.7 (intermediate) and 0.5 (very opportunist). The impact of these assumptions is presented as intervals of variation (+/- standard deviation) around the average results.

2.3.4.2 Current CFP regulation and management plans

According to the common fisheries policy, a transition to F_{MSY} is implemented for the species under quota regulation (sole, plaice, cod and whiting). It is implemented in the model through TACs computed as much as possible the same way as ICES working groups do (Figure 2.3.3, Table 2.3.1). The main difference comes from the fact that ISIS-Fish is not coupled with the assessment models of the species, thus SSB is assumed perfectly known on December 31st of the previous year, and recruitment is assumed equal to the last three years average.

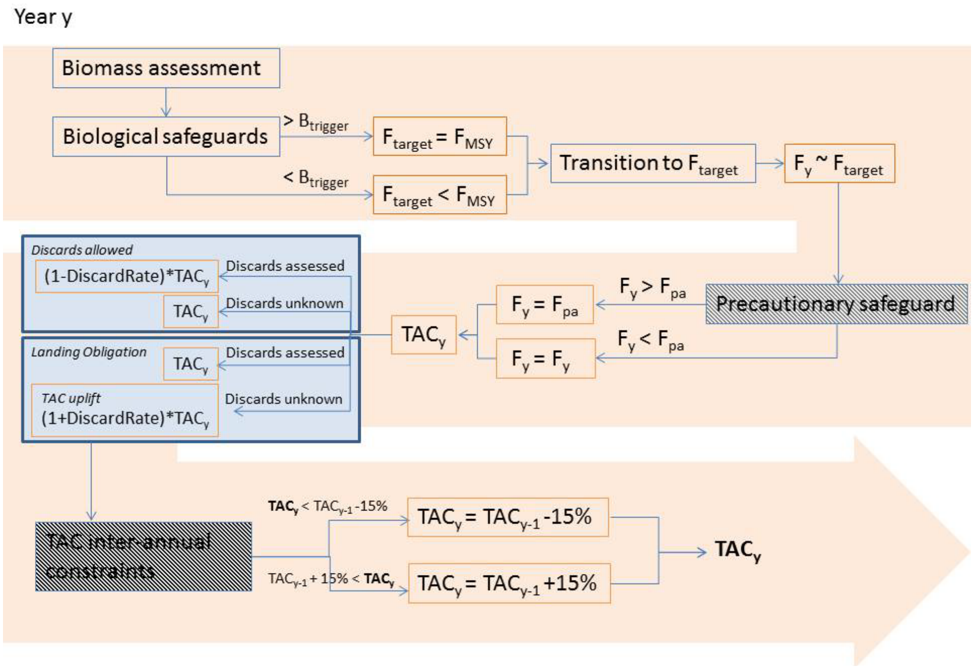


Figure 2.3.3: Annual computation of TAC for the species under management plan (transition to MSY between 2016 and 2020).

For each simulation year, the TAC depends on the management plan implemented, including biological safeguards (Btrigger, Fpa). Inter-annual variations in the TAC are limited to 15% and the transition from total allowable landing to total allowable catch assumes uplifts equal to the previously estimated discards. TACs and biological closures for scallops were carefully modelled.

Table 2.3.1: parameters of the management plans for the modelled species.

Species	Sole	Plaice	Whiting	Cod
Discard rates	0.0924 (2014-2015 WGNSSK 2016)	0.33 (2014-2016, WGNSSK 2018)	0.33 (2014-2016, WGNSSK 2018)	0.21 (2017,WGNSSK 2018)
Fmsy	0.256	0.25	0.15	0.31
Fpa	0.256	0.36	0.28	0.39
Btrigger	19251	25826	241837	150000

2.3.4.3 De minimis

Although still under discussion, exemptions ("*de minimis*") were envisioned for certain métiers in order to limit the risks of choke. A "*de minimis*" scenario was built assuming that exemptions will be delivered to the métiers (combination of gear and area (statistical rectangles)) in which the choke species represents less than 5% of the landings. These métiers are thus allowed to catch, and discard fish caught under LO when the quota is exhausted.

2.3.4.4 Discard avoidance

Despite the doubt shown by fishers regarding their capacity to avoid catching potential choke species, avoidance strategies were discussed during the meetings. The main strategy proposed to avoid unwanted catches was the avoidance of areas and seasons with high probability of catch of the species at risk. A tool was designed within WP4 to help identify the areas and seasons of interest and used to draw three avoidance scenarios for sole and whiting.

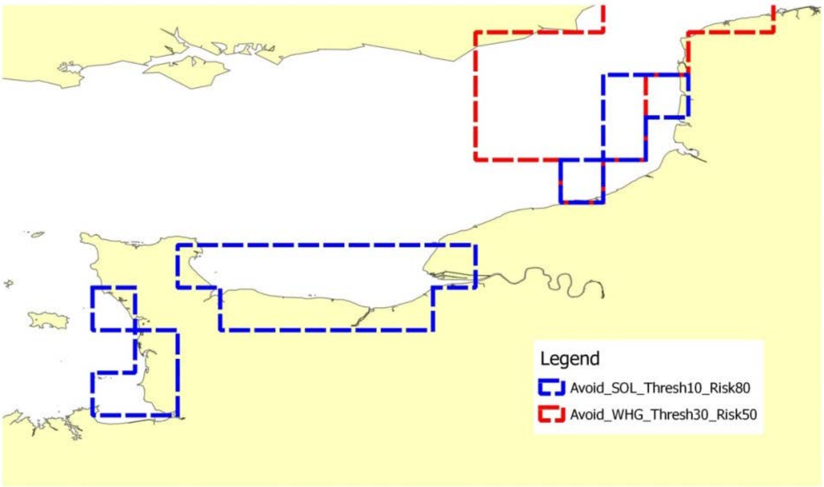


Figure 2.3.4: Avoidance areas for Sole and Whiting as proposed based on WP4 results.

The first scenario Avoid-SolQ2 proposes to close areas located on sole coastal nurseries in the Baie de Seine and off the Baie de Somme during the second quarter for trawlers. In these areas and period more than 70% of the trips consist of more than 10% of sole (Figure 2.3.4). The two other scenarios Avoid-WhgQ1 and Avoid-WhgQ23 are closing an area located in the Strait of Pas de Calais (Figure 2.3.4) respectively in the first quarter and from April to September, where whiting constitute more than 30% of the catch in more than 50% of the trips.

2.3.4.5 Simulation settings:

Simulations are run for 15 years, starting in 2010 with a spin-up period of 6 years constrained with observed effort, quotas, recruitment and migrations before implementation of the management plans and LO (when appropriate). In projections recruitment is constant (last three years average), migrations and total effort per fleet are constant (2008-2014 average, corresponding to the calibration period).

2.3.5 Selected Outputs:

As required by fishers, results are evaluated both based on biological and economic outputs of the scenarios and at the fleet scale. Population biomasses, age structure, discards, as well as expected changes in revenues for each fleets and quota utilization are assessed relative to the base case scenario: Discard as usual (DAU). Results at short (4-6 years) and long term (10 years) are explored as fishers stressed the crucial importance of the transition phase.

Fishers show interest in the quantification of the sorting time as a result of the simulations. Different ways of approximating the value were discussed but it was finally considered too speculative given the time step of the model (month) and the likely multi-factorial determinism of this quantity.

Following the presentation of preliminary runs, fishers pointed out the necessity to present the result graphs in simple ways, and possibly sequentially make them more complicated in order to avoid confusion when displaying multi-dimensional results. Results were therefore made available through a shiny interface, where the type of outputs, years of interest, scale (cumulated or disaggregated), fleets, populations are user-selected thus the graphs may be built and modified by the fishers themselves.

2.3.6 Presentation of results

2.3.6.1 Impact of the landing obligation

Long term results

The implementation of the LO produces long-term benefits both to the fish populations and the fleets. Biological impact is mainly apparent on Sole and Cod with a 40% and 9% increase in biomass respectively (Figure 2.3.5). Benefits also propagate to non-regulated stocks such as red mullet, squids and cuttlefish, although the results should be carefully interpreted given the high variability of these stocks‘ dynamics (recruitment and spatial distribution) that could not be accounted for in the model.

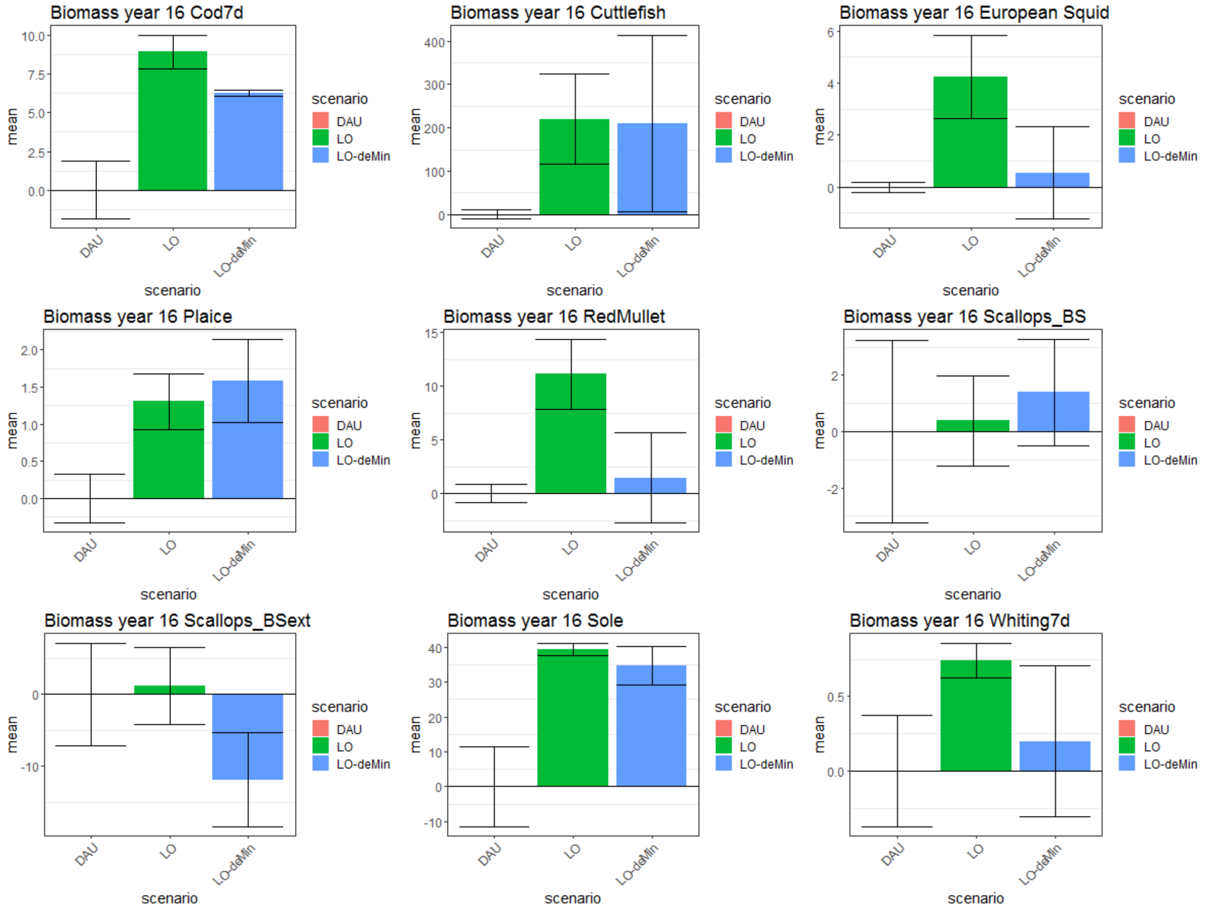


Figure 2.3.5: Average biomass in the last year of simulation with the LO (green) and LO-deMinimis (blue) scenarios relative to the DAU scenario. Arrows represent the standard deviation of the mean when fleet opportunism is varied.

As for economic benefits, annual revenues after 10 years of LO implementation are 25% higher than in the base case scenario (Figure 2.3.6). The benefits mainly arise from higher sole revenues, since landed values for the other target species show no or negative change. Indeed, the simulations suggest that plaice will be the choke species during the first years of implementation (2016-2018), with a late closure of the fishery around November or December, before sole takes over, and make the fishery close earlier between August and December (depending on fleet behavior and years, see below).

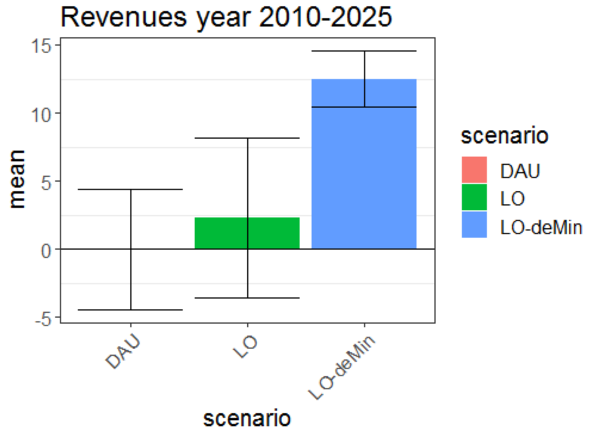


Figure 2.3.6: Average cumulated revenues per scenario (LO: green, LO-deMin: blue) relative to the DAU scenario. Arrows represent the standard deviation of the mean when fleet opportunism is varied.

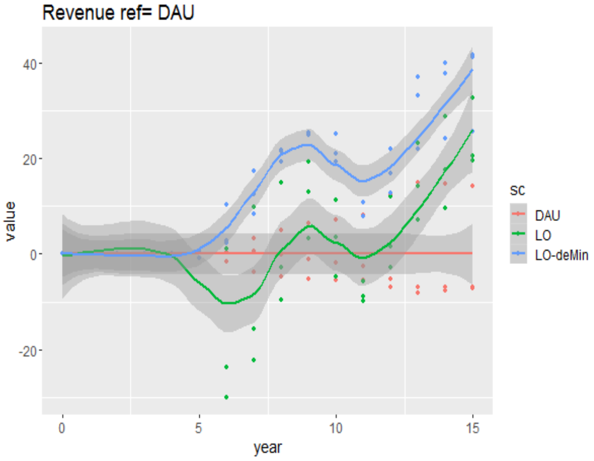


Figure 2.3.7: Evolution of the average relative revenues of the fishery in LO (green) and LO-deMin (blue) scenario compared to the DAU scenario. Shaded areas represent the standard deviation of the mean when fleet opportunism is varied.

Short term results

However, simulations indicate that difficulties are expected for the fleets during the first 6 years of implementation with a temporary decrease in their annual revenues of about 10% compared to the DAU scenario (Figure 2.3.7). This corresponds to the time needed for Sole revenues to increase enough to compensate for the losses of other species.

Impact of "de minimis" scenarios

In this regard, the implementation of *de minimis* as assumed, allows avoiding this transition period (Figure 2.3.7), especially by limiting losses on scallops, whiting, red mullet and squids which were a consequence of the early stop of the activity in areas of mixed catch. Interestingly discards stay low (-95% compared to DAU) in this scenario and the biomass of most stocks is not significantly impaired by the extra catch compared to the LO scenario (between -0.5% and -5% for sole, cod, whiting and red mullet). Cuttlefish and scallops off the Baie de Seine present more significant decreases (-10 to -20%) compared to the LO scenario (Figure 2.3.5). However, the drop in biomass occurs at the beginning of the simulation and biomass starts rebuilding after 4 to 6 years of implementation.

Impact of fleet opportunism

The variation in results obtained by changing the level of fleet opportunistic behavior provided interesting insights in the ability of fleets to adapt to the LO and the robustness of the results to this form of uncertainty. Indeed, at the fishery scale, cumulated revenues over the simulation with the DAU vs. LO scenarios are not significantly different if fleet behavior is regarded as a source of uncertainty (Figure 2.3.6). As such, the performance of the fishery is affected by the assumptions made about fleet behavior. It is observed that revenues of whiting increase with fleet opportunism, revenues of sole decrease as opportunism increases and the response varies depending on the scenario for cod and plaice (Figure 2.3.8). While the increases with opportunism is expected, since fleets intensify their effort on the most profitable métiers, the observed decreases are a direct consequence of the LO. In this regulatory context, being more opportunistic also means more efficient and therefore faster exhaust the quota. Simulations indeed evidence than the fishery closes faster (e.g. for sole: November at the earliest with opportunism = 0.1, August at the earliest with opportunism = 0.5) as opportunism increases.

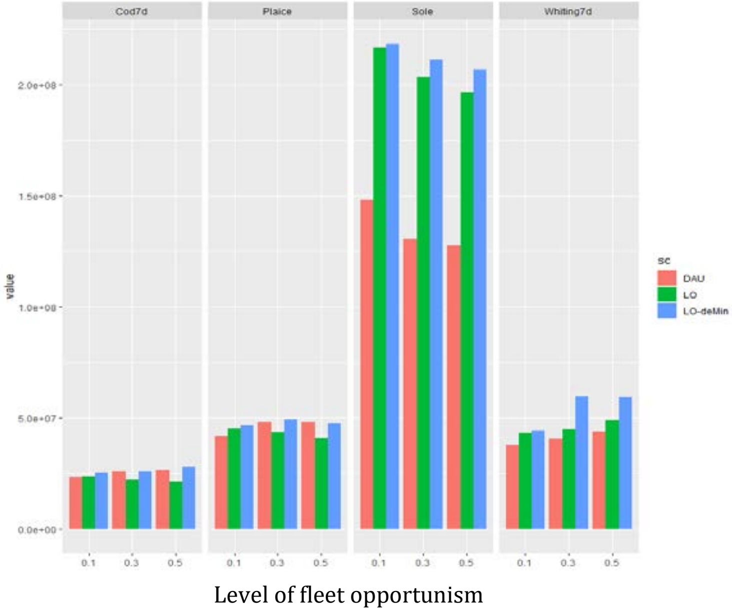


Figure 2.3.8: Revenues over the simulation per species in the three scenarios (DAU: red, LO: green, LO-deMin: blue) for various levels of assumed fleet opportunism (x-axis, 0.1 : traditional to 0.5: very opportunistic).

Results at the fleet level

As expected by fishers, the picture is quite different when results are examined at the fleet level (Figure 2.3.9). Indeed, some fleets can be qualified as "winners" as the LO and even more the *de minimis* scenario ensures higher revenues over the simulation period. It is the case of netters, who benefit from sole recovery and dredgers especially from Normandie even more with the de minimis, which allow them to continue fishing scallops off the Bay of Seine even when sole chokes. The situation is more contrasted among trawlers. Trawlers from Normandie are the "losers" as their revenues over the simulation period are expected to drop by 10 to 15% under the LO with little improvement brought by the *de minimis*. Trawlers from the North of France should expect losses of less than 10% in their revenues with the LO implementation, but *de minimis* would results in higher revenues than in the DAU scenarios. This illustrates the ability of the later fleet to operate in areas with less mixed catches.

Heterogeneity between fleets is also evidenced as the intensity of response to opportunism level is concerned. Surprisingly the size of the boat is not the major factor affecting flexibility and the contrast mostly pertains to region of origin. Globally the revenues of the fleets from Normandie are highly variable with the level of opportunism which demonstrates a larger flexibility in their activity. In contrast, fleets from the North of France appear more constrained especially smaller boats.

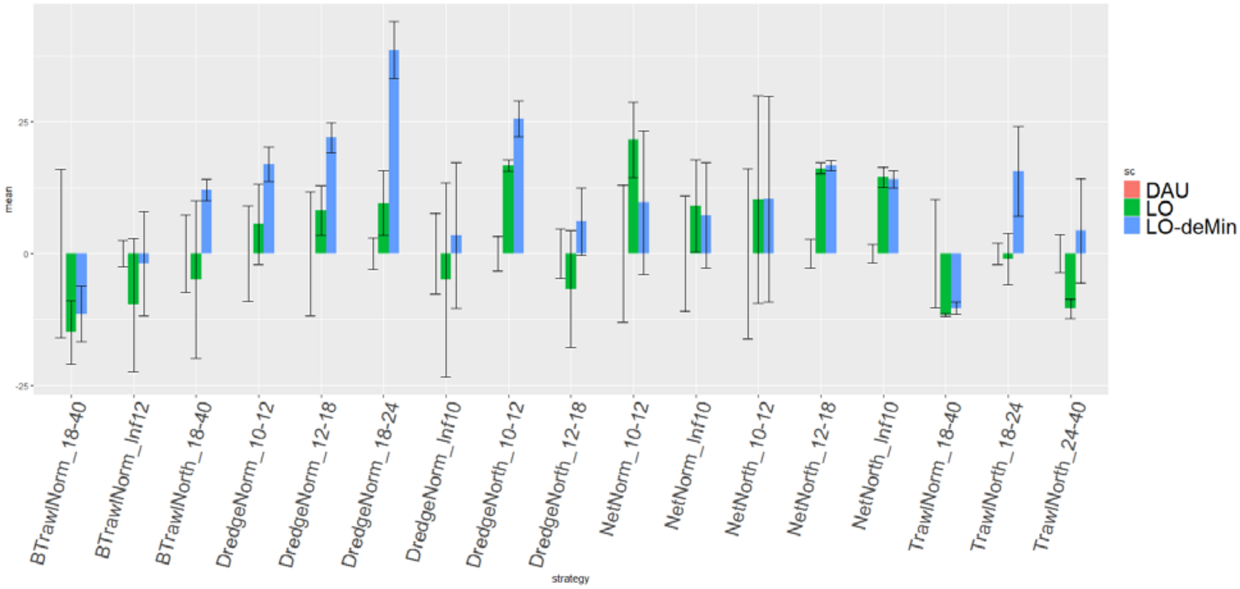


Figure 2.3.9: Average changes in individual fleet revenues (cumulated over the simulation period) with the LO scenario (green) and the de minimis scenario (blue) relative to the DAU scenario (BTrawl = Bottom trawlers; Trawl = Mixed trawlers; Dredge= Dredgers; Net = Netters; North = home region North of France; Norm = Home region Normandie; numbers indicate the size class of the boats). Arrows represent the standard deviation of the mean when opportunism is varied.

2.3.6.2 6.2 Avoidance strategies

Whiting closures for trawlers

Although whiting was not a choke species in the current simulations, variations in recruitment are expected to occur and possibly make the quota limiting. Two strategies were therefore proposed to limit catches of whiting. Both are successful in diminishing catches of whiting, however the closure in Q1 allows a larger decrease in catch of whiting (-18% vs. -5%) (Figure 2.3.10) for equivalent economic losses on the other species particularly cod and cephalopods (-2.5% vs. -1% at the fishery scale). Depending on the fleet concerned, economic losses with the closure in Q1 range from 0 to -14%, with trawlers being more impacted than dredgers.

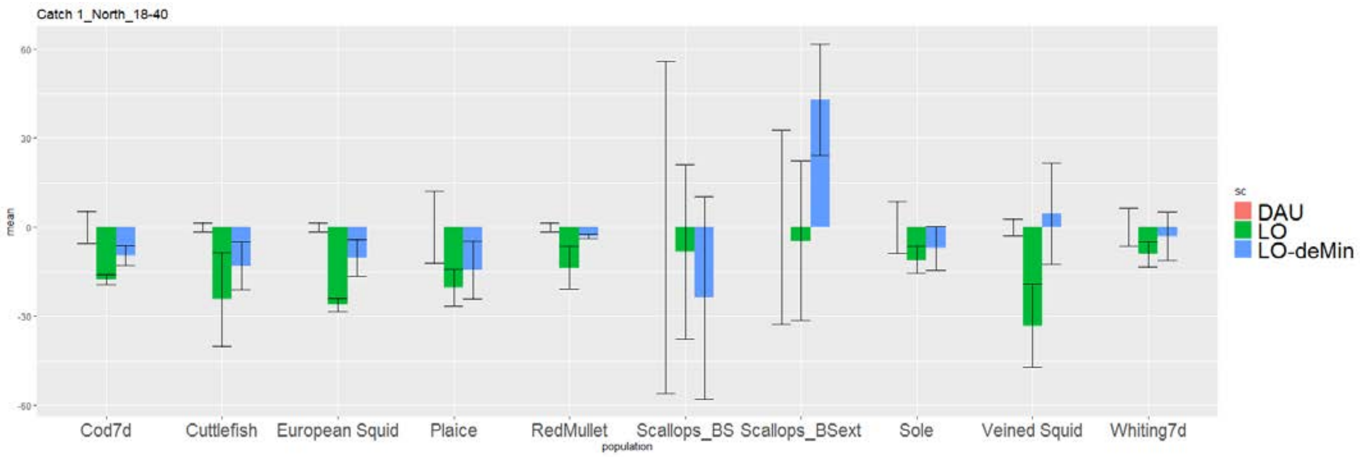


Figure 2.3.10: Average relative change in trawler catch per species over the simulation period with the whiting avoidance scenarios (Lo-avoid_WHG_Q1 in green, and LO-avoid_WHG_Q23 in blue) compared to the LO scenario. Arrows represent the standard deviation of the mean when opportunism is varied.

Sole closure for trawlers

The avoidance strategy for sole did not show the expected effects. Indeed, the objective is a significant decrease in sole catches with maintenance of the catch level for the other species. Here however catch of sole are identical but a significant decrease in catch of whiting, red mullet and cod (-3 to -7%) are observed for trawlers. On the positive side however, choke situations are globally more frequent over the 10 years of simulation for sole, but choke occurs later in the year than in the LO scenario (Figure 2.3.11a) and the fishing mortality is displaced toward older individuals while global revenues are maintained (Figure 2.3.11b). Although not directly relevant to mitigate the impact of the LO, this scenario is interesting to promote a more sustainable exploitation of the sole stock.

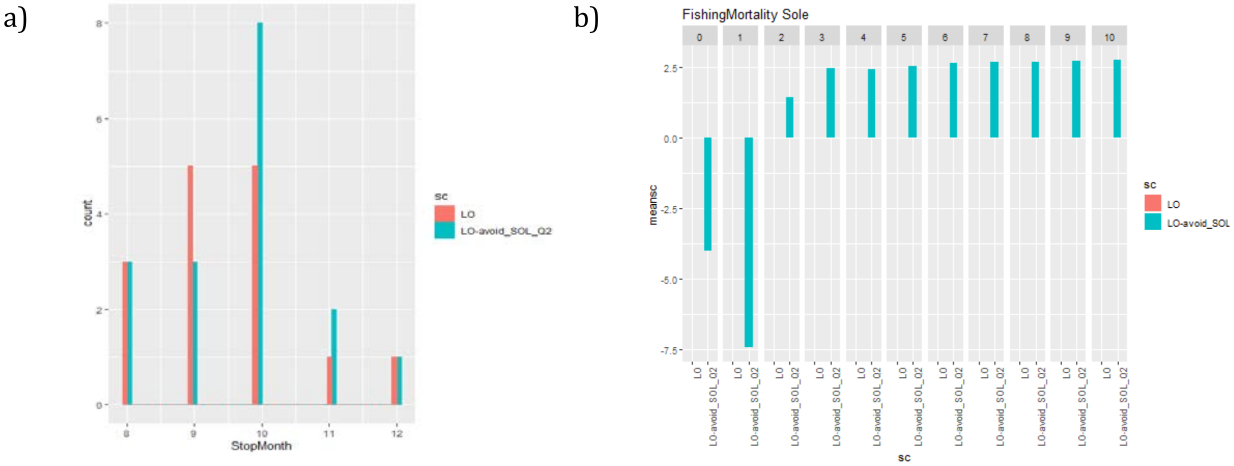


Figure 2.3.11: a) Distribution of choke dates (month number 8: August, 12: December) for sole in the LO scenarios (red) compared with the sole avoidance scenario (blue). b) Relative change in sole fishing mortality at age in the sole avoidance scenario relative to the LO scenario.

2.3.7 Discussion, conclusions and perspectives

The participatory approach allowed drawing conclusions on the likely impact of the LO on the demersal fishery in the EEC. It confirmed expectations that quotas may not be limiting given the current stock conditions and if the uplifts correspond to the discard rates. The choke on sole was somehow unexpected as the discards are estimated to be quite low (9%) by the ICES working group. However, discards estimates used in the model based on available data were much higher. This mismatch likely explains the early choke predicted by the model and further analyses are ongoing to understand its source. The evaluations at fleet scale and in the short time evidenced the difficulties that some fleet may still meet in the first years of implementation. The impact of *de minimis* was particularly encouraging as it provided higher revenues for equivalent fish biomasses. However, it is recognized that such exemptions will likely make control more complex and the exact way they will be implemented is not clear yet. Finally, a fine analysis of the performance of the alternative modelled behaviours (more or less opportunistic) and avoidance strategies should provide fishers with leads to adapt to the regulation and limit these impacts.

These results will be presented to fishers during a restitution meeting in November 2018. The discussions will likely enrich the conclusions and open new perspectives for improvements of the model and study. Currently a few limits are pointed out and solutions examined particularly regarding the behavior model, the modeling of quota, and the scenarios of evolution of the ecological and economic conditions.

Polyvalence and flexibility of fleets was accounted for by changing the opportunism level in the behavior model. This level was changed jointly for all fleets to evidence the effect of increased opportunism at the fishery level. However according to discussion with fishers' representatives, the current level of opportunism is likely different depending on the fleet concerned (e.g. small netters from Normandie having kept the skills to practice pots or lines if the economic conditions are unfavorable to nets, while some trawler fleets have specialised in a unique gear). It might be of interest to calibrate the opportunism level at the fleet level or to resort to empirical behavior models (such as Random Utility Models, Vermard *et al.*, 2008) in order to better reflect the actual abilities of fleets to copy with unfavorable conditions.

Similarly, the gravity model used here has simple assumptions regarding effort distribution, and particularly the influence of regulatory constrains is not accounted for explicitly but only through the decrease of métier attractiveness. While in a context of "race for quota", one can realistically assume that increase opportunism would lead to quota reached earlier; in a context of quota allocated to POs and LO, opportunism would likely drive fishers toward more profitable métiers only if they target species that do not represent a risk of choke.

The assumption behind the gravity model used was also that fleets would change the time spent on métiers already practiced but no new métiers could be tested. The assumption is realistic regarding the constraints already expressed by fishers pertaining to the regulation (licenses and quota availability) and to physical limitations (size of the boat). However, it may underestimate the ability of some owners to develop new activities, as demonstrates the recent construction of new boats dedicated to Danish seine. This example evidences the difficulty for modeling studies to catch up with fishers' reactivity to management constraints.

Finally, an alternative behavior model for the trawler fleet was built within the DiscardLess project (Bourdaud, 2018). It optimizes fishing effort distribution in space and time during the year as to maximize profit while avoiding any quota overage. Unlike ISIS-Fish, it assumes an early planning of the annual activity at the beginning of the year, with possible resting periods to avoid early quota exhaustions. On the other hand, this model does not allow fishers to adapt to unpredicted environmental or economic conditions in course of the year. Discussions with fishers' representatives suggested that the truth be in-between both models, which offers interesting leads for further development of realistic behavior models.

The current parameterization assumes a global quota for French fleets when it is in fact distributed among fisher organizations. The choke effect might consequently be less important as it may concern only a portion of the fleet. The relationships with POs consolidated during the project should enable an easier access to this type of information in the future and quota per PO to be implemented in simulations.

Results evidenced the limited risk of choke for the species considered in the study and some opportunities to avoid unwanted catch. However recent concerns emerged regarding other species, which are important by-catch in the trawler fishery such as rays and mackerel. The wide distribution and relatively less informed dynamics of these species make it difficult to envision adding them to the model explicitly. An alternative would rather be to evaluate the impact of various choke dates attributed to these stocks and avoidance strategies on the fisheries dynamics. Similarly, further scenarios including fuel price increase and recruitment failures, or peaks would help evaluate the robustness of fishery's performances to the LO in an uncertain context.

2.4 Basque mixed demersal fishery in Bay of Biscay

2.4.1 Introduction

The Basque trawling fleet operating in the Bay of Biscay is composed of bottom trawlers and their activity can be divided in four métiers. The first métier is the pair bottom trawl (PTB_DEF_>=70) targeting hake (Pair). This métier uses a very high vertical opening bottom trawl to target, mainly, hake. A second métier is the bottom otter trawl targeting demersal species (OTB_DEF_>=70) (Otter). Hake, megrims, and anglerfish are the main target species in this métier. However this is a very mixed métier including many other species (pout, dogfish…). A third métier, only operates in the winter season of the year and is the Bottom otter trawl targeting mixed cephalopod and demersal species (OTB_MCF_>=70). Squids, cuttlefish, and mullets are the main target species in this métier although many other species (pout, seabass, hake…) are also harvested. Finally, there is a bottom otter trawl métier targeting a mix of demersal pelagic species (OTB_MPD_>=70), it also operates in the winter season. Apart from hake, this métier also targets mackerel and horse mackerel. These last two métiers have not been simulated independently (seasonal activity) but incorporated in the main Otter metier described above.

This document aims to provide some insights on the likely effect of the landing obligation (LO). As part of the Discardless deliverable D2.3, it mixes information from several WPs, including WP2, WP3, WP4, and WP5, given that one of the aims of the model work in WP2 has been to integrate information and findings from WPs3-7 in the model work, to the extend possible. It includes the results of bio-economic simulations of different scenarios of two particular fleets, in a very simple framework. As such, no equilibrium is identified, neither partial nor stategic (competition among the fleets)., The simulations convert a mix of harvest control rules (HCR) and implementation of that HCRs (LO and exemptions and flexibilities to this LO) into diferent financial indicators for the fleets in question. Adittionally, for the case of Pair trawlers, a change in the Minimum Mesh size is simulated (from 100mm to 120mm), to give answer to a request of the industry (Prellezo et al. 2017). Results, of these simlations (under a different scope) have allready been discussed in published papers such Prellezo et al (2017) and Prellezo et al (2016).

2.4.2 Analysed scenarios

Table 3.5.1 presents the scenarios analysed for the trawlers (Otter and Pair) in the Bay of Biscay case study of Discardless. Only one scenario, the *Base* scenario, allows discards, i.e. projects how the fishery would have evolved without the LO. This Base scenario has been simulated for the two métiers independently, given that their catch profile is quite different[10].

The remaining scenarios all assume that the LO has been implemented.

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[10] We called it métiers, although they can be considered fleets. Essentially, one pair trawler could without any change (but change in fishing net) operate as otter trawler, and the other way around. In the past the two metiers used to shift from one to the other within a year. However, in the last years (from 2012) this has not occurred. The simulation has considered these two metiers as two different fleets, although the term metier is retained, because the data collection keeps this structure.

Table 2.4.1. Scenarios analysed for the Basque trawler in the Bay of Biscay case study.

Scenario	Name	Description
Base (Otter)	Business as usual	LO not implemented, i.e. discards allowed.
Sc-1 (Otter)	LO, no exemptions.	Full implementation of the LO from 2018 to 2025 without any exemption or flexibility
Sc-2 (Otter)	LO, *de minimis* exemption.	As Sc-1 but with a 5% *de minimis* implemented, i.e. fishermen are allowed to discard undersized fish of species that constitute less than 5% of their total catch.
Sc-3 (Otter)	LO, inter-species year-to-year flexibility.	As Sc-1, the quota in year t of a given species can be increased up to a 10% with the obligation to reduce the catches produced in t in the year t+1. However, in contrast Sc2, this extra quota can be landed and sold.
Sc-4 (Otter)	LO, de minimis +inter-species flexibility	Sc 2 and Sc3 combined.
Base (Pair)	Business as usual	LO not implemented, i.e. discards allowed.
Sc-5 (Pair)	LO, No exmptions. Current MMS.	LO is applied to a fleet (pair trawlers targeting hake). They use a Minimum Mesh size (MMS) of 100mm
Sc-6 (Pair)	LO. No exmptions. Increase on MMS.	As Sc-5, but with a change in the MMS, from 100mm to 120mm.

Sc-1 is the full implementation of the LO all else equal, i.e. how the fishery, as it operates before the LO, will evolve given the LO. In Sc-2 it is assumed that a *de minimis* exemption is implemented. In Sc-3 it is investigated the of aplying the inter-species year-to-year flexibility. In Sc-4 it is defined considering the *de minimis* exemption and the year-to-year flexibility simultaneously, on top of the baseline scenario. The exemptions and flexibilities are assumed to be the same for all the fleets of the fishery.

Sc5 and Sc 6 represent the analysis of the pair trawler metier (PTB_DEF_>=70). This metier conducts an almost single species fishery targeting hake. Therefore, these two scenarios were selected to analyse changes in selectivity coming from the use of a higher Minimum Mesh Size (MMS), from the current 100mm MMS to 120mm (in accordance with the discussions and analyses presented in WP3), when catching hake.

2.4.3 The FLBEIA model

Simulations have been performed using FLBEIA (Garcia et al., 2017). This is a simulation bio-economic model coupled in and providing feedback between all its dimensions (economic, biologic and social). It has been developed in R (R-Core, 2014) using FLR libraries (Kell et al., 2007). The model follows the Management Strategy Evaluation approach (MSE), which is widely used in fisheries management to analyse, by means of simulations, the performance of management strategies against predefined management objectives, before they are put in place (Punt et al., 2014). The approach of the simulation consists of projections over a given time period of the performance of the fleets that exploit the stocks under different management schemes described above.

2.4.3.1 Population dynamics

Twelve stocks have been introduced in the biological operating model (Table 2): Megrim (*L. whiffiagonis*), Hake (*Merluccius merluccius*), Black anglerfish (*Lophius budegassa*), White anglerfish (*Lophius piscatorius*), Western Horse mackerel (*Trachurus trachurus*), Mackerel (*Scomber scombrus*) Blue whiting (*Micromesistius poutassou*), Rays (*Leucoraja naevus*), Inshore squids (*Loliginidae*), Seabass (*Dicentrarchus labrax*), Cuttlefishes and bobtail squids (*Sepiidae, Sepiolidae*) and Red mullet (*Mullus surmuletus*). These stocks cover the 81% of the total catches and more than the 88% of the total income of the Basque fleet.

Hake has been simulated using an age structured dynamic stock projection model and the data necessary to condition this model has been taken from ICES assessment working group reports (ICES, 2014a). The stock recruitment relationship (S-R) used is a Bayesian segmented regression (Butterworth and Bergh, 1993; Barrowman and Myers, 2000) which is consistent with the methodology used by ICES on estimating the reference points of this stock (ICES, 2014a). The population has been projected combining this S-R relationship with an exponential survival equation (Quinn and Deriso, 1989). The reference point used is the MSY fishing mortality (F_{MSY}). The value for hake is 0.27 and has been calculated by ICES (ICES, 2014a). The TAC advice is generated using the Harvest Control Rule (HCR) provided by ICES in the framework of the Maximum Sustainable Yield (MSY) (ICES, 2012). This HCR implies that F_{MSY} for hake is advised unless the biomass falls below a trigger biomass (46200 tonnes, cf. ICES, 2014a). If this happens a linear reduction of this biomass is advised to recover the biomass. There is also a third reference point, the limit biomass (33000 tonnes, cf. ICES, 2014a). If the biomass falls below this last limit, the F advised is zero (TAC=0).

Megrim has likewise been simulated using an age structured dynamic stock projection model. The conditioning has been based on the stock assessment model used by ICES to give advice. Currently, this is used by ICES only as trends (ICES, 2014a). The S-R relationship used is a deterministic segmented regression. The population has been projected combined this S-R relationship with an exponential survival equation. Megrim does not have a defined FMSY, however, TAC advice is provided using the ICES annex IV decision rule (ICES, 2012). The TAC advice is obtained using a biomass index representing the previous 5 years before the advice group takes place. If the index of the last two years is 20% higher than the index of the first three years (of this 5 year period) the TAC advised is increased in a 15%. If the index of the first three years is a 20% higher than the index of the last two years the TAC advised is reduced in a 15%. In any other case in between these two cases, TAC is not changed[11].

Western horse mackerel, blue whiting and mackerel are widely distributed stocks exploited by several fleets apart from those considered here. Although the catch of these stocks is important for the Basque fleet, the amount of catch harvested by it is small in comparison with the international catch of these stocks. Hence, the catch of the fleets considered in the present context is supposed to have little impact on the dynamics of these species. Conditioning has been done using data from working group reports (ICES, 2014b). However, as it is practically impossible to include in the model all the fleets that catch these stocks, in the projection part of the simulation it has been assumed that the biomass of these stocks stays constant and equal to the average of the last three-year biomass (2011-2013).

For, rays, inshore squids, seabass, cuttlefishes, bobtail squids and red mullet there is no assessment. However, it has been important to consider that their catches are related to the effort deployed by the fleets. An arbitrary biomass has thus been set with the only condition that this must be consistent with the catches at all the levels of fishing effort observed in the past. Given this biomass, the production function of each fleet for each stock has been estimated accordingly.

Discard data has been obtained from two sources. For hake and megrim, the discard data used in the ICES assessment group has been included in the model, and the fleet share used by it included. However, for the Basque fleet this data has been conditioned by métier using the data obtained from AZTI's discard sampling program. Discards of hake are, between20% and 30% of the TAC and discards of megrim are around 15% of the TAC of megrim. The Basque fleet discards approximately 4.4% of their hake quota. According to Rochet et al. (2014) 99% of these hake discards are of individuals under the MCRS. In terms of megrim, the discards levels in the métiers of the Basque fleet are negligible.

In the simulated period discards of these stocks have been modelled calculating a catch retention ogive. It is done dividing landings by age with catches by age over the historical period (years 2011-2013). When the LO is not active discards are the sum of the catches under the MLS or the minimum conservation reference size (MCRS) and those coming from the over-quota (catches by stock beyond the quota share of each fleet). When LO is in place catches under MCRS count against the quota and it is assumed that the income coming from them is zero. They are considered as extracted from the natural system with a zero-survival rate. Finally, when LO is in place there are no over-quota discards unless exemptions (*de minimis*) are considered.

12 stocks are not enough to capture the multi-species characteristic of the fishery studied, given than more than 30 species are landed and sold. Nevertheless, and in terms of conditioning the model, it is very difficult to incorporate all the stocks explicitly. To overcome this limitation an "others" (OTH) stock which accounts for all the catches of the species not explicitly considered, but that are economically relevant has been created. There are as many *other* stocks as metiers.

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[11] It should be noted that from 2017 onwards, megrim has an analytical assessment an FMSY reference point. However, at the time of doing this simulation this was not in place.

No stock dynamics are considered, although, catches of these *other* stocks are assumed proportional to the effort deployed by each metier assuming an arbitrary "big" added biomass.

2.4.3.2 Uncertainty

Stochasticity in the model is introduced using Monte Carlo simulation and has been incorporated only in the biological side (in the S-R relationship). For hake and megrim, a lognormal multiplicative error around the S-R curve (with a variation coefficient equal to the one observed in the historical period) has been used. 250 iterations have been run.

For the case of hake there is another source of uncertainty derived from the Bayesian stock recruitment model fit. At each iteration of the simulation, parameters are drawn from the joint posterior distribution of the Bayesian model fit.

No further uncertainty is considered because there is not matching data available to condition this uncertainty.

2.4.3.3 Fishing Effort

The catch and effort relationship was based on a Schaefer production model (Schaefer 1954) at the age level. In the simulation process it was also modelled how much effort is exerted. This is an extra limitation of the conditioning (not of the model) because elasticity parameters equal to 1 for biomass and effort are considered. This affects the necessary effort required to catch the quota assigned to each fleet-stock. The reason for not using other estimated catch-effort elasticity is that it has been impossible to obtain robust estimates of these elasticities at age level, for each stock.

The approach taken for effort intensity was based on the Fcube method (Ulrich et al., 2011). The effort corresponding to the TAC-share of each stock caught by the fleet was calculated. It was further assumed that the effort share along metiers was fixed and that the selection of the effort level is done in each time-step. Essentially, we assumed that there are not alternative métiers. This is what has been observed in the past, but it must be noted that it is not necessarily what may happen under the LO.

2.4.3.4 Vessel storage requirements

The storage requirements by trip were calculated for boxes of 12 kg. If the maximum number of boxes that can be stored in a fishing unit is higher than the needs, the additional costs will be zero. If not, the additional trips necessary to land the fish must be evaluated at a variable cost (changing with the effort, if more trips can be made to catch the same amount) or at the market price if the catch is smaller (additional trips cannot be made due to a physical limit).

Our analysis suggest that storage requirements are not a limitation for the fleets analysed, so there are not constraints on this side (cf. the discussions of the outcomes from in WP5). For otter trawlers, the limits are faced on effort (they will have to stop fishing before storage limits are reached, due to quota constraints).

For pair trawlers, the necessary effort to catch its share of hake (i.e. the quota) was not constrained by the capacity. Because of the obligation to retain all the catches, extra storage was required (10% increase in the number of boxes). During an average trip, these fishing units catch approximately 30 t of fish (2500 boxes), with a maximum of 59 t (4900 boxes). The refrigeration capacity of one vessel is around 50 t (4000 boxes); the fishing unit has a refrigeration capacity of 100 t. This shows that the refrigeration storage capacity (meeting the safety requirements) does not limit the fishing effort within one trip.

However, this does not imply that there might not be additional landing costs incurred by buying the boxes necessary to store the extra fish or the cost of ice to keep the catch fresh, although they have not been considered in the simulation.

2.4.3.5 Capital: Number of vessels

The investment or disinvestment in new vessels (capital changes) have also been simulated following the model described in Salz et al. (2011). This model relates the investment and disinvestment in new vessels with the ratio between revenue and break-even revenue, that is, the amount of revenue needed to cover both fixed and variable costs. The annual investment for each fleet is determined by the possible maximum investment (the maximum amount available for investment) multiplied by the profit share (ps in Eq. 1), representing the amount that will be used for investment; however, investment in new vessels will only occur if the operational days of existing vessels are equal to maximum days. If they aren't, the algorithm increases the effort of the current fleet. If they are equal to the maximum days, the investment decision follows the rule below:

$$
If \begin{cases}
\dfrac{REV-BER}{REV} < 0 \;\; and \;\; ps\left|\dfrac{REV-BER}{REV}\right| < 0.2 \;\; Investment = ps \times \dfrac{REV-BER}{REV} \\
\dfrac{REV-BER}{REV} < 0 \;\; and \;\; ps\left|\dfrac{REV-BER}{REV}\right| > 0.2 \;\; Investment = -0.2 * Fleet_{t-1} \\
\dfrac{REV-BER}{REV} > 0 \;\; and \;\; ps\left|\dfrac{REV-BER}{REV}\right| < 0.1 \;\; Investment = ps \times \dfrac{REV-BER}{REV} \\
\dfrac{REV-BER}{REV} > 0 \;\; and \;\; ps\left|\dfrac{REV-BER}{REV}\right| > 0.1 \;\; Investment = 0.1 * Fleet_{t-1}
\end{cases} \tag{2.4.1}
$$

In equation (2.4.1) REV stands for the revenues obtained by the fleet and BER stands for the breakeven revenue (the level where the fleet expects to generate neither profits nor losses from the total number of landings). Profit-share (ps) has been set at 0.3 and comes from conversations with the vessel owners in where it has been stated how approximately a 30% of the profits are re-invested in the fishery. However, this value can be quite variable and in reality, depends on external (e.g. overall economy situation) and/or particular (e.g. expected future revenues, expected retirement date etc.) factors. 0.1 stands for the limit on the increase of the fleet relative to the previous year. The reason for that limit is that the observed increase in the number of vessels of this fleet from year to year has never been beyond a 10% (Prellezo, 2010). The increase in number of vessels for a given segment is then obtained dividing the final investment in new vessels by the maximum number of days that a vessel in the segment operates in one year. Furthermore, if in the projection the number of vessels does not increase, it implies that this limit is not active and that is not affecting the results. Finally, 0.2 stands for the limit on the decrease of the fleet relative to the previous year. The number of 0.2 is again based on the historical observations of the variation number of vessels of this fleet from one year to other. The fleet has never been reduced in more than a 20% per year in terms of number of vessels (Prellezo, 2010).

2.4.3.6 Prices of fish

Prices of fish have been assumed to be constant (Table 2.4.2). For the stocks for which their dynamics have been explicitly modelled, prices by age group are used. For the other (OTH) groups, average prices by metier have been calculated.

Table 2.4.2. Stocks considered and first sale prices

Code	Common name	Scientific name	Stock	Age	Average Price
ANK	Black anglerfish	*Lophius budegassa*	6, 7, 8abd	all	5.53€/kg
HKE	Hake	*Merluccius merluccius*	6, 7, 8abd	<3	2.27€/kg
HKE	Hake	*Merluccius merluccius*	6, 7, 8abd	3	2.16€/kg
HKE	Hake	*Merluccius merluccius*	6, 7, 8abd	4	2.07€/kg
HKE	Hake	*Merluccius merluccius*	6, 7, 8abd	>4	2.89€/kg
MEG	Megrim	*L. whiffiagonis*	6, 7, 8abd	<7	4.02€/kg
MEG	Megrim	*L. whiffiagonis*	6, 7, 8abd	7	4.11€/kg
MEG	Megrim	*L. whiffiagonis*	6, 7, 8abd	>7	5.14€/kg
MON	White anglerfish	*Lophius piscatorius*	6, 7, 8abd	all	4.38€/kg
HOM	Horse mackerel	*Trachurus trachurus*	Widely dist.	all	0.84€/kg
MAC	Mackerel	*Scomber scombrus*	Widely dist.	all	1.68€/kg
WHB	Blue Whiting	*Micromesi. poutassou*	Widely dist.	all	1.19€/kg
MUR	Red Mullet	*Mullus surmuletus*	-	all	3.87€/kg
SQZ	Squids	*Loliginidae*	-	all	5.71€/kg
CTL	Cuttlefish	*Sepiidae*	-	all	3.29€/kg
SKA	Skates	*Raja spp*	-	all	3.83€/kg
BSS	Bass	*Dicentrarchus labrax*	-	all	7.14€/kg
		Metiers			
OTH	Others	OTB_DEF_>70	-	all	1.16€/kg
OTH	Others	OTB_MPD_>70	-	all	0.99€/kg
OTH	Others	OTB_MCF_>70	-	all	1.16€/kg
OTH	Others	PTB_DEF_>70	-	all	1.96€/kg

An extra income from selling the catch under the MCRS. A commercial fishmeal plant was consulted and cited the average price between 50 and 120 €/t, depending on the fish quality (freshness and oil percentage of the raw material). At this price level, approximately 10% of the extra landing costs could be covered (see WP6 for extra information on this). Nevertheless, this possibility has not been considered in the simulations.

2.4.3.7 Selectivity changes

To simulate the selectivity change, it was considered that the catchability (q) can be decomposed in a product of the selectivity of the gear used and a parameter that incorporates the vulnerability, accessibility and availability of the fish, as described in the paper of Arreguín-Sánchez (1996). Mathematically,

$$q_{a,ms}=S_{a,ms}\, r_a\,, \tag{2.4.2}$$

where $S_{a,m,s}$ stands for the selectivity of fish of the age a related to the MMS. ms and r_a stand for the factors affecting catchability and are not related to the MMS. If the catchability and selectivity at the age a for a given MMS are known, r_a can be calculated by applying equation (2.4.2). It can be used afterwards to estimate the hypothetical catchability for the MMS for which age selectivity is known.

Selectivity of the fish length for pair trawlers with 100-mm MMS has been estimated by IEO (2006). In the same study, the selectivity of 80-mm MMS has been also provided. A logistic selection curve (Equation 2.4.3) was fitted to the results for the 100-mm MMS.

$$r(l)=exp(a+bl)/\,(1+ exp(a+bl), \tag{2.4.3}$$

where a and b are the parameters to be estimated. The results of the estimation were a=-6.53 and b=0.2. This curve has the property that the length for 50% retention r(l50) is such that r(l_{50})=0.5 and therefore l_{50} =-a/b.

However, there are no studies providing the length selectivity for hake for pair trawlers with 120-mm MMS. Furthermore, several factors affect the size selection of the towed fishing gears for a given mesh size. These are the spatial and seasonal variations (Ozbilgin and Wardle 2002), gear design, netting materials and twine diameters (Herrmann 2005). There are also vessel-level factors affecting the cod-end selectivity (Tschernij and Holst 1999). This explains the large variability in the results of size selection experiments with towed fishing gears.

To overcome these difficulties, the percentage change in l_{50} between 80 and 100-mm MMS was calculated. It was used as a proxy of the l_{50}, keeping the shape of the curve (parameter b of Eq. 2.4.2) constant.

The results showed that the l_{50} with a MMS of 80 mm was 22.6 cm and with a MMS of 100 mm, 34.6 cm. Following that, it could be inferred that the l_{50} for MMS of 120 mm was 40.8 cm. This last value was within the range of the expected l_{50} (from 22 to 43 cm, according to ICES 2015a).

2.4.4 Data

The model covered the period 2013-2025. In the conditioning period there were 26 vessels in the Basque fleet. The analysis is centred on the Basque fleet. However, this is not the only fleet considered in the simulation. Fleets included are those used in ICES (2014a), that is, those included in the ICES working group assessment of the northern stock of hake and megrim. It includes trawlers, gillnetters and longliners operating in the sub-areas VIII and VII, from UK, Ireland, France and Spain. There is therefore a group of "other fleets" that accounts for the fishing mortality of hake and megrim that is not covered by the fleets included in the model. Thus, all fishing mortality of the hake and megrim stocks has been included in the model, although divided by fleets.

Not all these fleets are equally conditioned. The only fleet for which an analysis by métier, and costs and prices are included is the Basque fleet. The discards and landings data used to condition the Basque fleet has been obtained AZTI's data sources as part of the Data Collection Framework of the EU (EC, 2008). It combines the information from log sheets, landing declarations, discards sampling trips and sales notes. The time series used goes from the year 2009 to the year 2013. Basque fleet has a quota share of 7% for hake, 12% for megrim, 12% for white anglerfish and 3.5% for black anglerfish.

Costs of fishing of the Basque fleet has been obtained from the Annual Economic Report of the EU fishing fleet (STECF, 2014). To adapt these values to the specific conditioning of the case study, the cost average values have been weighted by the proportion of vessels that each segment comprises, and then converted into weighted averages for the fleet (Table 2.4.3). Three types of cost dynamics have been considered in the study. Variable costs and fuel costs change with the fishing effort, crew costs change with the income obtained from the landings and, finally, capital, depreciation and fixed costs change with the number of vessels. The average unit value of these costs (e.g., fuel cost per fishing day or fixed costs per vessel) is kept constant in all the years of the simulation.

Table 2.4.3. Costs data of the fleet considered in the simulation

Variable	**Basque trawlers**	**Units**
Fuel Cost	1.240	€/days
Crew Cost	33%	% from the fishing income
Variable Cost	875	1000€/days
Fixed Cost	15.449	€/vessel/year
Capital Cost	64.438	€/vessel/year
Depreciation	20.952	€/vessel/year
Max days	150	days
FTE (direct)	11	FTE per vessel

Source: STECF 2014. Note that given that these fleets also operate in the North Western Waters (ICES areas 6 and 7), fixed costs, capital costs, depreciation and max days have been weighted by the fishing days that these fleets exerted in the 8abd. This cost structures is shared among pair and otter trawlers.

2.4.5 Results

Results from the comparison of the different scenarios are presented in Table 2.4.4.

Table 2.4.4. Comparison of results, from the landings, discards, fishing effort point of view (sum over the simulated period 2016-2025). Net present value of the profit per vessel and gross value added over the same period using a discount rate of 3.5%. '%' displays the percentage change relative to the base scenario.

	Landings		**Discards**		**Effort**		**Profit per vessel (NPV)**		**GVA (NPV)**	
	1000 tonnes	%	1000 tonnes	%	1000 DAS	%	1000 Euros	%	1000 Euros	%
Base (Otter)	61,06	-	11,33	-	25,52	-	4.336	-	178.774	-
Sc1	62,85	3%	0,00	-100%	25,93	2%	4.424	2%	182.422	2%
Sc2	62,77	3%	2,87	-75%	26,97	6%	4.190	-3%	172.694	-3%
Sc3	61,57	1%	0,00	-100%	26,33	3%	4.391	1%	181.246	1%
Sc4	62,12	2%	2,92	-74%	27,37	7%	4.181	-4%	171.977	-4%
Base (Pair)	50,23	-	1,66	-	13,32	-	7.639	-	96.202	-
Sc5	55,94	11%	0,00	-100%	14,38	8%	8.493	11%	106.517	11%
Sc6	56,71	13%	0,00	-100%	15,08	13%	8.501	11%	108.137	12%

Form the biological side, everything is driven by the HCRs for all stocks. These force catches of all stocks to achieve the F_{MSY} by year 2020, so at the end of the simulation the F by stock should be around the value calculated for this F_{MSY}. There are some deviations to this rule when the year transfer is simulated (Sc3); in this case, given that the assessment process does not introduce this flexibility, Final F can be higher that the F target advised. In fact, in our simulations and for hake, in the year 2025 the final F will be 0.29, above the F_{MSY} of hake (0.27). The consequences of this flexibility on reaching the explicit objective are discussed in Prellezo et al (2017). On the contrary when the LO is introduced without any exemption or flexibility, final F will be below FMSY, (0.26 for hake in the simulation performed). This is due to the choke effects.

In Table 2.4.4 eight different scenarios are presented. The first five represent the simulations performed for the otter fleet. Base (*otter*) is the reference (no LO) and as it can be seen the alternatives (all under LO) perform higher landings and lower discards. To do so fishing effort has to be increased, which implies that scenarios with flexibilities and exemptions are not necessarily better off.

To understand why the results are like that we must describe the redistributive effects of the LO:

The first effect is the direct LO effect. Discards of megrim by the Basque fleet are small. However, the overall discards of this stock are positive, given that this stock is discarded by other Spanish fleets and UK fleets that operate in ICES sub-area 7 but fish the same stock. When the LO is implemented, those fleets with positive discards have to land all the megrim caught, and this catch count against the quota. The overall catches of megrim are lower under full LO implementation (Sc1) than in the baseline. And this happens until year 2020. It has a positive impact on the biomass and hence on the TAC advised which is used by the Basque fleet to catch more. If Sc1 is better off than the no LO scenario, any exemption or flexibility is worse for the same fleet (Sc2 – Sc4), simply because this redistributive effect will be lower.

The second effect is the choke effect. Some fleets will have a new choke species derived from the LO. In this case, hake act as the major choke species of many fleets. It reduces the effort of these fleets and makes these fleets incapable of fishing their quota shares of non-choke species. The overall effect is that fishing mortality of megrim will be reduced, and biomass will grow. The redistributive effect has the same effect as the previous one but in this case the source is the effort constraint.

There is also a third effect that counts in favor of Basque trawlers economic performance. Even if the harvest control rule to advise next year's F is the same with or without LO, the TAC under LO is given in terms of catch in contrast with what was done without LO in where it was given in terms of landings. This is called the uplift redistributive effect. This effect is not neutral to the fleets given that they have different characteristics, and in particular different discard levels. In a situation of non-equal discards levels of a given stock, those fleets for which the ratio of their discards to the total discards of the stock is lower than their quota share of this stock, will be relatively benefited from the uplift. For example, for the case of hake the uplift size is of approximately 14000 tons of hake, close to the approximately 14800 tons of hake discards accounted in the simulation (these two numbers cannot be the same because the system is not linear). A fleet with a relative gain is the Basque fleet with a discard level of hake of 4.4% and a quota share of 6.7%. Megrim will cause a similar uplift effect that will be positive for the Basque fleet given that the quota share of megrim is higher than its discard rate.

Sc5 and Sc6 are compared again to the Base (no LO) for two different MMS (100mm and 120mmm) for the pair trawlers. These results are also based on the redistribution of the uplift. It should be noted that this fleet discarded hake under the MCRS (27cm), and that under LO there is an uplift of the quota. Again, Basque trawlers are benefitted from that.

Catches of hake are the same for the two MMSs. The landings of hake destined for human consumption are higher for 120 than for 100-mm MMS. Therefore, the gross revenues will also be higher. However, this result is obtained at the cost of an increased fishing effort, which implies an increase in variable costs. This effort increases, because to catch the same quantity with a lower retention level of the 120 MMS, more effort is required. To determine which of these two factors has a stronger effect, two different economic indicators were used: Gross Value Added (GVA) and gross profit. Simulations showed that GVA was larger for 120-mm MMS than for 100-mm MMS. This causes of an increase in the gross revenue, which is higher for 120-mm MMS net use. However, variable costs of the effort required to obtain these landings (crew costs, fuel costs and other variables costs) were also higher for the larger MMS. The overall result shows that the increase in revenues is sufficient to compensate for the extra costs, generating an overall increase in the GVA of 1.5% per year. The crew compensation will also increase as they receive a percentage of the gross revenue. Overall, the use of 120-mm MMS resulted in the crew share increase of 2% per year.

The other component of GVA is the capital compensation; it can be illustrated using profit as an indicator. Profit does not change when the 120-mm MMS is used. This is because a third of the extra gross revenue goes, through the crew share, to the crew itself. Thus, from the point of view of the capital owner, it is not worth increasing the MMS, or at least, there are no financial incentives for this change.

From the capital side (number of vessels), there are not difference among scenarios in terms of the evolution of the number of vessels.

2.4.6 Discussion/conclusion

LO will create a strategic game in which less discards and better selectivity are awarded. LO will not affect equally all the fleets involved and, hence, there will be, in relative terms, winners and losers, at least in economic terms. If exemptions are emended (in this case all the fleets have exactly the same amount and implemented in the same year), the winning-losing effects will be alleviated. If they are high enough, the fishery will back to the original situation (no LO). The higher the percentage of the exemption or flexibility (*de minimis* or both exemptions together) the weaker will be the redistributive effects and the final result will be closer to the no LO situation.

For the case of pair trawlers, the simulation performed showed no private incentives for increasing the MMS. However, this conclusion cannot be necessarily extrapolated to other areas or to other fleets. Other case-specific studies must be conducted to reach a detailed understanding of the subject. The lack of private incentives should not discourage the society from supporting the increase in the selective fishing activities. From the social perspective, there is room for incentives that increase the selectivity of the gear, at least for the fleet analysed in the present context. These incentives can be created by penalising the lower selectivity of the 100 mm MMS or rewarding (for example, with a higher quota or effort possibilities) the use of a more selective gear.

In general, the LO seems to provide better results than the previous situation of no LO. However, this is just partly an artefact of the simulation performed. It is true that the distributive effects of the uplift could benefit some fleets, and this work highlights this issue. Additionally, the lower overall catches (from other fleets fishing the same stocks) can benefit the Basque fleet. However, it has be mentioned that choke effect is not necessarily having an effect on an aggregated level but rather on an individual vessel level. This implies that this effect is clearly underestimated in the simulations presented here. Furthermore, the reaction of other fleets can be different from the one simulated here (in fact no reaction has been simulated) which can change the results significantly.

The simulations performed here do as such not give a final answer of what is going to happen but provides some insights on what are the main elements on what we should focus on for further evaluation of what the economic consequences will be for the Bay of Biscay fishing fleets given the implementation of the LO.

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2.5 Icelandic mixed demersal fishery

2.5.1 Introduction

The Icelandic mixed demersal fishery represents a key sector in the Icelandic economy and is as well extremely important for regional development in the country. The demersal fishery accounted for 38% of the landed volume and 76% of the landing value in 2017; and products produced from demersal catches represented 69% of the total seafood export value. The mixed demersal fleet is extremely variable, consisting of approximately 1,300 vessels that range from small dinghies to factory vessels. The fleet operates within the two sub-sections of the Individual Transferable Quota (ITQ) system, where 12-15% of the demersal quota is allocated especially to coastal vessels using hooks as fishing gear (longlining and jigging); and the rest is allocated to a full ITQ system where all types of fishing gear are permitted. Coastal vessels can choose to operate in either one or the other system, but not in both at the same time. In 2017 the mainstay of the demersal catches was caught in bottom trawls (58%) and longline (23%); with the rest caught in Danish seine (7%), gillnets (6%) and jigging (4%).

A discard ban was first introduced in the Icelandic demersal fishery in 1977, when discarding of six of the most important species was forbidden. This ban was then gradually expanded and today the ban covers all catches within the Icelandic EEZ. During the four decades that the discard ban has been in effort the authorities have tried to implement various mitigating measures in order to create incentives for compliance. The economic effects of some of these measures are estimated using the model presented in this Chapter.

2.5.2 Analysed scenarios

The main mitigating measures that have been built into the Icelandic demersal fishery to create incentives for compliance with the discard ban are:

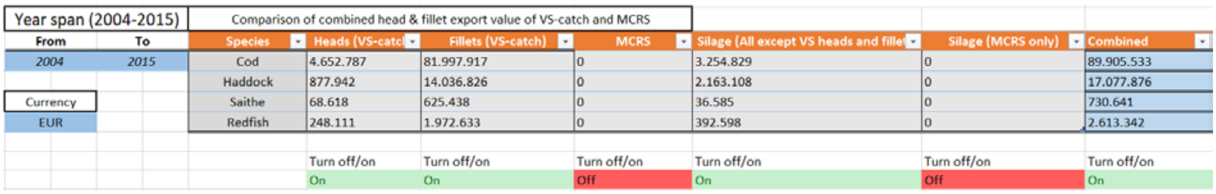
a. The transferability of the ITQ system, which enables fishermen to swap, lease or permanently purchase quotas for whatever species they want. The fishermen can even acquire/swap quotas after the catch has been landed.
b. Quota can be transferred between years, where 15% of each vessel's quota can be transferred to the following year or 5% of the following year can be transferred to current year.
c. Catches under minimum size can be landed, and of these only 50% of the weight will be deducted from the current quota of the vessel in question. There is no restriction on what these catches can be used for.
d. Catches that marginally exceed the quota, usually of choke species, can be landed without being deducted from quota. But the vessel does then only receive 20% of the landing value. The rest goes to a fisheries research fund. Each vessel can use this option for up to 5% of its total catches. These are called VS-catches, as the acronym for the research fund is VS (Verkefnasjóður).

The scenarios analysed with the model are focusing on mitigating measures c and d. Both alternatives are well documented, which gives us the possibility to give reliable estimations on the economic returns of these measures. Estimating the effects of mitigating measures a and b is almost impossible, as there is no data available on what the discard rates would be if these measures were not in place. The species included in the analysis are cod, haddock, saithe and redfish during the period 2004-2015.

MCRS and VS catches may be used in several ways when brought ashore. Most likely uses of VS landings is filleting and exporting fresh, while the heads are dried and also exported. However, other uses, e.g. used for silage, is also possible. For MCRS landings the most likely use is for silage or for export as frozen products. However, when the MCRS and VS-catch is brought to shore, it becomes a part of the total landings (also from other sources) so there is no traceability of these specific landings and therefore it is not possible to specify what precisely they are used for, and as such not possible directly to specify the value they represent compared to the case where they would be discarded. This value must thus be estimated, based on possible usage scenarios, which is done with the applied model presented below.

2.5.3 The model

The model is an Excel model that, as discussed above, enables the user to put a value, depending on usage, on the "unwanted" catches of cod, haddock, saithe and redfish that were landed due to mitigating measures c and b identified in the previous sub-chapter. The model assumes that these catches would have been discarded if these mitigating measures were not in place. The model covers landings made during the period 2004-2015 and the values are given as estimated export value (fob) taking into consideration average utilisation factors and average export value of each product/by-product. The model can give results in different currencies (EUR, GBP, USD, ISK, NOK). The user can choose from different options of possible usage of the various by-products of the species. Currently, the options include firstly to export the heads of cod, haddock and saithe as dried products while the redfish heads are exported as frozen products. This is in fact by far the most common utilisation of cod, haddock and saithe heads; whilst the utilisation of redfish heads is more fragmented. Exports of frozen redfish heads to be used as bait in lobster and crab fisheries is though quite common. Secondly it is assumed that the remaining part of the VS fish (minus the heads) can be used for filleting. These fillets of VS-catch are assumed to be exported fresh in the model. Thirdly, for MCRS landings, the user can choose whether to export these landings as whole or frozen products. Fourthly, there is an option to see what can be gained by using the total MCRS landings in silage production. Figure 2.5.1 displays an example of the user interface of the model.



Year span (2004-2015)

From	To
2004	2015

Currency

EUR

Comparison of combined head & fillet export value of VS-catch and MCRS

Species	Heads (VS-catc	Fillets (VS-catch)	MCRS	Silage (All except VS heads and fille	Silage (MCRS only)	Combined
Cod	4.652.787	81.997.917	0	3.254.829	0	89.905.533
Haddock	877.942	14.036.826	0	2.163.108	0	17.077.876
Saithe	68.618	625.438	0	36.585	0	730.641
Redfish	248.111	1.972.633	0	392.598	0	2.613.342
	Turn off/on	Turn off/on	Turn off/on	Turn off/on	Turn off/on	Turn off/on
	On	On	Off	On	Off	On

Figure 2.5.1: The menu for choosing what to do with VS-catch and fish under MCRS in the Excel model

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The usage of fish products can be turned on or off through a drop-down menu at the bottom like shown in Figure 2.5.1. It is important to realise that both ”MCRS” and ”Silage (MCRS only)” cannot both be turned on at the same time, as the first option requires that all catch under MCRS is to be exported as whole, frozen products while the last one calculates the gains of using everything for silage production.

Besides the interactive sheet in the Excel document, there is a sheet for the calculations, where the data behind the numbers and graphs presenting the results is stored. This will be further discussed in Chapter 2.5.4.

2.5.4 Data

The model covers the period 2004-2015. The data consists of landing data consisting of a) undersized catches landed with 50% discount of quota; and b) catches landed without deducting it from quota using the exemption where 80% of the landing value is allocated to fisheries research fund (so called VS-catches). Data was obtained from Statistics Iceland (Hagstofa) regarding potential prices of exported goods, but the total weight of VS-catch was found at the Directorate of Fisheries. The total landings of both VS-catch and fish under MCRS can be seen in Table 1 and Table 2, respectively.

Table 1: Total landings of VS-catch

	VS-Catch (kg)			
Year	**Cod**	**Haddock**	**Saithe**	**Redfish**
2004	1.567.989	151.220	54.411	22.532
2005	1.816.603	78.097	42.457	6.368
2006	1.482.252	89.845	9.137	5.789
2007	1.633.896	54.301	12.508	4.474
2008	2.782.653	20.005	7.441	58.181
2009	3.877.077	14.456	6.306	177.813
2010	3.394.569	106.039	82.189	170.210
2011	2.078.210	253.831	74.311	164.327
2012	1.640.024	300.790	54.774	120.829
2013	1.351.345	908.443	37.898	125.058
2014	1.180.775	940.856	29.199	78.466
2015	1.046.012	745.720	2.848	64.018

Table 2: Total landings of fish under MCRS

	Below minimum size (kg)			
Year	**Cod**	**Haddock**	**Saithe**	**Redfish**
2004	1.372.610	607.501	16.792	504.547
2005	1.712.838	913.188	2.911	352.861
2006	1.532.091	1.693.116	7.533	334.127
2007	1.147.843	1.841.744	4.602	477.424
2008	1.163.907	1.086.060	3.702	286.108
2009	1.112.646	743.814	11.130	190.534
2010	1.042.827	755.057	26.490	115.808
2011	1.313.349	450.306	16.729	81.097
2012	1.358.041	197.076	34.716	65.737
2013	1.251.648	152.327	2.630	79.337
2014	1.145.077	131.208	3.440	59.714
2015	1.073.159	96.103	20.002	80.000

As observed, the main volumes both in VS-catch and landings of fish under MCRS are from cod, while haddock is also found in abundance for some years. There is a minimal profit gained from saithe, mainly due to the low volumes compared to the other species.

As mentioned at the end of Chapter 2.5.3, the output displayed in the interactive sheet is taken from a secondary sheet, which stores all data and calculations. In this calculations sheet, there are three main categories in which the data can be divided into.

These categories are

a. The total landings of fish as VS-catch and catch under MCRS around Iceland.
b. The export price of the products that can be derived from the four species in question.
c. The ratios in which each fish is divided into when processed (heads, offal, skin/bones, fillets).

As mentioned at the start of this chapter, the total landings of fish as VS-catch and fish under MCRS was obtained from the Directorate of Fisheries in Iceland and the export prices of the various products obtained from the four species analysed was found at Statistics Iceland. To estimate the total export value of fish under MCRS, it was assumed that it was to be exported as whole, frozen fish given that this is the most used method for selling undersized cod from Iceland. For the VS-catch, it was assumed that cod, saithe and haddock were filleted, and the fillets exported fresh on ice, while the heads were dried and exported. Nigeria has long been the main market for dried fish heads and this gave a viable option for where to sell these additional products. Regarding the redfish, it was assumed that the fish was filleted, and the fillets then block frozen, and that the heads were exported as frozen goods.

To be able to estimate the amount of raw material for each application, whether it was the export of heads, fillets, silage or whole fish, the processing ratios had to be defined. The ratios used for cod can be seen in Table 3.

Table 3: The utilization ratios of cod (example), from the Excel model

Cod - utilization ratios		
Reference weight of whole fish (kg)	*Gutting ratio*	*Post-gutting weight*
10	0,85	8,5
Heads ratio	Filleting	Skin, bones and leftovers
0,3	0,46	0,24
Weight of heads	Weight of fillets	Weight of rest
2,55	3,91	2,04

These ratios were also defined for the other species, varying slightly as they differ in their composition. In that regards, the redfish has by far the highest head ratio compared to the whole body, while the highest ratio of fillets can be achieved from haddock. For silage, it was estimated that the total profit for each ton of the product was around 140 Euros, or around 65% of the total price of fishmeal protein. It is essential to note that these numbers are estimates as it is difficult to specify the value of silage on today's market, but they give nevertheless a good indication of what might be expected.

2.5.5 Results

With export values of the products obtained from Statistics Iceland from the year 2004 up until 2015, the total accumulated profit for each product was calculated and, depending on the assumed use, the total sum of expected profits in a given period calculated.

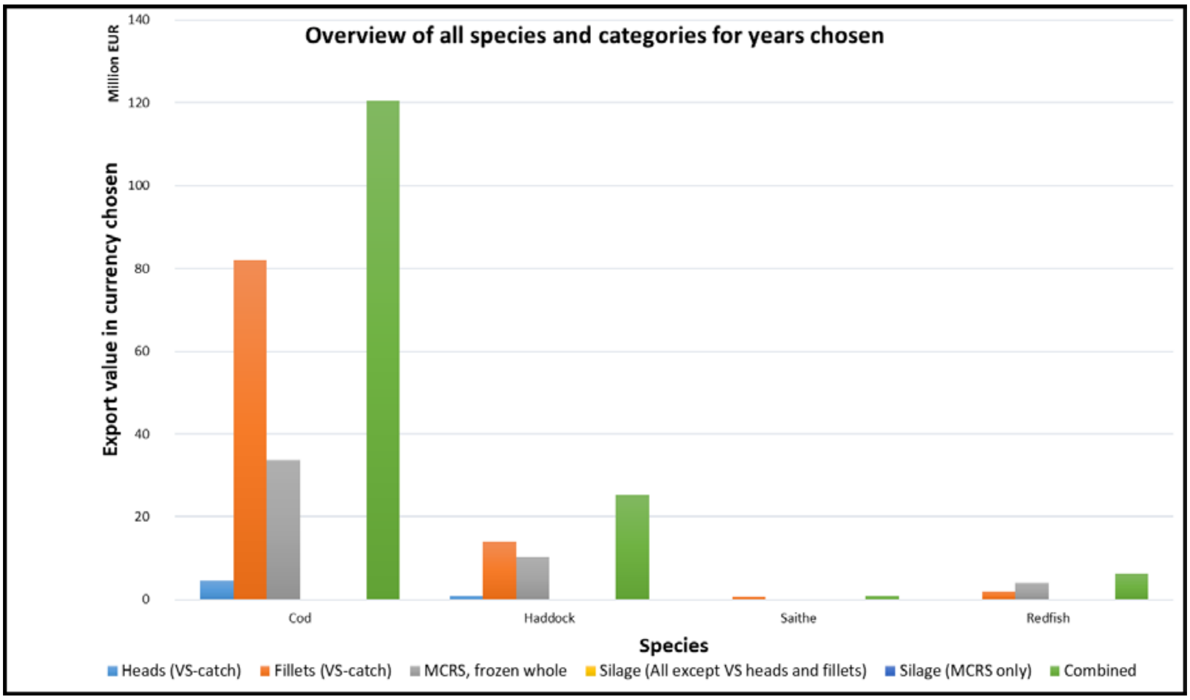

Figure 2.5.2: Comparison of export revenues of fresh, iced fillets of all VS-catch, dried heads and frozen redfish heads along with frozen catch under MCRS for all species, years 2004-2015.

Figure 2.5.2 presents the export values in the case where it is assumed that the VS-landings will be used for both filleting and head exports, while the MCRS landings are exported whole and frozen. It is seen that the revenues generated by selling VS landings vastly surpass those achieved by selling the landings under MCRS.

As previously mentioned, the revenues generated from cod are the highest at approximately 120 million Euros over the span of 2004-2015, while the least amount is achieved from saithe at just over 900 thousand Euros. That is mainly due to very low landing volumes compared to the other species. It is also important to note that this scenario only looks at the three utilization possibilities mentioned above, that is exporting all catch under MCRS as frozen, whole products and processing the VS-catch into fillets and dried heads for export.

In line with the solutions offered for excess material, an option to use all catch under MCRS as well as by-products of the VS-catch for silage production was also set up. This is demonstrated in Figure 2.5.3 with the yellow bars showing the export values of the silage. Again, the value generated from cod is the highest due to the largest landing volumes at roughly 3.2 million Euros. With the total value of the silage relatively low, the revenues generated by this method are not high. This might however, in some instances, be the only viable option of how to deal with the by-products and leftovers from production of main species and catch under MCRS. To put the price difference between silage and the export of frozen, whole catch under MCRS into perspective, the Excel model was used to display the export values of whole, frozen catch under MCRS and compare it to the value generated by turning that same catch into silage. This is displayed in Figure 2.5.4.

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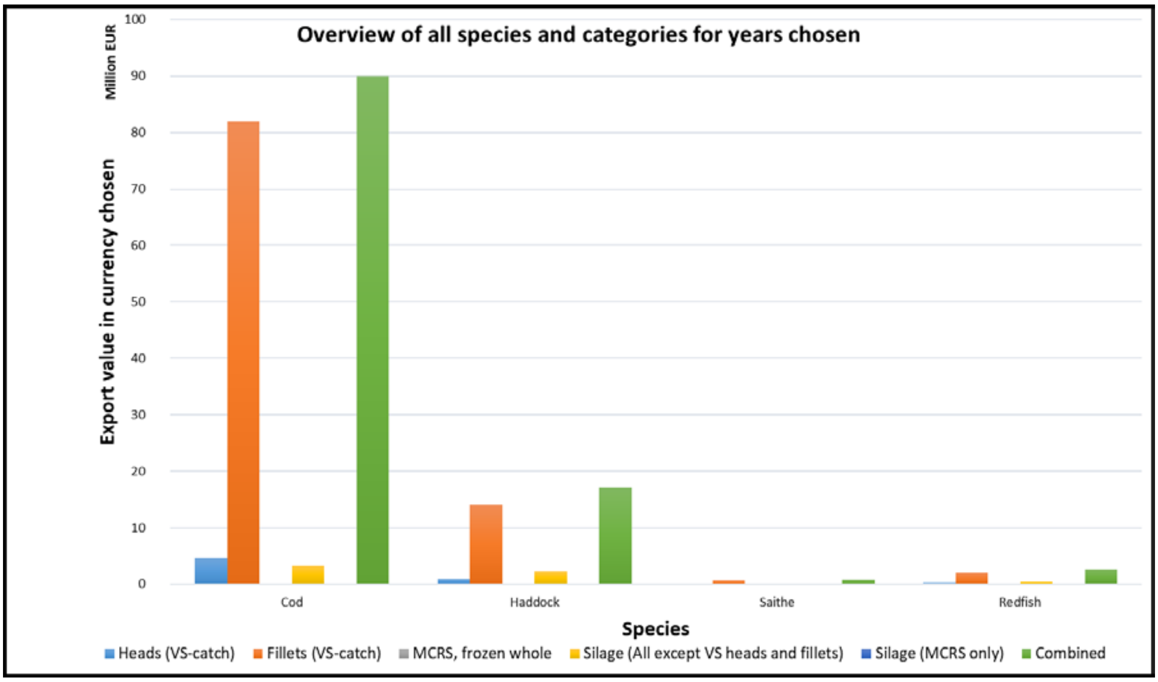

Figure 2.5.3: Comparison of export revenues of fillets and heads with silage production for all other catch and materials, years 2004-2015.

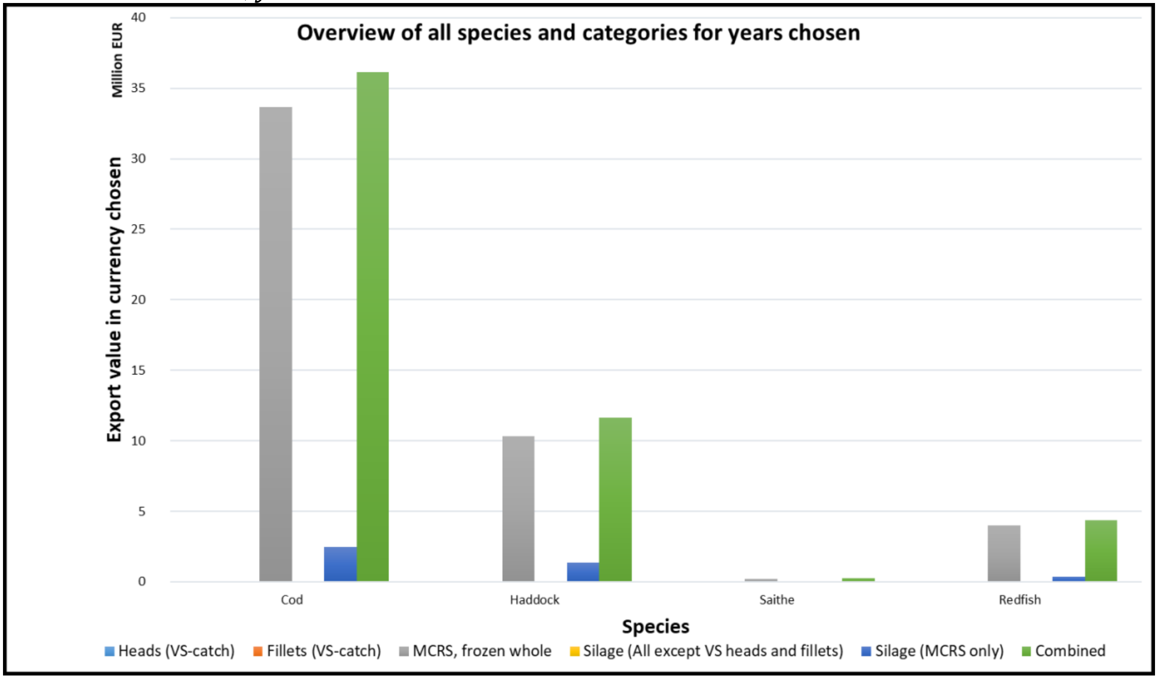

Figure 2.5.4: Comparison between the exported values of frozen, whole catch under MCRS and silage production of the same catch, years 2004-2015.

The figures clearly show that the silage does not generate nearly the same level of income as other methods of processing currently applied in the Icelandic fishery. However, as mentioned before, it should be noted that in some cases it is the only applicable option and therefore will be preferable over discarding the catch.

2.5.6 Conclusions

A lot is currently being gained from utilizing the VS-catch and fish under MCRS in Icelandic waters. Estimated revenues generated between the years 2004 and 2015 for all four species in question were in the vicinity of 150 million Euros, when utilizing VS-catch for filleting and export of dried heads and the catch under MCRS as frozen, whole products (which is the most common utilisation method). Production of silage is not a commonly used alternative in Iceland, as other means of utilisation are more profitable. The model does however explore that alternative, in order to link with suggested utilisation methods identified for example in WP5 and WP6 of the DiscardLess project. The model clearly shows that silage production renders much lower values than the other alternatives that are currently being used. The comparison between exporting the MCRS catch frozen and producing silage from it, shows that the expected revenues generated from the latter prospect returned on average only 10% of the export value of the frozen products. However, in some cases, silage production might be the only viable option and, in those instances, depending on the volume of catches, some good amounts of silage might be produced. When done correctly, silage serves as a good precursor to either fish meal or protein and fish oils.

2.6 Spanish mixed demersal fishery in the W. Med

2.6.1 Introduction

The Balearic Islands (Western Mediterranean) constitute the geographical sub-area number five (GSA05) from the General Fisheries Commission for the Mediterranean (http://www.fao.org/gfcm/es/). Several decades ago the Balearic Islands were defined as an individualized fishing area in the western Mediterranean (Massutí, 1991). More recently, a comprehensive comparison including different aspects such as geomorphology, habitats, fisheries and exploitation state of resources and ecosystems between the Balearic Islands and the adjacent coast of the Iberian Peninsula, concluded that the Archipelago should be maintained as an independent unit for assessment and management purposes in the western Mediterranean (Quetglas et al., 2012).

The main commercial fisheries of the Balearic Islands include bottom trawl, small-scale, purse seine and pelagic longline. In 2016, the commercial fleet was constituted by 40 trawlers, 226 small-scale vessels, 7 purse-seiners and 3 long-liners. Landings of the bottom trawl fleet (BTF) have accounted for between 46 and 70% (mean 59%) in terms of biomass and between 60 and 69% (mean 64%) in terms of incomes of the total landings during 2000-2014. The BTF is highly multispecific with more than 100 commercial species. Commercial trawlers use up to four different fishing tactics (Palmer et al., 2009), which are associated with the shallow and deep continental shelf, and the upper and middle continental slope (Ordines et al., 2006; Guijarro and Massuti, 2006). Vessels mainly target striped red mullet (*Mullus surmuletus*) and European hake (*Merluccius merluccius*) on the shallow and deep shelf respectively. However, these two target species are caught along with a large variety of fish and cephalopod species. The Norway lobster (*Nephrops norvegicus*) and the red shrimp (*Aristeus antennatus*) are the main target species on the upper and middle slope respectively. The Norway lobster is caught at the same time as a large number of other fish and crustacean species, but the red shrimp fishery is the only Mediterranean trawl fishery that could be considered monospecific.

The main target stocks of the BTF from the Balearic Islands are overexploited (Quetglas et al., 2017). Among them, hake shows the worst stock status, with the current fishing mortality being more than seven times the biological reference point $F_{0.1}$. Such high overexploitation levels for hake are found all around the Mediterranean (Vasilakopoulos et al., 2014), which demands strong management measures or even a recovery plan in the region (Quetglas et al., 2017). The exploitation pattern of hake in the Mediterranean consists of a high harvest rate of immature recruit and juvenile individuals on the deep shelf and upper slope (Lleonart and Maynou, 2003a). Currently, the species is regulated by a Minimum Landing Size (MLS) of 20 cm total length under Annex III of Regulation (EC) Nº 1967/2006.However, the length at first capture of hake with the legal mesh size

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used by the BTF (40 mm squared cod-end) is of 15.2-15.3 cm (Ordines et al., 2006; Guijarro and Massuti, 2006). More importantly, both the MLS and the length at first capture are well below the size of first maturity (L_{50}): 27 cm for males and 33 for females (Hidalgo et al., 2008). This incongruence between the MLS and the length at first capture results in hake being the most discarded demersal resource of the BTF from the Balearic Islands (Guijarro and Massuti, 2006).

The Mediterranean fisheries are regulated by minimum landing sizes for the main target species, temporal and spatial closures and effort control. The Spanish BTF in national waters is regulated by the Royal Decree 1440/199, which establishes different rules on vessel's characteristics, fishing effort, mesh sizes andspatial measures. In 2010, there was a change in the fishing regulation that aimed at improving the BTF selectivity (Council Regulation Nº1967/2006), which led to a shift in the geometry of the 40 mm mesh from diamond (40D) to squared (40S).At local level, the main technical measures currently applied to the BTF from the Balearic Islands consist of: 1) vessel length must range between 14 and 24 m; 2) the maximum allowed gear power is 500 HP; 3) fishing time at sea is restricted to 12 h per day and 5 days per week; 4) minimum mesh size allowed in the cod-end is 40 mm (squared) or 50 mm (diamond); 5) there are minimum landing sizes for different fish species; and 6) trawling is only permitted at depths higher than 50 m.In addition, the local Order AAA/1504/2014 forbids certain fishing practices, including BTF, in several protected areas from the Balearic Islands.

As mentioned above, the general overexploitation status of hake and high volumes of discards in the Mediterranean, together with its economic importance for the BTF, demands the implementation of technical and economic management measures to improve its harvesting. This can be approached by using bio-economic models, which integrate the analysis of fisheries biology and economics and provide tools for the analysis of fisheries development that allows assessing the impact of different alternative management strategies (Lleonart and Maynou, 2003a; Maynou et al., 2006).

2.6.2 Analysed scenarios

Different scenarios for hake were tested in order to assess the impact of several management strategies based on i) selectivity improvements and ii) the potential effects of the effective implementation of the LO. These scenarios were then compared with the present functioning of the fishery. The following scenarios were tested:

1) *BAU* - Business as usual:
    - Description: It described the present functioning of the fishery.

- Parameter details: the current fishing mortality levels (F) per age class were applied. The rest of the model parameters were set to the present values for the fishery.

2) *FI* - Full Implementation of the LO:

    - Description: Here the theoretical implementation of the LO is modelled. The daily costs are those caused by the fishing activity including fuel consumption, net mending, daily food expenses, etc. A theoretical increase in costs is assumed, accounting for the fact that keeping the undersized fish on the boat can result in an increase in fuel consumption. In addition, more crew members were expected in order to help sorting and storing the undersized fish on board.

    - Parameter details: A 10% increase of daily variable costs and one more crew member per boat were applied.

3) Use of selectivity measures to avoid catches of specific fractions of the population:

    3.1. F_0 - Fishing mortality at age 0.

    - Description: Here an absence of fishing mortality (F) for individuals of hake at age 0 (TL ≤ 18 cm) is assumed. Length at age was obtained from the Von Bertalanffy growth function (Table 2.6.1).

    - Parameter details: $F_0 = 0$ in the vector of F per age class.

Table 2.6.1. Length at age for hake from the Balearic Islands.

TL (cm)	0	1	2	3	4	5	6
Age (yrs)	0.0256	0.0771	0.1292	0.1817	0.2347	0.2882	0.3422
TL (cm)	7	8	9	10	11	12	13
Age (yrs)	0.3967	0.4518	0.5074	0.5636	0.6204	0.6777	0.7356
TL (cm)	14	15	16	17	18	19	20
Age (yrs)	0.7941	0.8533	0.9130	0.9734	1.0345	1.0962	1.1587

3.2. F_{MLS} - Fishing mortality MLS.

- Description: Here an absence of fishing mortality for hake under the MLS (20 cm TL) is assumed.

- Parameter details: $F_0 = 0$ in the vector of F per age class and 10% decrease in F_1 ($F_1 = 1.96$ to $F_1 = 1.77$) for avoidance of catches of individuals with TL < 20 cm.

3.3. F_{IMM} - Fishing mortality of immature individuals

- Description: Here an absence of fishing mortality in immature individuals (<30 cm TL) is assumed, computed as the mean L_{50} for males and females from Hidalgo et al. (2008).
- Parameter details: Modification of the vector of the current age-selectivity parameters to avoid catches of immature individuals (TL<30cm).

2.6.3 The MEFISTO model

The bio-economic analysis of hake caught by the BTF from the Balearic Islandswas done using MEFISTO (Mediterranean Fisheries Simulation Tool; https://mefisto2017.wordpress.com/). MEFISTO is a bio-economic fisheries simulation model based on an age-structured population dynamics that was specifically designed to address management issues under the Mediterranean regulation system (Lleonart et al., 2003b). A bio-economic model is more appropriate than a biological one because Mediterranean fisheries are in some aspects self-managed by fishermen through economic mechanisms (Lleonart et al., 2003b). The MEFISTO model comprises three modules (Fig.2.6.1):

1) Stock module: simulates the dynamics of the fishery target stock. The inputs for this module are the fishing effort and the catchability, whose product is the fishing mortality (F), and the output is the catches. The fish stocks are modelled by an age-structured dynamic model and the population dynamics follows the Beverton and Holt formulation.

2) Market module: converts the catch into landed value by means of a price function. This takes into account the base price of the main species (expressed as the annual average in euros/kg), the size of fish and the amount of fish offered on the market.

3) Fisherman module: simulates the economic behaviour of the fishing firms. The parameters are specific for each fleet. It contains economic parameters that affect fleets in general (e.g. cost of fuel), and technical and economic parameters characteristic of each fleet (e.g. average number of crew members).

   For technical details on these modules see the tool user guide available on the MEFISTO website.

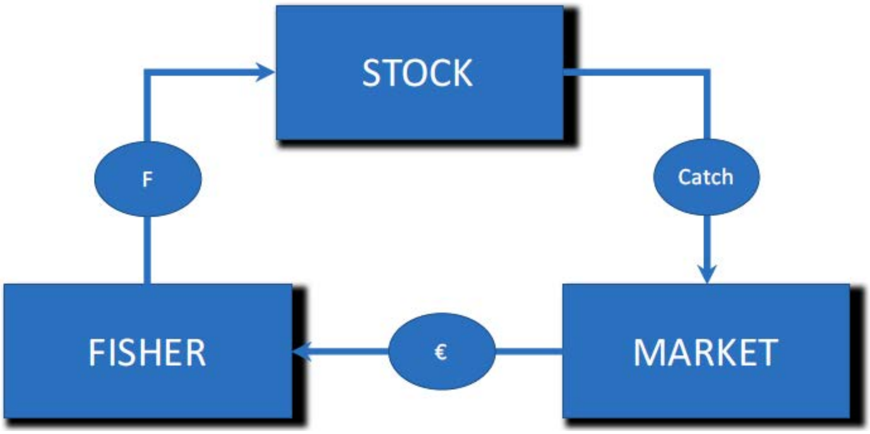

Figure 2.6.1. Conceptual model of MEFISTO (MEFISTO 4.0 Userguide, 2017).

2.6.4 Data

The information used to perform the bio-economic model included the following biological, fleet and economical data:

1. Biological data: included vectors of natural mortality (M), proportion of mature individuals, mean fish weight, initial number of individuals (N_0), fishing mortality (F) and selectivity (expressed as percentage of capture) per age class (Table 2.6.1). In addition, the initial number of recruits and its standard deviation are also required. All these data were available from stock assessments of hake in the Balearic Islands presented at the GFCM (Guijarro et al., 2015).

Table 2.6.1. Biological parameters per age class (0 to 5) used as input data for MEFISTO. M: natural mortality; Maturity expressed as ratio; Weight: mean fish weight; N_0: initial number of individuals (in thousands); F: fishing mortality; S: selectivity (expressed as ratio of capture).

Age class	0	1	2	3	4	5
M	1.24	0.58	0.45	0.40	0.37	0.35
Maturity	0.00	0.15	0.82	0.98	1.00	1.00
Weight	0.028	0.101	0.406	0.943	1.642	2.474
N_0	4365.80	1166.63	118.14	13.37	2.02	0.48
F	0.088	1.965	1.379	1.200	1.308	1.308
S	6.13E-05	0.896	0.999	1.000	1.000	1.000

2. Fleet and economic data:

2.1. time series of fishing effort, expressed as total number of fishing days conducted annually (during the last 10 years) by all vessels (see table below).

Table 2.6.2: Time series of total fishing effort applied by the BTF over the period 2005-2014.

Year 1	2	3	4	5	6	7	8	9	10
7424	6961	6654	6973	6284	6597	6706	6422	6177	5821

2.2. average fish price of the main target species (European hake), expressed in euros/tonne (=4563).

2.3. incomes from landings of secondary species, expressed as the annual revenue from the total catches (euros/year)/annual revenue from the main species (euros/year) (= 19.12).

2.4. trade costs from fishermen's association taxes, local taxes, VAT, etc., expressed as percentage of the total revenues (= 9.8%).

2.5. owner's share, remainder of the revenues divided in parts or shares, one for the owner and another for the crew, expressed in percentage (= 50%).

2.6. number of crew members, expressed as average per vesselfor the fleet (= 4.69).

2.7. subsidies, expressed in percentage (= 3%).

2.8. daily costs caused by the fishing activity (e.g. fuel consumption, net mending, food expenses, etc), excluding labour costs, expressed in euros/vessel (= 778.88).

2.9. capital of the vessel, mean capital of the vessels divided by the mean annual number of fishing days accounting for the annual depreciation rate (= 10%), expressed as euros/(vessel*day) (= 1937.431).

2.10. depreciation rate of the capital, expressed as percentage (= 10%).

2.11. real interest, calculated taking into account the annual nominal interest rate of the country and the inflation rate, expressed as percentage (= 0.0365%).

These data were obtained from different sources including the fish auction wharf of Mallorca, the Fishermen Association of the Balearic Islands and the Annual Economic Report on the EU Fishing Fleet from the Scientific, Technical and Economic Committee for Fisheries (STEFC).

2.6.5 Results

The main results obtained with the different scenarios tested (*FI*, F_0, F_{MLS}, F_{IMM}) compared to the present situation (Business as Usual; *BAU*) are summarized in the following paragraphs (for a summary of the results see table 2.6.3):

- The scenario testing the elimination of the fishing mortality for immature hake (scenario 3.3-F_{IMM}) provided by far the most significant differences with the BAU, considering both the biological (Fig.2.6.2; blue line) and economical (Fig.2.6.3; blue line) indicators: the fishing mortalitydecreased down to 0.4,the Spawning Stock Biomass (SSB) and yields increased to about 450 tons and 300 tons, respectively; the incomes, crew wage and profits also improved a lot with this scenario. The results of the rest of modelled scenarios were very similar and far from the outputs of scenario 3.3-F_{IMM}: the F remained above 1 and the SSB and yield below 100 and 150 tons, respectively.

- The simulation of the effective implementation of the LO (scenario 2-*FI*) provided the worst economic outputs (Fig.2.6.3; pink line), causing a reduction in the crew wage and profits. The biological outputs remained similar to the *BAU*.

- None of the scenarios tested provided differences in the projection of number of recruits since there is a generalized lack of significant relationship in the stock-recruitment function in the Western Mediterranean fisheries.

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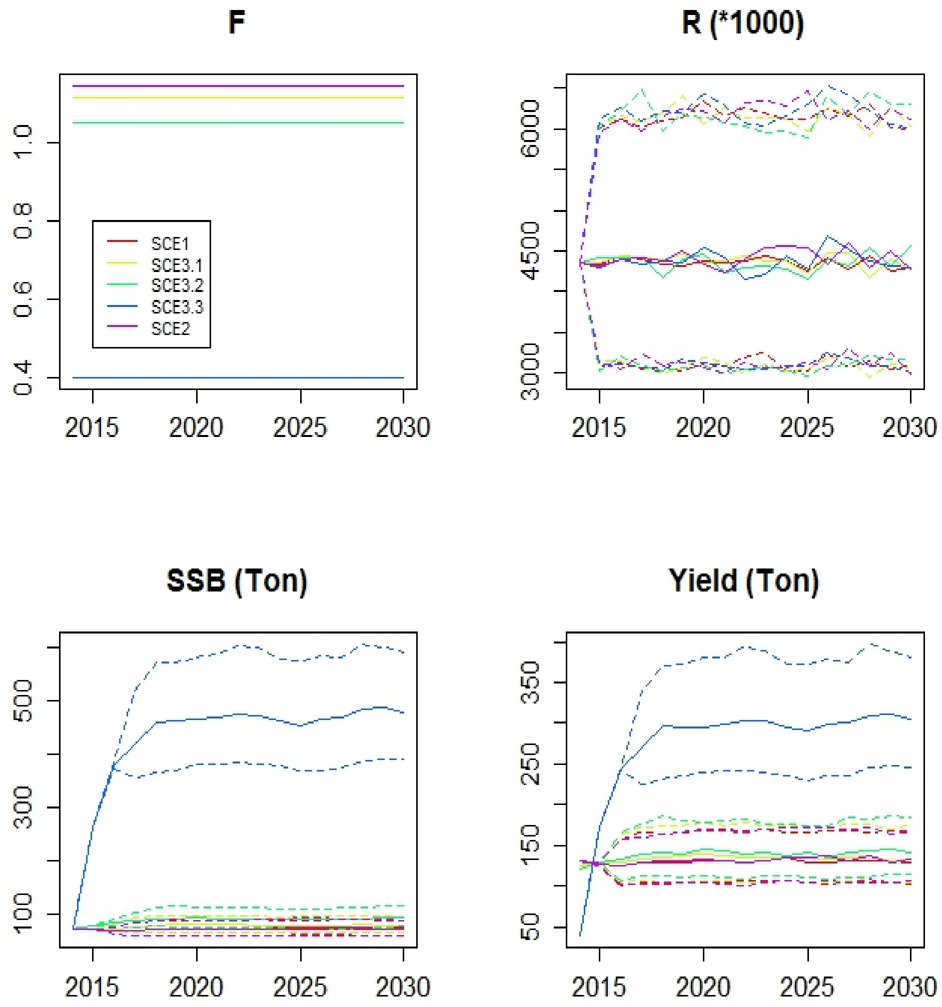

Figure 2.6.2. Biological outputs from the five scenarios tested with MEFISTO. Sce 1 (red line) - BAU; Sce 2 (pink line) - FI; Sce 3.1 (yellow line) - F_0; Sce 3.2 (green line) - F_{MLS}; Sce 3.3 (blue line) - F_{IMM}. F: fishing mortality; R: number of recruits (in thousands); SSB: spawning stock biomass (in tons). Dottet lines represent 25 and 75% quantiles.

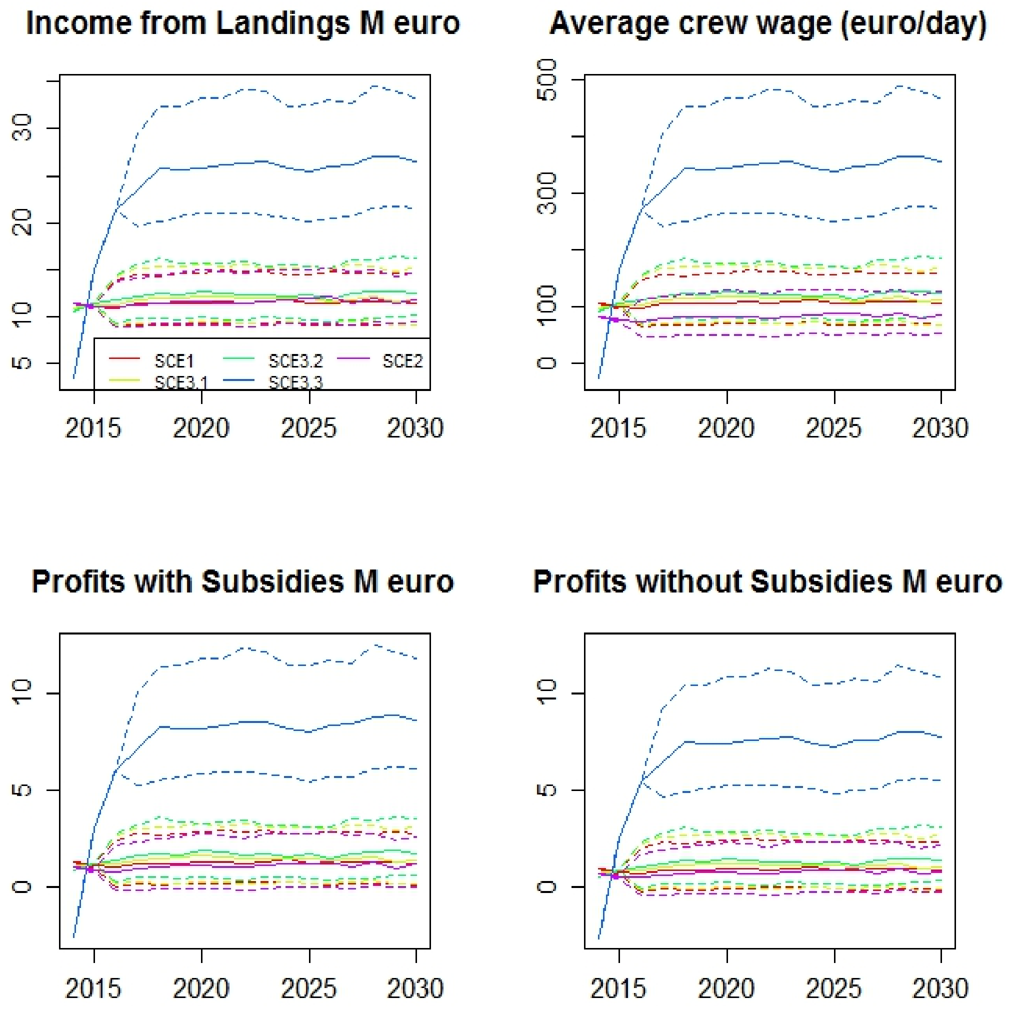

Figure 2.6.3. Economic outputs from the five scenarios tested with MEFISTO. Sce 1 (red line) - BAU; Sce 2 (pink line) - FI; Sce 3.1 (yellow line) - F$_0$; Sce 3.2 (green line) - F$_{MLS}$; Sce 3.3 (blue line) - F$_{IMM}$. Dottet lines represent 25 and 75% quantiles.

Table 2.6.3. Results from the different scenarios tested using MEFISTO compared to the BAU scenario. F: fishing mortality; R: number of recruits (in thousands); SSB: spawning stock biomass (in tons).

		Scenarios			
		2) *FI*	3.1) F_0	3.2) F_{MLS}	3.3) F_{INM}
Biological outputs	F	↔	Slight ↓	↓	↓↓
	# Recruits	↔	↔	↔	↔
	SSB (Ton)	↔	Slight ↑	↑	↑↑↑
	Yield (Ton)	↔	Slight ↑	↑	↑↑
Economic outputs	Incomes (€)	↔	Slight ↑	Slight ↑	↑↑
	Crew wage (€)	↓	Slight ↑	Slight ↑	↑↑
	Profits (€)	↓	Slight ↑	Slight ↑	↑↑

2.6.6 Discussion/conclusion

According to Article 15 of the Common Fisheries Policy (Regulation EU Nº 1380/2013), the LO in the Mediterranean applies to catches of species which are subject to minimum landing sizes (MLS) as defined in Annex III of Regulation (EC) Nº 1967/2006. As mentioned above, hake is the most discarded demersal resource of the Mediterranean bottom trawl fishery (BTF) as a consequence of the incongruence between its MLS (20 cm) and length at first capture (15.2 cm). Therefore, we have assessed the impact of a full implementation of the LO, as well as other scenarios aimed at improving the gear selectivity for hake in the BTF from the Balearic Islands (Western Mediterranean).

Among the different modelled scenarios, the most effective measure was, by far, to avoid taking individuals below the size at first maturity (scenario 3.3-FIMM). This represents a severe management measure when compared to the current length at first capture (15.2 cm), since it implies a twofold increase in the fish size to reach the size at first maturity (30 cm, Hidalgo et al., 2008). In accordance with the severity of the measure, the improvements observed at medium term in both the biological and economical indicators are very high, once overcome the losses observed after the first years of the measure implementation. Differences in the outputs of this measure compared to the rest of scenarios ranged between six-fold for Spawning Stock Biomass (SSB) and twofold-threefold for all other indicators (yield, incomes, profits and crew wage). However, such an increase in mesh size to manage hake would also entail important losses given that adults of small-sized, slender fish species with commercial value (e.g. *Spicara smaris, Trachurus* spp.) would not be caught. For some local stakeholders this measure would endanger the viability of the BTF from the study area (see interviews in Task 2.5). Certainly it is not an easy task to manage the highly multispecific Mediterranean fisheries based on a single target species (hake) when there is a large variety of fish sizes and forms, and it is extremely difficult to regulate the fishing mortality for each species independently (Ratz et al., 2007; Mackinson et al., 2009; Guillen et al., 2013).

Modelling the avoidance of hake individuals of age zero (scenario 3.1-F_0) and hake below the MLS (scenario 3.2-F_{MLS}) gave very similar results, with only slight increases in all indicators, relative to BAU. The worst outputs were observed for the scenario modelling the full implementation of the LO, which entailed reductions in the crew wage and profits.

The results of the different scenarios modelled in this work should be taken with great care becauseof uncertainties in the input parameters. This affected the scenarios testing the use of selectivity measures to avoid catches of specific fractions of the population (F_0, F_{MLS} and F_{IMM}). Some of the biological parameters for these scenarios were theorized based on the existing information. Secondly, the effects of the LO in the scenario testing its full Implementation (FI) were also hypothesized due to the lack of information on how the LO will in reality affect the fishery. Increments in the benefits from this scenario, given sale of previously discarded fish, were not applied because nowadays there are not processing industries to allow commercializing the discards in the study area. Finally, as mentioned above, we have only been able to approach the bio-economic analysis from a monospecific point of view though hake is caught in a highly multispecific fishery. Therefore, the real biological and economical outcomes of these scenarios for the BTF of the Balearic Islandsshould be modelled taking into account the consequences on the main by-catch species.

Nevertheless, the current simulations revealed that the biological and economical benefits of decreasing the fishing mortality of hake by means of improving thefishery selectivity are clear. The application of such measures in a multispecies context along with other measures like spatio-temporal management of recruitment areas can help improving the management of the Mediterranean BTF.

2.6.7 Problems encountered with WP2 - WP3-7 interaction

According to Western Mediterranean stakeholders the best way to reduce discards would be by means of improving the gear selectivity and the use of spatiotemporal management measures (see interviews in Task 2.5). Consequently, for interactions among different WPs we focused on the information available from WP3 ('Adaptation of gear technology') and WP4 ('Adaptation of fishing strategies').

The main aim of WP3-'Adaptation of gear technology' was to promote the avoidance of unwanted catches through technological means. In our case, the most suitable method was to incorporate selectivity improvements in the BTF. This is based on: i) previous work that had already demonstrated the effectiveness of such measures in the study area (Guijarro and Massutí, 2006; Ordines et al. 2006); and ii) the inconsistency between the MLS (20 cm) and the average length at first maturity (30 cm) of hake in the Western Mediterranean. The main objective of this exercise was to expand the unrealistic monospecific model approach used above to a more realistic multispecific context incorporating the main by-catch species taken by the BTF from the Balearic Islands targeting hake.

The main aim of WP4-'Adaptation of fishing strategies'was to develop industry led approaches to the strategy and tactics for minimising unwanted catches. Here, we used the work done under this WP4 on the identification of locations to avoid such undesired catch in the study area (http://sirs.agrocampus-ouest.fr/discardless_app/wp4-3/). Owing to the spatiotemporal heterogeneity in recruitment processes, our main objective was to incorporate this effect on the bio-economic model in order to get more realistic outputs.

However, the different attempts to include the above outputs from WPs 3 and 4 in the bio-economic modelling were unsuccessful. The main problems found with these attempts are summarized below.

1. WP3-'Adaptation of gear technology': The scenarios based on selectivity improvements were focussed on an increase in the mesh size. Given that no selectivity experiments have been conducted at sea to test larger meshes this measure was approached from a theoretical point of view. Consequently, the current selectivity curve for the 40-squared mesh of hake was shifted to theoretically simulate such an increase in mesh size and obtain the new selectivity age vector (Fig.2.6.4). This shift provides parameters from an 'unknown' squared mesh size. The same procedure cannot be applied to other by-catch species of the hake fishery because the displacement of the curve would be unknown and would not be the same for all species. Other procedures to overcome these difficulties, such as the one used by Prellezo et al. (2017)could not be applied here due to the lack of selectivity curves for other squared mesh sizes other than the 40 mm one currently used in the Mediterranean BTF in order to compare them.

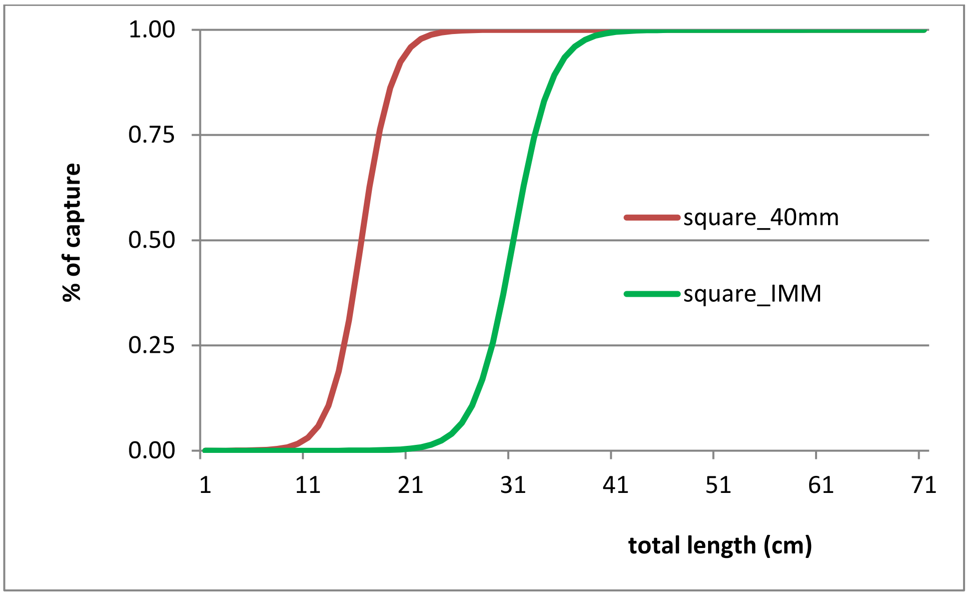

Figure2.6.4. Displacement of the 40S mesh selectivity curve (red) for hake to a theoretical curve (green) to avoid catches of immature individuals (30 cm).

In addition, there is a lack of some biological data (see section 2.6.4.1) from the by-catch species caught along with hake to perform the bio-economic analysis with MEFISTO. This is due to the fact that the stock assessments carried out regularly in the study area are focused on the main target species, but there is no information on the exploitation state of the by-catch species.

1. WP4-'Adaptation of fishing strategies':the MEFISTO version used in our bio-economic modelling did not allow including spatio-temporal management measures. However, a later version of this software recently released (MEFISTO 4.0) do allow incorporating temporal management measures but once again there is a lack of available data from the BTF of the Balearic Islands to feed the bio-economic model. More specifically, the available data allowed producing maps of the spatial locations with higher density of individuals under the MLS or immature ones but lacked the temporal component in order to identify the periods of the year when such catches are more likely to occur.

To conclude, all these drawbacks detected when trying to include outputs from both the WP3 and WP4 prevented performing bio-economic simulations of temporal closures in a multispecies context such as the case for hake in the BTF from the Balearic Islands.

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2.7 Greek mixed demersal fishery in the E. Med

2.7.1 Introduction

Mediterranean fisheries are multigear and multispecies targeting over 200 species that range from large-bodied, high-valued fish used for human consumption to small forage fish used for fishmeal and fishoil (Stergiou et al. 2016). The high biodiversity of the Mediterranean and the multigear nature of its fisheries along with a number of technological and biological interactions make it difficult for this fishery to be completely selective leading to a high number of unwanted species being caught, in some cases in large quantities depending on gear, season and area (Tsagarakis et al. 2014). The Mediterranean fisheries are regulated through technical gear specifications, temporal and spatial closures and minimum landing size (MCRS) for the main target species (Stergiou et al. 2016). According to these regulations, undersized individuals, i.e. those caught below a minimum landing size should have been discarded since the adoption of the Common Fishery Policy (CFP) in 1983 until the introduction of the Landing Obligation (LO) in the CFP in 2013, with implementation from 2015.

The obligation to discard fish under the MLS is generally an economic advantage in many fisheries with quota restrictions because it creates incentives to catch a larger part of the quotas and/or to highgrade, i.e. discard small low-value fish in favour of larger higher-value fish. In the Mediterranean however, where quota restrictions apply only to two large pelagic species (Atlantic bluefin tuna *Thunnus thynnus* and swordfish *Xiphias gladius*), discarding has been due to market and sorting inconsistencies, e.g. discarding of low-quality, low-valued or damaged fish. Thus, even though the actual outcomes of the LO may depend on several biological, technical and economic factors, the LO is generally expected to affect the economy of the Mediterranean fishery by increasing operating costs and wages and may lead to reduced profitability, at least in the short term.

The purpose of the present case study is to assess the effect of LO the economics of two fleets (trawlers and small-scale costal vessels) in Thermaikos Gulf, the largest fishing ground in the northeastern Mediterranean Sea. This is accomplished through examination of three scenarios of partial implementation of the LO and three scenarios of full implementation using the bio-economic fisheries model MEFISTO (MEditerranean FIsheries Simulation TOol), which has been specifically developed for the Mediterranean Sea fisheries (Lleonart et al. 2003b).

The theoretical basis of the included scenarios has been formulated according to the findings and reporting of other Work Packages (WPs). The perceptions of the Greek fishers on the LO and findings of scientists on actual discard rates (reported in WP4) have been used to formulate the scenarios with respect to establishment of extra crew and daily costs. The included selectivity scenarios have been based on previous research on the mesh selectivity of the Greek trawlers and netters (reported in WP3). Some extra cost scenarios were also included because of the discrepancy between officially reported discard rates and the actual discard rates according to research projects and relevant publications. It should be noted here that the applicability of the findings of the remaining WPs (WP5-7) is limited because of the special nature of the Mediterranean and especially the Greek fisheries (Stergiou et al. 2016).

2.7.2 Study area

2.7.2.1 Description of Thermaikos Gulf

Northwestern (NW) Aegean includes the Gulfs of Thessaloniki (also known as inner Thermaikos) and Thermaikos as well as the gulfs of Chalkidiki Peninsula (Figure 2.7.1; from Dimarchopoulou et al. 2018). The Thermaikos Gulf is the main fishing ground, which is considered one of the most productive in the Greek Seas. The Thermaikos Gulf is a shallow water area having a maximum depth of 50 m. Large river systems (Gallicos, Axios, Loudias and Aliakmon) discharge into Thermaikos Gulf about 207m^3/s, with significant temporal variability (Kallianiotis et al. 2004).

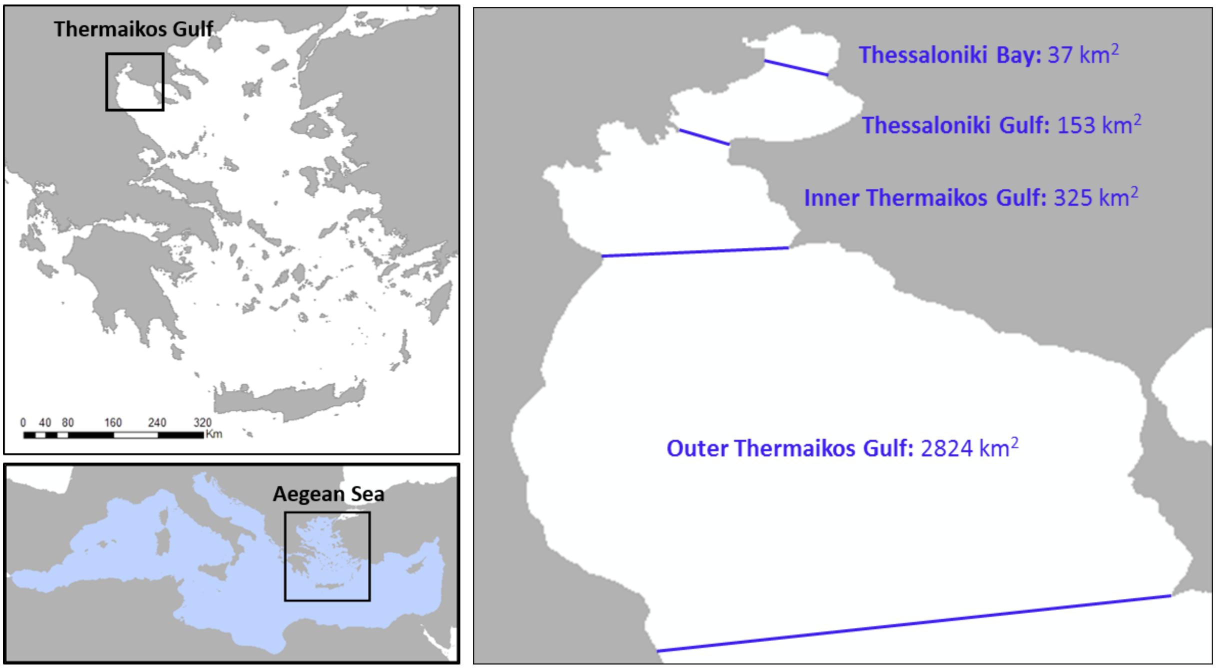

Figure 2.7.1. Map of Thermaikos Gulf and adjacent areas (redrawn with permission from Dimarchopoulou et al. 2018).

2.7.2.2 Fleet structure

According to the European Fleet Register for Greek vessels operating in national waters (CFR 2014), in 2014, 1460 vessels were registered in 7 ports of Thermaikos Gulf (Thessaloniki: 739 vessels; Skala Katerinis: 251 vessels; Nea Moudania: 232 vessels; Nea Michaniona: 82 vessels; Platamonas: 71 vessels; Agiokampos: 66 vessels; Stomio: 19 vessels). Based on the main gear used, 58 of these vessels are trawlers (using bottom trawls, OTB), 29 are purse seiners (using purse-seines, PS) and 1373 are small-scale coastal vessels using a variety of fishing gears.

The fleet segment is defined by the gear code (FISHING_TECHNIQUE) and the vessel length (VESSEL_LENGTH which defines the minimum and maximum vessel length of fleet segment) category. The segmentation, which is defined in Appendices III (level 2), VIII (level 3) and X (level 4) of the Commission Regulation 1639/2001, of the Thermaikos fleet is shown below (Table 2.7.1). For the purposes of the analyses presented in this report vessels were grouped per vessel category (gear) into trawlers (OTB) and small scale coastal vessels (various gears, mainly nets).; Purse-seiners were excluded in the present context because their discard rates are very low.

Table 2.7.1.The number and LoA of fishing vessels per fleet segment in Thermaikos Gulf based on Fleet Register (CFR 2014).

Vessel category (gear)	Segment	Number	Mean Length Overall (LoA)	Mean GRT
Trawlers (OTB)	VL0012	0	-	-
	VL1224	14	22.67	59.78
	VL2440	44	28.30	129.75
	VL40XX	0	-	-
Purse seiners (PS)	VL0012	0	-	-
	VL1224	17	20.81	46.27
	VL2440	12	27.15	98.33
	VL40XX	0	-	-
Small-scale coastal vessels (various gears, mainly nets)	VL0012	1365	6.66	1.75
	VL1224	8	13.60	13.67
	VL2440	0	-	-
	VL40XX	0	-	-
Segment codes: VL0012 = less than 12 m in length; VL1224 = between 12 and 24 m in length; VL2440 = between 24 and 40 m in length; VL40XX = greater than 40 m in length				

2.7.2.3 Fleet economics

Table 2.7.2 is presenting the main socio-economic performance indicators by fleet segment in the Greek national fishing fleet in 2012 by length class. At this stage the specific fleet economics for the area of Thermaikos Gulf are not available, so the data for the total Aegean Sea is presented.The total income of the Greek Fishing fleet reached 421.819.854 Euros in 2013, of which 99% are comprised from the sales of the catch. There was no net profit for the fishing fleet in 2013.

Table 2.7.2. Greek national fishing fleet economic performance indicators in 2013.

	Value (€)	% Total cost
Crew wages	105.420.429	21,97
Unpaid labour costs	80.058.019	16,68
Energy costs	108.188.604	22,55
Repair and maintenance costs	43.168.187	9,00
Other variable costs	77.604.070	16,17
Other non-variable costs	6.747.994	1,41
Annual depreciation	58.675.084	12,23
TOTAL COST	**479.862.387**	100,00
Revenues from landings	418.072.659	
Direct subsidies	3.747.195	
Revenues from landings	**421.819.854**	
Profit and wage from labour	**22.015.486**	
Net Profit	**-58.042.533**	

2.7.2.4 Target and non-target species

Trawlers (OTB)

The most abundant species in the bottom trawl catches in Thermaikos Gulf are red mullet (*Mullus barbatus*), cuttlefish (*Sepia spp.*), spottail mantis shrimp (*Squilla mantis*), caramote prawn (*Melicertus kerathurus*), deep-water rose shrimp (*Parapenaeus longirostris*), musky octopus (*Eledone* spp.), anglerfish (*Lophius* spp.), European hake (*Merluccius merluccius*), spotted flounder (*Citharus linguatula*), and octopus (*Octopus spp.*) (Dimarchopoulou et al. 2018). Red mullet and surmullet (*Mullus surmuletus*), caramote prawn, deep-water rose shrimp, European hake, cuttlefish and octopus are the main target species of the trawl fishery in Thermaikos Gulf (Dimarchopoulou et al. 2018). The number of non-target species is high including various species of the families Gobiidae, Labridae, Serranidae, Soleidae, Triglidae, among others (Karachle 2008).

Purse-seiners (PS)

Anchovy (*Engraulis encrasicolus*), sardine (*Sardina pilchardus*) and Atlantic chub mackerel (*Scomber colias*) are the main target species in the area. The catch of non-target species is very low, so are discard rates for purse-seiners.

Small-scale coastal vessels (various gears, mainly nets)

The small-scale coastal fleet of Thermaikos Gulf targets a wide variety of species some of which are also targeted by the trawling fleet (e.g. red mullet, hake, surmullet, and caramote prawn) and one by the purse-seiners (European sardine).

2.7.3 Materials and methods

The biological and economic data used in the Eastern Mediterranean case study referred to the stocks of hake and red mullet, which are the main target of the trawlers and small-scale coastal netters in the Thermaikos Gulf, along with surmullet and deep-water rose shrimp. Data on the biology and exploitation of the hake and red mullet stocks was obtained by the recent work by Tserpes et al. (2016).

Two fleets were selected, the small-scale coastal vessels and trawlers, which according to the fleet registry consist of 1373 and 58 vessels, respectively. Economic and technical parameters for the two fleets were taken from Maravelias et al. (2014), Tserpes et al. (2016) and the Data Collection Framework report (DCF 2016). Additional data on the market prices and daily costs were obtained from questionnaires and personal communications with local fishers[12]. All data refer to year 2015, which was the last year of available data when the analysis was initiated (Table 2.7.3).

The bio-economic model applied was MEFISTO (MEditerranean FIsheries Simulation TOol; Lleonart et al., 2003b), which is a multispecies and multifleet model accommodating the dynamic nature and economic relationships characterizing Mediterranean fisheries. MEFISTO was used to carry out projections over the period 2016-2025, using 2015 as reference year,

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[12] Katia Frangoudes, personal communication

under different management measures (scenarios). Simulations were projected under stochastic conditions (100 simulations), assuming uncertainty in recruitment. Recorded bio-economic indicators were the fishing mortality and spawning stock biomass (SSB) of hake and red mullet and catch, costs and profits per fleet.

Table 2.7.3. Input for the fleet structure and market parameters of the two fleets (coastal vessels, trawlers) operating in Thermaikos Gulf.

Fleet cost structure	**Coastal vessels (mean**	**Trawlers (mean values)**
Capital per vessel (euros)	67786	550000
Annual costs per vessel (euros)	10216	125372
Daily fuel consumption per vessel (litres)	20	509
Fleet structure		
GT per vessel	6.4	95.6
Crew per vessel	1.6	6.0
Fishing hours per day	8	12
Fishing hours per year	187	238
Number of vessels	1373	58
Market		
Hake price (euros per kilo)	11.6	7.8
Red mullet price (euros per kilo)	14.0	11.0
Opportunity cost (percent)	2.5	2.5
Financial cost (percent)	4.0	4.0
Fuel price (euros per litre)	1.1	0.4

Seven scenarios have been considered (cf. table 2.7.4), of which one (Sc-0) assumes that the LO has not been implemented, i.e. that the fishery is regulated under a 'Business as usual' regulation. Six scenarios assume that the LO has been implemented. Of these three scenarios (Sc-1 to Sc-3) assume to partial implementation of LO given that selectivity measures are applied to both hake and red mullet and three scenarios (Sc-4 to Sc-6) assume full implementation measures applied both to trawlers and small-scale vessels. The partial implementation scenarios are:

Sc-1. no fishing mortality for hake and red mullet at age 0,
Sc-2. no fishing mortality below MLS (by additionally decreasing the fishing mortality of age 1 individuals by 10%),
Sc-3. no fishing mortality for hake and red mullet at ages 0 and 1 through modification of age-selectivity parameters.

The three additional full implementation scenarios were based on varying discard rates, the range of which spanned between the officially reported rate and the one reported in the literature (Table 2.7.4). Assuming that the obligation to land previously discarded fish leads to higher daily costs and the need for extra crew menbers, these scenarios are:
Sc-4. 5% increase of daily costs, no extra crew member,
Sc-5. 10% increase of daily costs, 10% extra crew (the original full implementation scenario),

Sc-6. 20% increase of daily costs, 20% extra crew (based on the discard rates reported in Tsagarakis et al. 2014).

The reason for adding two extra full implementation scenarios (Sc-4 and Sc-6) to the original planning (Sc-5) was that according to official reports (DCF 2016) the percentage of hake and red mullet discards in Greece has dropped to less than 5% since 2013; thus, diverts a lot from initial estimates that were based on the literature (e.g. Tsagarakis et al. 2014).

Table 2.7.4. Summary of the various partial and full implementation scenarios for the Eastern Mediterranean Thermaikos Gulf fishery (trawlers and coastal vessels).

Scenarios	**Description**	**Description/model settings**
Business as usual	**Sc-0**	**LO not implemented**
Partial implementation scenarios (Selectivity measures)	Sc-1	No fishing mortality for hake and red mullet at age 0
	Sc-2	No fishing mortality for hake and red mullet at age 0 and lower mortality at age 1
	Sc-3	No fishing mortality for hake and red mullet at ages 0 and 1
Full implementation scenarios	Sc-4	5% increase of daily costs, no extra crew member
	Sc-5	10% increase of daily costs, 10% extra crew
	Sc-6	20% increase of daily costs, 20% extra crew

2.7.4 Results and discussion

A summary of the results of Sc-1 to Sc-6 (LO implemented) relative to Sc-0 (no LO) are presented in table 2.7.5. Here it is seen that the partial implementation scenarios (Sc1-3) affected the stock and the fleet components of the model and lead to a decline of overall fishing mortality and increase of SSB for both stocks and to increasing catches and profits when age 1 of hake and red mullet was not caught. The full implementation scenarios (Sc4-6) affected only the fleet component and lead to increasing costs and declining profits when daily costs and crew increased over 10%. Table 2.7.5 presents the aggregated results for both fleets included in the analysis. However, it should be noticed that the effect of applying the selectivity measures was not the same for trawlers and coastal netters because the latter rarely catch undersized hake and red mullet individuals. The individual fleet results per scenario are shown in detail in the following section.

In Scenario 0 (business as usual) hake, red mullet and total biomass gradually increase by about 10% from 2017 to 2020 to their maximum values that continue up to 2025 (Figure 2.7.2). F drops by 10% in 2017 and remains stable up to 2025. Catch per fleet initially declines for two years and then increases to 2015 levels for both fleets and stocks. The profit and the cost per fleet initially decline for two years but then recover back to 2015 levels and remain stable up to 2025.

In Scenario 1 (reducing F at age 0 of hake and red mullet from trawling and netting to zero) resulted in a drop of F and a gradual increase of biomass for both stocks (Figure 2.7.3). Compared to Scenario 0, biomass was higher, and F was lower for both stocks. The catch per stock and fleet initially declined for two years by 10% and then stabilized towards 2025 for both fleets to above the levels observed in scenario 0. Moreover, the catch was higher in 2025, compared with 2015, for the coastal vessels, while it was lower for trawlers. The profit and cost for the two fleets followed the pattern of the catch. Compared to Scenario 0, the catch and the profit of both fleets were higher and cost slightly higher, following a similar pattern. The profit of both fleets increases in scenario 1 compared to scenario 0, but in scenario 1 the coastal vessels had higher profits in 2025 compared to 2015, while the tralwers had lower profits, indicating that especially the coastal vessels benefit from incrasing selectivity. Likewise, revenues were higher for coastal vessels in the long term (after 2020).

Table 2.7.5. Summary of the main results obtained from the various partial and full implementation scenarios compared to the baseline business as usual scenario 0 (BAU), for the Eastern Mediterranean Thermaikos Gulf fishery (trawlers and coastal vessels). F0 = Age 0 fishing mortality, F1 = fishing mortality for fish below minimum landings size, 'Selectivity modifications'=Change in age selectivity to reduce catch of undersized fish.

SCENARIOS		**Sc-0**	**Sc-1**	**Sc-2**	**Sc-3**	**Sc-4**	**Sc-5**	**Sc-6**
		BAU	**partial implementation (selectivity modifications)**			**full implementation**		
Description / **Parameter**		**No LO, management as usual**	**$F_0 = 0$ for hake and red mullet**	**$F_0 = 0$ $F_1 = 10\%$ less for hake and red mullet**	**$F_0 = 0$ $F_1 = 0$ for hake and red mullet**	**% increase daily costs**		
						5%	**10%**	**20%**
						% increase in crew% increase in crew		
						0%	**10%**	**20%**
Stock	**F**	-	↓	↓	↓↓	↔	↔	↔
	Recruitment	-	↔	↔	↔	↔	↔	↔
	SSB	-	↑	↑↑	↑↑↑	↔	↔	↔
Fleet	**Catch**	-	↑	↑↑	↑↑↑	↔	↔	↔
	Cost	-	↑	↑	↑	↑	↑	↑
	Profit	-	↑	↑	↑↑	↓	↓	↓

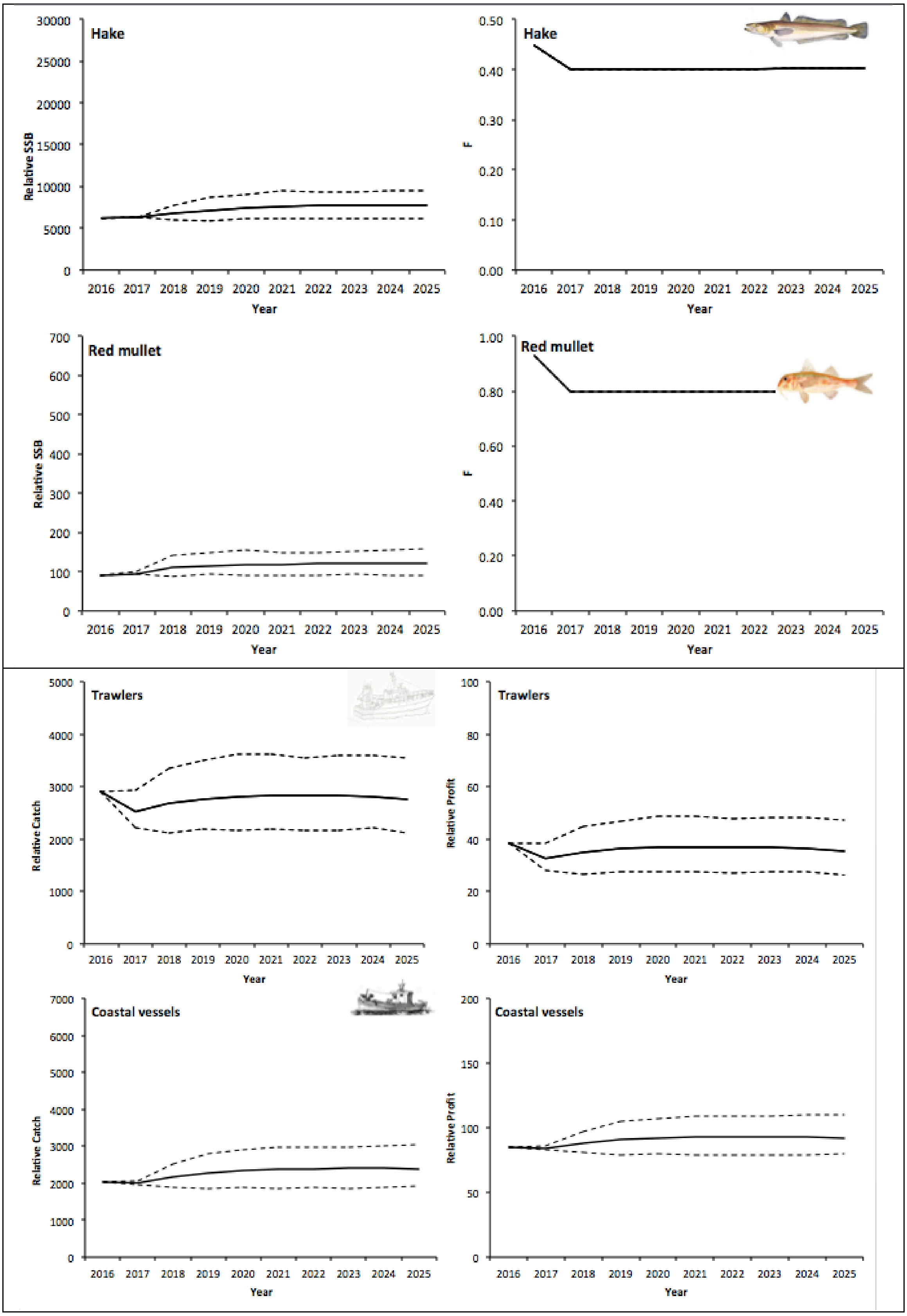

Figure 2.7.2. Stock biomass and fishing mortality per stock along with fleet catch and profit per fleet according to Scenario 0 (business as usual).

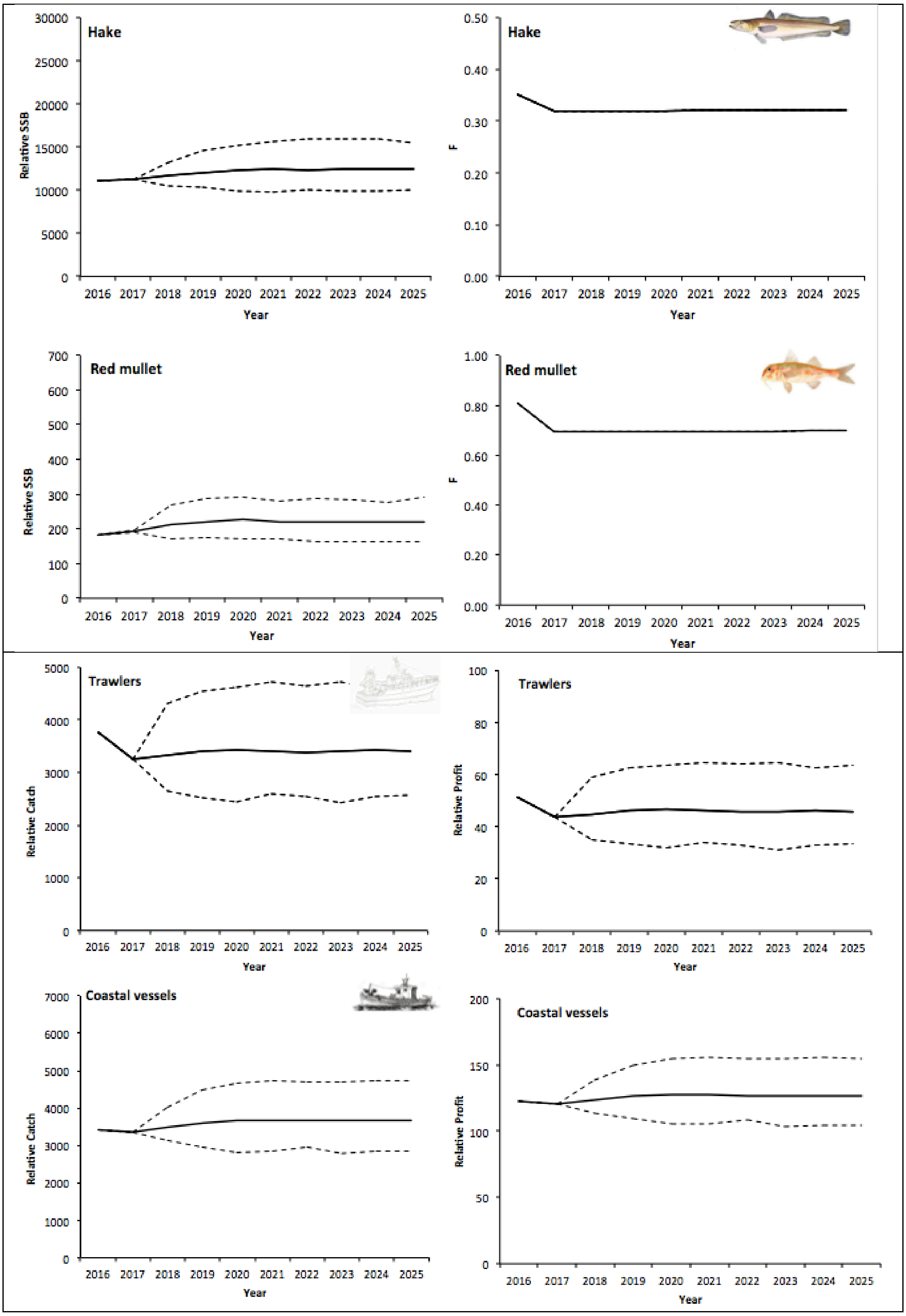

Figure 2.7.3. Stock biomass and fishing mortality along with fleet catch and profit according to Scenario 1 (reducing F at age 0 of hake and red mullet to zero).

In Scenario 2 (reducing F at age 0 of hake and red mullet from trawling and netting to zero and reducing F at age 1 by 10%) resulted, in a further decrease of F and a increase of biomass for both stocks (Figure 2.7.4) compared to scenario 1. As for scenario 1 it is seen that the catch per stock and fleet initially declined for two years and then stabilized towards 2025. The profit and cost per fleet followed the cach pattern. Compared to Scenario 0, catch, profit and costs were higher, but followed the same pattern. Compared to Scenario 1, catch and profit for the two fleet segments increased. The cost followed a similar level.

In Scenario 3 (reducing F at age 0 and 1 of hake and red mullet from trawling and netting to zero) resulted in an even further drop of F and an even higher increase of biomass for all stocks (Figure 2.7.5) compared to scenarios 0, 1 and 2. As such, of scenarios 1-3, this scenario provided the best results for both stocks, i.e. higher biomasses and lower fishing mortalities. The biomass gradually increased for both stocks and F declined. The biomass increase was higher for red mullet compared to hake. The catch was highest too of scenarios 0-3, per fleet and stock. The catch per stock and fleet were rather stable up to 2025. The profit and cost per fleet followed the pattern of catch (Figure 2.7.5). Compared to Scenario 0, the catch and the profit were considerably higher and followed the same pattern. Compared to Scenarios 1 and 2, the catch and the profit were higher and the cost at similar levels.

In Scenario 4 (increasing daily costs by 5% from Scenario 0 and keeping all stock components the same) resulted in the same F and biomass for all stocks (Figure 2.7.6) as in the baseline scenario. Generally, compared to Sc-1 to Sc-3, this scenario provided the least difference compared to the baseline Sc-0 regarding both stocks and fleets. Catch per fleet initially declines for two years and then increases to 2015 levels for both fleets and stocks. The profit and the cost per fleet initially decline for two years but bounce back to 2015 levels and remain stable up to 2015. Compared to Scenario 0, the profit was slightly lower because of the costs being slightly (less than 5%) higher.

In Scenario 5 (increasing daily costs by 10% from the business as usual baseline -Scenario 0- and keeping all stock components the same) resulted in the same F and biomass for both stocks (Figure 2.7.7) as in the baseline scenario. As for Scenario 4, this scenario was not different compared to the baseline scenario 0 regarding the stocks and was slightly different regarding the fleet. The catch per stock and fleet were rather stable up to 2025 with similar trend and magnitude as inSc-0. The profit and cost per fleet followed the pattern of the corresponding catch (Figure 2.7.7) with the overall profit being slightly lower and the cost slightly higher compared to baseline Scenario.

In Scenario 6 (increasing daily costs by 20% from the business as usual baseline Scenario 0 and keeping all stock components the same) resulted in the same F and biomass for both stocks (Figure 2.7.8) as in the baseline scenario. As with Scenarios 4 and 5, this scenario was not different compared to the baseline scenario regarding the stocks and was slightly different regarding the fleet. The catch per stock and fleet were rather stable up to 2025 with similar trend and magnitude as in Sc-0. The profit and cost per fleet followed the pattern of the corresponding catch with the profit being even lower and the cost even higher than Scenario 5, when compared to baseline Scenario 0.

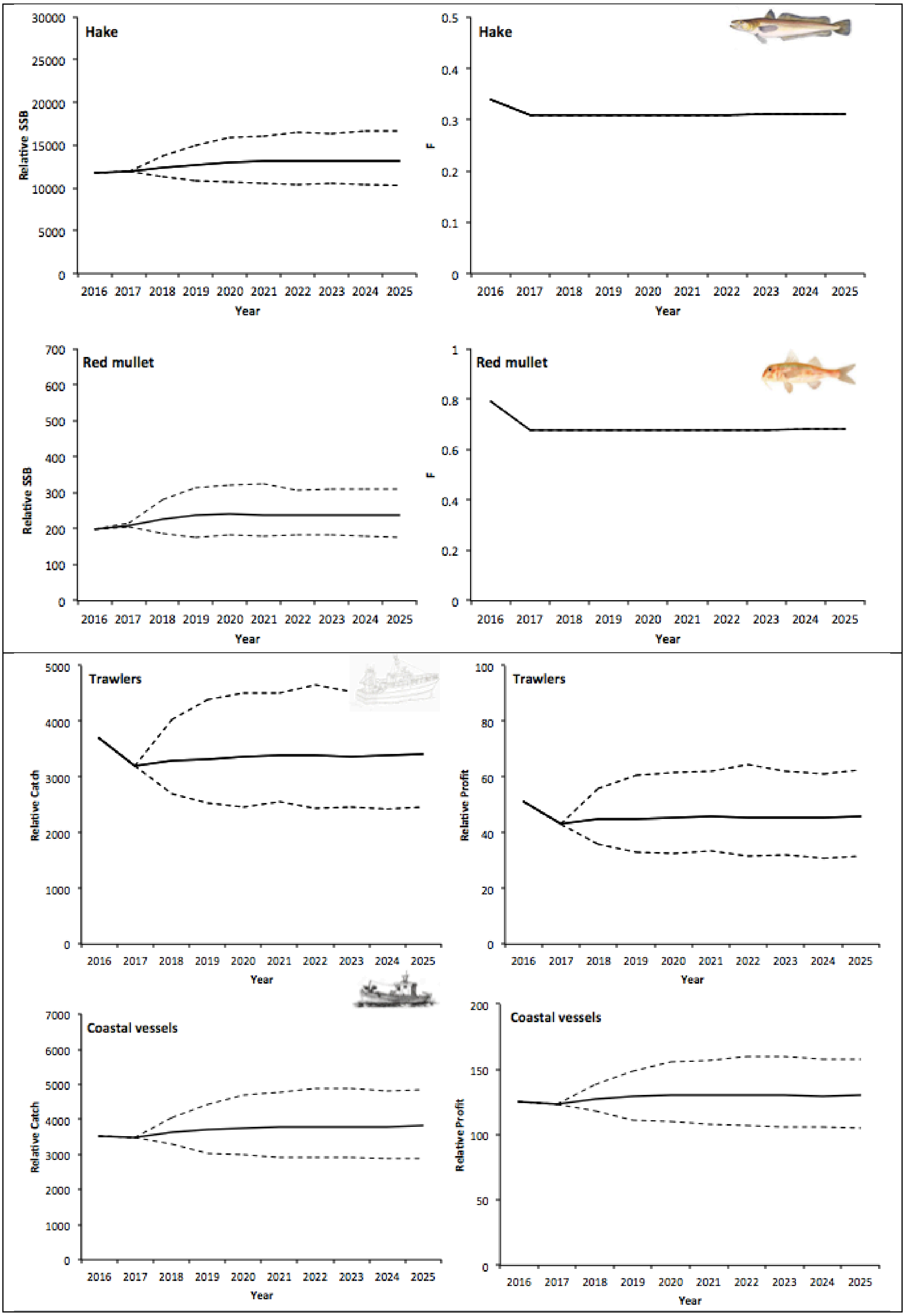

Figure 2.7.4. Stock biomass and fishing mortality along with fleet catch and profit according to Scenario 2 (reducing F at age 0 of hake and red mullet to zero and reducing F at age 1 by 10%).

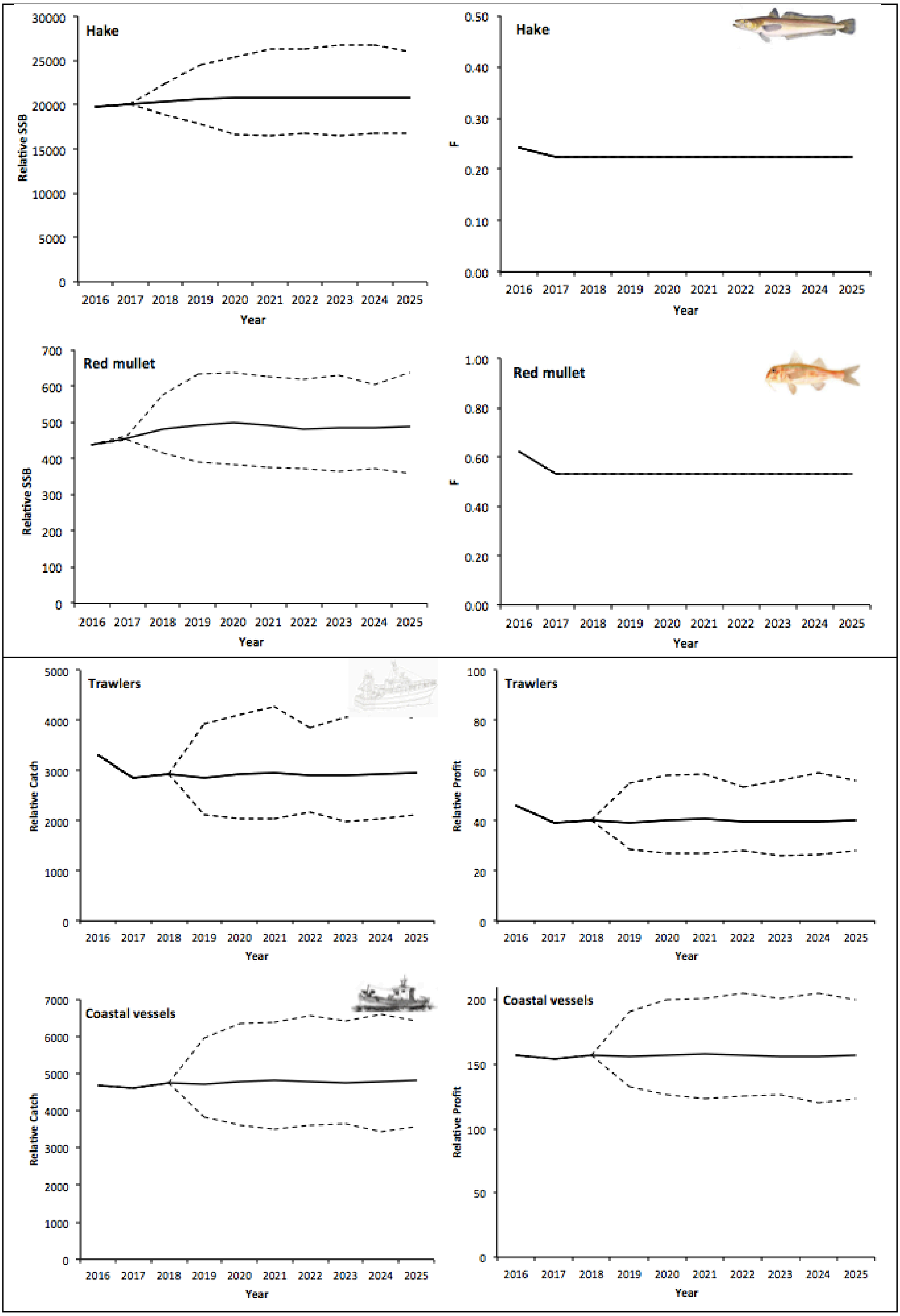

Figure 2.7.5. Stock biomass and fishing mortality along with fleet catch and profit according to Scenario 3 (reducing F at age 0 and 1 of hake and red mullet to zero).

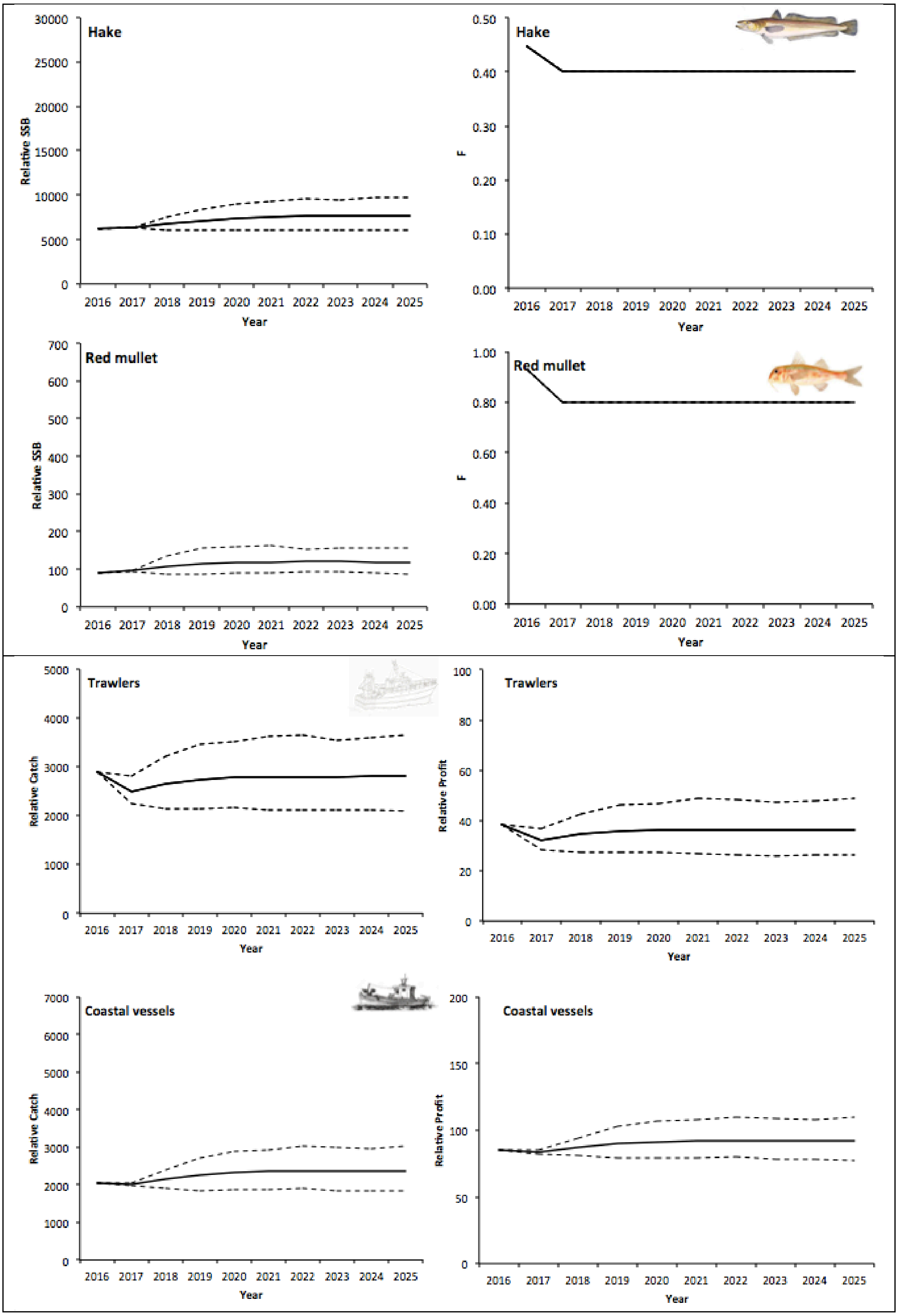

Figure 2.7.6. Stock biomass and fishing mortality along with fleet catch and profit according to Scenario 4 (increasing daily costs by 5%).

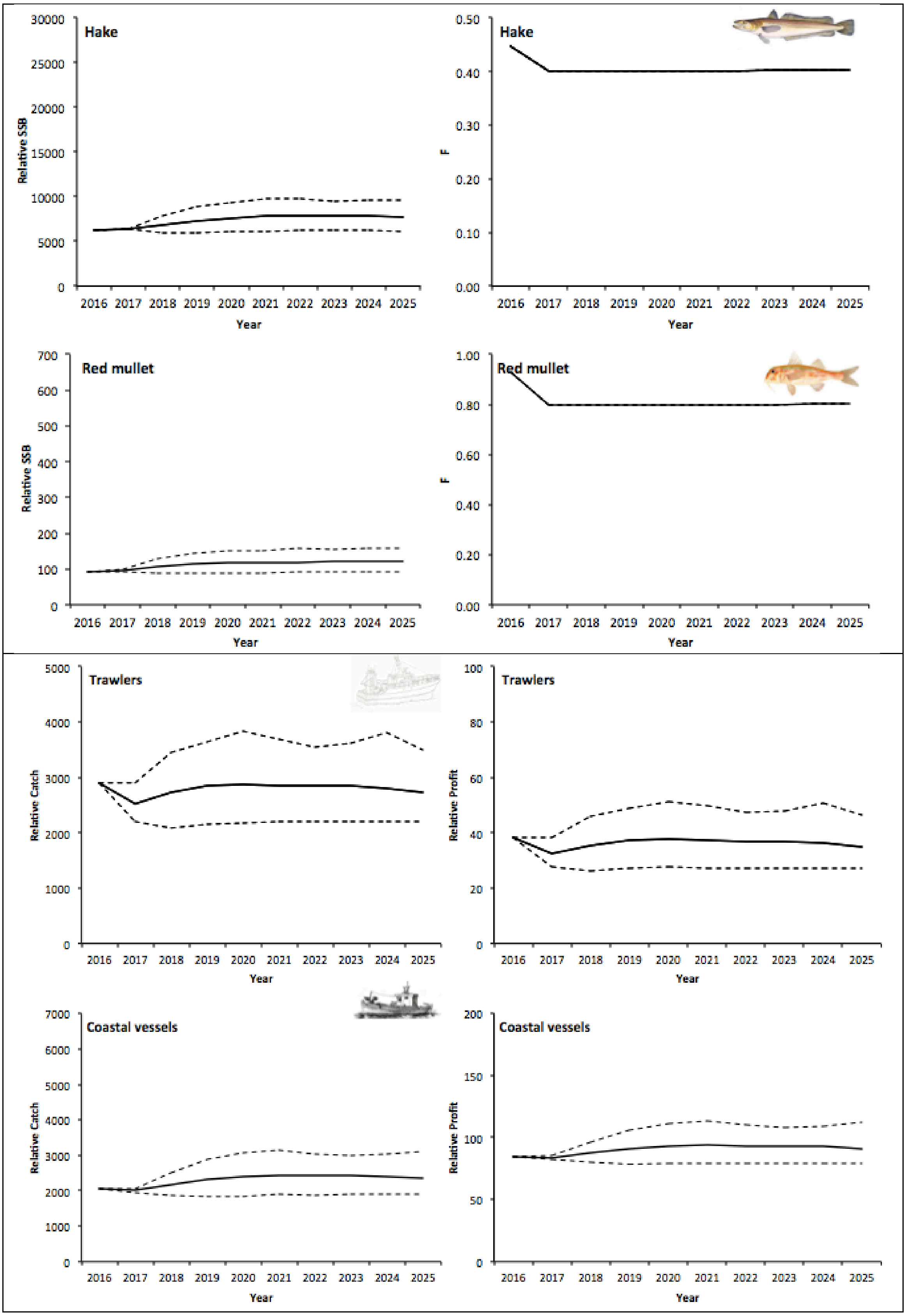

Figure 2.7.7. Stock biomass and fishing mortality along with fleet catch and profit according to Scenario 5 (increasing daily costs and crew number by 10%).

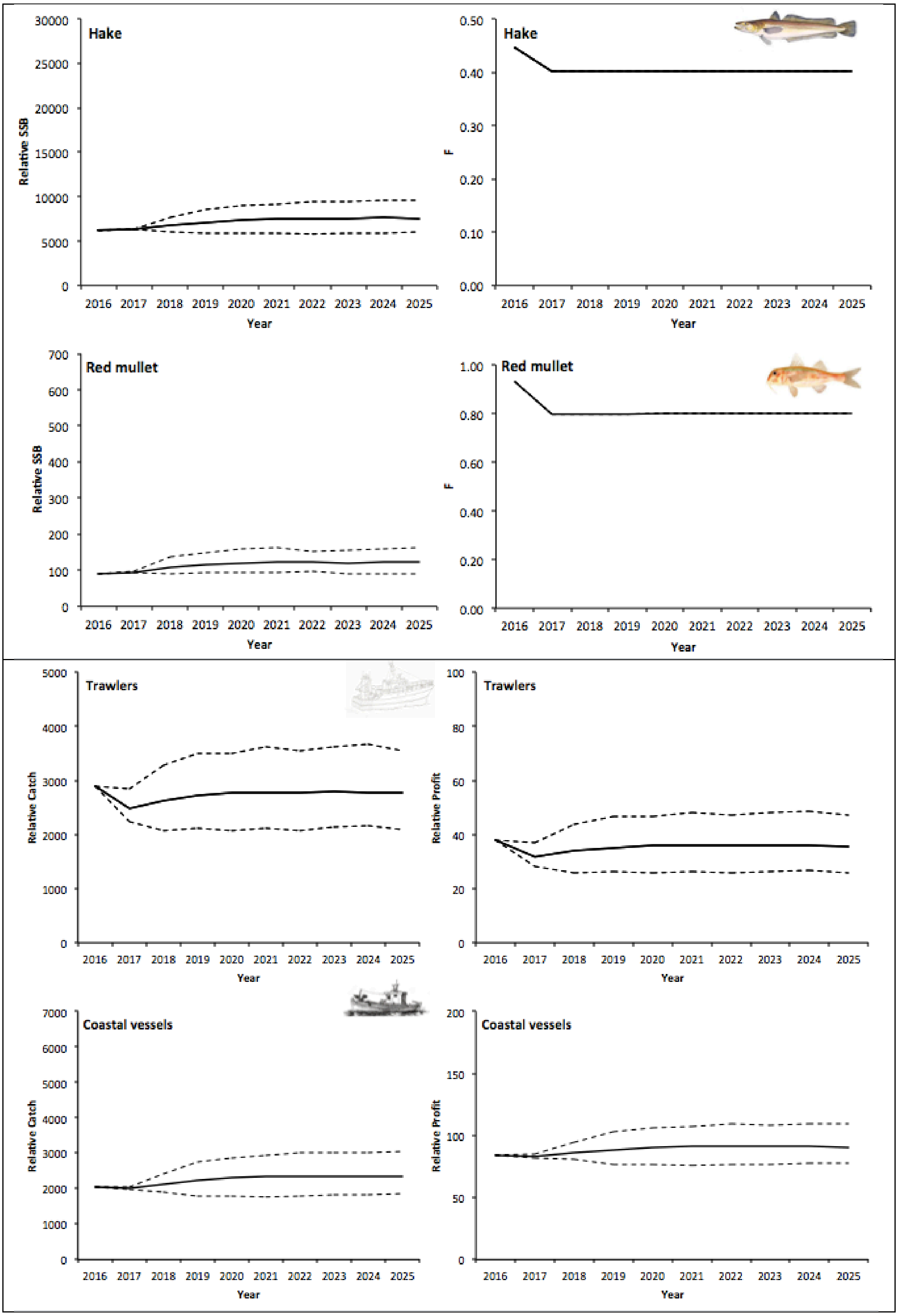

Figure 2.7.8. Stock biomass and fishing mortality along with fleet catch and profit according to Scenario 6 (increasing daily costs and crew number by 20%).

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In all selectivity improvement scenarios (Scenarios 1 to 3), the biomasses of hake and red mullet, and the catches of both the coastal and the trawler fleets increased in response to the selectivity management measures that reduced fishing mortality in ages 0 and 1, with scenario 3 having the best effect on stock status, total catch and total profits (Figure 2.7.9).

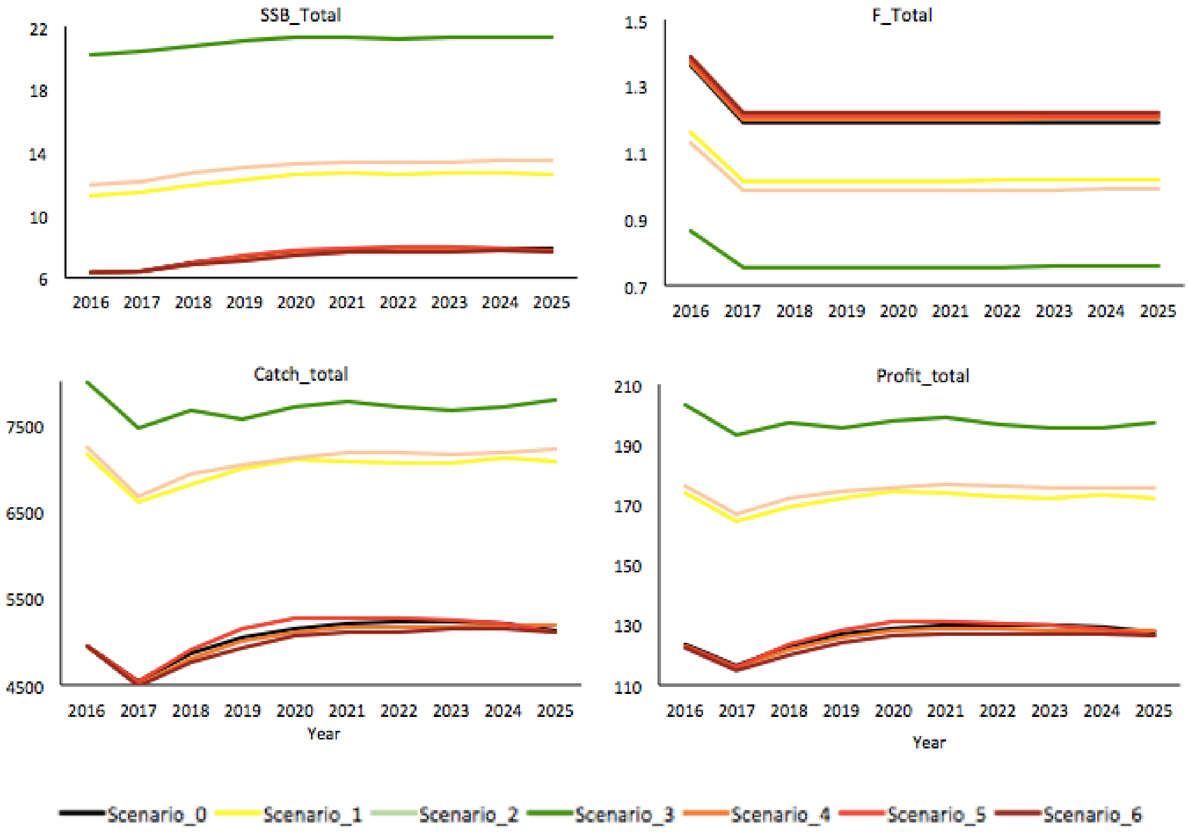

Figure 2.7.9. Stock biomass and fishing mortality along with fleet catch, profit and cost comparing Scenarios 0 to 6.

2.7.5 Conclusions

From the three partial implementation scenarios examined, Scenario 3 (decreasing fishing mortality of ages 0 and 1 for both hake and red mullet by increasing selectivity of trawls) is the optimal for the stock based on the bio-economic criteria examined, because it leads to the increase of hake SSB and decrease in fishing mortality. However, Scenario 3 results in profit loss for the fleets, mainly trawlers that are exploiting smaller sizes (and ages); these profit losses are lower with scenarios 1 and 2, which on the other hand are less beneficial for the stocks.

From the three full implementation scenarios examined, Scenario 4 (increasing daily costs by 5% and having the same number of crew) is the best option for both fleets based on the bio-economic criteria examined, because it leads the minimum profit loss for the fleets, mainly the trawlers. However, the full implementation scenarios did not make any difference to the stocks, which under these scenarios are being exploited as in the case where the LO is not implemented.

This is a clear indication that sustainable fisheries can be accomplished through decreasing overfishing and promoting selective gears. Overall, the LO can be beneficial for the stocks, and in the long term for the fleets, only if it is used to improve fisheries selectivity in the Mediterranean that will relieve juvenile fish from heavy exploitation.

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