Supplementary material 1: Parameters of the biological models

The model was parameterised over the period 2008-2014. The population module is based on assessment model parameters when available (ICES, 2015) and survey data for the spatial distribution and life history traits (CGFS survey, Ifremer and UK BTS survey, CEFAS, Ifremer COMOR survey for scallops). We assumed movements of mature fishes at the beginning of the spawning season from nurseries and presence areas and at the end of the spawning season back to presence areas.

Main parameters and assumptions are recalled below.

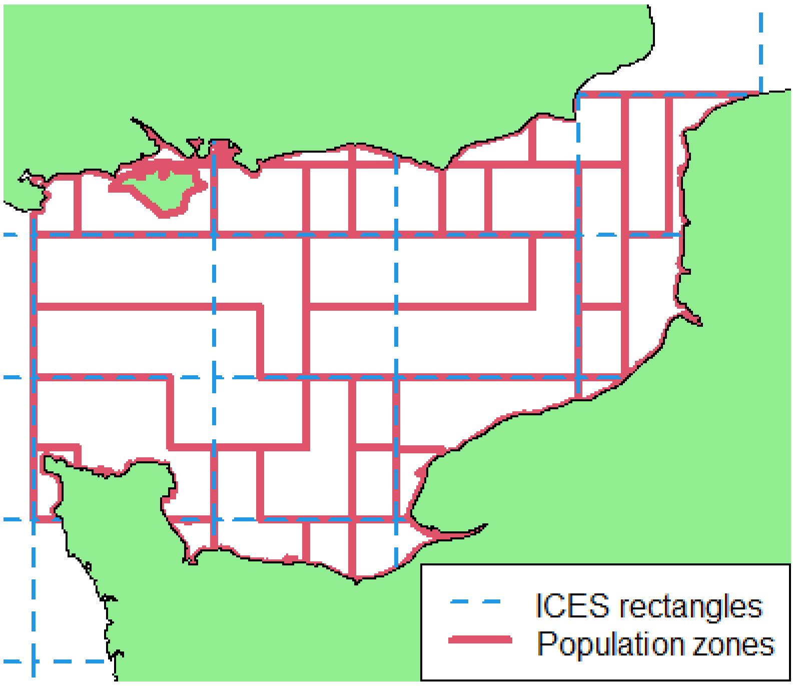

Figure S1: Spatial structure of the ISIS-Fish model of the EEC showing the overlap between population zones and métier zones (ICES rectangles).

Table S1.1: Species, populations, stocks modelled with spatial extend considered, number of age groups, and recruitment assumption in projection.

SPECIES	STOCK/POPULATION	POPULATION STRUCTURE (AGE GROUPS)	RECRUITMENT ASSUMPTION IN PROJECTION (THOUSANDS)	SOURCE OF MODEL PARAMETERS
SOLE (*SOLEA SOLEA*)	27.7d	11	17025 (av. 2012-2014)	WGNSSK 2015
PLAICE (PLEURONECTES PLATESSA)	27.7d	7	158901 (av. 2012-2014)	WGNSSK 2015
COD (GADUS MORUA)	Assuming a substock in 27.7d	6	10221 (av. 2012-2014)	WGNSSK 2015
WHITING (MERLANGUS MERLANGUS)	Assuming a substock in 27.7d	8	563833 (av. 2012-2014)	WGNSSK 2015
SCALLOPS (PECTEN MAXIMUS)	2 populations (baie de Seine interior and exterior)	5	42759/39918 (av. 2012-2015)	Survey data (E. Foucher, pers. Comm.)
RED MULLET (MULLUS SURMULETUS)	27.7.d	5	29622 (av. 2008-2014)	WGNSSK 2015
SQUIDS (LOLIGO VULGARIS AND LOLIGO FORBESI)	2 populations	1	45715/3997 (av. 2008-2015)	J.P. Robin pers. Comm.
CUTTLEFISH (SEPIA OFFICINALIS)		1	4024 (av. 2008-2014)	J.P. Robin pers. Comm.

Table S1.2: Main parameters of the dynamics of fish populations. VBGF: Von Bertalanffy Growth Function. Except otherwise specified, biological parameters are from Carpentier et al. (2009).

	Age group number	Growth	Weight	Natural mortality	Spawning period	Juveniles	Migration pattern	Origin of spatial distribution
Sole	11 (age 1-11)	VBGF: Linf=38.6 K=0.27 T0=-1.24	a=7.5e-06 b=3.09	0.1 (ICES, 2015)	February - June	Juveniles quit nurseries at age 3.	Assumed annual redistribution in February for spawning.	BTS survey, July.
Plaice	7 (age 1-7)	VBGF: Linf = 54.3 K = 0.17 T0 = -1.6	a=1.14e-5 b=3.02	0.3531,0.3132,0.292,0.2749,0.2594, 0.2474,0.232 (ICES, 2015)	December - March	Juveniles quit nurseries at age 3.	Dec.: matures to spawning area Apr.: To Coastal areas.	CGFS October; Coull et al. 1998
Red mullet	4 (age 0-4)	VBGF: Linf = 29.5 K = 0.7 t0 = -0.005	a = 1.31e-5 b = 3	derived from length using Gislason relationship 1.4,0.66,0.49,0.42,0.36	May - July	Juveniles quit coastal areas at age 1.		CGFS October;
Scallops Baie de Seine (coast)	5 (age 2-6)	VBGF (Antoine,1979) Linf = 139.23 K = 0.569 T0 = 0.527	a=2.74^{e}-7 b=2.9	0.1	July	Maturity at age 2.	na	COMOR survey
Scallops Baie de Seine (out)	5 (age 2-6)	VBGF (Antoine,1979) Linf=139 K=0.475 T0=0.494	a=2.74^{e}-7 b=2.9	0.6	July	Maturity at age 2.	na	COMOR survey
Cod	6 (age 1-6)	VBGF: Linf=131.8 K=0.229 T0=0.14	a = 9e-6 b = 3	1.326,0.962,0.233,0.2,0.2,0.2 (ICES, 2015)	January -April		Jan.: Matures to spawning grounds	CGFS October;
Whiting	8 (age 1-8)	VBGF: Linf = 35.1 K = 0.85 T0 = -0.257	a = 9.6e-6 b = 3	1.575,0.887,0.585,0.558,0.552,0.551,0.562,0.587 (ICES, 2015)	February-April			CGFS October;
Squid	1	Length from january to december Vulgaris: 20.5,24,28,28,0,0,0,0,0,13,14.5,17.5 Forbesi: 0,0,0,0,0,19,23.5,28.5,34,37,0,0	Mean =0.1 (Ifremer, 2014)	2.4 (Royer *et al.*, 2002) Adults die after breeding	End of autumn			BTS and CGFS surveys.
Cuttle fish	1 (age 1)	VBGF: Linf=30.5 K = 1.25 t0 = n/a	a = 2.27e-4 b = 2.26	1.2 (Royer *et al.*, 2006) Adults die after breeding	Spring		Winter migration offshore,	BTS and CGFS surveys.

					inaccessible to fishing.

Details on the distribution of the populations in space

Literature provided information on the timing, zones and movements of fish between feeding, spawning and nursery grounds. It was assumed that all mature individuals migrate to spawning grounds during the spawning season. Outside the spawning season, survey data were used to map species distribution, and individuals were distributed in model zones accordingly.

Prices

Similar as Lehuta et al. (2015), a price model was estimated for each commercial category of the populations based on sales slips over the period 2005-2015. We assumed a semi-log model considering the effect of month and commercial category and a negative relationship with landings at the monthly scale (elasticity). The bad adjustments of price equations for cuttlefish and scallops in Baie de Seine led to consider monthly prices constant over years for these populations.

$$price(species, cat) = \mu_{species} + \mu_{\mathrm{cat}} + \mu_{month} + \gamma_{species} * \log(landings_{species,month})$$

With cat, the commercial category, μ the fixed effects associated to the species (intercept), commercial category and month and γ the species-specific elasticity coefficient.

Table S1.3: Parameters of the price models

Species	Intercept	elasticity	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sole	34.83	-1.92	0.00	0.07	0.97	1.01	1.55	1.72	2.05	1.49	0.89	0.68	0.64	1.44
	commercial category (ccat)	10	20	30	40	51	52							
	Ccat coefficient	0.00	-0.47	-0.93	-1.42	-2.27	-1.48							
Red mullet	17.51	-1.12	0.00	0.18	1.26	1.85	1.93	1.43	2.64	2.36	1.22	0.26	-0.41	-0.27
	commercial category	10	20	21	22	30	32	32						
	Ccat coefficient	0.00	0.51	0.49	0.37	-0.61	-0.33	-1.51						
Cod	7.29	-0.29	0.00	-0.49	-0.33	-0.33	-0.19	-0.29	-0.36	-0.15	0.04	0.28	-0.06	0.22
	commercial category (ccat)	10	20	30	40	50								
	Ccat coefficient	0.00	-0.05	-0.20	-0.46	-0.74								
Plaice	4.48	-0.35	0.00	-0.02	0.21	0.37	0.34	0.35	0.42	0.50	0.50	0.46	0.49	0.11
	commercial category (ccat)	10	20	30	40									
	Ccat coefficient	0.00	-0.12	-0.26	-0.45									
Whiting	3.89	-0.16	0.00	-0.30	-0.27	-0.17	-0.24	-0.45	-0.31	-0.30	-0.01	0.19	0.28	0.24
	commercial category (ccat)	10	20	30	40									
	Ccat coefficient	0.00	-0.17	-0.28	-0.40									
Squids	20.00	-1.16	0.00	1.04	2.07	2.52	1.39	-0.14	-0.41	-0.36	-0.90	-1.33	-0.97	0.75
	commercial category (ccat)	11	12	20	30	40	50							

	Ccat coefficient	0.23	0.19	0.38	0.53	0.32	-0.18							
Scallops Baie de Seine exterior			2.84	2.59	2.70	2.47	2.40	0.00	0.00	0.00	0.00	2.41	2.89	3.21
Cuttlefish			2.62	2.70	2.61	2.32	2.21	2.55	2.79	2.32	2.50	2.43	2.29	2.51
Scallops Baie de Seine			2.90	2.80	2.90	2.60	2.50	2.40	2.40	2.40	2.30	2.50	2.70	3.30

Supplementary material S2: Parameters of the fleet dynamic model

Parameters of the fishing activity module are estimated based on analysis of declarative data (Ifremer, SIH, 2008-2014) and assessment data(ICES, 2015). Selectivity curves for gears and species are either extracted from literature (trammel nets selectivity for sole, cod and plaice, Madsen et al. 1999), derived from catch curves (onboard observer data, OBSMER 2005-2015).

Table S2.1: 17 Fleets considered fishing demersal species in the Eastern English Channel segmented according to home harbour into two regions (North and Normandie) and according to vessel length.

	Main gear	**Nord-Pas de Calais**		**Fishing efficiency**	**Normandie**		**Fishing efficiency**
Fleet		Vessel length class	Average vessel number (2008-2014)		Vessel length class	Average vessel number (2008-2014)	
Exclusive bottom trawlers	OTB	18-40m	11	2.32	<12m 18-40m	18 17	0.93 1.48
Mixed trawlers	OTB and other trawling gear	18-24m 24-40m	14 8	3.01 2.52	18-40m	7	2.35
Trawlers-dredgers	OTB, dredge and other trawling gear	10-12m 12-18m	13 8	2.83 2.79	<10m 10-12m 12-18m 18-24m	11 55 103 5	1.09 1.37 2.54 2.5
Netters	Trammel nets, gillnets and other gear	<10m 10-12m 12-18m	7 46 10	0.61 1.64 2.85	<10m 12-12m	21 10	1.18 1.34

Table S2.2: Intensity of targeting (TargetF) of the different species by the five gears considered in the model estimated by generalized linear model on catch per unit of effort data.

gear	cod	ctc	mur	ple	sce	sol	sqz	whg
DRB	3.356	0.187	0.200	1.901	457	3.145	0.866	0.239
GNS	4.868	10.193	1.646	10.953	0	4.396	0.046	2.573
GTR	12.661	1.935	0.856	12.005	0	55.016	0.086	0
OTB	23.704	1.777	40.965	7.111	0.331	6.784	30.214	10.057
TBB	8.839	0.069	0.188	25.761	5.790	31.266	0.446	0

Table S2.3 Characteristics of the fleets

<table>
<tr><th>Fleet type</th><th>Main gear</th><th></th><th>Main species</th><th>Main discarded species</th></tr>
<tr><td>Bottom trawlers</td><td>OTB</td><td>All year</td><td rowspan="2">red mullet, cephalopods, cod, whiting, plaice and sole</td><td rowspan="2">Sole (undersized), plaice and whiting</td></tr>
<tr><td rowspan="3">Trawler-dredgers</td><td>OTB</td><td rowspan="2">Rest of the year</td></tr>
<tr><td>TBB</td><td>sole, plaice, cod</td><td></td></tr>
<tr><td>DRB</td><td>Winter</td><td>scallops</td><td></td></tr>
<tr><td>Netters</td><td>GTR</td><td>All year</td><td>Sole, plaice and cod</td><td>Undersized plaice</td></tr>
</table>

Supplementary material S3: Management parameters

Table S3.1: 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

Scallops regulation :

Harvest of scallops in the Baie de Seine area is strictly regulated by national law (JORF n°0198 du 25 août 2017, https://www.legifrance.gouv.fr/jorf/id/JORFTEXT000035454472). Licence limit the size and number of vessels allowed to catch scallops. Daily and weekly catch per vessel are limited in the coastal and more offshore area and depend on vessel size. Harvesting is allowed only part of the year from October to May. Access is further restricted in the coastal area of Baie de Seine, and only allowed from mid-November to March to protect the resource and the spawning season.

In ISIS-Fish, catch limits were modelled as monthly catch limits per fleet depending on vessel size and number. November catch limit was half the value in other month to account for the closure of the fishery at the in the first weeks of the month. Zones were closed and scallops métiers forbidden seasonally as indicated in the regulation.

Avoidance areas :

From a Landing Obligation perspective, if a species is potentially seen as choke species, then fishermen may try to avoid it by redistributing their effort along the year and across their fishing areas. Lots of maps have consequently been produced to spatialize landings based on the coupling of logBooks and VMS. These maps are either based on monospecific landings or based on clustering of species composition of the landings. When mapping landings of a species in volume or average proportion in landings, it is not possible to determine if areas with high landings (or high proportions) result of numerous fishing operations with the species as by-catch or of few targeted operations. These two situations have very different implications in terms of avoidance ability.

We instead propose a tool that maps the risk of catching a given species in a given area at the fleet and gear (métier) scale. Logbooks were merged with VMS data to allow aggregating landing at any spatial scale (.25’*.25’ in the following document). All landings by species were then expressed as a fraction of the total landings reported for a fishing operation (as estimated by the VMS reallocation). The user then defines a maximum proportion (resp. minimum) of the species in the landings (proportion threshold), he is willing to accept depending on the objective i.e. avoiding or targeting the species. Indeed the acceptable proportion may depend on the species and situation: e.g. TAC already reached (then the proportion must be null), de minimis (a threshold is imposed by the regulation), or optimization of quota over the year (avoiding is not compulsory but may allow spreading activity over the year). The probability of avoiding (resp. targeting) the species is then mapped as the proportion of the fishing operations that meets the objective at the cell scale. The time scale is user-defined (either year/quarter or month).

By playing with the proportion threshold and the risk level, fishermen can visualize areas to avoid and target. For instance they may choose to avoid a species by fishing in areas with high frequency of low proportions. Alternatively they may take the risk to go fishing in areas where that species was seen in the landings in high proportion but only occasionally. They can choose this strategy in a case where some technical avoidance can be put in place or they can endorse that risk in term of quota: proportion threshold high but frequency low. It also provides guidance for a reorganization of the activity within the year by allowing comparison of risk maps between seasons and months.

Supplementary material S4: Additional result graphs

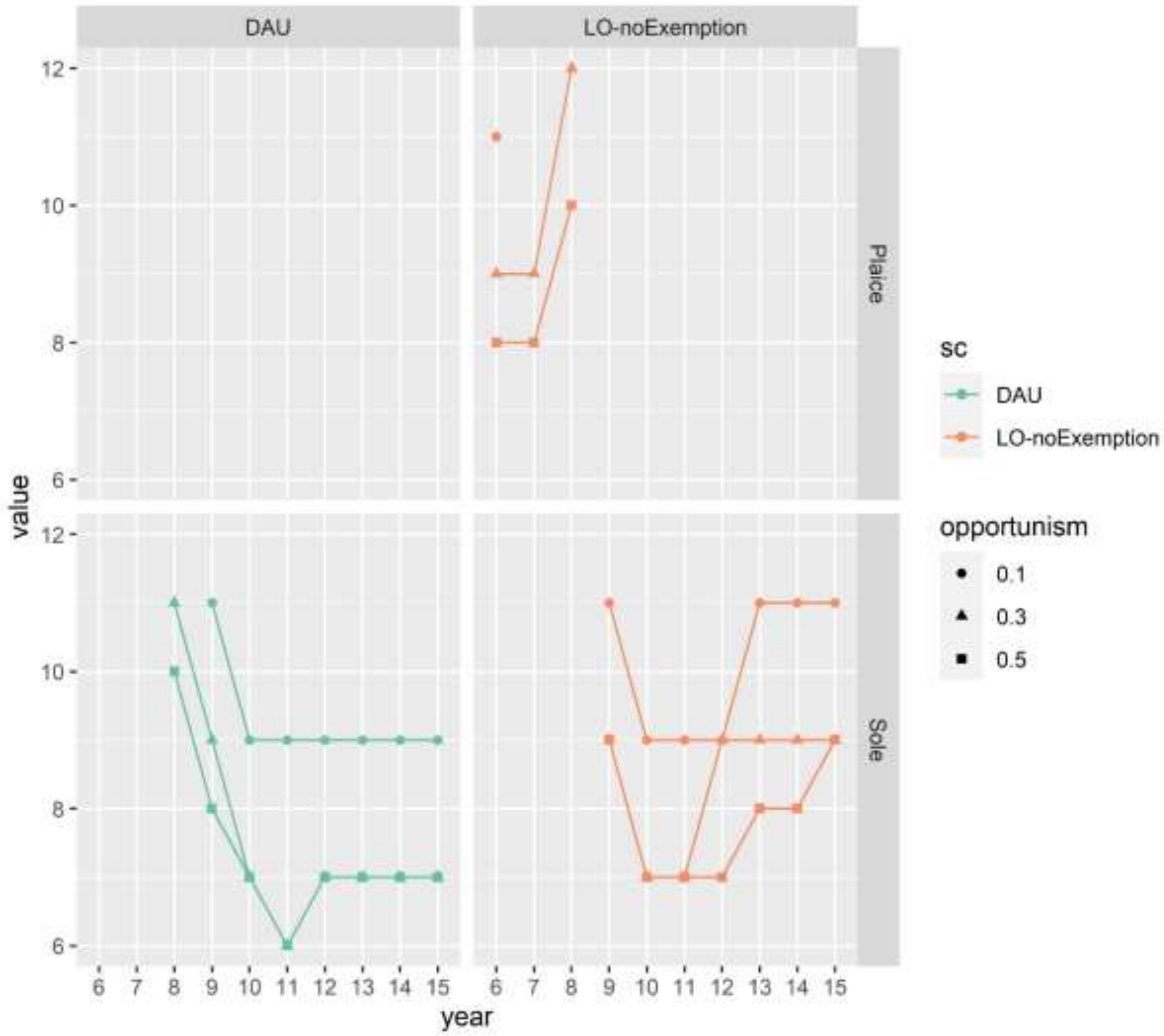

Figure S4.1: Months when the TAC of plaice (top panels) and sole (bottom panels) were reached every year by French fleets in the scenario Discard as usual (DAU, left panels) and landing obligation without exemption (right panels, LO-noExemption). The 3 lines in each graph, are for the different value of opportunism (shape of the points).

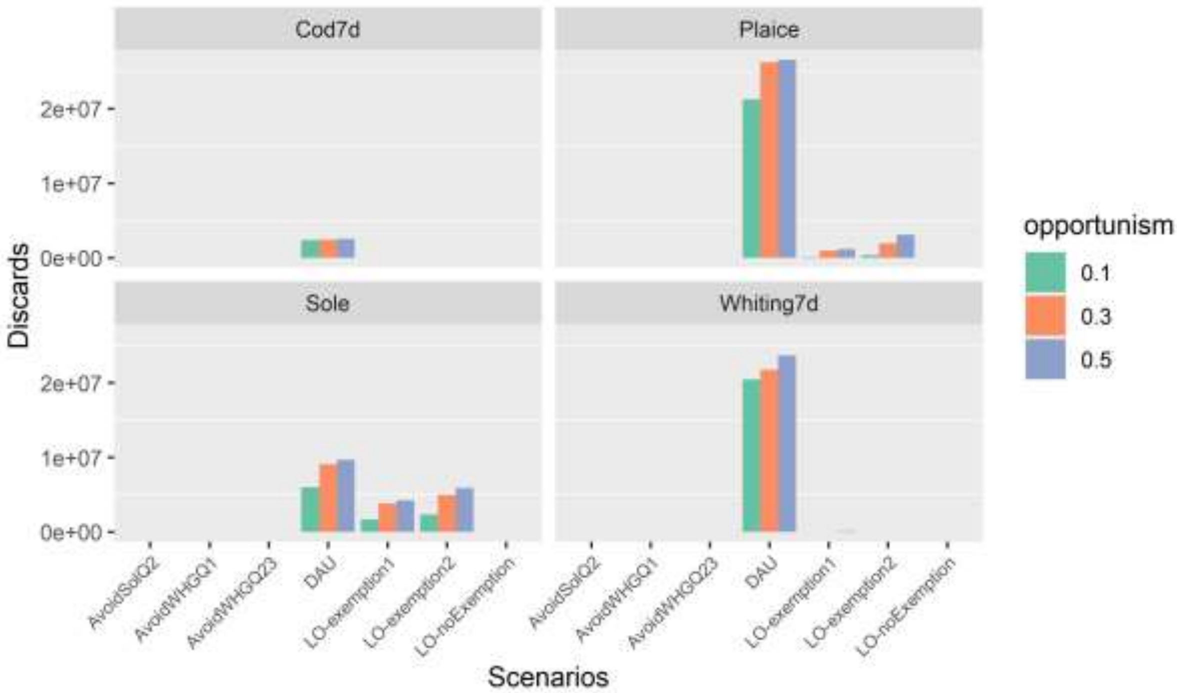

Figure S4.2: Discards (kg, cumulated over years >2015) across scenarios and species with the influence of opportunism level.

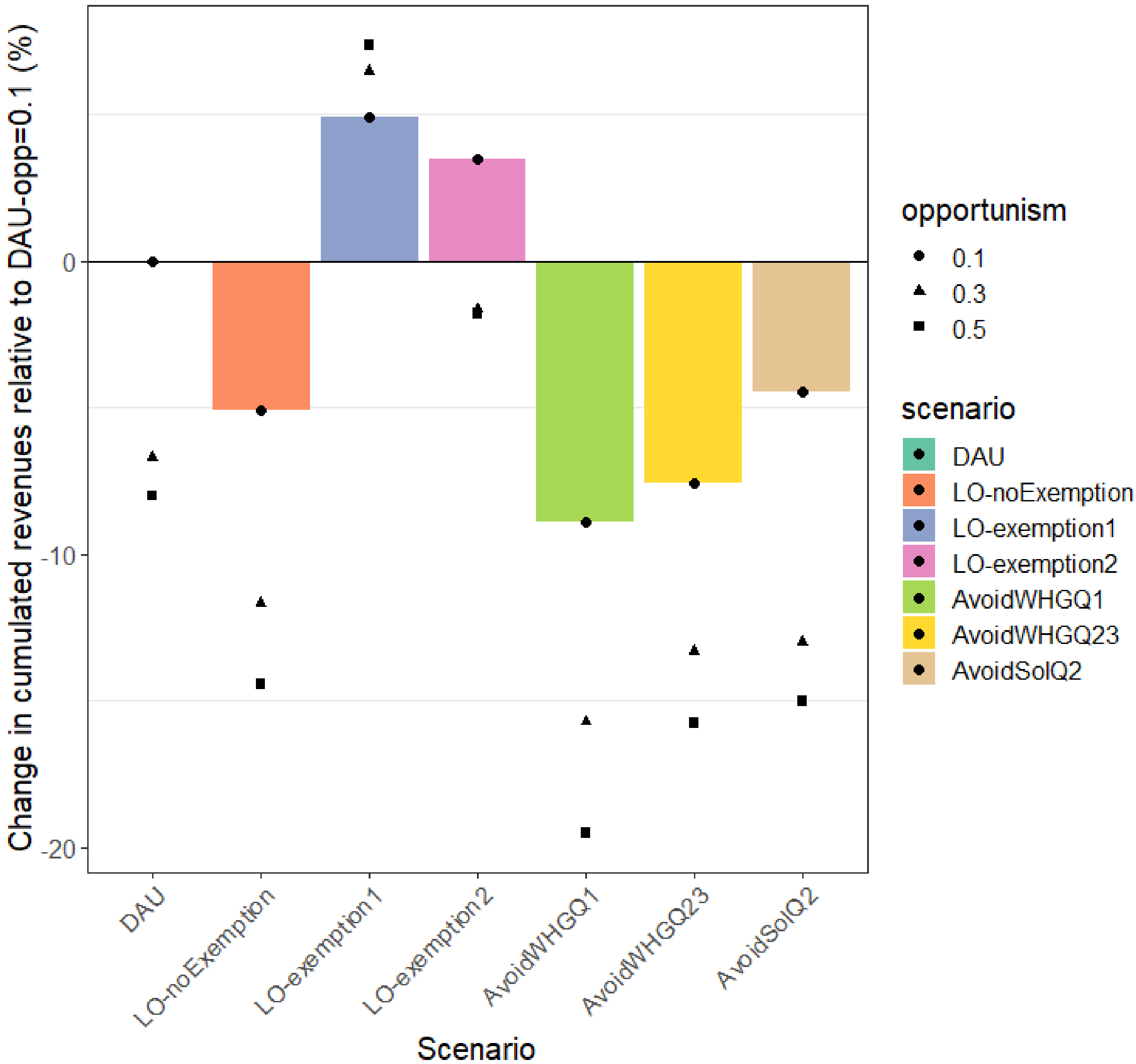

Figure S4.3: Changes in cumulated revenues across scenarios relative to the Discard as Usual Scenario (with opportunism = 0.1). Dots indicate the value in the same scenario for the other values of opportunism. It shows the loss due to the landing obligation and the mitigation brought by the exemption scenarios. Avoidance measures on whiting worsen the impact of the landing obligation on revenues. Avoidance measure on sole reduces the impact of the landing obligation on revenues.

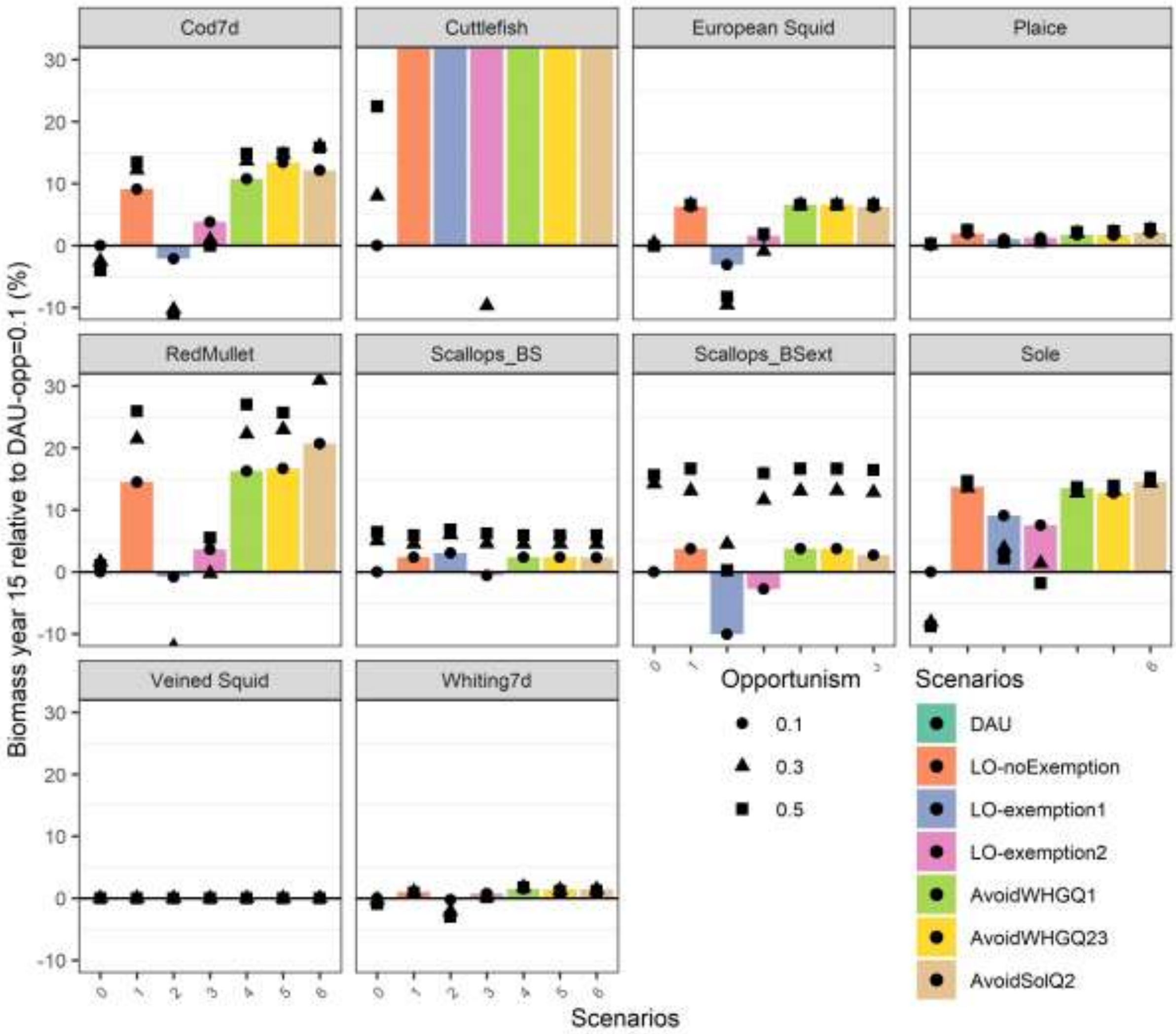

Figure S4.4: Biomass (%) of the ten stocks in year 15 under the 7 scenarios (X axis) and 3 assumptions of opportunism level in fleet behaviour (point shape) relative to the reference scenario "Discard as Usual" and very traditional fleet behaviour (low opportunism) (DAU; opp=0.1). Scale is fixed [-10;30].

Supplementary material S5: Validation Graphs

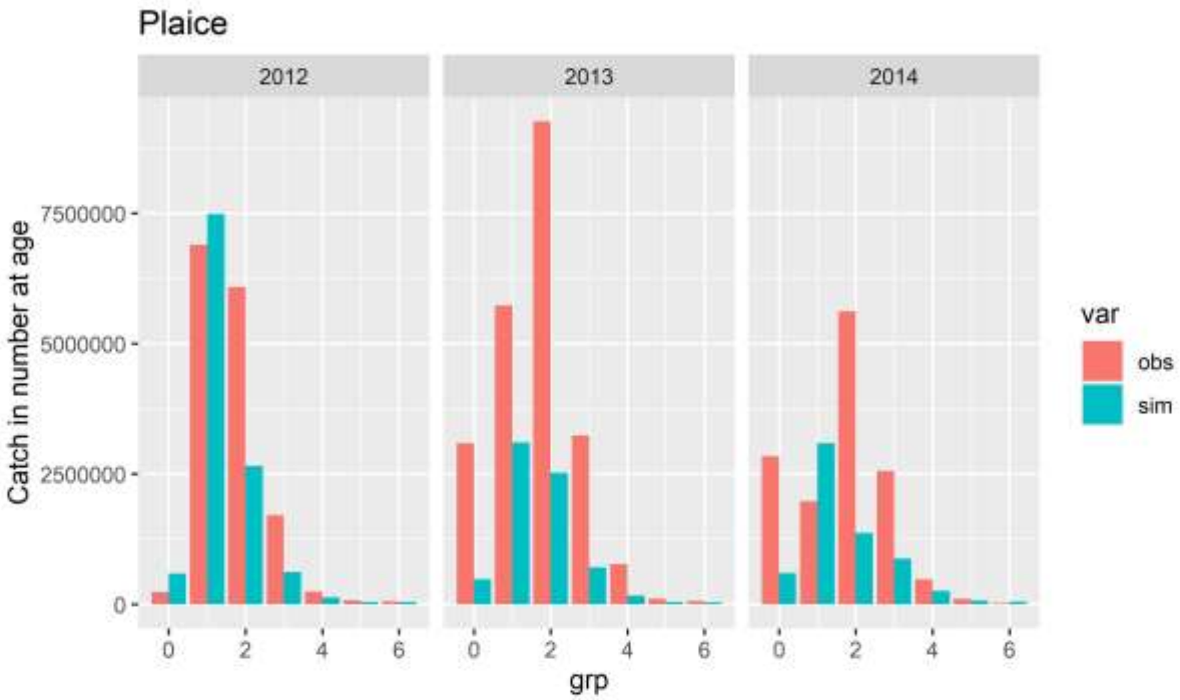

Figure S5.1: Catch in number at age of Plaice by French fleets between 2012 and 2014 derived from observations "obs" (declarative data ventilated by age) and simulated "sim".

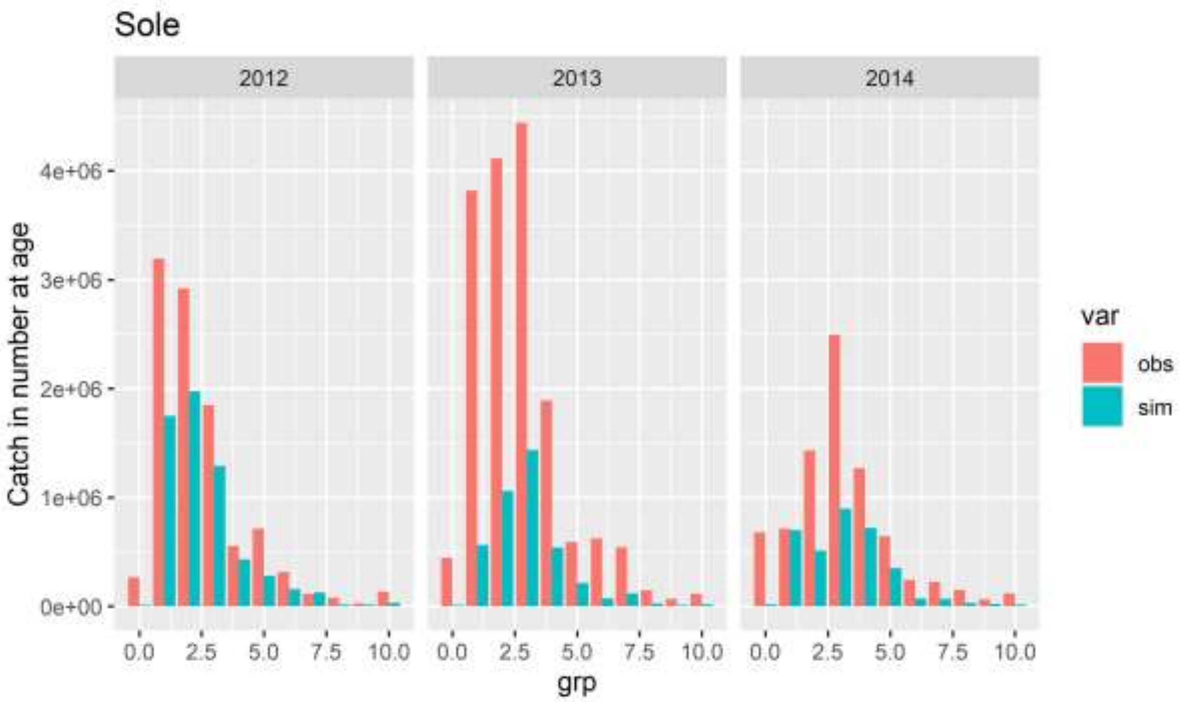

Figure S5.2: Catch in number at age of Sole by French fleets between 2012 and 2014 derived from observations "obs" (declarative data ventilated by age) and simulated "sim".

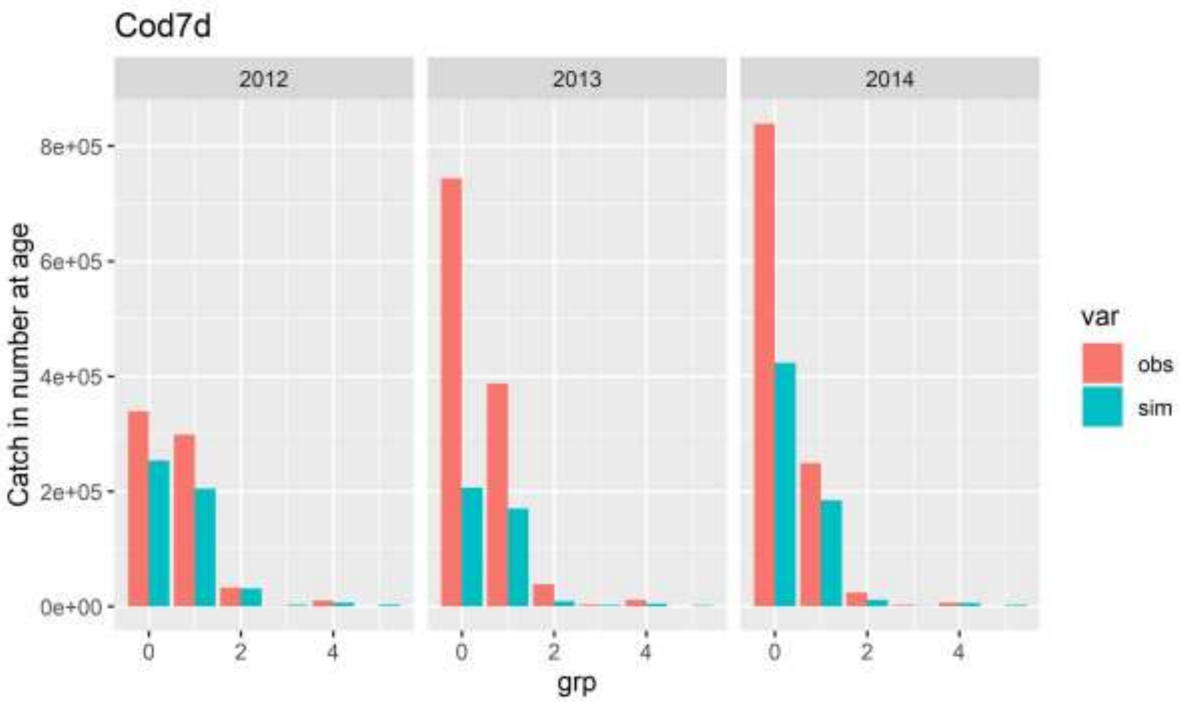

Figure S5.3: Catch in number at age of Cod by French fleets between 2012 and 2014 derived from observations “obs” (declarative data ventilated by age) and simulated “sim”.

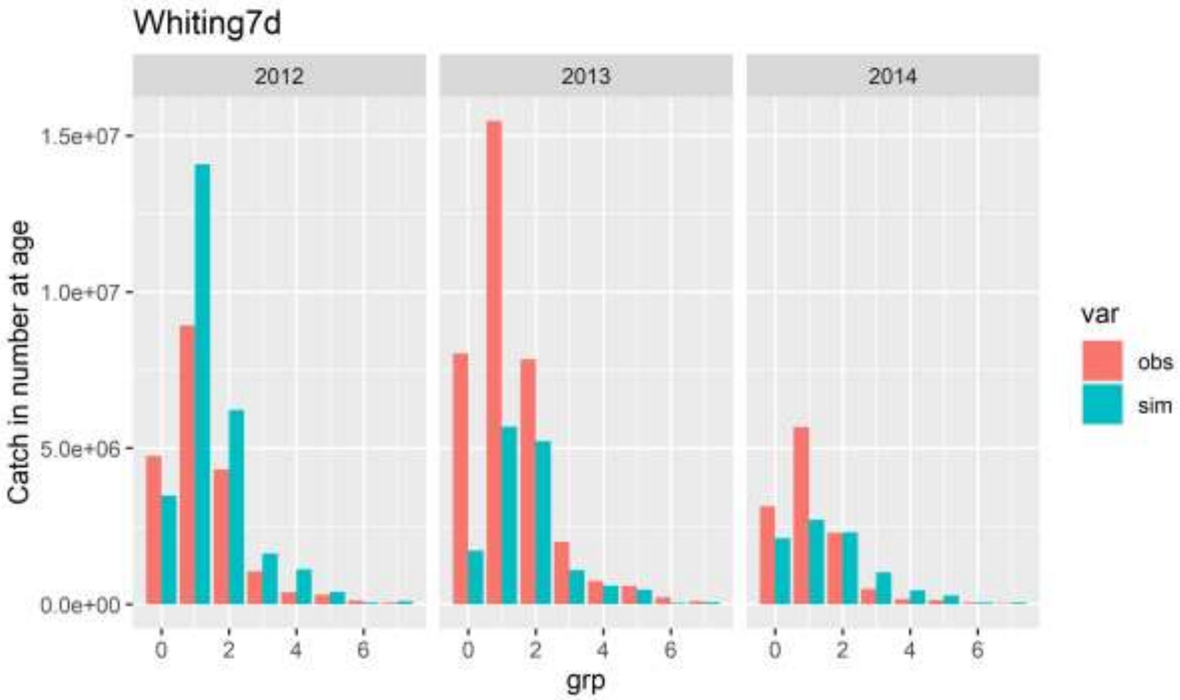

Figure S5.4: Catch in number at age of Whiting by French fleets between 2012 and 2014 derived from observations “obs” (declarative data ventilated by age) and simulated “sim”.