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### ► To cite this version:

Z. Provot, S. Mahevas, Laurie Tissi re, Charlotte Michel, S. Lehuta, et al.. Using a quantitative model for participatory geo-foresight: ISIS-Fish and fishing governance in the Bay of Biscay. *Marine Policy*, 2020, 117, pp.103231. 10.1016/j.marpol.2018.08.015 . hal-02172338

**HAL Id: hal-02172338**

**<https://hal.science/hal-02172338>**

Submitted on 16 Jun 2022

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# Using a quantitative model for participatory geo-foresight: ISIS-Fish and fishing governance in the Bay of Biscay

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# 1 Introduction

The diversification of offshore activities continues to increase (e.g. offshore wind farms, marine aggregate extraction, aquaculture, etc) and maritime space is more than ever the subject of social, economic and environmental conflicts (Mackinson and Wilson, 2014; Thébaud et al, 2014). The diverse nature of the changes affecting this space is such that a sectorial approach is no longer adequate and a system-wide approach is required for successfully sharing the space and its resources within a multi-stakeholder framework (van Hoof et al 2012). Several framework directives (e.g. Directive 2014/89/EU establishing a framework for maritime spatial planning and Directive 2008/56/EC Marine Strategy Framework Directive) have provided the basis for the measures drawn up by the European Commission (EC) covering the good environmental status of marine waters and the planning for the use of these waters.

In general, the fisheries management measures adopted by the EC result from a (not very transparent, Gascuel et al, 2008) compromise between economic, environmental and social objectives. Each year, the EC consults the working groups of the International Council for the Exploitation of the Sea (ICES) and the Scientific, Technical and Economic Committee for Fisheries (STEFCF) to provide guidelines for its decisions on marine fishing management (Lequesne, 1999). These bodies assess the status of the fishing stocks using indicators (e.g. biomass  $B$ , fishing mortality  $F$ , fishing effort  $E$ , etc) on the one hand and, on the other, evaluate the management measures which would maintain the good environmental status of fish stocks and fleet performances (e.g. total allowable catch (TAC), marine protected areas, and, more recently, landing obligation) (Caddy and Mahon, 1996). Scientific working groups make extensive use of quantitative models. By studying the consequences of the management measures on marine population dynamics, fishing dynamics and the economy (Lehuta et al., 2013, Fulton et al., 2011), quantitative models are determinants for decision-making processes (Lehuta et al 2016, Fulton et al., 2011). However, certain gaps in the knowledge of the dynamics studied (e.g. growth rate, recruitment, fishing effort transfer) constitute an obstacle to sustainable management of the whole socio-ecosystem. To reduce potential bias in stock estimates (Biais, 1993) and improve the evaluation of management measures and their acceptance, it appears to be essential for fishermen,

29 managers and scientists to share knowledge (Tissière et al, 2018a, Linke et Bruckmeier, 2015,  
30 Stephenson et al. 2016).

31 To encourage this, the EC calls on the participation of stakeholders in the decision-making  
32 process (reform of the Common Fisheries Policy (CFP), 2002; setting up of Regional Advisory  
33 Councils (RAC), 2004). So far, the lack of transparency in the decision process and the complexity  
34 of the models were seen as impediments to the participatory processes (van Hoof 2015). However,  
35 methods exist to introduce stakeholders to (complex) quantitative models, and make models a  
36 support to share actor's expertise, discuss the design of management scenarios, and endorse the  
37 outputs of the evaluations which form the basis of policy decisions.

38 Geo-foresight can be used to orchestrate a participatory approach managing the complexity of  
39 the studied system, the spatial aspects of the system and the participation of stakeholders. It  
40 combines "future studies" (i.e. making preparations for the short term and setting the foundations  
41 for the future (De Jouvenel and Fish, 2004), geography and modeling (Gourmelon et al., 2012;  
42 Houet and Gourmelon, 2014). It is a discipline in development with no fixed definition or formal  
43 methodology. Geoforesight sets out to build a range of scenarios for a system by taking into  
44 account the three keystones of sustainable development (i.e. ecology, social science and  
45 economics) (De Jouvenel and Fish, 2004; Houet and Gourmelon, 2004; Godet, 2001; Mermet,  
46 2005). Scenarios are defined here as alternative dynamic stories telling about integrated and  
47 provocative alternative futures (Peterson et al 2003, Kahn and Wiener 1967). Geo-foresight  
48 includes and is structured around spatial aspects at all stages in drawing up the scenarios  
49 (Gourmelon et al., 2012). By encouraging debate, this approach helps stakeholders to anticipate  
50 changes, in particular spatial long-term changes in their environment and activities (De Jouvenel  
51 and Fish, 2004; Godet, 2001).

52

53 Such an approach has been carried out in the Bay of Biscay, where a group of stakeholders  
54 concerned with maritime fisheries governance were invited to discuss the future of this maritime  
55 space, particularly in terms of spatial changes and to create (narrative) scenarios of the future of  
56 the fishing industry. As part of this study, discussion workshops were held over two years. A

57 complex quantitative model was used to illustrate with quantitative variables the qualitative  
58 scenarios formulated during these workshops with a focus on the demersal fisheries of the Bay of  
59 Biscay (see Tissière et al 2016, Tissière et al 2018b for the details of this participatory foresight  
60 approach).

61 In this paper, we focus on one of the original aspects of this study, which lies in the nature and  
62 function of the model used. Usually, scenario planning is based on co-constructed models which  
63 help comprehend the complex nature of the systems (Etienne, 2006). These may be grouped as  
64 “companion modeling” approaches (see ComMod [www.commod.org/en/](http://www.commod.org/en/)), which include various  
65 forms such as conceptual models (Etienne, 2006; Étienne, 2009), multi-agent systems and  
66 modeling platforms (Bousquet et al., 1998, Bousquet et al., 2013) and role-playing models  
67 (Barreteau et al., 2002). In a “companion modeling” approach, the model brings new information  
68 at each step of the playing session to put in situation the players and see how the participants react  
69 at each step. These conceptual models enable players to draw up scenarios for the future but they  
70 do not allow their quantitative evaluation. On the contrary, the ISIS-Fish model used in this study  
71 is a spatialized quantitative complex model of fisheries dynamics built by scientists within an  
72 academic framework (Mahévas and Pelletier 2004, Pelletier et al 2009) and is only involved in the  
73 final phase of scenario planning. Unlike standard “companion models”, it is not used to create the  
74 scenarios but to simulate some of their main variables thus providing quantitative projections of  
75 the evolution of the studied system. The purpose is to give a tangible counterpart to the narratives,  
76 by translating scenarios into quantitative assumptions and simulation settings and make the  
77 projections based on the modelled functioning of the fisheries instead of mental models.

78 ISIS-Fish is usually used in fisheries science to evaluate the consequences of management  
79 measures on the dynamics of species and fisheries. It is a spatial, multi-species and multi-fleet  
80 model and can be used for a wide range of applications (Gasche, 2014; Mahévas and Pelletier,  
81 2004; Pelletier et al., 2009; Lehuta et al., 2013). This complexity makes it closer to the decision-  
82 making models used by scientific working groups. This model was selected for its availability and  
83 operational status. Furthermore, it was specifically developed to account for the spatial dynamics  
84 of the system, making it directly suitable to handle the geographic aspects of geo-foresight. Finally,

85 parameters can easily be modified to account for new information provided by the actors. The  
86 mixed demersal fishery of the Bay of Biscay is a major structuring fishery in the area, in terms of i)  
87 landed values of the main target species hake, *Merluccius merluccius*, Norway lobster (Dublin Bay  
88 prawn), *Nephrops norvegicus*, and European common sole, *solea solea*, ii) management concerns  
89 (STECF, 2015), and iii) spatial conflicts with other activities, given that the fishery operates mainly  
90 close to coast and in a major conservation area : the “Grande vasière”. The ISIS-Fish application  
91 to this fishery was consequently selected to conduct the scenario evaluations.

92  
93 This study examined whether ISIS-Fish, a complex quantitative model designed independently  
94 of the participatory foresight can contribute to the ambitious objective of this process, that is  
95 sharing a common vision to improve fisheries management and fisheries science. The approach is  
96 simulation-based combining qualitative and quantitative expert-knowledge to support discussion  
97 between scientists and stakeholders on the functioning and the future of the demersal fishery in  
98 the Bay of Biscay. A three-stage approach was carried out to address these issues : (i) translation of  
99 a narrative scenario drawn up by stakeholders into quantitative sub-scenarios that could be  
100 parameterized in ISIS-Fish; (ii) simulation and study of the consequences of the sub-scenarios on  
101 the dynamics of mixed demersal hake, Norway lobster and common sole fishery; and (iii)  
102 participants feedback on the relevance of the model, the possibility to detail the narrative scenario  
103 further and the general contribution of ISIS-Fish to geo-foresight.

## 104 **2 Materials**

### 105 2.1 Study site

106 The mixed demersal fishery in the Bay of Biscay (Figure 1) is fishery composed of a little more  
107 than 700 vessels over 12m long. Landed value mainly distributes among hake, Norway lobster and  
108 common sole (STECF, 2015, Leblond et al., 2012). The fishery is characterized by the variety of  
109 fishing gear used (trawl, nets and lines), the interactions among fleets and the many technical  
110 interactions between species. The most prominent concerns trawlers activity targeting Norway  
111 lobster on the “grande vasière” which is also a nursery area for hake. This activity thus leads to

112 numerous bycatch of juveniles hake under the legal landing size and subsequent discards. Hake,  
113 common sole and Norway lobster stocks are assessed by ICES and the fishery is subject to a  
114 number of management measures (TACs and quotas, minimum landing sizes, in the context of the  
115 hake recovery plan since 2004, the common sole management plan, a multi-species management in  
116 progress, as well as the application of framework directives (Marine Strategy Framework Directive  
117 and framework for maritime spatial planning)).

118

119 Fig1: here

## 120 2.2 ISIS-Fish model

121 A brief description of the model is given here. A more detailed description can be found in  
122 Mahévas and Pelletier (2004) and Pelletier et al. (2009). The ISIS-Fish model simulates fishery  
123 dynamics. It sets out to describe explicitly the spatial and seasonal dynamics of fishing stocks,  
124 fishing activities and regulation of access to resources. It provides information on the functioning  
125 of fisheries and evaluates fishery management scenarios.

126 ISIS-Fish is a mechanistic model with a monthly time step which couples three sub-models in  
127 time and space (with a variable resolution grid, Zones variable in Table 1) (Figure 2):

- 128 (i) the population dynamics model describes the seasonal movement, growth, reproduction,  
129 recruitment and natural mortality for each species of the fishery (Species variables in Table 1);  
130 (ii) the fleet dynamics model describes the seasonal and spatial allocation of the fishing effort for  
131 computing the fishing mortality depending on the characteristics of the vessels, activities  
132 (métiers) and annual fishing strategies (Gear, Fishing métier, Type of trips, Type of Vessel,  
133 Fleets and Strategies, Table 1); (iii) the fishery management dynamics model described the  
134 fishing limits for the fleet and the changes in fishing strategy in response to these limits  
135 (Management measures variables, Table 1).

136 The geographic scope of the ISIS-Fish model in this study covers the whole of the Bay of  
137 Biscay (Figure 1) and the spatial grid is based on ICES statistical rectangles (ICES 1977). We used  
138 a first application of the ISIS-Fish model describing the demersal fisheries of the Bay of Biscay  
139 (Worsøe C. L. et al., 2016). The application was initially developed to investigate multi-species

140 reference points based on fishing effort and to assess the impact of fishing effort reduction on  
141 fisheries dynamics and benthic habitats (Mahévas et al, 2015). The spatial and seasonal dynamics of  
142 hake, Norway lobster and common sole mimic the life cycle of these species. The fishing activity  
143 module includes nine fleets, six French fleets and three Spanish fleets (using trawls, nets and lines),  
144 divided into sub-fleets according to their specific annual strategies. The database used was  
145 calibrated on ICES working group observations for 2010 (ICES 2015). Biological and fishing  
146 exploitation information required to set the model are detailed in Annex 1 and the database can be  
147 downloaded on the ISIS-Fish website (<http://www.isis-fish.org/download.html>, Bay of Biscay  
148 scenario dataset). The explicit spatial structure of ISIS-Fish enables the description of the technical  
149 interactions between Hake, Norway lobster and common sole that have long been the focus of  
150 managers in this region.

151

152 Fig2: here

153 Table 1 : here

154

### 155 2.3 *Geo-foresight*

156 The geo-foresight performed to “dream up” a future of the demersal fishery of the Bay of  
157 Biscay at the horizon 2050 can be described as mixed. Indeed it combines both qualitative and  
158 quantitative methods with explicit temporal and spatial dimensions. This exercise took place  
159 between April 2015 and May 2017 and the methodology is based on surveys punctuated by three  
160 workshops for the iterative construction of scenarios. This section gives a brief description of the  
161 major aspects of the geo-foresight required for this study. For further details see Tissièrè et al.  
162 (2018 b) and Tissièrè et al. (2016). The group of stakeholders was composed of representatives of  
163 fisheries (PO representatives and the president of the regional fishing and fish-farming advisory  
164 committee) and representatives from the offshore wind farm industry. State services were also  
165 invited represented by members of the InterRegional Marine Directorate, the Marine Protected  
166 Area agency and from local authorities. Scientists from various disciplines related to marine fishing  
167 were also part of the working groups (fisheries scientists, geographers and foresight experts). All



168 accepted the invitation with the exception of local environmental protection associations (NGOs).  
169 The modeling expert also attended the scenario planning workshops and took part in creating the  
170 scenarios, more as an observer than as an active contributor. The first workshop highlighted the  
171 main maritime fishing stakes of the Bay of Biscay encompassing fisheries management,  
172 cohabitation of multiple uses and environmental status. The main associated drivers characterized  
173 by trends and uncertainties were also pointed out. In the second workshop, the stakeholders drew  
174 up qualitative scenarios on the future of fishing in the Bay of Biscay up to 2050 using variables and  
175 assumptions defined during the first workshop. The stakeholders were divided into several groups  
176 and built three scenarios. The first, entitled “Jaws in the Bay”, was based on the collapse of the  
177 French interventionist model (i.e. the government lost its authority at sea in favor of private  
178 organizations). The second, entitled “Sinking fishing”, was based on the break-up of the European  
179 Union, leading to the fragmentation of marine fisheries management. The third, entitled “Fishing  
180 takes on water”, assumed the disappearance of towed gear and a change in the fisheries economic  
181 model with a strategic coastal organization. The quantitative study focused on the first scenario  
182 “Jaws in the Bay” (further details are available in Annex 2). The same type of approach could have  
183 been applied to the other scenarios but the time allocated to this study was too limited. A  
184 traditional foresight approach would have stopped at the end of the second workshop with a  
185 report and at best, with a restitution of the narrative form of the scenarios to the stakeholders  
186 (Figure 3). Mixing the quantitative complex model with the creation of the scenarios has led to  
187 holding a third workshop for the consultation of stakeholders involved in “Jaws in the Bay”  
188 scenario regarding the simulation work (Figure 3). Therefore this study covers the work done in  
189 between the end of the second workshop, and the third workshop of the geo-foresight.

190

191 Fig3 : here

### 192 **3 From the narrative scenario to simulation with ISIS-Fish**

193 This section described the proposed approach to operate the quantitative modelling tool ISIS-  
194 fish in the geo-foresight exercise simulating one of the qualitative scenario created by stakeholders.

195 The end of the second workshop was dedicated to the presentation of ISIS-Fish to stakeholders.  
196 The main mechanisms of the model were presented in a short video (available from [isis-fish.org](http://isis-fish.org)).  
197 The method breaks up in three steps: the translation of the “Jaws in the Bay” scenario into  
198 quantitative sub-scenarios (Section 3.1), the modeling and simulation of the sub-scenarios with  
199 ISIS-Fish (Section 3.2) and the presentation of the results to the stakeholders (Section 3.3).

### 200 *3.1 Translating the “Jaws in the Bay” scenario into quantitative sub-scenarios*

201 The “Jaws in the Bay” scenario described the future of fisheries governance in the Bay of Biscay  
202 whereas the ISIS-Fish model focused on mixed demersal hake, Norway lobster and common sole  
203 fishery. Between the second and third workshops (Figure 3), stakeholders working on “Jaws in the  
204 Bay” were questioned during telephone interview to precise some points of the scenario at the  
205 scale of the demersal fishery.

206 First, the modeling expert and stakeholders agreed on six synthetic features structuring the  
207 scenario (Table 2): Operating mode of fishery management, Fleets, Vessels, Multiple marine uses,  
208 Controlling system, Science. Indeed, the operating mode of fishery management in “Jaws in the  
209 Bay” scenario is privatized leading to an access of maritime space and marine resources based on  
210 financial markets. Fleets are standardized through an harmonization of vessels characteristics to  
211 make economies of scale (e.g. reducing purchase price and exploitation costs). Vessels become  
212 ultra-modern and ultra-selective to meet sustainability and performance criteria of fisheries  
213 management. The cohabitation of multiple uses of the Bay of Biscay is managed by a spatial  
214 division of space into a patchwork of economic concessions to maximize the profitability of the  
215 maritime space (as illustrated in the schematic spatial representation in Annex 2). A controlling  
216 system relying on the “polluter pays” principle is established through a “sustainable fishing” charter  
217 defined based on environmental, social and financial criteria. Science becomes precarious and  
218 privatized, resulting in a scientific expertise subject to lobbying (financial and political) with an  
219 applied research dedicated to a selection of strategic topics. Only a selection of these features can  
220 be modeled in ISIS-Fish.

221

222 Table 2 : here

223 In a second step, the modelling expert therefore explained which features could be translated in  
224 the model using some of the structuring variables (Table 1) and illustrated how using examples  
225 (Table 2). These illustrations supported by references to the video presented during the second  
226 workshop have raised questions on the meaning of general concepts used in the scenario (e.g.  
227 privatization or standardization) in the particular context of the demersal fishery of the Bay of  
228 Biscay. The decision to focus on two of the synthetic variables, Fleet and Multiple marine uses,  
229 was reached by mutual agreement considering time constraints and the risk of dispersion. During  
230 the interviews, the modeler realized that a single formulation in the narrative scenario was actually  
231 translated in multiple possible values for ISIS-Fish variables Fleets, Types of vessels, Zones and  
232 Management measures. They reflected several possible assumptions about the functioning of the  
233 fishery, that were not detailed in the narrative but needed to be made all explicit in the model to  
234 avoid biasing the initial “Jaws in the Bay” scenario. This required the modeling expert to go back  
235 to the stakeholders for further precise these four variables and limit the number of possible  
236 assumptions and subsequent simulations. Regarding the Fleet variable (Table 2) the assumptions  
237 concerned the level at which standardization applied. Does it apply to the type of fishing (coastal,  
238 mixed, deep-sea)? Does it apply to the equipment (engine power, selectivity, length of vessel)?  
239 Stakeholders agreed on considering four options: a base case without standardization implying to  
240 keep all the vessels in the fishery as they are (“all vessels”), and three schematic declinations of  
241 standardization consisting in keeping alternatively one or two of the three existing segments of the  
242 fleet identified according to vessel length (“vessels of length 12m - 18 m”, “vessels over 18 m  
243 long”, “vessels less than 12 m and more than 18 m long”). The description of the Multiple marine  
244 uses variable raised the following questions: Are the economic concessions localized on the coast,  
245 the continental shelf or deep-sea? Is fishing allowed within the other economic concessions or is it  
246 pushed further offshore? Stakeholders considered a drastic spatial planning of marine uses  
247 localizing other uses than fishing within a coastal zone (called restricted zone “RZ”, and referring  
248 to the patchwork in the schematic spatial representation in Annex 2), banning fishing in this zone  
249 and pushing fishing activities offshore.

250 Crossing these assumptions, the stakeholders drew up four sub-scenarios derived from the  
251 initial “Jaws in the Bay” scenario that could be parameterized in the ISIS-Fish model: JB 1, JB 2,  
252 JB 3 and JB 4. All included a fishing ban in the RZ zone. The difference between the sub-scenarios  
253 depended on the length of the vessels allowed to fish. The JB quantitative sub-scenarios were:

254 JB 1 = RZ + vessels of length 12m - 18 m

255 JB 2 = RZ + vessels over 18 m long

256 JB 3 = RZ + vessels less than 12 m and more than 18 m long

257 JB 4 = RZ + all vessels

258 Before banning fishing activities from RZ, most vessels were fishing in this zone. The  
259 establishment of the ban has required modelling a fishermen reaction through a reallocation of  
260 fishing effort. Stakeholders agreed to consider that fishermen comply with the regulation and  
261 report their activity outside the ban on their remaining fishing zone (i.e. their usual fishing zone –  
262 RZ zone). RZ zone is close enough to the coast so that the remaining area for fishing is not empty  
263 and does not induce a stop of fishing in the fishery. The four sub-scenarios were then simulated  
264 using ISIS-Fish, limiting the active fleets described in ISIS-Fish to the standardized lengths and  
265 using the closing fishing area management option available in the simulation tool to ban fishing in  
266 the RZ zone.

### 267 3.2 *Simulations of sub-scenarios*

268 Simulations started in 2010 (model parameterization reference year) and lasted for 40 years to  
269 study the change in fisheries over the scenario period (2015-2050). The simulation took an average  
270 of 40 minutes. Each simulation corresponded to a quantitative sub-scenario based on the  
271 qualitative “Jaws in the Bay” scenario and, therefore, to a particular development path for the  
272 fisheries. The study considered the spatial and temporal changes in the populations of hake,  
273 Norway lobster and common sole and the fleets in the Bay of Biscay. There were four output  
274 variables: biomass, catch, fishing mortality and fishing effort.

275 The results were presented at the third foresight workshop (Figure 3). The video of ISIS-Fish  
276 functioning was played again to facilitate the understanding of the translation of the “Jaws in the

277 Bay” scenario into quantitative sub-scenarios and the simulations outputs. Then the four sub-  
278 scenarios were presented orally and the overall trends of the results were described.

279

### 280 3.2.1 *Global description of outcomes*

281 Figure 5 shows the change in biomass, fishing mortality and catch for hake, common sole and  
282 Norway lobster, for each JB sub-scenario for the period 2010-2050. The biomass increased over  
283 the period 2010-2050 for each of the three species. Once stable, the biomass for the hake and  
284 common sole had tripled and that of the Norway lobster was six times greater in 2050. The  
285 biomass of the hake and common sole stabilized rapidly (i.e. in 2017 and 2021 respectively)  
286 whereas the biomass of the Norway lobster increased progressively and tended to stabilize in 2050.  
287 The transitory phase for the common sole biomass between 2010 and 2016 (Figure 5 and Figure  
288 6b) was due to the recruitment which was forced to values assessed by the ICES working group  
289 for this period then replaced by a stock recruitment relationship (ICES, 2014). The changes in  
290 fishing mortality and catch depended on the scenario and the species. The fishing mortality  
291 stabilized at values higher than the initial values for hake while it dropped to values close to zero  
292 for Norway lobster and common sole. The catches followed roughly the same trends as the fishing  
293 mortality. They were constant for hake and tended towards zero for the Norway lobster and  
294 common sole.

295

296 Fig5 : here

### 297 3.2.2 *General trends and Spatial dimension of sub-scenarios*

298 Using global models (e.g. Schaefer, 1954) with an annual time step and no spatialization, an  
299 increase in abundance, or biomass, leads to an increase in catch if the fishing mortality is constant  
300 (Pelletier and Mahévas 2005). Using ISIS-Fish, this trend was not found for Norway lobster or  
301 common sole (figure 5) for any of the sub-scenarios. This behavior was explained by the non-  
302 linear effect of biomass on fishing mortality and catches due to the uneven spatial distribution of  
303 the biomass and fishing effort. For sub-scenario JB1 (Figure 6) in particular, the change in biomass

304 for Norway lobster and common sole is shown for each statistical rectangles. For Norway lobster,  
305 rectangles 23E6 and 23E5 stand out with a considerable increase in biomass up to 2050, reaching  
306 more than 70 thousand tones. Rectangles 22E7 and 24E6 display an increase in biomass three  
307 times greater than rectangles 23E6 and 23E5. The biomasses of the five remaining rectangles tend  
308 towards zero over the period Figure 6). The rectangles where the biomass increases are those  
309 covered by the area restriction RZ. The same trends are found for common sole (Figure 6b and  
310 6d). The north and south coastal zones are completely covered by an area restriction RZ resulting  
311 in increasing biomass. On the contrary, the biomass in the central coastal zone tends towards zero  
312 after 2015 although four fifths of the zone is covered by the area restriction RZ. Indeed, the ISIS-  
313 Fish model assumes that, if the intersection between a fishing zone and a population zone is not  
314 empty, the fishing effort allocated to the intersection applies to all the fish in the population zone.  
315 This reflects the assumption that a mobile species does not remain localized in a small part of the  
316 population zone but, over a month, moves uniformly throughout the zone. Consequently, for  
317 common sole, the restriction reduces the fishing effort applied to the central coastal zone  
318 population but does not protected it. Still overall, (Figure 5), the biomass increases. The fishing  
319 mortality and catches decrease as there is only one rectangle where common sole can be targeted,  
320 resulting in very low fishing pressure and very low catches. The reductions are less marked for  
321 Norway lobster as more rectangles where the lobster is found remain open to fishing.

322

323 Fig 6 : here

324

### 325 3.2.3 *Sub-scenario specificities interpretation*

326 The biomass increased for the four sub-scenarios for all species (Figure 5). For Norway lobster  
327 and common sole, the dynamics of sub-scenario JB 4 were significantly different from the other  
328 sub-scenarios before stabilization, whereas, for hake, the dynamics for all the scenarios had a  
329 similar form but reached different equilibrium values. These results should be viewed in relation  
330 with the fishing effort associated with each scenario (Table 3) and its spatial distribution depending  
331 on the specific fishing grounds of each fleet segments. Overall, the greater the number of vessels,

332 the greater the fishing effort and the lower the biomass. The values for the fishing effort given  
333 here are those when the model has reached equilibrium and have become constant over time.

334 Simulation outcomes showed that given a particular narrative story at the scale of the socio-  
335 ecosystem of the Bay of Biscay, the quantitative model ISIS-fish can draw up several separate  
336 futures of the demersal fishery. The standardization of fleets through the homogenization of  
337 vessels types to reduce costs and the spatial organization of maritime uses lead at the horizon 2050  
338 to different paths of fleets and biomass of targeted species evolution. The discrepancies between  
339 paths can be explained on one hand by the changes in the number of vessels and the associated  
340 change in fishing power, but also by spatial heterogeneity of fishing activities and targeted species  
341 in the Bay of Biscay, that only a spatially explicit model can anticipate.

342

343 Table 3 : here

344

#### 345 3.2.4 *Feedback from stakeholders regarding the model and model outputs*

346 Unlike standard scientific slide presentations a within the context of meeting involving scientists  
347 and various stakeholders, we opted for a video of science popularization for fishing actors to  
348 present ISIS-Fish. The schematic of the model and its components enabled the actors to visualize  
349 the functioning of the model fairly easily (i.e. interactions of the three sub-models, monthly time  
350 step, spatialization and seasonality of the processes). They appeared very receptive to this format  
351 and expressed their understanding of the ins and outs of model, of its interest in simulating the  
352 dynamics of mixed fisheries and how it should be used. This was also well illustrated during the  
353 telephone interview with the sub-group of stakeholders involved in “Jaws in the Bay” scenario,  
354 facilitating the discussion thanks a common understanding of modelled processes and vocabulary  
355 used to describe them. The actors had understood the structural variables that the modeler can  
356 varied. It was therefore easier for the modeler to focus the suggestion of requested precisions on  
357 assumptions identified in the scenario and to reach the agreement of the examples presented in  
358 Table 2. The interfaces designed for the parametrization of ISIS-Fish were presented to

359 stakeholders and also helped in the design of the sub-scenarios. Indeed it demonstrated how easily  
360 parameter values can be modified with the evolution of knowledge or simply to test different  
361 hypotheses. This part of the presentation raised many questions about the origin of the values,  
362 how they were estimated, what data were used. But it was also an opportunity to show that the  
363 model was feeding on the knowledge available on marine species and fishing activity evidencing  
364 the valorization of both declarative data and scientific surveys. This data-driven transparent  
365 approach was highly appreciated and the flexibility of the model induced by user-friendly interfaces  
366 to test new values of parameters was well understood and makes it as easy to consider that the  
367 spatial location of the activities assumed in the “Jaws in the Bay” scenario could be integrated in  
368 ISIS-Fish by changing the fishing areas and adding a fishing ban area.

369 The presentation of the defined four sub-scenarios to the stakeholders not involved in the  
370 “Jaws in the Bay” scenario has raised debates on the coherence between the sub-scenarios and the  
371 “Jaws in the Bay” scenario rather than on the model outputs. For example, the fleet  
372 standardization variable was translated into a selection of certain fleets, in other words by the  
373 disappearance of the other fleets. The stakeholders stressed that the translation of this hypothesis  
374 was not an exact match for the vision of the “Jaws in the Bay” scenario. For example, they  
375 proposed changing the number of vessels in the remaining fleets to maintain a constant number of  
376 boats.

377 On the contrary to the two previous steps, the presentation of the simulation outputs did not  
378 raise much discussion. However some of the counter intuitive results were more deeply  
379 investigated and explained in order to evidence the mechanisms, often spatial interactions,  
380 responsible. These examples seemed to raise stakeholder awareness of the many interactions  
381 involved which can possibly make projections derive from their mental model. Unlike traditional  
382 scenario simulations, the analysis is not a comparative analysis to a reference scenario  
383 corresponding to the « business as usual » evolution of the system (Lehuta et al, 2013). Here we  
384 seek to compare possible evolutions of the system within the future dreamed up in the “Jaws in  
385 the Bay” scenario far from the current situation of functioning of the system. The objective is to  
386 provide concrete quantitative illustrations of what this virtual scenario could be at the downscale



387 of the fishery. The use of the ISIS-fish tool, which is close to management and decision-support  
388 tools gives a more decision-making and management dimension to the foresight exercise. The  
389 actors seemed to give credit to the outputs of the model.

390

## 391 **4 Discussion**

392 This study set out to use the ISIS-Fish model as a support for the collaboration in the  
393 construction of scenarios for fisheries management in the Bay of Biscay. It showed that the lack of  
394 collaboration in building the model (which was conceived by academics), contrary to  
395 recommendations for participatory approaches (Etienne 2006, Étienne, 2009; Bousquet et al.,  
396 1998, 2013; Barreteau et al., 2002), was offset by a good appropriation of model assumptions  
397 through the movie and an appropriate parametrization for the Bay of Biscay. The use of the ISIS-  
398 Fish model in this study was justified both by its structural characteristics and for practical  
399 reasons. First, the aim of foresight is to anticipate changes in fisheries management and ISIS-Fish is  
400 a quantitative model that is able to produce information on the consequences of fishing  
401 management scenarios. It has been largely argued that Decision Support Tool (especially for  
402 Marine Spatial Planning) should consider spatial and temporal dynamics, be easy to use and free  
403 available, and assist operational process of management (Pinarbasi et al 2017). The spatially explicit  
404 aspect of ISIS-Fish, a keystone of geo-foresight, was thus an advantage. Secondly, there was an  
405 off-the-shelf parameterization of the ISIS-Fish model for the Bay of Biscay mixed hake, Norway  
406 lobster and common sole fishery which was central to the governance considered in the scenario  
407 planning. Thirdly, the interfaces within the ISIS-Fish system provided considerable flexibility for  
408 testing alternative parameters and comparing different visions of the fishery. Even if stakeholders  
409 were not involved in model building itself, they worked in close cooperation with the modeler for  
410 implementing the scenario in ISIS-Fish. The “Jaws in the Bay” scenario was built entirely by the  
411 stakeholders and it was translated with their assistance into quantitative sub-scenarios for  
412 simulation using ISIS-Fish. The model was evaluated and discussed with the stakeholders and the  
413 coherence of the simulations with the JB scenario was verified by the stakeholders. It is well-

414 known that transparency and participatory process facilitate and structure discussion between  
415 scientists and actors (Stelzenmuller et al 2013). Modelling should not be seen as a priority but  
416 rather as a tool to trigger discussions. Here the necessary explanation of sub-scenarios results  
417 clearly contributed to collective learning (Röckmann et al 2012).

418 Discussion between the stakeholders about the ISIS-Fish model began with the presentation of the  
419 model. A complex quantitative model, regardless of how complex it is, must be presented using  
420 easily understood terminology and with maximum clarity . Sharing a common language and vision  
421 contribute to trust in fisheries community (Glenn et al 2012). In this study, the simplified  
422 presentation using a video established a good relationship between the modeling experts and the  
423 stakeholders. Several questions emerged from the discussions and indirectly informed on  
424 important aspects of their activity they felt needed to be modeled. What degree of precision is  
425 required to enable qualitative scenarios to be translated into quantitative scenarios? How many  
426 variables can the model handle? Can it handle variables exogenous to fishing such as changes in  
427 fuel? The model was seen as a representation of the fishery under study, that participants were free  
428 to criticize and improve to make it closer to their own vision. This study showed that a quantitative  
429 model is an effective means of strengthening participation and that quantitative and qualitative  
430 approaches must be combined.

431 ISIS-Fish proved to be a basis for constructive criticisms to refine the JB scenarios in the mixed  
432 demersal fishery compartment of the Bay of Biscay. The transition from qualitative to quantitative  
433 required the definition of the processes and variables to be modified and parameterized (i.e. rules  
434 to be applied, fleets selected and restricted zone defined). This stage required several assumptions  
435 to be made, in particular due to the inherent lack of precision in the terminology used for the  
436 qualitative scenario. Joint discussions with the stakeholders enabled fitting the model closely to  
437 their perception. For instance, the Fleet standardization variable was translated by selecting certain  
438 fleets, causing the disappearance of other fleets. During the report workshop, the stakeholders  
439 who were not consulted questioned the translation of this assumption, finding that it was simplistic  
440 and was rather far-removed from their vision of the “Jaws in the Bay” scenario. They proposed  
441 alternative means of translating the scenario and additional assumptions (e.g. varying the

442 proportions of the fleets). This critical feedback reflects the importance of the translation stage  
443 involving the stakeholders and of the wide variety of possible declination of a qualitative scenario  
444 into quantitative ones. This also led the stakeholders to consider the functioning of the mixed  
445 hake, Norway lobster and common sole fishery in greater detail. During this stage, the modeling  
446 experts noted that there were differences in the terminology used by members of the fishing  
447 industry, reflecting also the different visions of stakeholders (D'Aquino et al., 2002). The  
448 translation stage enabled the stakeholders of the "Jaws in the Bay" scenario to define a common  
449 terminology and share a common vision (Glenn et al 2012).

450 The presentation of the quantitative results of the effect of fleet standardization and  
451 displacement of the fishing further offshore to allow other activities by humans led to discussion  
452 on the perception of the functioning and in particular the spatial interactions between the  
453 dynamics of the fish populations and human activities at sea. The results showed that the area  
454 restriction RZ had a great effect on the fishery dynamics. Moving fishing further offshore to allow  
455 the establishment of fixed activities such as aquaculture, offshore wind farms and the extraction of  
456 aggregate relieved the common sole nurseries of fishing pressure and allowed them to grow.  
457 However, potential impact of these new coastal activities on the three species was not considered  
458 in the model. Furthermore, the drastic reduction in Norway lobster and common sole catches near  
459 the coast led to the disappearance of certain coast-based fishing métiers and the transfer of the  
460 effort to other fishing métiers which considerably modified the nature of fishing. Discussions with  
461 the stakeholders showed that it might be possible to reorganize concessions in the coastal zone to  
462 assign some to fishing and suggested adding or testing hypotheses regarding the impact of  
463 activities other than fishing on the dynamics of common sole and Norway lobster. This exercise  
464 demonstrated the importance and feasibility of including spatial variations in foresight.

465 The discussions following the presentation of the results revealed the initial value of this  
466 exercise for the various stakeholders (van Hoof et al 2014). Firstly, unlike the usual meetings  
467 attended by stakeholders, there was no high economic or management stakes, and these  
468 workshops provided the opportunity for discussing and confronting ideas and representation of  
469 the system functioning and evolution. Discussion threw light on quantitative models for fisheries

470 stakeholders. There was critical feedback from the stakeholders on the accessibility of the model,  
471 the coherence of the results and the use of the model for scenario planning. The quantitative  
472 model, which was similar to the models used for evaluation by scientific working groups (ICES,  
473 STECF), was compared with the vision stakeholders have, which is not usually the case in  
474 decision-making processes (Lehuta et al 2016). This approach facilitates the transfer of information  
475 on fisheries management and increases collaboration between stakeholders and modellers (Opdam,  
476 2010). It also contributed to legitimate complex models and moves forward improving fisheries  
477 science and management (Glenn et al 2012). In this case, fisheries system stakeholders produced  
478 relevant input for both modeling and management strategies.

479 While the ISIS-Fish model was considered appropriate for the exercise for the reasons exposed  
480 above, a few limits of the current settings were highlighted. The current spatial resolution (a cell =  
481 Ices rectangle = 60 nautical miles x 30 nautical miles) for parameterizing the hake, Norway lobster,  
482 common sole fishery is not ideal for dealing with a certain number of problems. During  
483 discussions between the stakeholders on the “Jaws in the Bay” scenario, the problem of the extend  
484 of the restricted zone was raised since the 12 nautical miles coastal strip (i.e. limit of territorial  
485 waters) is much narrower than the model spatial resolution. Although this problem was overcome  
486 by designating the coastal zone as a restricted area, it would be useful to propose a finer resolution.  
487 Realistically, on the basis of available information, (e.g. Vessel Monitoring System for fishing  
488 effort, Scientific surveys for population distribution), it could be an 1/8<sup>th</sup> of the statistical  
489 rectangle. Temporal scale on the other hand was considered appropriate. Foresight prepares for a  
490 distant future (De Jouvenel and Fish, 2004; Mermet, 2005; Michel, 2007). This requires a model  
491 able to carry out long-term simulations, as is the case for ISIS-Fish given its mechanistic nature.  
492 This is an asset which had never before been explored in studies using ISIS-Fish which tended to  
493 analyze the transition phase in changing fishing dynamics (e.g. Gasche et al 2013; Lehuta et al  
494 2013b). Furthermore, scenario planning in foresight must take account of all possible changes and  
495 depletions of stocks (De Jouvenel and Fish, 2004; Mermet, 2005; Michel, 2007). The model must  
496 be able to simulate these changes. A major advantage of ISIS-Fish is its flexibility in programming  
497 processes. It was designed to be able to study a wide variety of fisheries (e.g. single species / multi

498 species, single fleet / multiple fleets, large / fine spatial and temporal resolution) and be able to  
499 change certain assumptions easily.

500 It would have been interesting to go further in the analysis till the translation of model runs into  
501 the socio-economic context (Bellanger et al. 2018, Le Floc'h et al. 2015). However the time  
502 duration constraints of the geo-foresight (induced by the COLSELMAR research project  
503 supporting this study) did not allow for assessing the consequences of change in catch and biomass  
504 of the three targeted species of the fishery using social and economic indicators.

## 505 **5 Conclusions and future developments**

506 To our knowledge, this is the first time a complex spatial quantitative model such as ISIS-Fish is  
507 used for foresight. This study showed that the model and its results could be integrated into the  
508 approach and aroused interesting discussion on the synergy between complex modeling and  
509 scenario planning. Without ISIS-Fish, the participatory process would have ended with the second  
510 workshop and would have only delivered three narrative scenarios (like the JB scenario described  
511 in Annexe1). The ISIS-Fish model has enabled 1) to describe one of these scenarios at the scale of  
512 the demersal fishery, 2) to show that several hypotheses of mechanisms of fishery dynamics could  
513 be derived from the narrative scenario and 3) to demystify complex models supporting fishing  
514 management through discussion about the model and its inputs.

515 The qualitative scenarios formed the basis for modeling and the ISIS-Fish results expanded  
516 these scenarios with quantitative information. The advantage of mechanistic models such as ISIS-  
517 Fish is their ability to consider complex processes and the interactions between them, sometimes  
518 highlighting unexpected chain reactions. The simulation results showed the relevance of using a  
519 spatial model to explore the changes induced by the various sub-scenarios.

520 This study also had the advantage to present to stakeholders a spatialized fishing management  
521 model similar to those used by scientific working groups. The management models used for  
522 fisheries science are often complex and appear to be black boxes to most uninitiated (Link et al  
523 2010, Lehuta et al 2016). Stakeholders tend to reject both models and results assuming their  
524 functioning is inaccessible. This causes even more problems when it is these uninitiated who are

525 mainly concerned by the consequences of management measures. This study is, therefore, an initial  
526 step towards making complex models and decision-making processes more transparent and  
527 acceptable and proving this is doable. This approach comes close to participatory fisheries research  
528 which has great potential for maritime fisheries (Wiber et al., 2009). It could reduce the gap  
529 between the stakeholders, scientists and decision-making bodies

530 The results of this study provide support for the use of the ISIS-Fish model for geo-foresight.  
531 Its flexibility enables it to model and simulate environmental scenarios. Using the model for geo-  
532 foresight could also be considered for research rather than policy by alternating description of the  
533 system and modeling during scenario planning, like a research/training/policy system (Lardon et  
534 al., 2008). This would train stakeholders in quantitative modeling and increase the relevance and  
535 synergy between the two approaches. Furthermore, even if some disappointment or tension arised  
536 during the modeling phase, mostly related to some simplistic features in sub-scenarios, they should  
537 not be viewed as a failure but rather as normal evolution in the development of the concept. Levin  
538 et al (2018) referred to the “hype cycle” described for emerging technologies to describe the phases  
539 of development and the acceptance of new fisheries assessment models. According to this theory,  
540 the adoption of a new technology (here a model), follows phases of high expectations and  
541 disillusionment, that will ultimately be followed by a slope of enlightenment and a plateau of  
542 productivity. This should encourage collective perseverance in combining quantitative and  
543 qualitative approach.

544 Finally, although this study did not intend to build probable or strategic scenarios we are  
545 confident that the richness of the input by stakeholders would sufficiently strengthen the input  
546 data and mecanisms (e.g. social processes) to make this objective realistic. It already proved  
547 efficient in improving the relationship between the stakeholders and fishery scientists, which might  
548 have been tensed historically. As one of the stakeholders commented, actors increasingly realized  
549 that their future somehow depends on the results of these strategic model results, and it is their  
550 own interest to help making them more robust and realistic.

## 552 **6 Acknowledgments**

553 This work was supported by grant from the Regional Council of the Pays de la  
554 Loire (Convention COSELMAR 2012-09684) and from Ifremer (Project APPELS). We would like  
555 to thank all stakeholders who participated to the geo-foresight and who critically facilitated this  
556 work. Many thanks to the three anonymous reviewers for their comments, which greatly improved  
557 an earlier version of the manuscript.

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**Figure 1.** Mixed Hake, Norway lobster and common sole fishery study area (sub zone VIIIab, ICES)

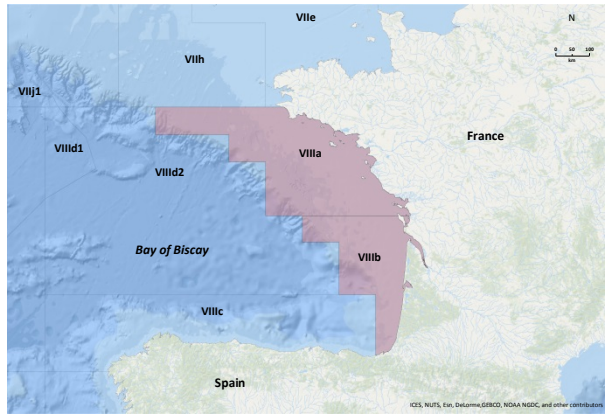
**Figure 2.** Overview of the model decomposed into three sub-models, adapted from Mahévas and Pelletier (2004). The ovals correspond to the sub-models which interact in time and space (Zones variable in Table 1). Intersection 1 is the relationship between the fishing effort and the population distribution, and fishing mortality. Intersection 2 is the dynamic distribution of the fishing effort as a response to fishery management measures and intersection 3 is the fishery management dynamics in response to the status and distribution of fish populations and fleets.

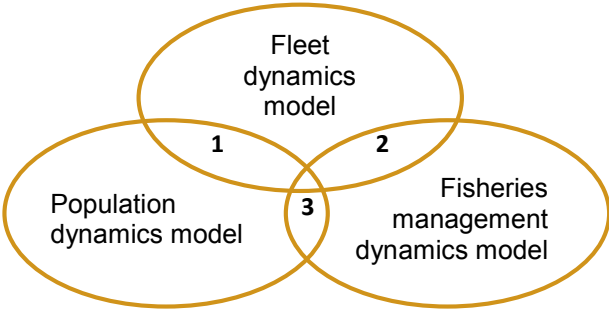
**Figure 3.** Organization of the scenario planning into three workshops with all the players and a step implementing the ISIS-Fish model.

**Figure 4.** General flowchart : S is the scenario.  $S_A$ ,  $S_B$  and  $S_C$  represent the three scenarios produced by the scenario planning workshops. Scenario  $S_A$  is the “Jaws in the Bay” scenario and  $S_{A1}$ ,  $S_{A2}$ ,  $S_{A3}$  and  $S_{A4}$  are the four sub-scenarios. The red boxes represent the translation stages converting the qualitative scenarios into quantitative scenarios that could be modeled in ISIS-Fish. The grey boxes are the stages for the simulation and presentation of the results at the following workshop.

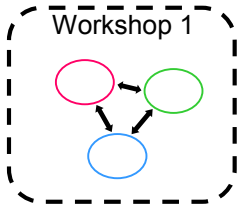
**Figure 5:** Change in biomass, fishing mortality and catches for each of the 4 JB sub-scenarios for each species. The biomass and catches are in thousands of tonnes and the fishing mortality varies from 0 to 1. The biomass is the biomass in January each year, the fishing mortality is the mortality for each type of fish each year in December and the catch is the total catch for each year.

**Figure 7.** (a) (b) Change in biomass (in thousands of tonnes) for Norway lobster and common sole as a function of the population zones defined in the ISIS-Fish model for sub-scenario JB 1. (c) (d) Maps showing the location of each population where RZ is the restriction zone. For Norway lobster, the curves correspond to the statistical rectangles (e.g. 21E6), whereas, for common sole, the curves and fishing zones are color coded. Only sub-scenario JB 1 is shown as the trends for all scenarios are similar.

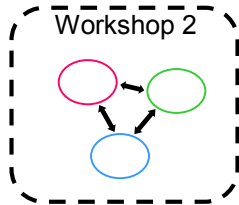




**Environmental scenario planning**



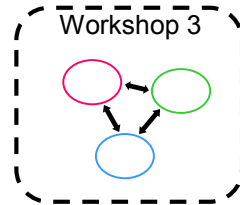
State of the art



Exploratory scenarios

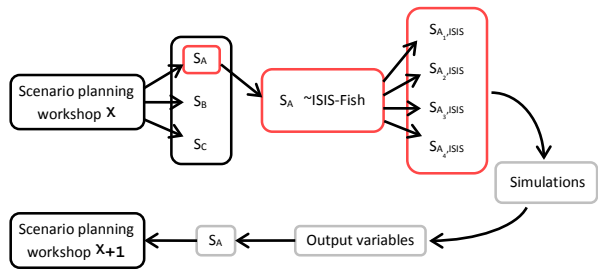


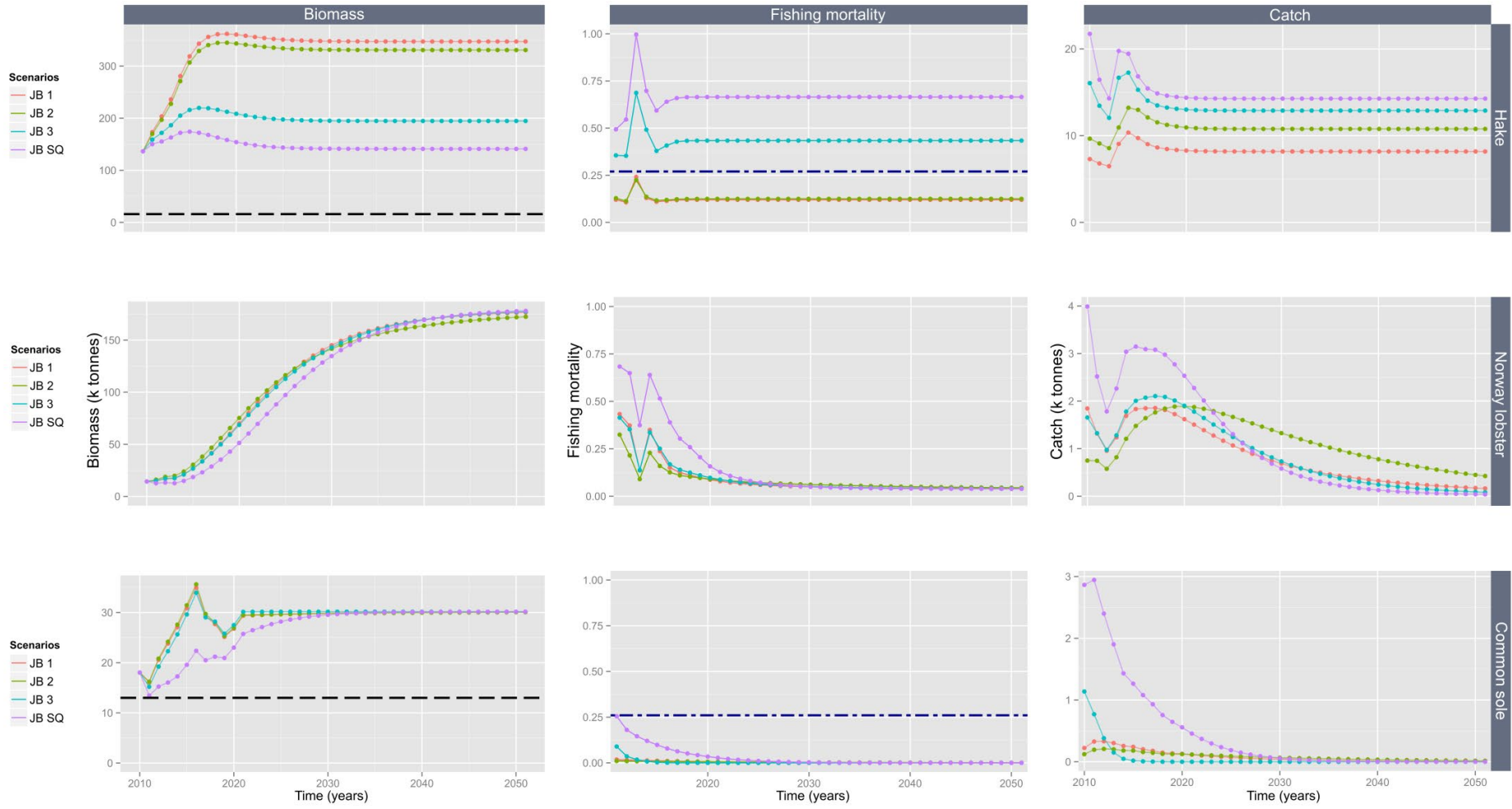
Quantitative sub-scenarios and simulation

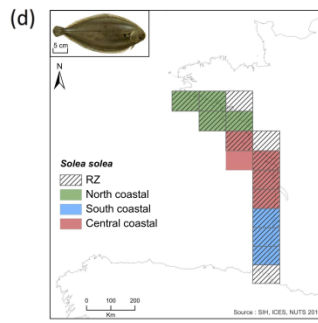
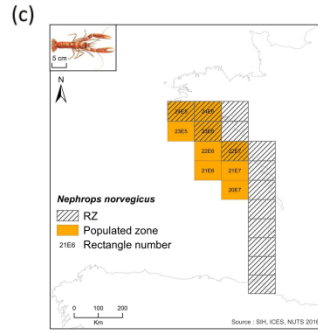
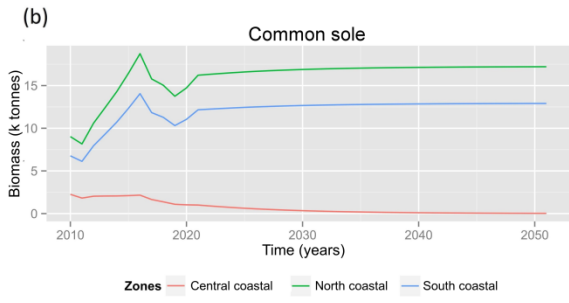
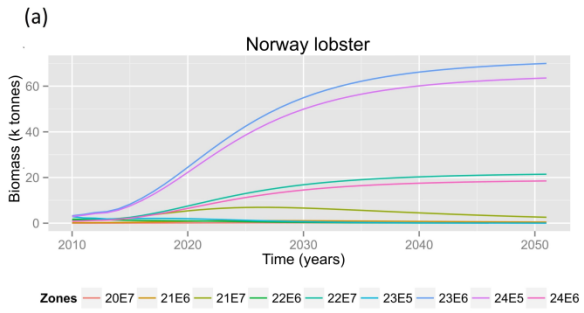


Scenario validation









**Table 1.** Structural variables of the ISIS-Fish model

**Table 2.** Variables of the “Jaws in the Bay” scenario, their description, their ability be modeled (yes = ✓ or no = ✗, first tick) in ISIS-Fish and if the variables selected (yes = ✓ or no = ✗, second tick) for simulation of sub-scenarios with ISIS-Fish

**Table 3.** Sub-Scenarios JB, associated annual fishing effort and number of vessels involved

Variable	Characteristics
Zones	Spatial distributions of fish populations, fishing métiers and area restrictions
Species	Seasons, life traits (natural mortality rate, average weight, maturity ogive), reproduction, group (size or weight class), catchability, migration, commercial value (prize)
Gears	Range (mesh size, net length, etc), selectivity, catchable species
Fishing métiers	Season and zones, target species, tightness of targeting
Type of trip	Duration, minimum time between two trips
Types of vessel	Length, speed, maximum duration of trip, costs
Fleets	Home port, type of vessel, number of vessels, fixed costs, efficiency, fishing métiers and fishing effort and financial parameters
Strategies	Fleet, proportion of fleet, inactivity equation, proportion of fishing méteiers per month
Management measures	Total Allowable Catches, Marine Protected Area, Selectivity restriction, Fishing effort reduction, associated fishermen reaction, seasons and zones

Variable	Description	Variable that could be modeled in ISIS-Fish (with an example for those selected for modelling sub-scenarios)
Operating mode of fishery management	Privatization : access to maritime spaces and marine resources is based on financial markets	✓ ✗ Management measures (TAC set by industrial lobbies to reach economic reference points)
Fleets	Standardization : vessels are harmonized to reduce production costs	✓ ✓ Types of vessels, Fleets, Strategies (Decommissioning scheme : withdrawal of fishing vessels from the fleet to keep vessels of the same length operating the same annual fishing strategy)
Vessels	ultra-modern and ultra-selective vessels to meet the fisheries sustainability and performance criteria	✓ ✗ Types of vessels, Fishing métiers (ban of trawling: change of fishing gears moving from trawl to net or and line operated by vessels with low gas emission)
Multiple marine uses	Spatial partition of the Bay of Biscay : patchwork of economic concessions to maximize the profitability	✓ ✓ Management measures, Zones, Fishing métiers (Banning fishing activities from a coastal area in favour of sediment extraction or wind farm)
Controlling system	Strengthened polluter pays system through a “sustainable fishing” charter	✓ ✗ Management measures, Fishing métiers (Reduction of fishing time in proportion to the environmental impact of fishing métiers)
Science	Precarious and privatized monitoring : scientific expertise subject to lobbying (financial and political), applied research dedicated to strategic topics	✗ ✗

Sub-scenario	Fishing effort (hours yr <sup>-1</sup> )	Number of vessels
JB 1	95562	201
JB 2	227466	232
JB 3	324109	502
JB SQ	422187	703