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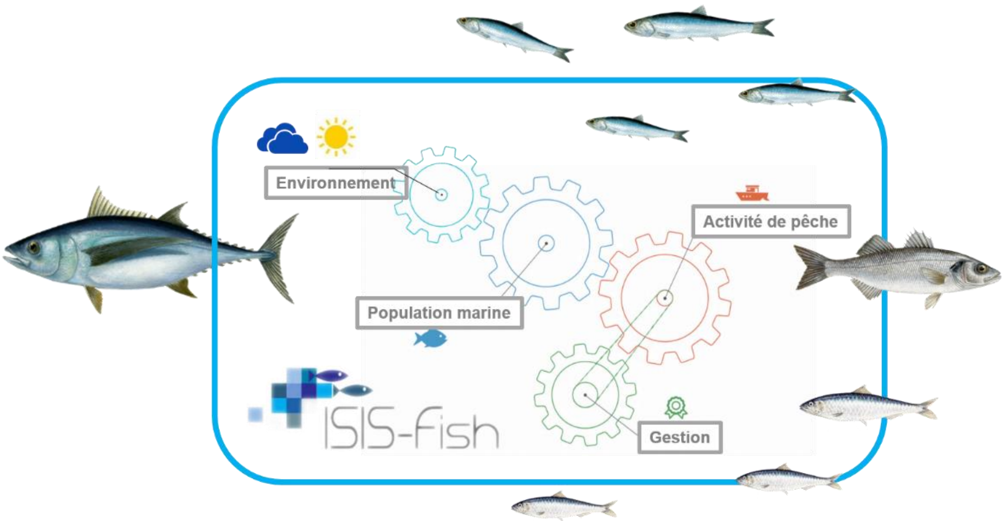
Modélisation du système pélagique du Golfe de Gascogne en réponse au changement climatique

Pierre ISSAC



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INTRODUCTION

In recent years, numerous studies have been focusing on investigating the potential effects of climate change on marine ecosystems (Doney et al., 2011; Harley et al., 2006; Hoegh-Guldberg and Bruno, 2010). Those studies highlight potential drastic changes in sea temperature, ocean circulation, stratification, oxygen and nutrient level available etc… that can drive species invasion, population shifts, and change in distribution because of intolerance towards new levels of physical parameters and even species extinction in some cases. In parallel, there is a growing demand in fisheries management from scientists and stakeholders to include environmental processes in fisheries management (Aburto et al., 2012; Pikitch et al., 2004) in order to adapt current management to future climate change issues (Clark, 2006). It can be done by linking environmental variables to population dynamic processes, like temperature effect (Planque and Frédou, 1999) or river flow effect (Nicholson et al., 2008) on fish recruitment. Other approaches include the importance of habitat and environment production in the determination of fish abundance (Pittman et al., 2004) or explore the link between fluctuation of salinity, temperature, primary production and growth (Möllmann et al., 2005). Most of those studies are dedicated to explain the environment influence on fish population dynamic and the future evolution that climate change would induce in a system restricted to environment and marine populations. However, few studies try to understand the potential impact of climate change at a larger scale on the socio-economic fishery (Allison et al., 2009; Sumaila et al., 2011). This kind of work needs to dig into the complexity and inherent structure and drivers of the fishery in order to project the economic response to climate change.

In this broader context, the pelagic fishery of the Bay of Biscay constitutes an interesting case study to apprehend climate change effect on fishery dynamic. Indeed it involves small pelagic fishes such as sardine and anchovy, species that are known throughout the globe to be highly sensitive to environment (Briones et al., 2006; Checkley et al., 2009). In particular the link between environment and small pelagics' recruitment have been widely investigated (Cury and Roy, 1989; Fréon et al., 2005). Indeed knowledge concerning the biology of sardine and anchovy of the Bay of Biscay suggests links between larval mortality, spatial distribution and environmental parameters such as temperature, stratification and wind regime and potential evolution in the habitat like a northern expansion for anchovy (Huret et al., 2009; Lett et al., 2010; Petitgas et al., 2012). However, quality of information for other biological process, such as stock identity and stock assessment remains highly heterogeneous among the major pelagic species of this fishery. This heterogeneity in data quality for different populations limitsour capacity to explore climate change effect.

Information about the Bay of Biscay's ecosystem itself seems to indicate that climate change will induce important modifications of physical oceanographic process (Charles et al., 2012) like modification of wind intensity, stratification and increase in sea temperature, which can lead to potential change in abundance (Hemery et al., 2008) and fish community organization (Poulard and Blanchard, 2005). All those information about environmental influence and biologic-ecologic response can lead to potential impact in the fishery dynamic by propagation of the perturbation. The response of the fishery is related to his complexity and structure.

The pelagic fishery of Bay of Biscay is indeed relatively complex; it is a mixed-multi species fishery catching mainly anchovy (*Engrasicolus engraulis*), sardine (*Sardina pilchardus*), horse mackerel (*Trachurus trachurus*), mackerel (*Scomber scombrus*), sea bass (*Dicentrarchus labrax*), Albacore tuna (*Thynnus alalunga*) and even some demersal species like hake (*Merluccius merluccius*) and anglerfish (*Lophius piscatorius*). Those species are caught using different gears mainly pelagic trawls operating in pair, purse seine and other gear aimed at demersal and benthic fishes like bottom trawl or dredge. The complexity can also be seen in the diversity of fleets and harbors involved, with French purse seiners operating near Brittany and Basque country, French pelagic trawlers from St-Gilles-Croix-de-Vie and La Turballe and

Spanish Cantabrian purse seiner harvesting the pelagic ecosystem of the Bay of Biscay. Those fleets have also different seasonality and fishing zones in the Bay of Biscay and can even fish in adjacent zones such as the western English Channel. Thus Breton purse seiner fish throughout the year in coastal southwest Brittany with a peak season in a summer main while pelagic trawlers are more likely to operate offshore with a peak season in spring in the southern part of the Bay of Biscay when anchovy begins its spawning aggregation (Uriarte et al., 1996).

This fishery is also an enriching case study in term of fisherman behavioral understanding considering that it has experienced several crises and evolutions mostly due to the collapse of the anchovy stock in 2005 (Andres and Prellezo, 2012; Vermard, 2009) followed by a stricter control on seabass, one of its other main target species (Boyra et al., 2013). From 2000 to 2015, three distinct periods of almost equal duration can thus be distinguished; 2000 -2004, before the anchovy ban, 2005-2009 during the ban and 2010-2015 after the reopening of the anchovy stock to harvest. Behind an apparent flexibility, the crisis demonstrated the lack of resilience of part of the fleets to the loss of their main target species with around 30% of the boats exiting the fishery between 2005 and 2010. Their adaptability to the changes induced by climate change is thus questioned.

Investigating the relation between climate change and fisheries requires that both population dynamics and fleet dynamics be taken into account and their seasonal and spatial interactions are accounted for. Mecanistic modeling is a logical way to integrate available knowledge on these processes and project them under new environmental conditions. We choose the spatially explicit model ISIS-Fish (Integration of Spatial Information for Simulation of FISHeries) as a modelling framework for the study. This choice is driven by the flexibility of this platform, that can take in account the adequate complexity and information available both for fish populations and fishing fleets (Mahévas and Pelletier, 2004). It also provides the spatial-time scale corresponding to our need for modelling the fishery and target species dynamics (month). Another reason is that this model emphasized the structure and complexity of the fisheries. This suits our needs because we tried to evaluate the potential response of the fishery to climate change.
Thus, our aim in this study is to answer the question:

How can the overall dynamic of the Bay of Biscay pelagic fishery be affected by climate change?

This problematic raised several subsequent questions:

- Do we have the knowledge to project these impacts?
- How to include environmental effects in the model and link them to the fishery's dynamic?
- How to describe the dynamic of the fishery in response to a change in the environment?
- How to evaluate and quantify the impact of climate change on the fishery?

The general exploratory approach of this work to answer those questions was to analyze historical fisheries data that include the anchovy crisis to try to understand its structure. Then we tried to explain the fleet's dynamics in response to changes in its income. The impact of environmental changes on the fishery will then be assessed through the population dynamic of the target species that will be the link compartment between environmental changes and the fishery. Known relationships between fish populations and environment will thus be explored and extrapolated to reflect the likely impact of temperature scenarios. Possible impacts of these scenarios on fleets will finally be quantified.

The following chapter will describe the methodology used to construct the model and especially the two different compartments of fishery and target species populations that constitute the core of the model, as well as the scenarios of climate change retained. We will then present the results in the third chapter and the discussion in a fourth chapter.

MATERIAL & METHODS

I) ISIS-FISH: A MODELLING PLATFORM FOR COMPLEX SPATIAL FISHERY

ISIS-Fish model (Mahévas and Pelletier, 2004; Pelletier et al., 2009) is based on three sub-models to describe interactions between fisheries and marine species: a fishing activity model, a population model and a management measures model. Each sub model needs to be filled with a limited number of parameters explained in Figure 1.The time step of the model is the month.

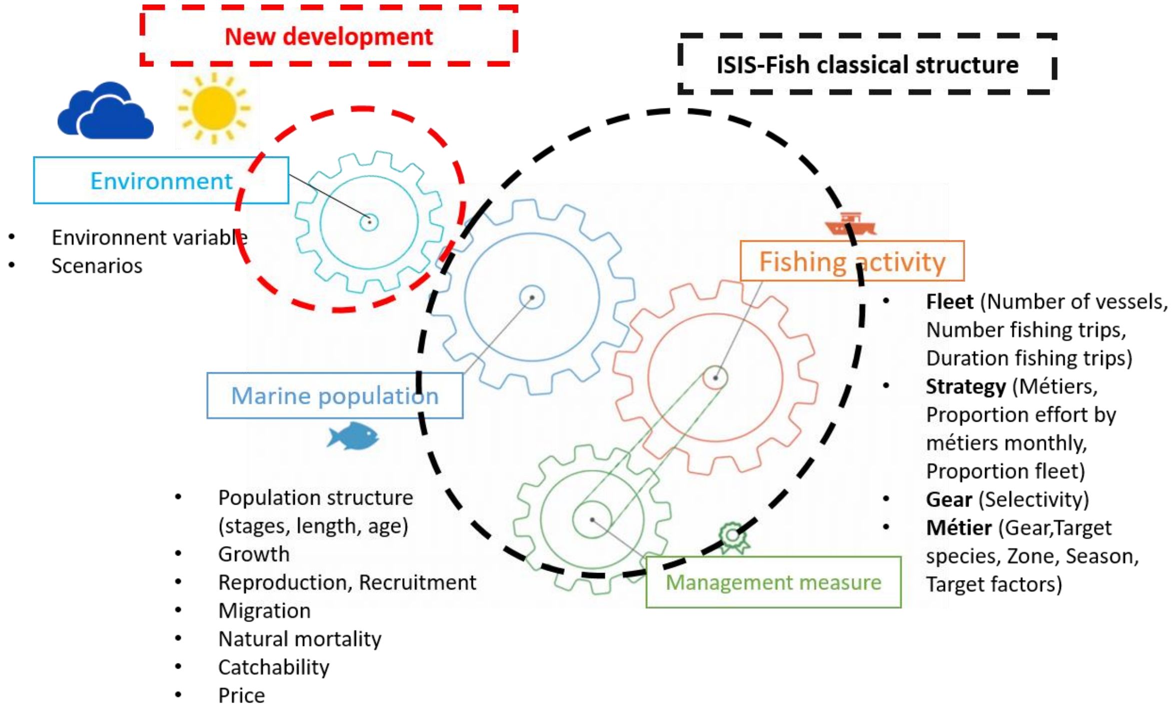

Figure1: ISIS-Fish model structure and input parameters

1) Fishing activity sub model: A hierarchical structure

The fishing activity sub model is divided in different nested layer, which range from the more refined “Métier” to the bigger, fleet (see Figure 2). Fisheries are operating different “Métiers” that represent the activity practiced during a fishing operation and are characterized by one or several specific target species, a given fishing area, season and a particular fishing gear (Biseau, 1998). In order to render fisherman’s desire of catching a specific species a target factors is associated to each target species for a given Métier. The layer above is called strategy, which is a set of métiers associated with a proportion of effort distributed among all the months of the year. It represents the larger fishing pattern at a yearly scale. Fleet is the largest brick in this fishery structure; it is a group of vessels share similar size, power engine, strategies and métiers. It is a useful management unit and usually regroup vessel from the same country or location. In a given fleet, a number of vessels can vary yearly and this total number of vessels is then spread among all the strategies of the fleet according to a given proportion.

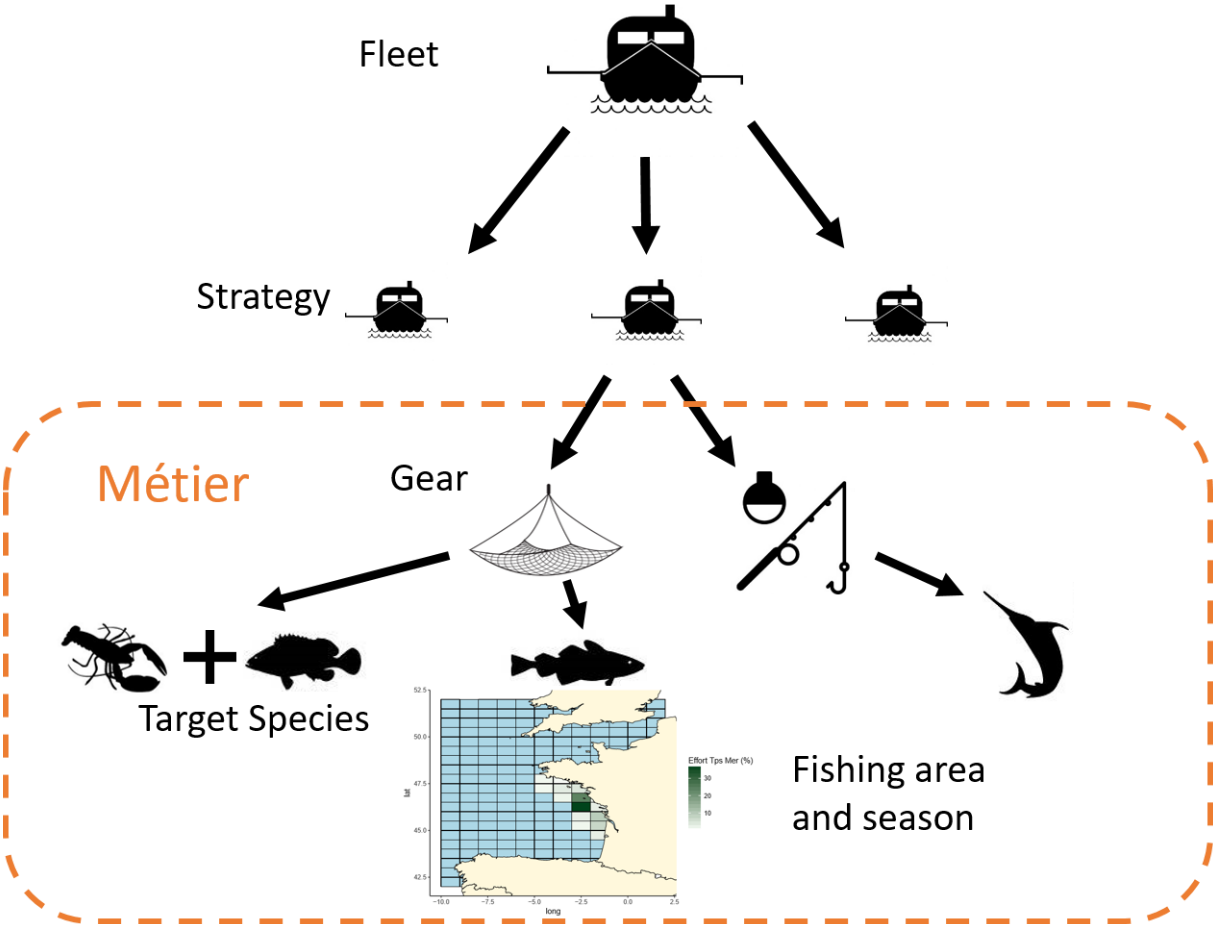

Figure2: ISIS-Fish fishing activity tree structure to define; Fleet, Strategies and Métiers

These concepts of métiers, strategies and fleets are useful tools, particularly to describe a mixed-fishery that operates with different gears and target different species such as our case study. The construction method to build the fishing activity sub model and dynamic will be detailed in the following section (II.2). The sub-model produces every month a map of effort distribution for each fleet, strategy and métier.

2) Population dynamic sub model: A flexible structure to the available information

The population dynamic sub model works with independent marine species populations. Each population is structured whether by stage, length or age based on the choice of the modeler and the available information. For length- and stage-based populations a class-transition matrix must be provided to inform on population changes from stage to stage through time. Growth, migration, natural mortality, recruitment must be informed in order to reproduce known population dynamics throughout the year. The sub-model updates every month the population's spatial distribution by age or length classes. Catchability parameters can vary from stages, age class or season according to the population structure.

3) Management sub model and link between fishing activity & population dynamic

The management sub model integrates different fisheries management rules such as TAC (Total Allowable Catch), landing obligation or marine protected areas. It possibly modifies the level or distribution of effort, the selectivity of gear or other characteristics of the fishery in response to enforced management. In this work, no management rules were considered for the fishery and this sub-model was not used.

ISIS-Fish principle is that fishing mortality is computed each month based on the overlap between effort maps and abundance maps. For each population group, in each population area, F is a function of local abundance and effort deployed in the area, accessibility to fishing, targeting intensity, gear selectivity, and fleet efficiency.

4) How to integrate the environmental effect in ISIS-Fish structure?

ISIS-Fish currently does not include an environmental sub model. To allow propagation of climate change effect through the system, we made the hypothesis that climate change effect will primary affect the population dynamic of the target species via biological mechanisms such as growth, reproduction or recruitment and then affect by a domino effect the fishery (Fig 1).

II) FISHERIES DYNAMICS: FROM PAST CRISIS TO FUTURE DYNAMICS

The main hypothesis in this work is that we can understand the dynamic of the fishery by studying past crisis and observed behavior to forecast fisheries dynamic under different climate change scenarios. Fishermen behavior was then studied through modelling approach.

1) Fishery dependent data description and reliability

In order to describe the fishery structure and behavior we used two main sources of fishery dependent data. The first one is provided by Ifremer's SACROIS algorithm, which links VMS (Vessel Monitoring System) data, fishing sales data and fishermen's logbook data to provide fishing data at the scale of the fishing sequence (boat x day x gear x statistical rectangle). A large number of information is available from this database and the one used for the analysis are presented in the following table (Table 1). These data at fine scale are used to identify métier at the scale of the fishing sequence for each vessel.

Table1: Available information from SACROIS operational data used for the fishery analysis

Operation ID	Description/Unit
Vessel ID	—
Species caught	One or several species per operation
Gear	—
IFREMER's fleet classification	4 sub classification depending on main gear used
Sale value	euros
Landings weight	Kg
Vessel's fishing port	---
Fishing time	Hours
Time at sea	days
ICES Rectangle	Geographical rectangle unit 1°lon x 30' lat

Before running the analysis, some cleaning of the database needs to be done to keep only the relevant one for our case study. The following filters were applied:

- Only vessels operating in ICES area VIII (Bay of Biscay) that have at least 50% of their total yearly landings composed of Sardine and Anchovy for one or more years of the 2000-2015 time period were considered. This filter enables to keep record of vessel activity and changed in fishing pattern throughout the period and thus after the anchovy ban in 2005-2009.
- Preliminary analysis of landing data showed that most of the anchovy and sardine catches are made by pair trawlers, pelagic trawlers or purse seiner. We therefore keep all the vessels that were registered as pelagic pair trawlers, pelagic trawlers or purse seiner in previous IFREMER's fleet classification (See Table 1).
- A final correction was made by controlling for each vessel their percentage of gear utilization by year. Vessels that for instance have been selected has pair trawler but are revealed to use 90% of the time dredge in all the period are removed.

Finally, those filter resulted in a list of 145 different vessels responsible for approximatively 90% of the total landings of our two main pelagic species, sardine and anchovy.

Those data were however only available for the vessels operating under French flag. The Spanish fleet of purse seiners is not registered in the SACROIS database; we tried nevertheless to include them in the model considering their importance in the fishery (more than 80% of the anchovy landings in all the period) (Boyra et al., 2013; Uriarte et al., 1996).

Thus, we a second source of fishery dependent data was used: The European STECF (Scientific and Technical European Council for Fishery) database. This database is in fact the only spatially explicit available database for European fisheries (https://stecf.jrc.ec.europa.eu/dd/effort/graphs-quarter). In this database, the spatial resolution is the ICES rectangle exactly like SACROIS data. However, the effort and landings data are only available aggregated quarterly starting from 2010, and aggregated over the entire Spanish pelagic fleet. We assumed that the fishing pattern between 2000 and 2005 was the same as the one reported for 2010-2015. Nonetheless, during the anchovy ban effort on anchovy is assumed to equal zero.

2) Method for describing the fishing activity in a hierarchical structure

a) Splitting the vessels among fleets and strategies:

Fisheries are structured by fleets, assuming that the vessels of the same fleet are relatively homogeneous in terms of size, power engine and operating in not too distant fishing harbor.

We decided to treat separately French trawlers, which are for the majority mixed with a wide range of gear (pair trawls, pelagic trawls, bottom trawl, dredge, longline etc…) and French purse seiners, who mainly use purse seines. Based on the description of their activity found in the literature (Uriarte et al.), and on reported differences in vessels lengths, harbors, seasonality, we assumed that the Spanish purse seiner fleet constitutes a single homogeneous fleet distinct from the French purse seiners and using a different gear.

Then, three different fleets were defined; a trawler fleet, a French purse seiner fleet and a Spanish purse seiner fleet. Inside that fleets, the strategies need to be defined. Yearly landing profiles in term of proportion of species of each vessel were used to discriminate the different strategies. We assumed that strategies are defined at a yearly scale and each vessel can change strategies from year to year. Multivariate analyses were used as a method for treating this data table of vessel-year individuals. A PCA (Principal Component Analysis) followed by hierarchical clustering method were applied on landings proportion for the 20 most important species in terms of landings in the fleet as quantitative variable. In parallel, we realized the same kind of analysis with the proportion of total fishing operation by gear as quantitative variable. We use the maritime district as a supplementary qualitative variable for understanding the result. Relatively stable strategies in time were then distinguished by combining all those three type of information.

b) *Métier analysis: characterization of fishing operation*

The next step to characterize fleet activity is to identify métiers practiced in each strategy. Métier is composed of a gear; a set of target species, a season, and a zone for a fishing operation (see I.1). Only four different gears were considered in the analyses: French Purse Seine, Spanish Purse seine, pelagic trawl and lines (Basques purse seiner use lines to catch tuna species) because they represent the most important gear to target pelagic species accounting for more than 90% of landings of pelagic fishes. We voluntary avoided modelling gear targeting demersal and benthic species because we restrained our exploratory analysis only on the pelagic ecosystem and demersal gears are only responsible for a limited fraction of the pelagic species catches.

For each gear, target species are identified by analyzing landing composition at the scale of the fishing operation using the VMSTools package (Hintzen et al., 2012). It consists first in selecting the most important species by applying a PCA followed by a cluster analysis. This method groups all the fishing operations using a same gear for a same strategy into métiers that present the same pattern in term of landed species.

In a second time, once the target species associated to an operation with a given gear were identified, season and fishing zone were investigated to cope with the previous métier's definition (I.1). Seasonality for the métier is assumed to be based on the strategy's seasonality. We took the strategies defined above (II.2.a) and calculated the average monthly proportion of landings by species throughout the all period. We assumed that those fishing seasons do not vary much between periods. These hypotheses were made to obtain a fishing structure that is robust through time and the flexibility to change in fishes population and thus landings come from the distribution of effort through métiers and strategies inside a fleet. The only data available for Spanish purse seiner were available quarterly with important contrasts between quarters landings composition; we assumed thus that the seasonality was divided quarterly.

The last part of the métier identification consists in the definition of a fishing zone. For each Métier (Gear-season-Target species) previously identified we associated the corresponding fishing effort. We choose to use time at sea as a measure of effort because it accounts for searching time, which is a better proxy of the nominal effort deployed by the fisherman in pelagic fisheries. Time at sea is a measure of the time spent at sea from leaving the harbor to the end of the fishing trip. For fishing trips with multiple fishing operations, time at sea needs to be divided by the number of fishing operation. This assumes that there homogeneity between fishing operation inside each fishing trip. This hypothesis doesn't seem to be a big assumption (Annex F). The following equation (1) derives the fishing effort by fishing operation.

Equation 1)

$$Effort_{op,trip} = \frac{TimeAtSea_{trip}}{\sum_{op=1}^{op=n} op}$$

For each Métier (Gear-TargetSpecies-Season) the previously calculated $Effort_{op,trip}$ was summed by year, vessel and ICES statistical rectangle. This result was then averaged by year and vessel in order to get the effort distribution of an average vessel in a strategy for a given Métier. The average effort map was then plotted to define the spatial effort pattern of an average vessel practicing the given métier (See Figure 3).

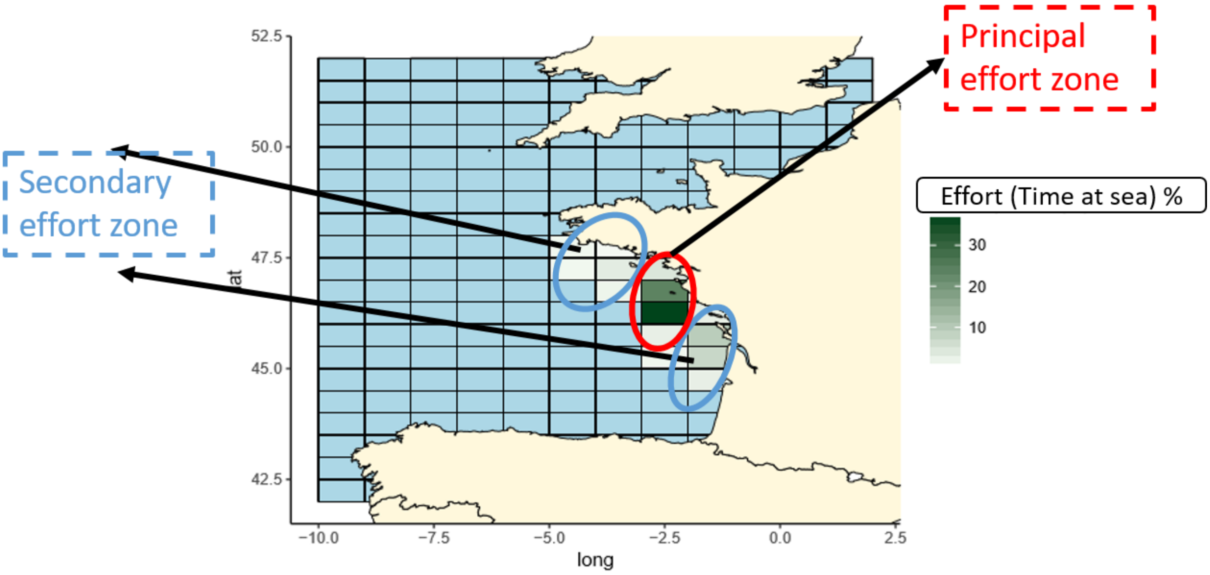

Figure3: Average effort pattern map for a given métier (Gear-Target species-Season) in a given strategy.

Métiers were then defined (Season, Gear, target species) by two different areas, a principal area where most of the effort is a concentrated and a secondary effort area where in average vessels practicing those métier spend less than 10% of the total effort.

Available information did not allow more detailed métier identification for Spanish fleets. A unique métier was thus assumed that targets all of the species reported in the landings in every of the areas were effort is reported at the given quarter. Maps of fishing zones were derived from average declared effort for the Spanish métiers.

c) Target factors estimation: a measure of the fisherman choice

In ISIS-Fish, the effort needs to be standardized among species for each métier to account for the targeting intention of the fisherman. This allows each métier to catch different species including bycatch species but with a target factors lower than the targeted ones. Thus, we accounted for a more realistically fishing model where for instance a métier targeting sardine may catch a small amount of seabass if it operates in a population zone where seabass is present.

The targeting factors are assumed independent between periods and thus constant for a métier (Gear-TargetSpecies-Season-zone) in the all hindcast period 2000-2015 and for future projections.

Some concern arrised with the logbook data of pair trawlers as it seems that in some cases only one of the pair trawlers report all the landings. This can lead to potential issues in the definition of targeting factors. We tried to remove this issue by working with the average monthly data in the following analysis.

The data used to estimate targeting factor were LPUE (Landing per unit Effort) associated with different species. Each fishing operation was associated to a métier, the following calculation can then be applied:

Equation 2)

$$LPUE_{Vessel,month,year,met} = average(\ LPUE_{Vessel,op,year,met})$$

Working with average monthly LPUE reduced the issues of missing important bycatch species for a métier, which can sometimes include a lot of zero at fishing operation level.
A glm with lognormal error distribution (Equation 3) was then fitted to estimate the coefficients of interaction Métier-Species (Lehuta et al., 2013):

Equation 3)

$$Log\left(LPUE_{Vessel,month,year,met}\right) = \mu + Fleet + Strat + \ Metier_{ts,season,gear,zone}{:}\,Species_{sp} + IA_{sp,year} + \ \varepsilon$$

Where IA is the index of abundance for a given species (sp) in a given year and ε follow a Gaussian distribution ($\mu\ = \ 0\,;\ sd\ = 1$)

d) Selectivity

Selectivity of the different gears was assumed to be constant and equal to 1 for all species except for anchovy for which the selectivity was set to different values for different gears. Selectivity was assessed from ICES catch at length between French and Spanish fleet (Boyra et al., 2013). It seems that the Spanish fleet consistently caught smaller anchovy in comparison with their French counterpart (smallest fishes caught by Spanish fleets = 7 cm against smallest fishes caught by French fleets = 9 cm) throughout the period 2000-2015. We thus set French selectivity higher than Spanish and so selectivity is:

$$S_{French,Anchovy} = 1\ if\ (length > 9cm), 0\ otherwise$$
$$S_{Spanish,Anchovy} = 1\ if\ (length > 7cm), 0\ otherwise$$

e) From effort to catch: how to reproduce the observed effort?

In ISIS-Fish, fishing effort (E) is a function dependent on the number of inactivity days in a month, the trip duration, the number of fishing operation by trip and the monthly proportion allocation of effort by métier. Standard fishing effort can then be computed (SE) at time step t and métier met as the following function:

Equation 4)

$$SE_{met,t} = \ \mathrm{TF}_{\mathrm{met,t}}.\,\mathrm{Std(gear)}_{\mathrm{met}}.\,\mathrm{Nop}_{\mathrm{met}}.\,\mathrm{E}_{\mathrm{met,str,t}}$$

Where TF is the targeting factor, $\mathrm{Std(gear)}_{\mathrm{met}}$ is gear's standardization factor, $\mathrm{Nop}_{\mathrm{met}}$ the number of fishing operation. We assume here that $\mathrm{Std(gear)}_{\mathrm{met}}$and $\mathrm{Nop}_{\mathrm{met}}$ are similar for all métier and standardization is only dependent of the previously computed targeting factor.

Two input parameters are still missing to fully compute the fishing effort; the number of inactivity days and the number vessels. In hindcast calibration the number of inactivity days is directly derived each year and month from observed effort in SACROIS data.

Equation 5)

$$InactivityDays_{month,year} = (30 - \frac{Effort_{obs}}{24})$$

With $Effort_{obs}$ being a vessel average effort in for given strategy, month, year.

The monthly distribution of effort proportion on each métier of a given strategy is assumed constant inside a period. This allowed changes in the métier allocation to better reproduce changes in fishing pattern for each period.

The number of vessels in each fleet and the proportion of this number among strategy change every year in hindcast period based on observed data.

Thus, effort input are almost all forced to reproduce exactly the average observed effort from our dataset in hindcast modelling.

3) Analysis of fishery history: What are the consequences of anchovy fishing ban and sea bass stricter control?

During our hindcast period (2000-2015), two major consecutive event happened to change the fishing activity, a ban on anchovy from 2005-2009 followed by catch limitation by vessel for sea bass. We tried here to investigat how the fishing activity has evolved throughout time in term of strategy, seasonality and spatial pattern.

In order to do so, we derived for each period previously explained (P1= 2000-2004; P2= 2005-2009; P3= 2010-2015) the average values in:

- The evolution of number of vessels per strategy
- Evolution of landings composition and possible change in target species
- Spatial mapping of effort between Strategy/Effort
- Spatial mapping of landings composition

4) Projecting the future dynamic of the fishery:

After calibrating the model in the hindcast period, some methods to forecast effort need to be implemented . The first section decribe the method to compute input parameter to the model of effort allocation for simulating fleet dynamics based on observed data.

a) How vessel change from a strategy to another in response of perturbations

Fishing fleet dynamic is needed to model potential changes and adaptation of fishing boats to perturbation from the environment. To build this fleet dynamic model, the observed reactions of the fleet to perturbation was scrutinized in order to extract the main variable that can be used to describe fleet behavior. In our case study two major event have affected the pelagic fishery, the ban on anchovy from 2005 to 2009 and increased management control on seabass from 2010. First in the 2010s seabass catch made by trawler were limited to 5tonnes per vessel and per week and license system was introduced in 2012 (Armstrong and Drogou, 2015; Drogou, 2013). This led to major changes in the structure of the fishing fleets. The analysis of the fishery's history showed that vessels could have some flexibility to change their fishing pattern from year to year, which means in our model a change in strategies inside a fleet.

A common method to describe this kind of behavior is by applying a discrete choice model with different socio-economic or fishery driven explicative variables, such as income, tradition or risk (Girardin et al., 2017). In our case study, these choices seemed to be based on previous experience, meaning the strategy practiced the previous year and the dependence in terms of landings and thus income of the major pelagic species.

An entry/exit model was built to describe the fisherman choice to stay or not in a strategy (Figure 4). Only the trawlers fleet is subjected to this dynamic considering the relative stability of the other fleets through time. The model describes the probability of choosing between the three identified strategies or leaving the fishery. We choose a multinomial non-ordered model (equation 6) to explain fisherman's decision.

Equation 6)

$$Log\left(\frac{Pstrat(y) \rightarrow strat\ (i)}{Pref = leave\ fleet}\right) = \mu strat_i + \beta strat_y + \sum_{sp} \left(\beta strat_{i,sp} * \%Income_{sp}\right) + \beta FishingBan_{sp} * Test + TotalIncome + MaritimeDistric + BoatOwnerAge$$

With Pstrat (y) -> strat (i) the probability of changing strategy to strategy (strat) i at t+1 knowing that the vessel was in strategy y at time (year) t, %Income (sp) corresponds to the % of income coming from species sp over the whole revenue of that boat in year t.
Price equation to calculate the income is detailed in Annex E.

The model was fitted using the *multinom* function from r package *nnet* (Ripley and Venables, 2016). A stepwise procedure was applied to select the variable according to the AIC criteria. Model performance was assessed using a confusion matrix between the observed choices and the simulated one.

Once the parameters were estimated, the model has been incorporated into ISIS-Fish to predict the probabilities of changing strategies knowing the realized incomes.
We made the assumption that strategies (% of effort per métier in a given strategy) are constant in projection and equal of the average observed strategy in the third period.

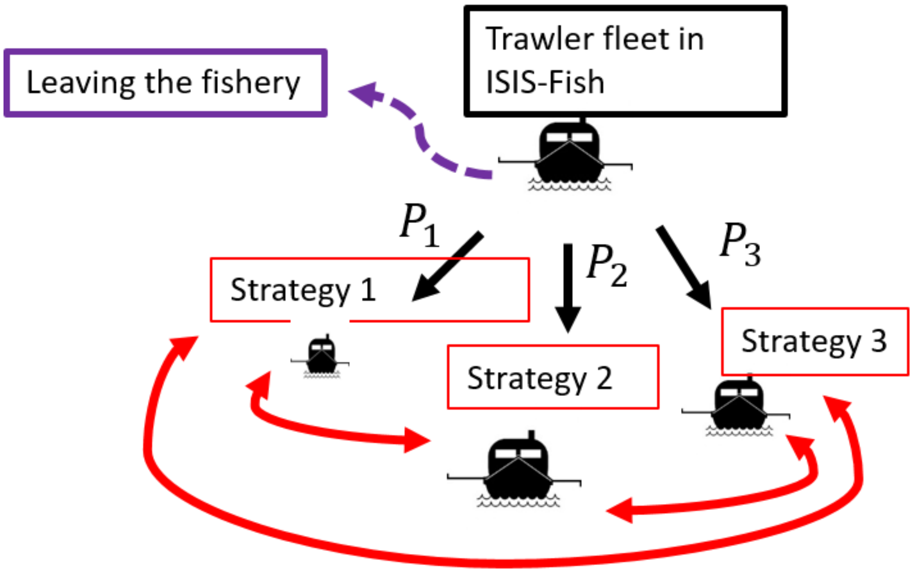

Figure 4: Schematic view of the exit/entry choice model for trawl strategy. (P1 to P3 are the proportion of the fleet in each strategies)

b) *Forecast assumption and scenarios for fishing activity*

In order to adapt to possible change in fishermen behavior in forecast, they are allowed to change from a strategy to another or even leave the fishery given their realized past activity. Climate change might drive a response of fish population and in reaction fishermen will modify their effort by choosing to stay or not in their respective strategy. This model of choice is only implemented for trawlers as describe above, other strategies will remain with a constant fishing effort pattern during the forecast.

Table 2: List of effort input assumption for pelagic trawlers made during forecast

Strata	**Input parameter**	**Hypothesis taken in forecast**
Fleet	Number of vessel by fleet	Average from P3
Strategy	Proportion of vessel by strategy	Dependent on a multinomial model (see section above)
Métier	Proportion of effort by métier-month	Average from P3
Effort	Inactivity day by strategy-month	Average from P3

III) POPULATION DYNAMIC

In the previous chapter, we described how fishing activity could evolve in response to change in landings composition, management measure and generally speaking change in fish population catchability. Our main assumption is that changes in environmental variables will potentially drive a response in fish population. In this chapter, we thus present (1) the method used to link environmental data to population dynamics as well as (2) the modeling of population dynamics in ISIS-Fish.

1) Understanding the link between environment and population dynamic: Review of known mechanisms

One of the difficulties that restrain the integration of climate change effect on population dynamics is that it potentially plays a different role at different scales in the environment and at different phases of a species life cycle. Synergic and antagonist effects are hardly predictable and processes are often studied independently. When trying to model climate change impact on population dynamics, three aspects need to be considered:

- The abiotic parameters involved in the population dynamic and potentially influenced by climate change.
- The types of response possible. According to Rijnsdorp et al. (2009) three types of responses can be distinguished: a physiological response, a behavioral response and a population dynamic response.
- The mechanism and corresponding statistical relationship linking the abiotic parameter and the fish population response.

We reviewed literature related to environmental effect on biological process and sorted out relationships evidenced based on mechanistic modeling from those base on statistical relationships. Scenarios of evolution for the environmental variables in the Bay of Biscay were then looked for.

Finally, our choice of the mechanisms to model were guided by:

- Available knowledge on the mechanisms
- Available scenarios of change on the abiotic parameters

2) Modelling the pelagic population of interest in ISIS-Fish.

Logbook analyses of landings and landed values evidenced that the pelagic fishery catches several species with important contrast of importance between strategies. It was decided to take only in account the most important pelagic fishes in term of landings and income of the fleets (see Results I). Species that replaced the anchovy during the ban in the second period were also included in order to better illustrate the dynamic of the fishery.

Finally, four different species and five populations were selected, their stock delineations are extracted from ICES's stock annexes (Armstrong and Drogou, 2015; Arrizabalaga et al., 2016; Boyra et al., 2013; Drogou, 2013; Duhamel et al., 2013).

- Anchovy population of Bay of Biscay.
- Sardine population of Bay of Biscay.
- North Atlantic Albacore Tuna.
- Seabass Bay of Biscay.
- Seabass Western Channel, North Sea and Celtic Sea.

Each population dynamic sub model is described by a spatial habitat that can differ for presence, spawning and recruitment; a population structure (in age or length); a natural mortality that can vary spatially or among age/length groups; a reproduction or recruitment equation; a growth equation and a price equation. The level of details and complexity of each sub model accounts for (i) the importance of the species in the fishery and (ii) the available knowledge.

a) Bay of Biscay anchovy: a complex spatially explicit life cycle with environment dependence

Anchovy in the Bay of Biscay is one of the most important species in terms of landings and income for the pelagic fishery and especially for the Trawl2 strategy (Results I.1).

Anchovy is a short-lived species with few individuals exceeding the age of three-years-old (Uriarte et al., 1996). Reproduction starts in April until the end of August with full maturity generally obtained at one year old. Reproduction is located in the south Bay of Biscay especially in areas close to the river's mouth of Adour and Gironde (Motos, 1996; Motos et al., 1996). During the spawning period anchovies have the tendency to form large aggregation thus making them more vulnerable to fishing activity (Uriarte et al., 1996). In his entire life cycle, the Bay of Biscay anchovy follows several migrations to fulfill reproduction, feeding and wintering (Taboada and Anadon, 2016). Anchovy is known to be highly dependent on environmental conditions and is therefore assumed to be sensitive to climate change at various stages of its life cycle (see section Result.IV.1). The modeling of this species dynamics was guided by the necessity to describe as much as possible environmental influence on the biological processes.

First, we described the spatial dynamic of this population, which is highly intertwined with its life cycle. Moreover, although current scenarios of environment change under global warming are not available at fine scale, the spatial dynamic of the species will induce the dynamics of the fleets. One of ISIS-Fish fundamental assumption is that abundance within a population zone is homogeneous and that catches are the result of the superposition of population zone and fishing zone. These hypotheses make the spatio-temporal description of the population a crucial point for the rest of the analyses, Population zones were thus defined by reviewing a large range of studies, which investigate spatial distribution of anchovy throughout his life cycle and especially during the spawning migration, trying to identify specific distribution patterns.

In April at the beginning of the spawning season, the individuals are distributed in different zones of the south Bay of Biscay. Those zones are known through the yearly scientific survey PELGAS occurring every year in April and May (Doray et al.year). Based on this campaign (Petitgas et al., 2011, 2014; Vaz and Petitgas, 2002) suggested that the distribution of anchovy among those zones is size dependent. We retained four zones during the spawning period, the two river's mouth of Adour and Gironde, the Rochebonne shelf and a northern zone (see Figure 7). Spawning is restricted to the first three zones of Adour, Gironde and Rochebonne shelf (Bellier et al., 2007; Planque et al., 2007). Migration occurs in April, and migration coefficients for 5cm length bins were inferred every year using the PELGAS survey and the observed distribution of the different length class of anchovy. The average of these coefficients over 2000-2015 is used in projection. We assumed that no additional movements occur among the zones during the spawning season. After the spawning period in September, the adults (age 1+), migrate in the northern part of the Bay to reach autumn feeding ground until the end of December (Petitgas et al., 2010). Feeding ground delineation is derived from Politikos et al., (2015) and still covers a large part of the Gironde's mouth.

In January those adults start migrate back to the southern part of the Bay of Biscay and are more homogeneously distributed throughout this area a single zone derived from Planque et al. (2007).

After hatching, recruits and fishes younger than 1 year old are distributed in a juvenile's zone which covers the whole Bay's shelf and a part of the Cantabrian Sea. According to the autumn Spanish survey Bioman the distribution of individuals in this zone is supposed homogeneous (Boyra et al., 2013).

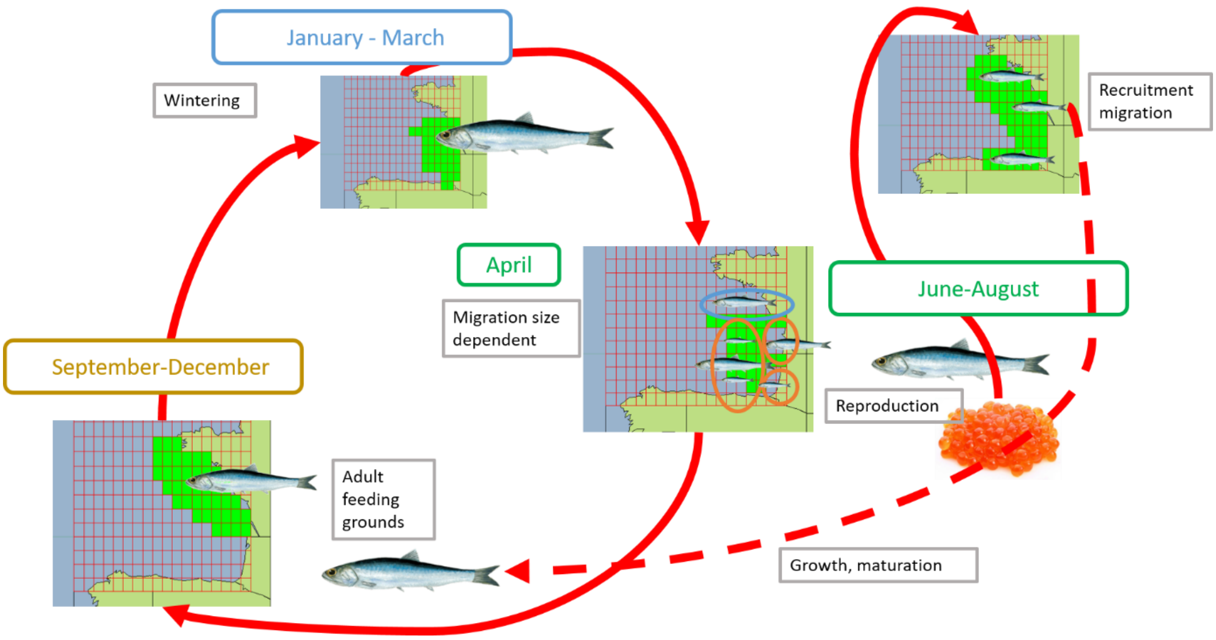

Figure 5: Migration and life cycle modelled for the Bay of Biscay Anchovy

A second input in the model is the structure of the population. Since we are interested in temperature effect on growth, especially on the K coefficient of the Von Bertalanffy equation, we need to describe finely the first life stages. Spawning spreads over five months. Previous results showed that birth month is highly determinant for early survival (Huret et al., 2017) and that the spawning ogive may depend on winter temperature (Huret et al., 2017). Although the scenarios investigated in this study will not address these effects, we designed the model to allow these future investigations.

Fifteen length classes are defined that cover all the life span of the species, the last class is a plus group that contains all the individuals older than three year old. The twelve first length classes correspond to the first year of the individuals and are the juveniles' stages. This slicing allows us to keep track of the monthly cohorts of different length class until the next April at the time of their spawning migration. Given that migration is length dependent, 1-year-old fish migrate to different spawning zones depending on their month of birth. Natural mortality varies among those stages. Values for the older ages are derived from ICES stock assessment input (Boyra et al., 2013). To calculate the value of natural mortality for each juveniles stages, we use an exponential decay (Pareto regression) between daily egg mortality for larval stages (Lo et al., 1995) and the adult mortality of 1 year old (Annex A).

Growth is assumed to follow a Von Bertalanffy equation for all stages (Von Bertalanffy, 1938). The growth parameters are constant for all stages and derived from ICES stock definition (Boyra et al., 2013, equation 7).

$$L_t = L_{inf}(1 - \exp(-K(t - t_0)) \text{ (eq. 7)}$$

With Linf= 18.77 cm, K= 1.25 and t0= -0.17

Similarly, the weight-length equation is extracted from ICES stock annex with the following equation (eq. 8) describing the conversion:

$$W = a.L^b \text{ (eq. 8)}$$

With a = 0.007 and b = 3.017

All the parameter input for anchovy population are detailed in annex A.

Recruitment in the hindcast period (2000-2015) is forced to reproduce the value of the ICES stock assessment output in January, which gives the abundance of 1-year-old fishes. In our model, we need to provide the corresponding number of eggs distributed in all the spawning period to get the value assessed by ICES stock assessment in January. The biomass provided by ICES is converted in fish number using the average weight of one-year-old fish. Then we retro calculate the corresponding number of eggs by applying the inverse mortality of stage 1 to 7 to get the number in April. Recruitment is then distributed in across the spawning period using a monthly spawning intensity ogive derived from egg concentration ÉCLAIR survey in 2008 (Huret et al., 2017).

April = 0.04; May= 0.26; June =0.28; July = 0.27; August = 0.15

In forecast, recruitment is fixed and equal to the average of the 2000-2015 values obtained from ICES stock assessment. The same retro-calcul of egg number and distribution over spawning months is applied as for the hindcast simulations.

b) Sardine population: A pelagic population with little biological and environmental knowledge

Less information is available for the life cycle and distribution of sardine than for anchovy. Although further work is ongoing to improve the description of sardine's life cycle and response to environment, in a first approach we did not want to reproduce the biology of the species in details but rather get the level of abundance correct.

ICES distinguishes three different stocks : the ibero atlantic that covers area VIIIc and IX, the Bay of Biscay in area VIIIa,b and d and the north stock in Celtic sea and English Channel. However, genetic studies and connectivity analysis suggest that the Western

Channel individuals are no different from their Bay of Biscay counterparts and Western Channel population was grouped with the rest of the Bay of Biscay stock (WKPELA, 2017). Additionally it seems that connectivity exists from area VIIIc in Cantabrian sea and the Bay of Biscay area VIIIb (Petitgas et al., 2010). Considering that for our strategies, catch of sardine range from Western Channel to Cantabrian Sea, we defined a unique population that covers all these areas.

Sardine seems to spawn all year round but the main season remains between October and June and occurs all along the shelf (Stratoudakis et al., 2007). Studies have investigated the spatial distribution during spawning but there is no clear pattern emerging with concentration zones such as anchovy (Bellier et al., 2007; Petitgas et al., 2010; Planque et al., 2007). For this reason, we considered that recruitment and spawning occurred uniformly in the population zone.

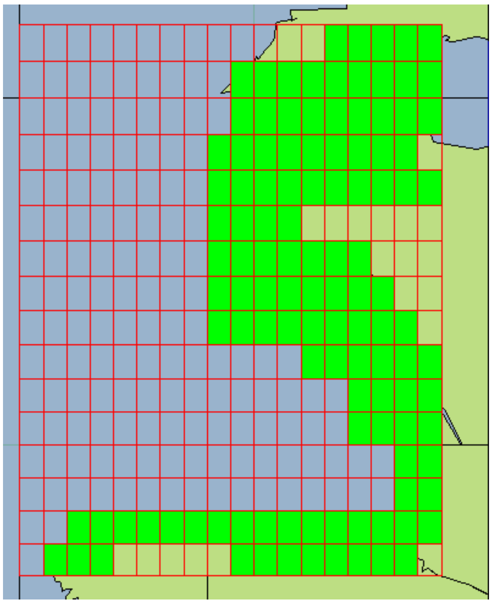

Figure 6: Sardine population zone in the model

Sardine life span generally extends nine years old with individuals that can live up to fourteen years old. We choose an age structured population from age 0 to age 6+ similar to the one adopted by ICES stock assessment in the Bay of Biscay (Duhamel et al., 2013). This allows to use the natural mortality parameters at age given in WKPELA (2017) with values decreasing throughout the life (Annex B).

Growth in length is limited to the first 4 years. After that, growth mostly consists of an increase in weight. The growth model however did not capture this heterogeneity and we applied a simple von Bertalanffy equation

(eq. 9, L_{inf}= 25 cm, K = 0.25 and t_0= -0.12)

And classic length weight relation

(eq. 10, With a = 0.0068and b = 3.0608)(Duhamel et al., 2013).

Sardine recruitment in hindcast simulations (2000-2015) is forced to reproduce ICES stock assessment in January for age 0. In forecast, we choose to use the average recruitment of the 2000-2015 period.

c) Sea bass and Tuna

Little knowledge is available for those three populations (two sea bass populations and one tuna population) but those species still represent an important part of the landings and are characteristic of some strategies. Outputs of ICES and ICCAT stock assessment respectively were used in order to reproduce their global dynamics.
The population zone for Bay of Biscay sea bass is identical to the one defined by Drogou, (2013) which is the ICES area VIIIa,b. The other seabass population is spread over central and southern North Sea, Irish Sea, English Channel, Bristol Channel, and Celtic Sea. For the purpose of the study we will only considered the Western Channel as the population zone, that is to say area VIIe from ICES (Armstrong and Drogou, 2015). Albacore Tuna population zone for our model is assumed to cover all the Bay of Biscay area that is to say ICES area VIII.
For the sake of simplicity, all three populations are modeled as a unique group. Natural mortality is fixed in this single age group (Annex C).In hindcast simulation, population biomass is forced every year with the biomass extracted from ICES and ICCAT stock assessments. Because we redefined the population zone and because the fishing mortality imputable to our strategies is low (12% of total catches of sea bass and less than 6% of total catches of tuna), we also added a fixed fishing mortality due to other fleets not modelled in ISIS-Fish.
To calculate this parameter we use the fact that Total fishing mortality is the addition of the fishing mortality applied by ISIS fleets (F_{ISIS}) and the other fleets fishing this population ($F_{otherFleet}$) (equation 11).

$$F_{Total} = F_{ISIS} + F_{otherFleet} \text{ (eq. 11)}$$

Then by extracting F_{Total} and total landings ($Landings_{Total}$) from the stock assessment, the partial fishing mortality from the other fleets $F_{otherFleet}$ follows the equation below:

$$F_{otherFleet} = \frac{Landings_{Total} - Landings_{ISIS}}{Landings_{Total}} . F_{Total} \text{ (eq.12)}$$

In forecast simulations, we use the average total biomass assessed annually over 2000-2015, thus assuming no impact of fishing from ISIS fleets on these populations.

3) Calibration method

In ISIS-Fish, accessibility represents the biological component of fish catchability (also called disponibility, Chadwick et O' Boyle, 1990). This parameter is hardly estimated and is commonly used in ISIS-Fish as a tunning parameter to adjust catch levels to observations.

Calibration was carred out over the period 2000-2015 and accessibility was assumed constant from year to year on the whole period. In the absence of information about changes in behaviour and subsequent accessibility of sardine in course of the year, it was simply assumed an age-dependent accessibility. Conversely, seasonal variations were assumed in accordance with migrations in the tuning of anchovy accessibility, which also depends on age, resulting in 9 values to estimate (3 seasons x 3 age groups). A unique value is assessed for Tuna, Western Channel Sea bass and Bay of Biscay Sea bass.
In calibration simulations, effort (numbers of boats per fleet, % of a fleet per strategy et % of effort per métier) was forced to yearly observed values for number of boats and % of a fleet per strategy and to monthly observed values for the % of effort per métier. Recruitment for anchovy and sardine and biomass for sea bass and tuna, were forced to observed values annually,

Two different methods were used depending on the number parameters to assess. A genetic algorithm readily available in ISIS-Fish was used for anchovy and sardine (see Annex D for the metaparameters). Sea bass and tuna accessibilities were refined sequentially, starting for a large interval of values sampled uniformly (10 values) and progressively narrowing the searching interval according to the two consecutive values that provided the best objective functions. The objective functions chosen reflect the will to achieve a satisfactory fit to observed catches both at the scale of the strategy, while respective their relative importance, and the fishing pattern across age classes. The following equations were used for anchovy and sardine (equation 13) and for tuna and sea bass (equation 14):

Equation 13)

$$Obj_1 = \sum (obs - sim)^2 \ with\ obs = \ \%Catch_{Age,quarter}$$

$$Obj_2 = \sum \left(\frac{obs - sim}{obs} . \frac{Landings_{Str,Year}}{LandingsTot_{Year}}\right)^2 \ with\ obs = \ Landings_{Str,month,Year}$$

$$Obj = \ Obj_1 + Obj_2$$

Equation 14)

$$Obj = \sum \left(\frac{obs - sim}{obs} . \frac{Landings_{Str,Year}}{LandingsTot_{Year}}\right)^2 \ with\ obs = \ Landings_{Str,month,Year}$$

IV) CLIMATE CHANGE SCENARIOS IN THE BAY OF BISCAY

4) Construction of different environmental scenarios for the Bay of Biscay

The goal is to explore potential changes in fishery dynamic due to climate change. Following the review of known mechanisms and available environmental scenarios, an increase in sea temperature is the only scenario considered. Credible scenarios of temperature increase in the Bay of Biscay are available from IPCC report and local studies (Charles et al., 2012; Costoya et al., 2015; L'Hévéder et al., 2017). In this exploratory approach, contrasted simulation settings are confronted to get insight in the likely trends and amplitude of the variations experienced by the fishery given the two mechanisms modelled: impact of temperature on growth, and response of the fishery in term of selection of the strategies. We were also interested in the linearity of impact of temperature increase and thus tested various level of increase. The simulation design consists in six simulations, projecting the fishery over 30 years, which is a relative long term to see notable differences in temperature (Table). The increase in temperature applies from the first year on. Initial population numbers are 2016 estimates.

Table 3: Scenarios definition for modelling environment impact on anchovy population dynamic

Scenarios	Temperature	Population dynamic	Projection
Baseline	No increase	Yes	30 year
Baseline-No	No increase	No	30 year
SC 1-Yes	+ 0.5°C	Yes	30 year
SC 1-No	+ 0.5°C	No	30 year
SC 2-Yes	+2°C	Yes	30 year
SC 2-No	+2°C	No	30 year

Impact will be quantified relative to the baseline (no increase in temperature) considering the number of boats participating in each strategies to understand the dynamic of the fishery. We compare landings between each scenarios not in absolute value but in relative terms because of the poorly performance of the calibration especially for anchovy (see Results III). In those scenarios, we expect that an increase in temperature accelerate growth (Figure 7) and thus change the size distribution of younger stages that could then migrate in April with the adult in spawning areas. Indeed migration among the spawning zone is size dependent (see III.2)

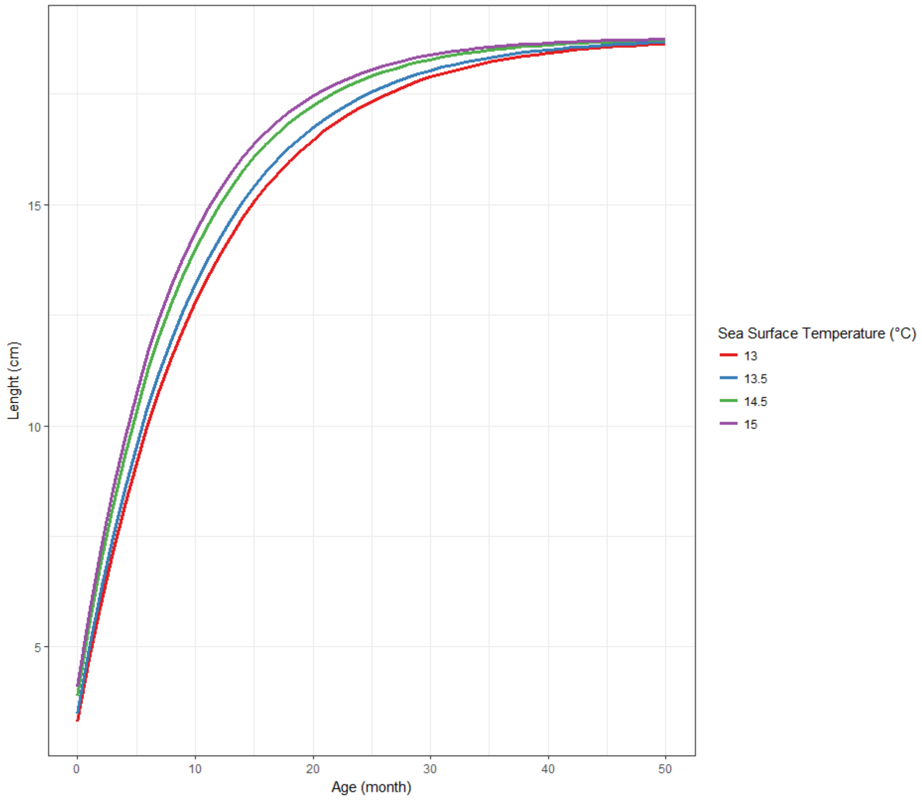

Figure7: Influence of temperature increase in the growth curve via the K parameter of Von Bertalanffy equation for Bay of Biscay Anchovy.

RESULTS

I) FLEETS & STRATEGIES CHARACTERIZATION

1) Structure of French Purse seiner: Two regional fleets

Multivariate analysis and clustering on landings composition brought to light important structuration of the French purse seiner fishery. Results from in Figure 8 show that Basques and Bretons' landings profiles are completely different. Vessel operating in southern Brittany are very homogeneous with on average 70% of landings composed of sardine caught with purse seine whereas Basques' purse seiners express a more diverse landing composition, catching Tuna species like Albacore (ALB) and Blue Fin Tuna (BFT) with longlines or handlines and mackerels (MAS), sardine (PIL) or Horse mackerel (HOM) with purse seine. Moreover, by studying individual vessel trajectory between areas there seems to be little overlap between the two groups of vessels. These two groups of vessels will then be treated as two different fleets. On the contrary, inside the Basques purse seiner fleet the two profiles previously described can sometimes overlap with vessel changing average landings composition from year to year. Two different strategies were then created inside the Basques fleet.

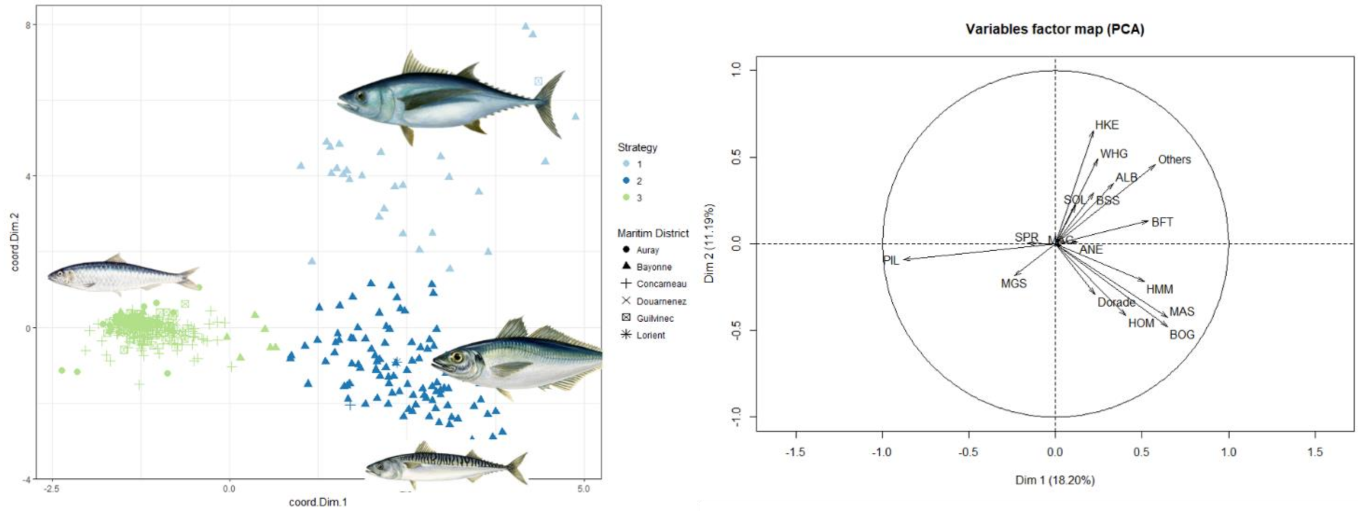

Figure 8: French Purse seiner PCA results on landings composition (strategies were defined by the clustering on the results of the PCA)

2) Three different landing profile in an heterogeneous trawler fleets

The Bay of Biscay trawlers belong to a mixed fishery, they operate mainly with pelagic trawl but they can use bottom trawl to target demersal and benthic species like hake or anglerfishes. They thus have access to a large panel of species and heterogeneous landings profiles. Some patterns can however bee identified in the multivariate analysis. Throughout the 2000-2015 period, three different profiles coexist and a detailed exploration of vessel fishing pattern evolution showed some exchange between fishing patterns. Looking at figure 9, we can see that two of the three strategies are predominantly pelagic but target different species. Indeed the first strategy fish mainly sardine (more than 50% of the landings). The strategy 2 is mainly associated with anchovy (about 20-30% of total landings), seabass and albacore tuna with respectively 15% and 10% of all the landings in average for a vessel of this strategy. The last strategy regroups vessels predominantly fishing on demersal species with the pelagic part accounting for about 10% of the total landings.

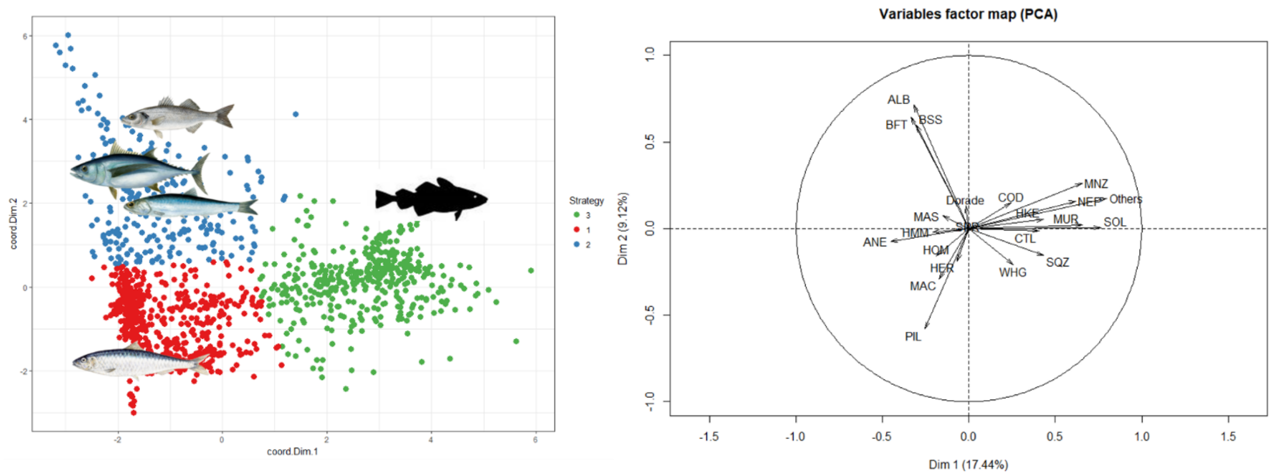

Figure 9: French Trawlers PCA results on landings composition (strategies were defined by the clustering on the results of the PCA).

The structure of the Bay of Biscay French pelagic fishery as implemented in ISIS-Fish is then resumed in the following two tables (4 & 5):

Table 4: Final fishery structure

Fleet	Strategy	Main species	Main gears
Trawlers	Trawl 1	Sardine, Horse mackerel, mackerel, hake	Pelagic Trawl, Bottom Trawl
Trawlers	Trawl 2	Anchovy, Tuna , Seabass	Pelagic Trawl
Trawlers	Trawl 3	Hake, Anglerfish, Anchovy, Sardine	Bottom Trawl, Pelagic Trawl
Breton Purse Seiner	Breton 1	Sardine	Purse Seine
Basque Purse seiner	Basque 1	Sardine, Tuna, Seabass	Purse Seine, Lines
Basque Purse seiner	Basque 2	Sardine, Anchovy, Mackerels	Purse Seine
Spanish Purse seiner	Spanish 1	Anchovy, Tuna, Sardine	Spanish Purse Seine

Inside a strategy, the average monthly landing composition (see Annex C) informs on the seasonality of a strategy. This seasonality will be used for all the given métier inside a strategy (Table 5).

Table 5: Seasonality for each strategy (same for all the métiers of the given strategy)

Fleet	Strategy	Season
Trawlers	Trawl 1	• S1 (October-March) • S2 (April-September)
Trawlers	Trawl 2	• S1 (October-April) • S2 (May-September)
Trawlers	Trawl 3	• S1 (November-May) • S2 (April-October)
Breton Purse Seiner	Breton 1	• S1 (November-April) • S2 (May-October)
Basque Purse seiner	Basque 1	• S1 (November-March) • S2 (April-July) • S3 (August-October)
Basque Purse seiner	Basque 2	• S1 (November-March) • S2 (April-July) • S3 (August-October)
Spanish Purse seiner	Spanish 1	• S1 (January-March) • S2 (April-June) • S3 (July-September) • S4 (October-December)

II) HISTORICAL EVOLUTION OF THE FISHERY

1) Evolution of fishing pattern through 2000-2015: Adaptability vs stability

After a description of the strategy and their landing profile, we can use this new structure to see how it evolved during and after a crisis.

a) Evolution of landings composition

Figure 10, shows that the major observed changes occurred for the strategy 2, which was the most anchovy driven strategy of the three. In order to compensate this important loss it seems that the vessels operating in the second strategy framework compensate with species highly valuable like Albacore tuna and seabass and also species that were previously targeted inside the strategy 2. The same mechanism can be observed with strategy 1 which compensate the loss of anchovy by increasing the proportion of its main targeted species, sardine.

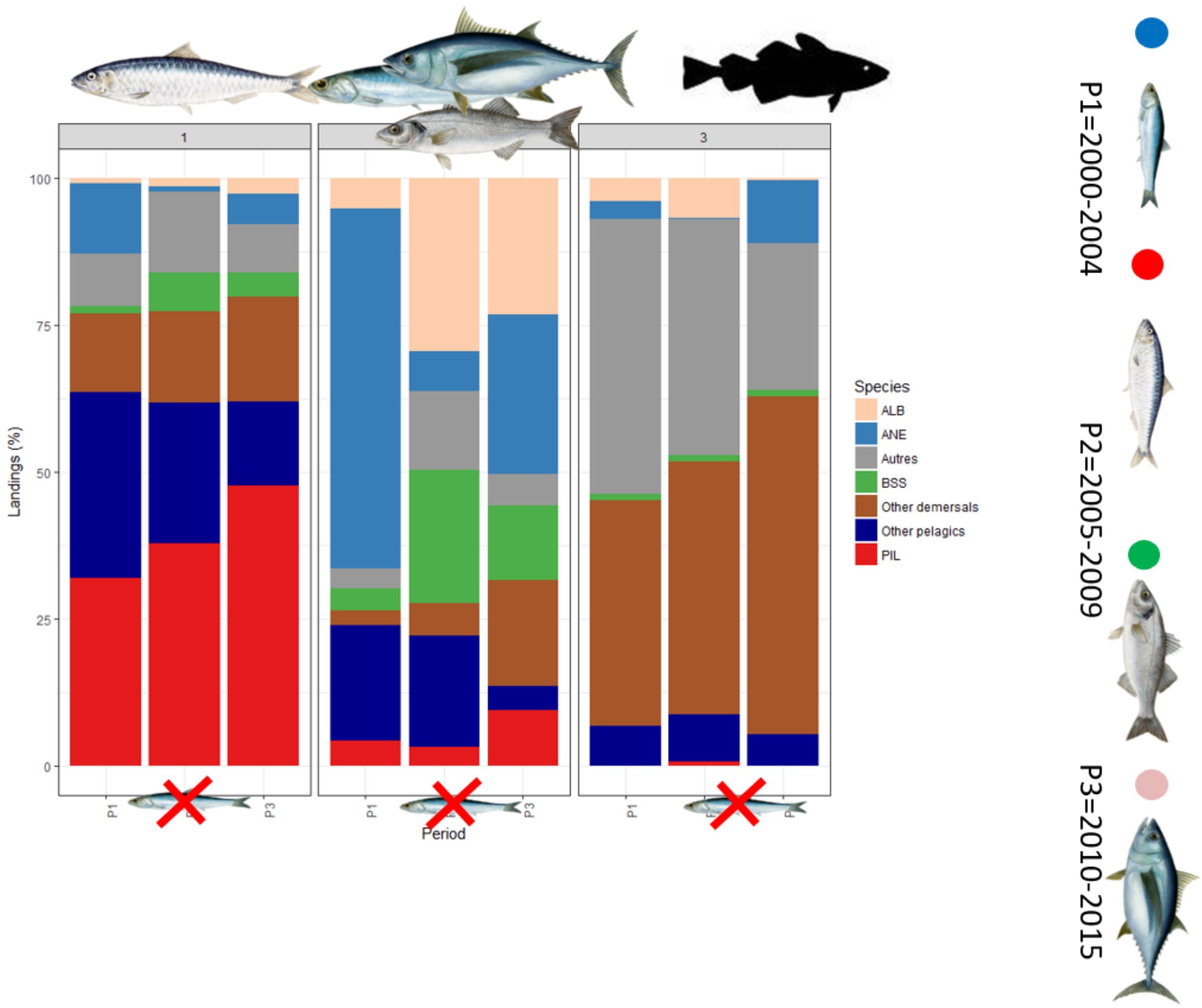

Figure 10: Evolution of average landings specific composition for all the three trawl strategy.

b) Evolution of spatial patterns in the landings

Figure 11 illustrates the simultaneous change in spatial pattern that followed the change in species composition for pelagic trawlers from strategy 2. Increase in seabass proportion in the landings came on majority from the western channel area. This switch, in fishing exploitation for a population that was already assumed to be overexploited (Armstrong and Drogou, 2015) may have led to a new management measure. Indeed, in response toward this change in fishing activity a limitation of catch to 6t a week per vessel was put in place to limit sea bass catches. This can be seen as the third period with important diminution of landings on the western channel. It also coincides with the reopening of the anchovy fishery.

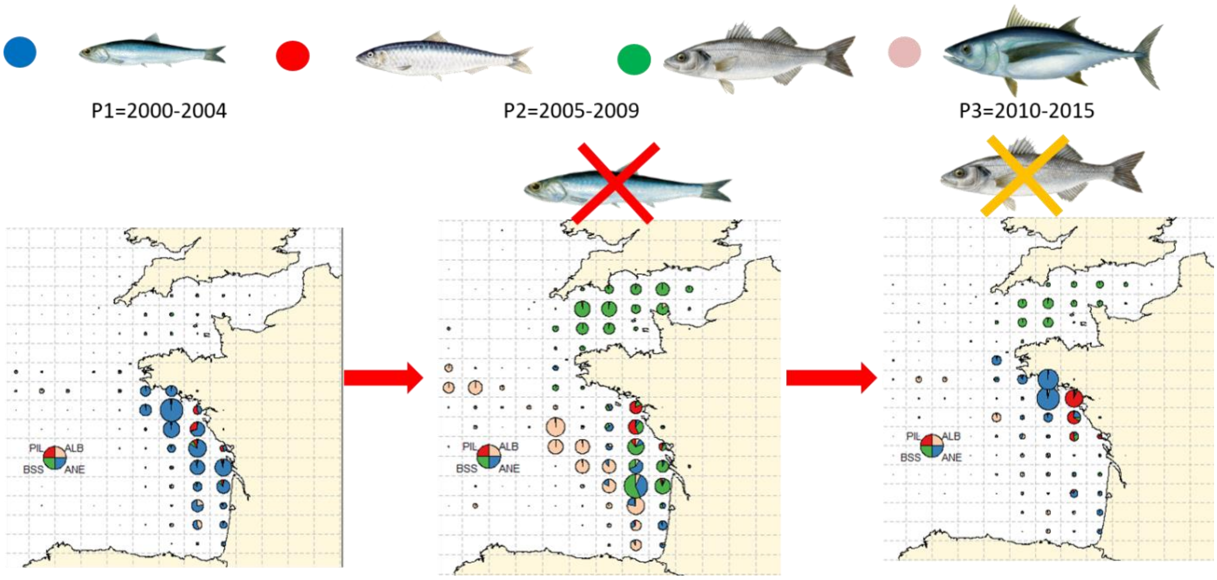

Figure 11: Average landings of the species modelled inside each period, for strategy Trawl2.

Another interesting result is the complete change of landings distribution of the anchovy before and after the ban with only the northernmost fishing area remaining highly harvested to catch anchovy. This can perhaps be explained by the disappearance of an important part of the southern part of the Bay of Biscay fishermen.

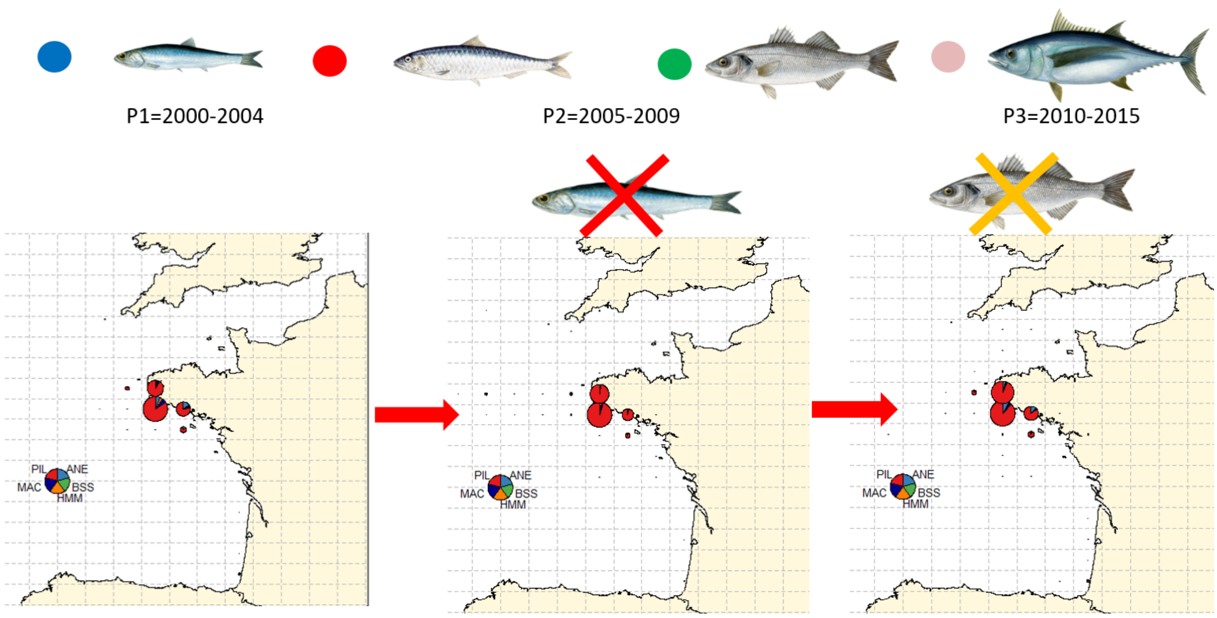

Figure 12: Average landings and species composition for each period : Strategy Breton purse seiner

On the contrary of what was said for the trawl2 strategy, Figure 12 shows that some fishery are very stable in terms of fishing activity even if they lost a species accounting for more than 10% of their total yearly income before the ban.

All those results highlight the fact that a further investigation in fishermen effort redistribution mechanism must be taken into account for a better understanding of the fishery.

c) Change between strategy

At the individual vessel's level, exploitation pattern can be followed and thus its choice of leaving or staying in a strategy. Figure 13 shows that some vessels from the strategy 2 chose to go for a more sardine-oriented strategy after the anchovy ban but overall the predominant decision made by fishermen was to leave the fleet. A withdrawal plan of fisheries was indeed taken by policymakers during this anchovy crisis and led to more than half the vessel leaving the fleet (Andres and Prellezo, 2012; Boyra et al., 2013; Vermard, 2009). The consecutive decision of toughen the control on seabass may have led to further diminution of vessels.

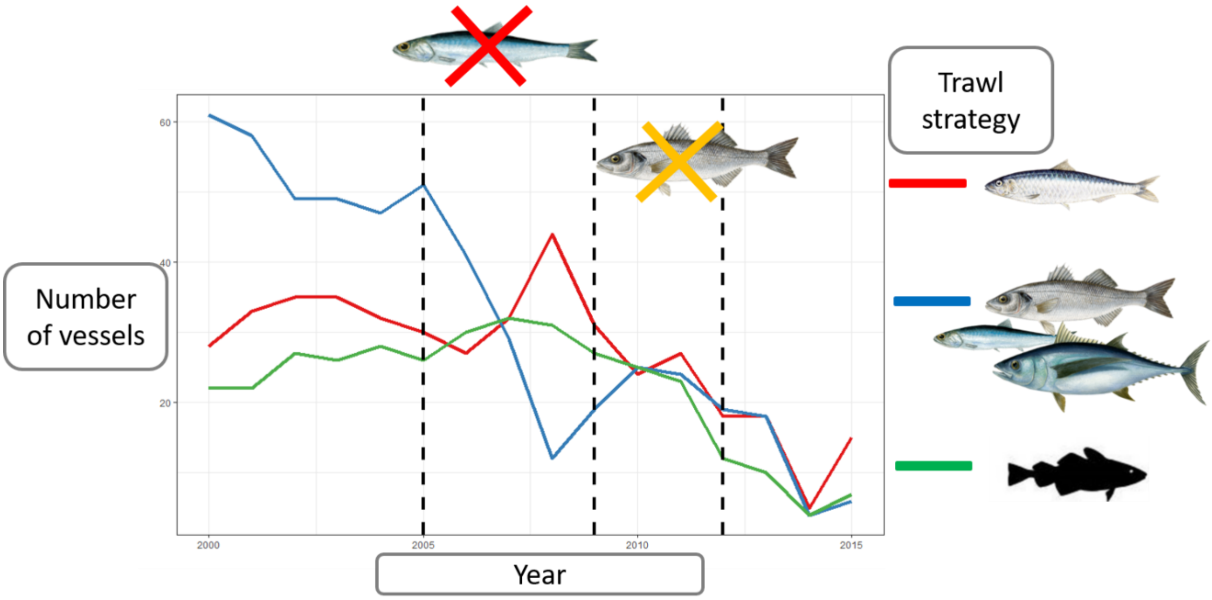

Figure 13: Evolution of the number of vessels in each strategy during 2000-2005

2) Understanding the mechanism behind strategy change

The phenomenon described above is assumed to be dependent on several socio-economic parameter and experience information (see Mat & meth II.4). The stepwise procedure that selected the meaningful variable in relation to AIC criteria selected the experience parameter $\beta strat_y$ that informes about the previous strategy choice made by the fisherman, the possibility of banning anchovy and the %of income of each species (equation 15)

Equation 15)

$$Log\left(\frac{Pstrat(y) \rightarrow strat\ (i)}{Pref = leave\ fleet}\right) = \mu strat_i + \beta strat_y + \sum_{sp} \left(\beta strat_{i,sp} * \%Income_{sp}\right) + \beta FishingBan_{sp} * Tes$$

This model then allows for exploring the impact of increasing the importance of a variable on the strategy's choice all other values set to constant. Figure 14 shows the impact of increasing the proportion of anchovy in the catches (the proportion over other species staying constant among other species). Coefficients of the model are described in Annex H.

Figure 14, illustrate the choice made by the fisherman one you increase the percentage of anchovy in his income, whichever choice he has made before the probability to leave the fleet (Strategy 4) will decrease and the probability of joining are staying the strategy 2 rise.

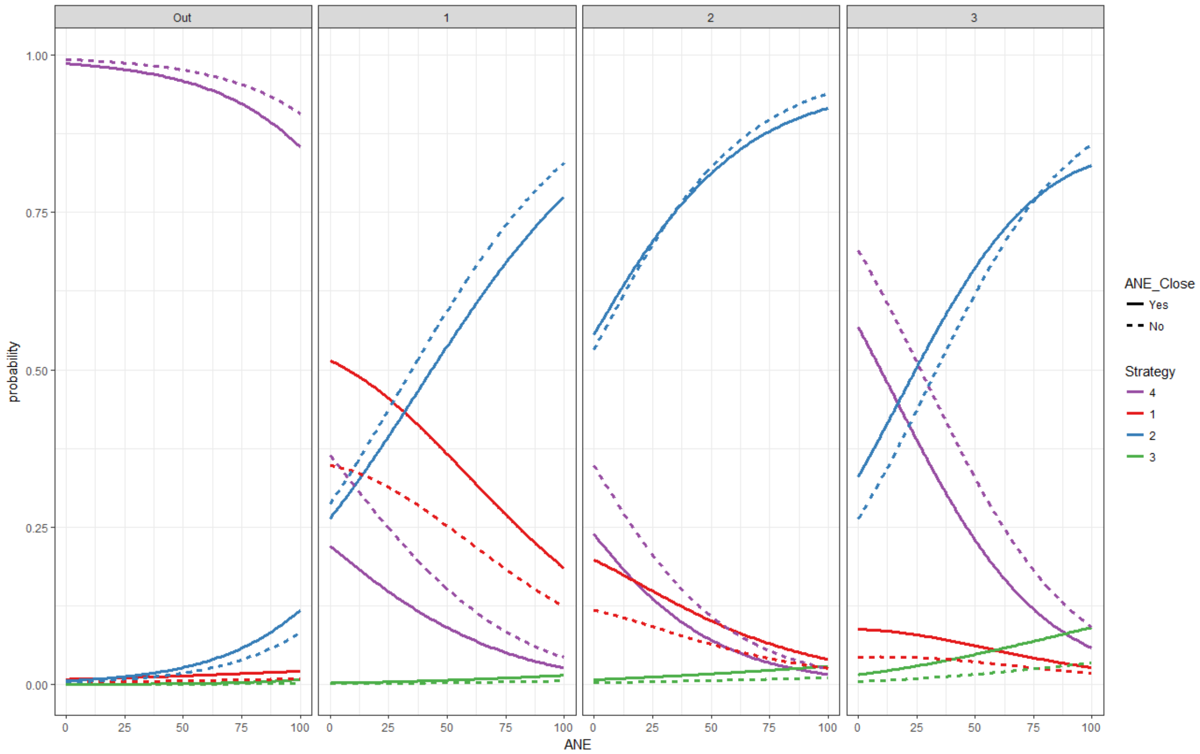

Figure 14: Evolution of the probability of changing strategy knowing the previous strategy and the % of income depending on anchovy (a box represents the strategy in year (y) and lines inside each box the probability of choosing a strategy year y+1, 4=leave the fishery, 1=sardine strategy, 2=anchovy/sea bass/tuna fishery, 3=other species strategy)

III) HINDCAST CALIBRATION

1) Calibration result for Albacore tuna and seabass population

Calibration for Tuna revealed satisfying especially regarding the seasonality of catch. Inter-annual variations are less well captured, which is not surprising since fishing mortality of the fleets not explicitly modeled was assumed constant over 15 years, which is a strong assumption. The same remarks apply to sea bass populations. However, the pattern of misfit is more structured in time, with a clear underestimation of catch during the second period (anchovy ban). It suggests that effort is not sufficient to explain the increase of sea bass catches and that fishing efficiency and/or also possibly increased at the time. It advocates for a calibration of q per period for further work. (See Annex G).

2) Calibration result for anchovy and sardine population

Result from anchovy and sardine population: The model was unexpectedly unable to capture the seasonality and inter-annual variability of sardine and anchovy catches (See Annex G). In deep analyses are needed to understand the origin of such a mismatch, although efforts and recruitments are forced. Catches at age for both population gives also disappointing result with a simulation that failed to reproduce the exact pattern in catch at age proportion. However the value obtained remain in the credible range of catch at age proportion.

At annual scale though, the level of landings is within the range of the 15 years observations. For the purpose of this analysis in which fishing activity is driven by relative annual landings, and before further calibration can be undertaken, the current values are used (see Annex G)

IV) CLIMATE CHANGE SCENARIOS

1) Understanding the link between environment and population dynamic: Review of known mechanism

Table 6 reviews known mechanisms that are physiological or population dynamic response to environment. Behavioral response such as change in habitat, migration or northern expansion of the stock are not taken into account because as opposed to growth and reproduction, stock distribution is known only in spring and the role of environment has not been clearly established (Petitgas et al., 2014; Planque et al., 2007). Table 6 also includes mechanisms evidenced on other species that can still be relevant for the anchovy population.

Table 6: Review of known mechanism between environmental parameter and population biology

Biological function	Species studied	Life stage	Environmental parameter	Population variable	Mechanism	Description	sources
Recruitment	Anchovy	Larval	Wind, Air temperature	Larval dispersion, larval mortality	Lagrangian biophysical model	Particles Transport modeling	(Huret et al., 2007, 2009; Lett et al., 2010)
Growth	North sea cod and Haddock	Larval	Temperature(T), Food (F)	Length	$L_{age} = \int_{t=0}^{t=age} f_1(age).f_2(T).f_3$	Length at age dependent on T and Food function	(Heath and Gallego, 1997)
Growth Recruitment	Anchovy	Larval and Adult	Temperature(T)	Length, Mortality at stage	$L_t = L_0 \exp(K.(1 - \exp(\alpha_T.t))$ $\alpha_T = cste_1.(ctse_2.T - cste_3)$	Modified Gompertz growth model	(Mullon et al., 2003)
Growth	Cod	Larval and adult	Temperature(T)	Weight at age (Wi)	$W_{i+1} = W_i(1 + cste_1.T.W_i^{cste2})$	Larval growth at age	(Kell et al., 2005)
Recruitment	Cod	juveniles	Temperature (T)	Recruitment (R), Spawning Stock Biomass (SSB)	$R = \alpha.SSB.\exp(-\beta.SSB + \delta.T)$	SSB (Spawning stock biomass) α, β and δ are constant	(Kell et al., 2005)

Reproduction	Anchovy	Adult	Temperature (T)	Start spawning	$T\_limite\ spawning$	Temperature control on spawning	(Koutsikopoulos and Le Cann, 1996; Motos, 1996)
Reproduction	Anchovy	Adult	Temperature (T) Food (F)	Number of egg, number of batch and starting date reproduction	DEB modelling	Diet Energy Budget	(Gatti et al., 2017)
Growth	Anchovy	Adult and Larval	Temperature (T) Food (F)	Length, Weight at age	DEB modelling	Diet Energy Budget	(Gatti et al., 2017)
Growth	Anchovy	Adult	Temperature (T) Food		$L_t = L\_\inf.(1 - \exp(-K(t - t_0))$ $K_T = \exp\left(\frac{T_A}{T_1} - \frac{T_A}{T}\right).K_{T_1}$	Von Bertalanffy growth equation with K depending on T	(Pecquerie, 2007)

As highlighted in table 5 there is abundant evidence of the relationship between growth and environmental conditions both from mechanistic models (Dynamic energy budget (Gatti et al., 2017; Pecquerie, 2007)) and from empirical analyses (Heath and Gallego, 1997; Kell et al., 2005; Mullon et al., 2003).

With regards to the different species of interest, despite recent studies (Gatti et al., 2017) little is known on sardine and we focused our efforts on the anchovy population, which is a key species in the fishery and for which more details of the life cycle are known.

The Bay of Biscay anchovy life cycle admit three distinct life stages that depend on several biological processes (Figure 15, (Taboada and Anadon, 2016; Uriarte et al., 1996)). Growth, reproduction and recruitment are frequently described as largely dependent on environmental conditions and therefore potentially affected by climate change (Checkley et al., 2009). The realization of these stages is also largely dependent on essential habitats and migrations that will likely be affected by climate change.

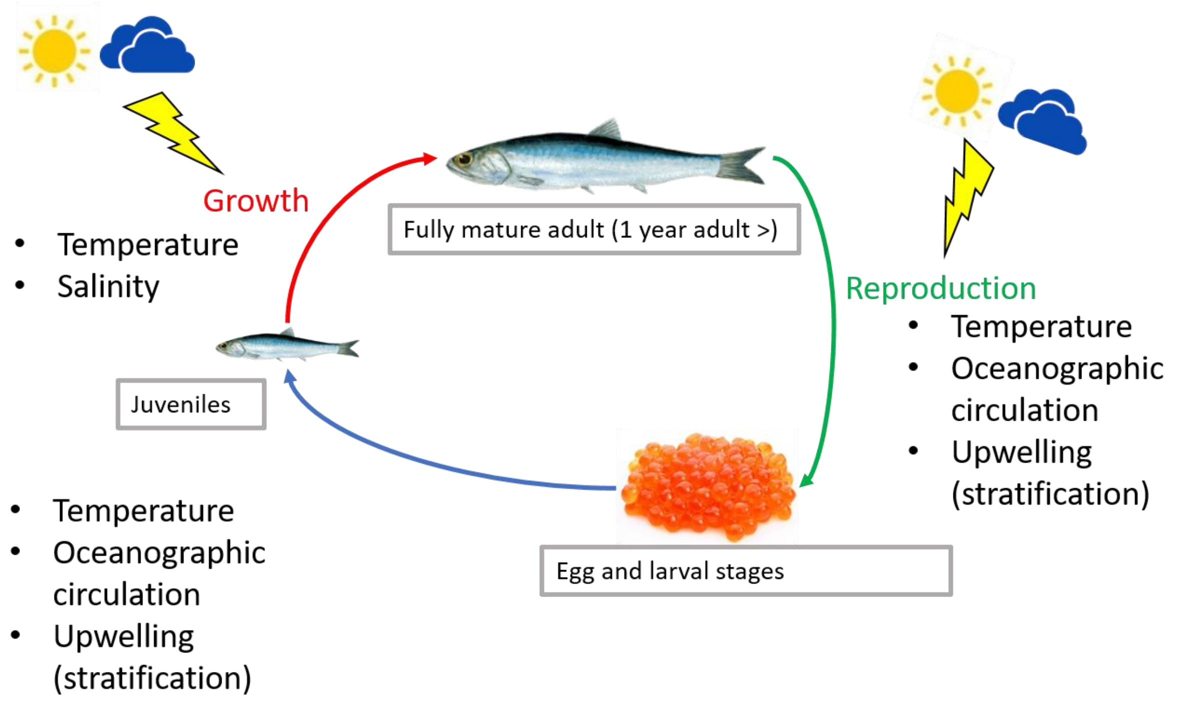

Figure 15: Bay of Biscay anchovy life cycle and possible environment influence on biological function

As a short-lived species, growth is central to anchovy dynamics. During the larval stage, survival is conditioned to the reach of a threshold size before metamorphosis (Allain et al., 2007).Research surveys evidenced that spatial distribution at spawning time is length-dependent (Petitgas et al., 2011) rather than age-dependent. Regarding fishing and economic aspects, although it is admitted that there is no selectivity of the gear, fleets are known to target specific sizes to match market demand (Dolores Garza-Gil et al., 2011) and prices are function of size (see annex E). It is consequently likely that climate effect on growth propagate through the system.

2) Integration of environment dependence: A Temperature dependent growth

In the following we chose to focus on the well documented effect of temperature on growth using the relationship proposed by (Pecquerie, 2007) based on a dynamic energy budget model.

Growth is an important function of the life cycle that can drive other process such as spawning migration, which is size dependent and by a domino effect influences catches made by each strategy and thus the all fishery dynamic previously described. The selected relation driving growth in relation to temperature is the one described in (Table 2) from (Pecquerie, 2007). Growth is still calculated via a Von Bertalanffy equation but the K parameter is temperature dependent and expected to soar in relation to an increase of temperature with the following equation (Eq 16):

Equation16)

$$K_T = \exp\left(\frac{T_A}{T_1} - \frac{T_A}{T}\right).K_{T_1}$$

With T_A the Arrhenius temperature in Kelvin and $K_{T_1}$the K parameter from von Bertalanffy at a baseline temperature. We selected here the minimal temperature at which spawning was observed for anchovy, 13°C.

Increase in sea surface temperature will thus lead to an increase in the K parameter according to our equation (Equa 16); with our scenarios, this will give the following values

K (T=13 °C) = 1.15
K (T=13.5 °C) = 1.21
K (T=15 °C) = 1.45

Local scenarios of temperature change were not available at the time of the study. Given the exploratory nature of the study, we used the scenarios of temperature available from the IPCC at global scale.
Although information was available on the effect of food availability on growth, we could not find consensual scenarios of evolution of the primary production and thus restrict scenarios to temperature.

3) Results from climate change scenarios: How a change in anchovy growth pattern can affect the fishery dynamic?

To understand how the different scenarios modify the fishery dynamic we first need to compare how the fishery react with or without a specify model to make trawler flexible in their strategies choices. Figure 16, in this process gives us a first insight at the question with major differences when we compare the ratio between landings of anchovy in a given strategy and scenario with the baseline landing, for scenario with and without fishery dynamic. Without any fishery dynamic model and only fixed fishing activity, landings grew considerably bigger than the baseline, which has dynamic in its fishing activity. Another result is that this response seems to vary from a strategy to another. Indeed, for Breton's purse seiner landings seems to decrease where on the contrary, landings from both trawlers seems to grow more and more. These differences can perhaps be related to the parametrization of those fisheries where trawlers have considerably higher targeting factor than purse seiner can. We can also blame the poor calibration of anchovy catchability that seems to greatly overestimated landings (See Annex G). Thus a possibility to understand those different patterns among strategies is that the vast majority of catchable anchovy is taken by trawlers and purse seiner landings decreases through time.

However, with fishery dynamic incorporated this issues seems to be resolved and we do not observed landings that suspiciously exceed the baseline. Figure 17, shows that the integration of dynamics reduce gradually the number of trawlers in the fleet by giving them the opportunity to leave the fleet. This explain the difference observed between scenario with and without dynamics.

Another important question is how anchovy landings react toward an increase in temperature. In all cases, it seems that the hotter scenario (SC2) consistently gives landings considerably higher than the baseline and then a smaller temperature increase (SC1). We can suppose here that anchovy that grow faster younger age class are potentially catchable and thus increase the landings. Additionally, when comparing the evolution of vessels in each trawler strategies (Figure 17), it seems that the strategy 2 which is the one targeting anchovy as more vessels taking the opportunity to choose this strategy. This perhaps mean a higher income perceptible with anchovy due to more individuals catchable for the fishery. In order to check for this assumption we need to look for mean length in the landings and in the population abundance.

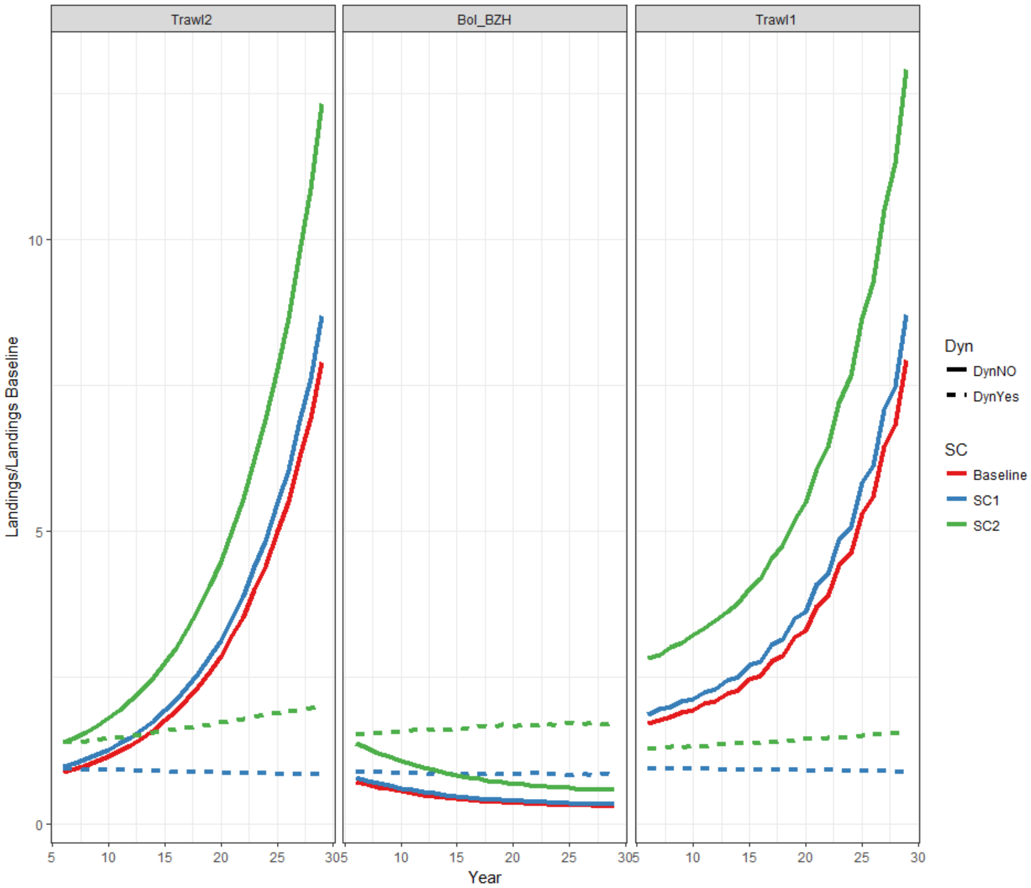

Figure 16 : Evolution of the Landings (str) / Landings baseline of anchovy throughout the 30years of simulation,for the three most anchovy-oriented fishery.

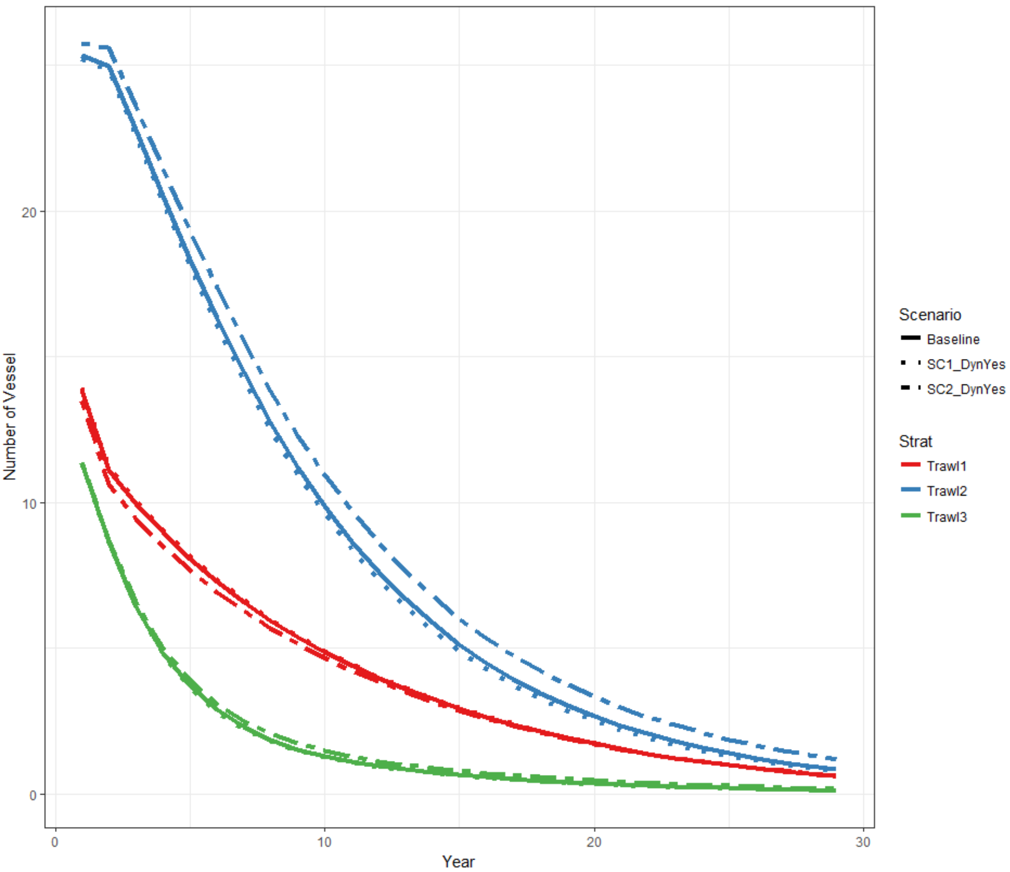

Figure 17: Evolution of number of pelagic trawler in each strategy for different temperature scenarios

The table in annex I is used to calculate and compare mean length of anchovy in the landings between baseline and SC2 (Table 10). The mean proportion of this stage in the landings weights each mean length at stage, and thus we obtained for both scenarios a value of mean length in the landings. For the baseline mean length in the landings is equal approximatively to 13.3 cm compare to 14.7 cm for scenario SC2.

This major difference in mean length can possibly explained the differences in landings. It seems that anchovy is caught younger and possibly migrate with the adults in the spawning grounds because migration is size dependent in our model. Those grounds are zones of high fishing activity and thus this migration will increase landings by increase the number of fish catchable.

After looking at the effect on the anchovy population, we want to understand how affecting anchovy population growth can change landings in the other fish population in the model. Figure 18, shows like expected that no further increase was observed between the scenarios without fishery dynamics, and only anchovy landings increase compare to the baseline and cooler scenario. With fishery dynamics, however it seems that landings (Scenario Dyn Yes), of Albacore tuna and both seabass population increase with the scenario with 2°C of sea temperature increase and on the opposite landings of sardine decrease with temperature increase. We can understand this as the result of increasing the attractiveness of strategy 2 with higher landings of anchovy and thus drive vessels from other strategies to join the strategy 2 more anchovy-oriented. The strategy, which is more likely to be affected by these vessels exit, is the strategy one more sardine-oriented (See Annex H coefficients model change strategy) and thus leads to decrease in sardine landings compare to the baseline for a cooler scenario where anchovy is less attractive.

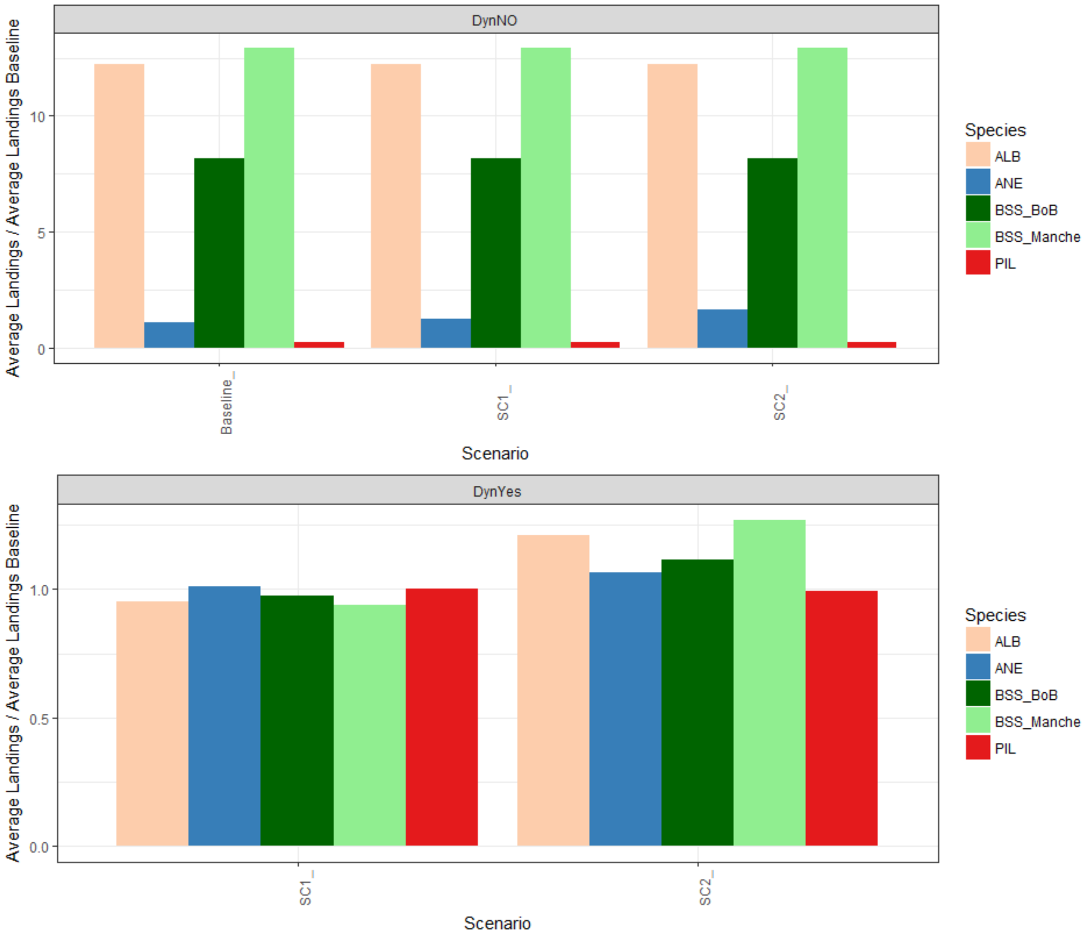

Figure 18: Comparing ratio Landings/Baseline for all the population across scenarios.

Figure 19, confirms this by looking at the direct variable that drive the dynamic of fishery: percentage of total income by species. This result does not include the proportion of other species not modelled in our platform and that we assume to be constant in each strategy. We want here to understand how the fishery dynamic mechanisms we have implemented really behave with temperature increase. We compare the results for the first 10-year and the last 10-year of the simulation to understand which choices were taken by trawlers before they all exit the fishery. In the beginning of the simulation we can see that has explained before the importance of anchovy in the income grows for all the strategies. This can particularly be seen within strategy trawl 1 where anchovy is almost as important in the landings as the main species of strategy 1, which is sardine.

Considering the coefficients estimation of the model, this increase in percentage of anchovy in the income will increase the probability of going from strategy 1 to strategy 2 (see Figure 14). In the last 10 years, because of a loss in vessels from strategy 1 to the profit of the more anchovy-oriented strategy 2 the % of anchovy in the income is reduced compare to the last ten years. This can be explained by the targeting factors and métier distribution, which is fixed for a given strategy. With less and less number of vessels in each strategy the % of species in the landings and by extension the % of species in the income will have the tendencies to reflect more this fixed pattern.

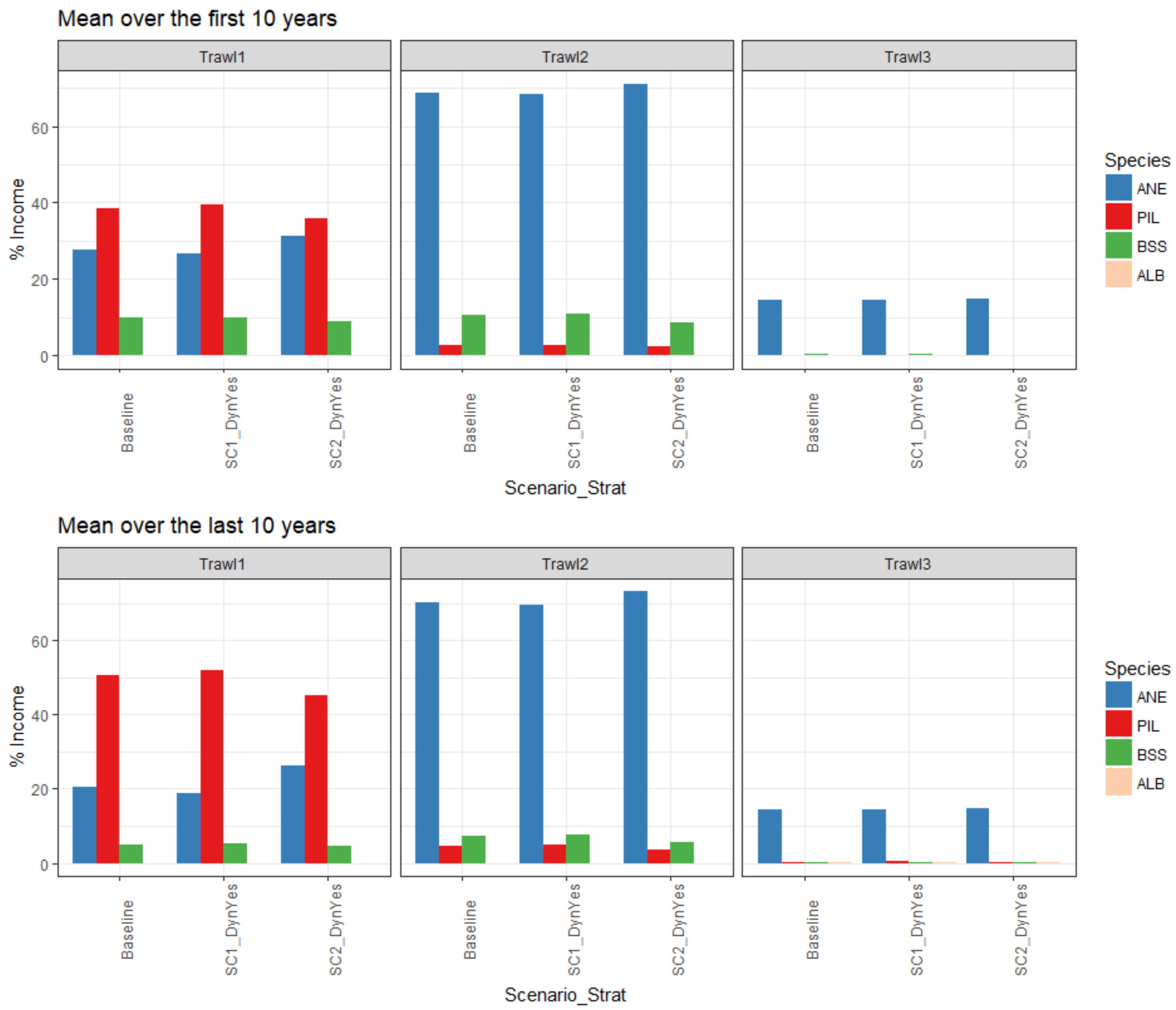

Figure 19: Mean percentage of total income by species for the trawlers strategies over the first 10-year and last 10 year. (BSS=Seabass; PIL=Sardine;ANE=Anchovy;ALB=Albacore tuna).

DISCUSSION

1) Purpose of our study: What have we learned in relation to our first questions?

Our main goal during this work was to explore the potential reaction of the pelagic fishery to an environmental stress linked with climate change.

This led us first to search for known mechanism and potential behavior of marine species in response toward a change in their environment. In order to project the potential impact of climate change we need information on the shape of the response or equation governing biological parameters. For some environmental parameter and species, knowledge about those relation was present but scattered between multiple biological function and sources. In order to review those mechanisms hierarchical methods must be taken to keep the most important function. However, for different species and variable few materials was available and assumption were to be made. The projection also needs credible value for the evolution of environmental parameter in relation to different scenario. These values are complicated to find for specific location and at a precise scale. Knowledge to fulfill our goal is therefore present partially and major assumption were made that we will discuss in the following section.

After the identification of the needed knowledge, we had to think of how integrate those biological behavior within the modelling framework we choose and with relation to fishing activity dynamic. We explored several options of known mechanism that can affect biological process, such as growth, reproduction or recruitment but at the end, due to limited time we only assess the impact on growth. This biological function is then related to fishing activity via fishing zone and landings because a change in growth affect the spawning migration which is assumed size dependent and the fishing selectivity. Climate change as thus a direct impact on fish biology and an indirect impact in fishing activity via landings of those fishes.

Fishery dynamic is then supposed to react toward environmental change. The exploration of past event and crisis in the fishery led to the construction of a fishing activity framework where percentage of effort by métier vary between strategies. Those strategies are then under the dependence of percentage of income by species and thus under the dependence of landings.

Analysis of the historic trend in the fishery and the consequences of anchovy could illustrate the sensibility of a fleet to a small number of key economic species that are necessary to assure the profitability of the fishing activity. The lack of adaptability of those fleet coupled with few species accounting for the majority of the incomes and a possible environmental perturbation that drive a low recruitment for some years can induced an important socio-economic crisis in the fishery.

The reaction in our case toward climate change seems to be rather an increase in anchovy, seabass and tuna landings due to anchovy that are more catchable and thus a more vessel choosing the anchovy-associated strategy. Climate change seems also to reduce the number of vessels leaving the fishery. However all those results were made under major assumptions? We tried here to describe more how the model reacted toward the increase in temperature and thus an increase in anchovy growth rate.

No credible evaluation of the impact can be made but we tried to compare our results with a baseline to quantify how the increase of temperature led to change in landings.

2) What are the limits of this exploratory approach?

Like we said before all these results and exploration were made under a wide range of assumptions that we need to discuss to understand our results and improve our methods.

First, we describe the dynamic of the fishery only through the prism of change between strategies, thus ignoring the important role of the fishermen producer organization which can manage the fishery through licensing system and help reducing the number of vessel when population of anchovy is too low like what they did during the anchovy crisis (Vermard, 2009). Fuel price can also be an important driver for fishermen choice and change the spatial pattern of exploitation (Sampson, 1991). Spatial definition of the métier where considered fixed in the model but we know that especially for small pelagic fishermen have the tendencies to follow the fish. We can possibly envisaging a proportion of effort inside each métier, which can depend on the spatial heterogeneity of fish density.

In a broader sense, all our approach toward fishing activity is based on the analysis of past behavior and trend to predict future evolution, this approach can be questioned. Indeed climate change can possibly transform the whole structure of the fishery by changing fish distribution and thus changing métier and targeting species (Briones et al., 2006; Rijnsdorp et al., 2009). Another issue with this approach is the use of very questionable data to predict future change, this is the case for our parametrization of the Spanish fishery, which is one of the major actor in terms of landings, but did not have operational data available to us. This can lead to miscalculation of parameters such as target factors.

In this exploratory approach, we only considered the temperature effect on the growth process and not in interaction with other biophysical process like reproduction or larval mortality due to oceanic circulation. The effect we observed could be attenuate are completely changed if we had considered those interactions. Some function like growth can be describe with different mechanism a sensitivity analysis with those different response is perhaps needed to understand the potential validity of projected results.

An uncertainty analysis is also needed for the most important parameter of the model, particularly estimation of natural mortality at stage for anchovy or migration coefficients in April. This will allow us to see if the pattern find in our results is meaningless toward compared with the projection error.

3) Perspectives

This work remain a preliminary approach and further work is needed to evaluate the impact of climate change on the fishery.

An important envisaged effect of climate change over fish population is the change it will probably create in terms of fish distribution. Thus studies have showed that anchovy is susceptible of expanding north due to modification of habitat by climate change (Huret et al., 2009; Petitgas et al., 2012), which can led to modification in the fishing activity structure, and possibly introduce new fleets with their own structure.

In the not too distant future, we can envisaged to coupled our model with a Diet Energy Budget model which describe mechanistically effect of temperature and nutrients on all the biological process of both sardine and anchovy (Gatti et al., 2017). Thus, it will be possible to link temperature and food availability with several process such as growth, reproduction and recruitment in the same time. Indeed the DEB parameters output informed us on the date of spawn, the number of batch and number of egg through times which can lead to better description of the reproduction pattern and avoid the forcing of the recruitment.

A possible reproduction equation linked with the DEB and thus with temperature and food availability could led to a better understanding of the climate change effect on both anchovy and sardine populations.

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ANNEXES

Annex A: Summary of input parameters for each anchovy stages.

Stage	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Age (year)	0	0.8	0.17	0.25	0.33	0.42	0.5	0.58	0.67	0.75	0.83	0.92	1	2	3+
Mean Length (cm)	4.3	5.8	7.1	8.2	9.3	10.2	11.0	11.8	12.5	13.1	13.7	14.2	16.0	18.1	18.5
Mean Weight (g)	0.04	0.17	0.31	0.50	0.71	0.95	1.21	1.49	1.76	2.01	2.31	2.58	3.69	5.27	5.79
Natural mortality (year-1)	45.7	9.9	4.2	3.2	2.6	2.3	1.9	1.7	1.5	1.4	1.3	1.3	0.8	1.2	1.2

Annex B: Summary of input parameters for each sardine ages.

Groupe	0	1	2	3	4	5	6
Age (year)	0	1	2	3	4	5	6+
Mean Length (cm)	0.73	23.8	24.9	24.99	24.99	24.99	24.99
Mean Weight (g)	0.0027	111.0	128.3	129.2	129.2	129.2	129.2
Natural mortality (year-1)	1.071	0.692	0.546	0.475	0.435	0.412	0.400

Annex C: Natural mortality and other fleet fishing mortality for the three populations of Bay of Biscay seabass, western channel seabass and Albacore tuna.

Population	Sea bass Bay of Biscay	Sea bass Western Channel	Albacore Tuna
Natural Mortality (year-1	0.24	0.15	0.3
Fishing mortality other fleet (year-1)	0.17	0.24	0.11
Sources	(Drogou, 2013)	(Armstrong and Drogou, 2015)	(Arrizabalaga et al., 2016)

Annex D: Metaparameters Genetic algorithm.

Parameter	**Value**
Population size	10
Crossover Method	1X
Crossover Variations Method	Geometric
Crossover threshold	0.5
Mutation rate	0.8
Elite Rank	2
Acceptation Rank	8
Criterion Type	Generation number
Criterion level	200

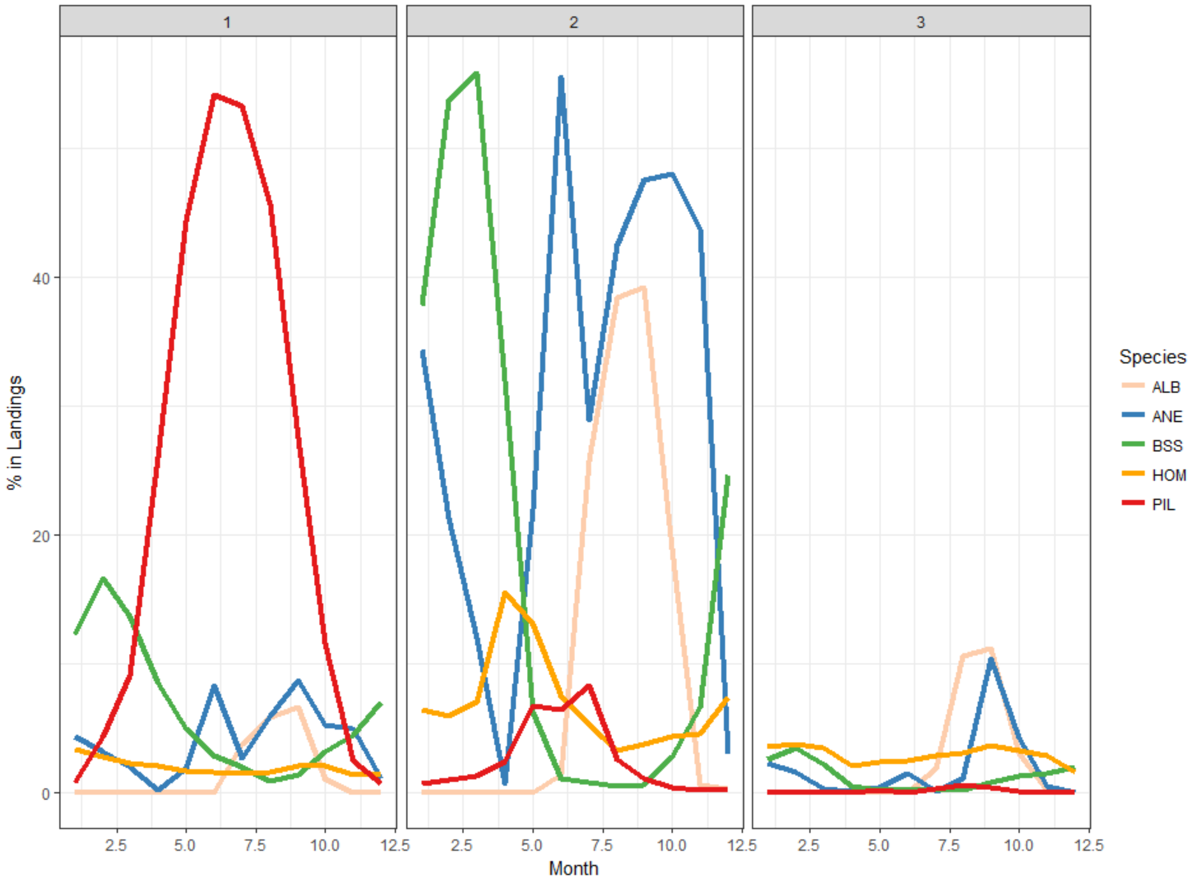
Annex E: Price Equation for the four species of the model

$$\boldsymbol{Price_{sp}} = \mu_{sp} + \boldsymbol{\beta 1_{month}} + \boldsymbol{\beta 2_{CatCom}} + \boldsymbol{elast} * \boldsymbol{Log}(\boldsymbol{Landings_{sp}})$$

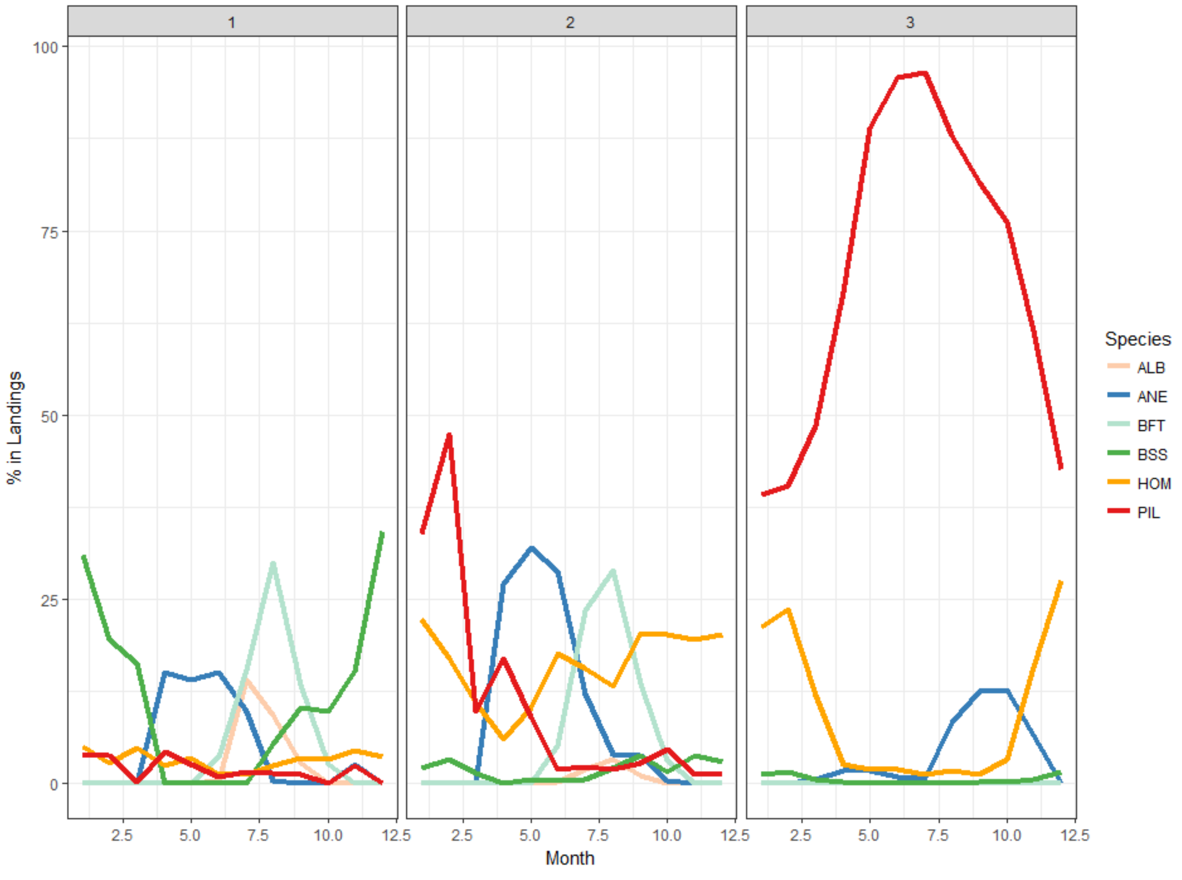
Species	**Anchovy**	**Sardine**	**Seabass**	**Albacore Tuna**
Intercept	4.793397	2.48295	10.81261	2.311988
Elasticity	-0.2242795	-0.1151255	0	0
Catcom 10	0.3363511	-0.31705877	0.3714775	0
Catcom 20	-0.00593894	-0.08405542	-1.7897079	0
Catcom 30	-0.53842477	0.1707226	2.7505297	0
Catcom 40	-0.2935713	0.34583786	-1.3322993	0
Month 1	0.02471558	-0.07106902	-3.80529929	0
Month 2	-0.27500928	0.01328236	-3.60952621	0
Month 3	-0.32398001	0.09040206	-2.23921559	0
Month 4	0.22003639	0.18154457	-0.03634697	0
Month 5	-0.85599467	0.04743849	2.91659911	-0.3524325
Month 6	0.09866929	0.11498531	2.29467931	1.0161635
Month 7	-0.28070336	0.116823	2.96137975	-0.1901823
Month 8	0.06990947	0.08515962	3.81877109	0.1866667
Month 9	-0.15897885	0.00815031	1.0467179	0.081210
Month 10	-0.06182479	-0.14004487	-1.03993209	-0.2996505
Month 11	0.20496885	-0.17750797	-2.31903504	-0.4417756
Month 12	1.33819138	-0.26916387	-2.31903504	0

Annex F: Seasonality overview from Trawlers and French purse seiners.

F.1) Landings seasonality based on average monthly proportion of landings (2000-2015), for the three trawl strategies.

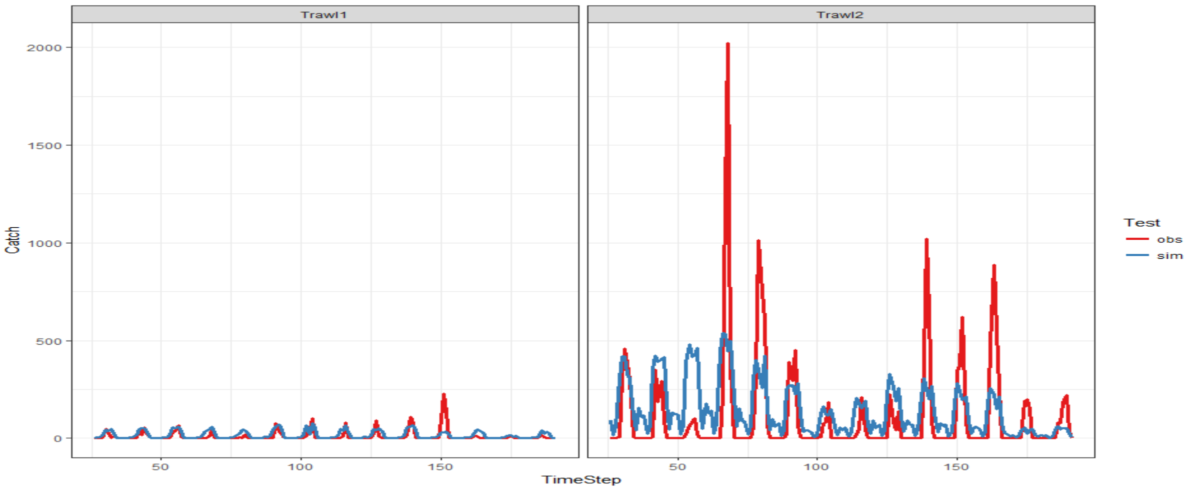


F.2) Landings seasonality based on average monthly proportion of landings (2000-2015), for the three French purse seine strategies. Where 1 is the Basque strategy 1, 2 the Basque strategy 2 and 3 the Breton purse seine fleet.

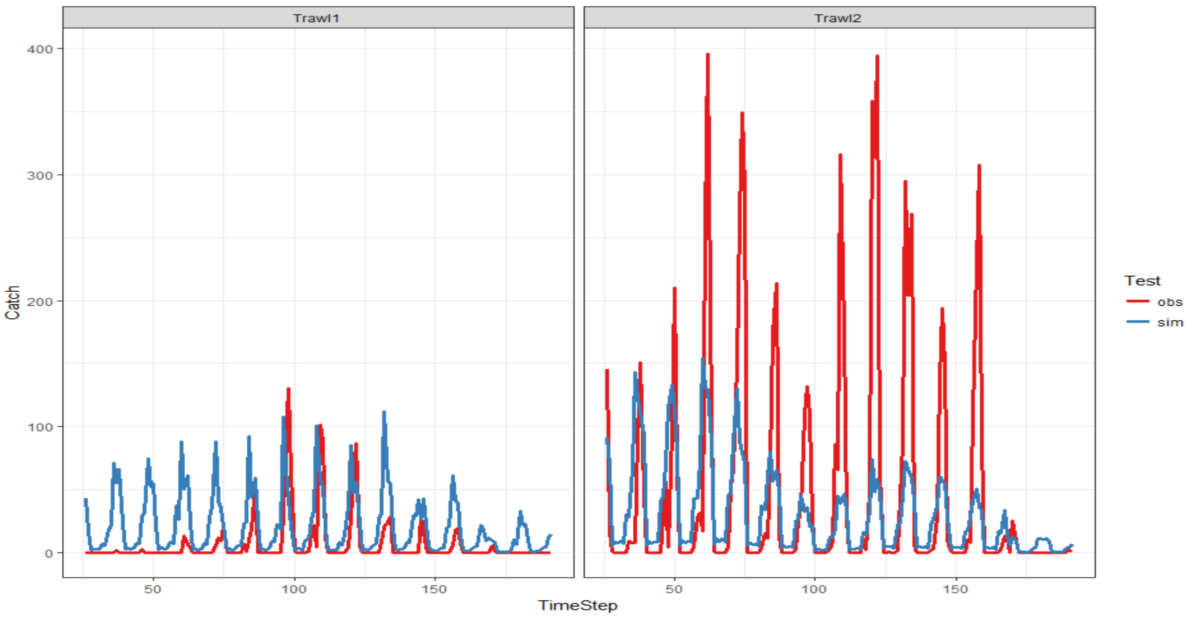


<u>Annex G:</u> Calibration result for all the populations: Observed vs simulated landings per month per strategy.

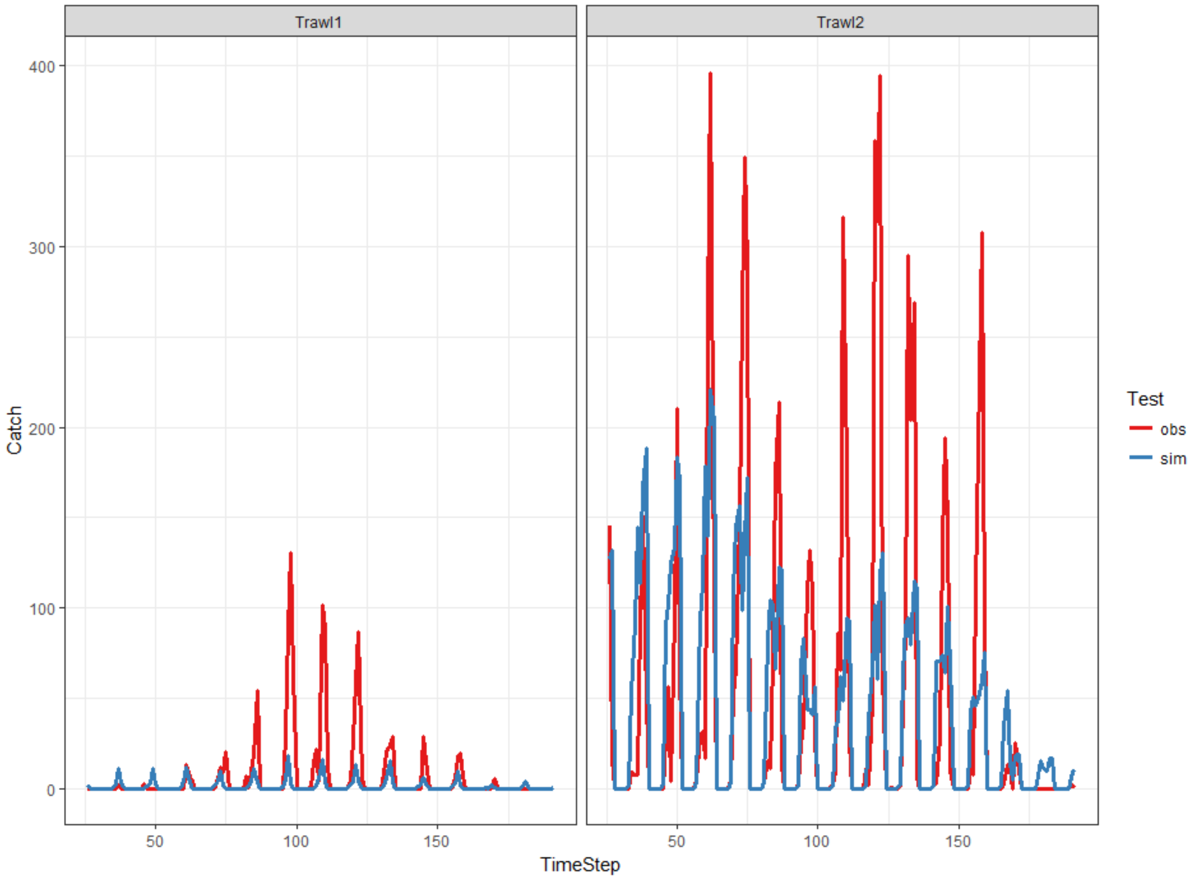
G.1) Albacore Tuna



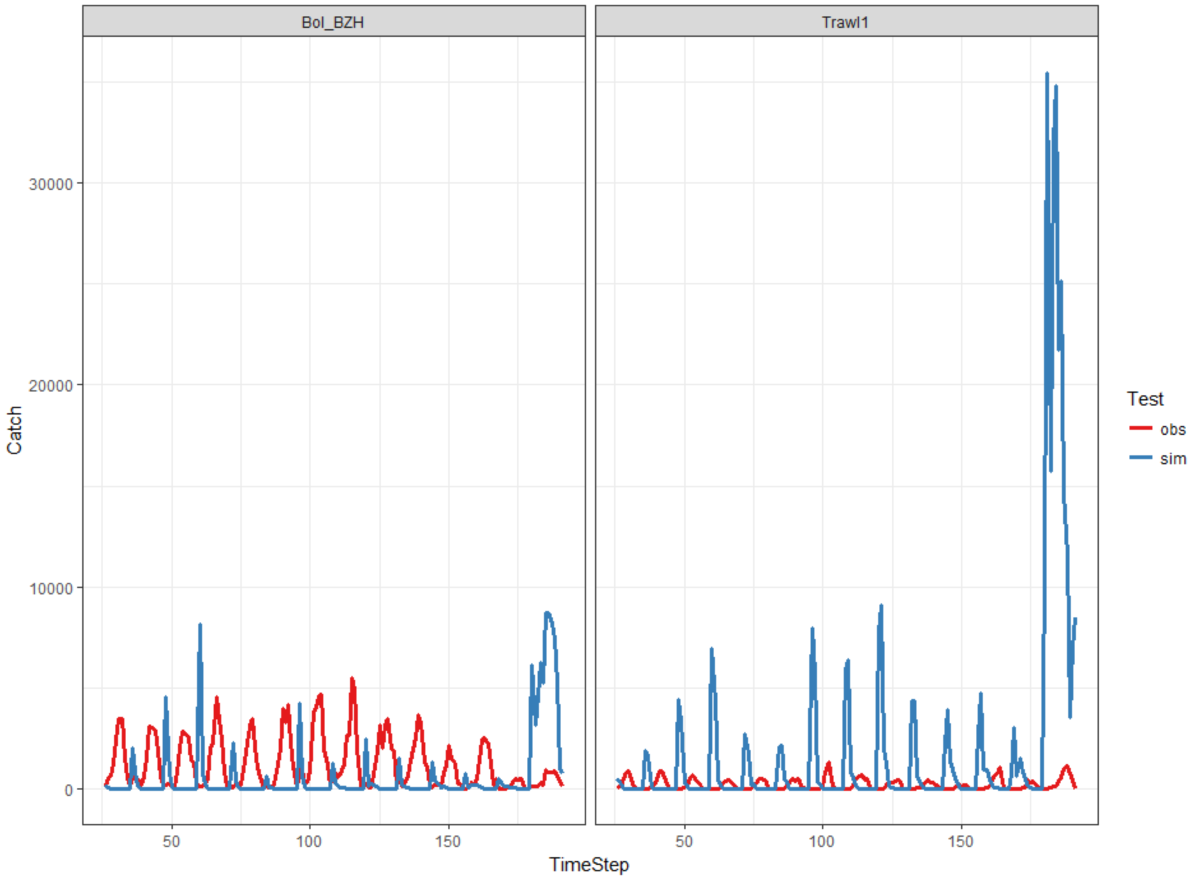
G.2) Bay of Biscay Seabass



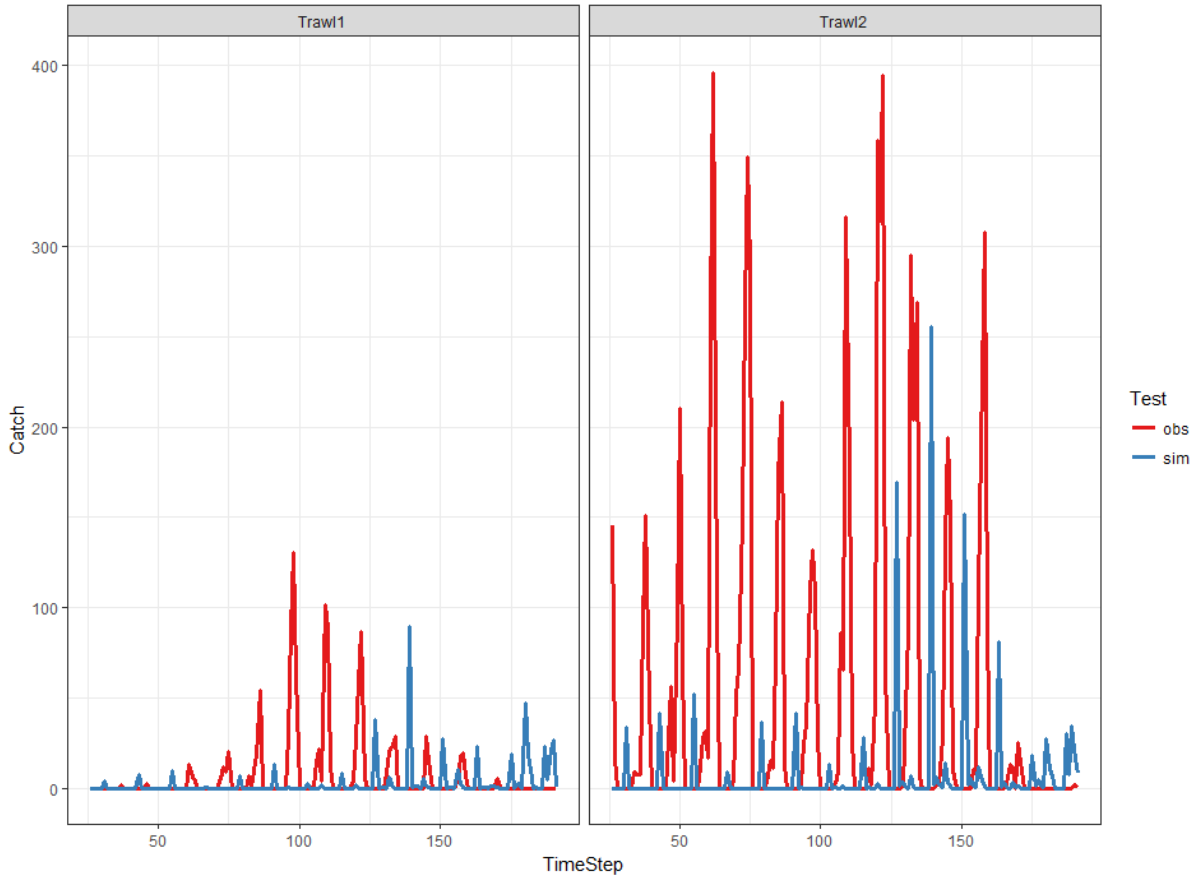
G.3) Population of seabass from Western Channel



G.4) Sardine population



G.5) Anchovy population



G.6) Calibration results for Albacore and seabass

Population	Objective value	Catchability
Albacore Tuna	1.2067E13	4.0486E-8
Bay of Biscay Seabass	1.4021E12	5.03944E-7
Western Channel Seabass	8.3053E11	3.60087E-7

G.7) Calibration results for Sardine

Population	Objective	Catchaility Grp 0	Catchaility Grp 1	Catchaility Grp 2	Catchaility Grp 3	Catchaility Grp 4	Catchaility Grp 5	Catchaility Grp 6+
Sardine	9.46E17	2.570E-4	9.7184E-6	7.384E-6	5.6195E-4	1.1710E-4	4.263E-5	3.0734E-4

G.8) Calibration results for Anchovy

Population Anchovy	Season	Age	Catchability
1.0321E-4	January-March	0	1.0321E-4
Objective	April-August	0	6.596E-4
2.705E9	September December	0	3.3119E-6
	January-March	1	6.02439E-4
	April-August	1	7.98684E-4
	September December	1	2.77053E-4
	January-March	2+	4.59967E-4
	April-August	2+	4.25126E-4
	September December	2+	4.455848E-4

Annex H: Coefficients estimation results for the multinomial model of strategies' choice.

	Coefficients:	Depart							
	(Intercept)	Strategy 1	Strategy 2	Strategy 3	% income ANE	% income BSS	% income PIL	Closing anchovy fishery (No)	% income ALB
1	-3,066682	6,00958	4,950299	3,306189	-0,00755303	-0,03477283	-0,00055996	-1,0251763	-0,02471766
2	-6,297201	5,663711	6,309995	4,959583	0,04201401	0,01434142	-0,01445897	-0,5237376	0,02705641
3	-2,204431	4,430207	5,61031	5,500116	-0,02594675	-0,11441054	-0,05105418	-1,5805799	-0,0388236
4	0	0	0	0	0	0	0	0	0

We choose the modality being out of the fishery as the reference modality and the contrast treatment set all the coefficients for this modality to zero. In red, we have the arrival strategy choice and in green, the previous year strategy experienced.

<u>Annex I:</u> Mean length at age and mean landings at age for oth scenario baseline and scenario 2. (Used to calculate mean length in the landings weighted by the landings proportion of each stages).

Dyn	Yes	Yes	Yes	Yes
Scenario	Baseline	Baseline	SC2	SC2
Group	Mean Landings (%)	Mean Length (cm)	Mean Landings (%)	Mean Length (cm)
0	0	4,3	0	4,9
1	0	5,7	0	6,5
2	0	7,1	0	7,9
3	0	8,2	0	9,1
4	15	9,2	12	10,2
5	7	10,2	6	11,2
6	7	11	6	12,1
7	7	11,8	6	12,8
8	7	12,5	7	13,5
9	9	13,1	7	14,1
10	9	13,7	7	14,6
11	6	14,2	8	15,1
12	21	16	25	16,6
13	5	18	11	18,2
14	5	18,5	6	18,6

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Titre français : Modélisation du système pélagique du Golfe de Gascogne en réponse au changement climatique.

Titre anglais: Bay of Bicay pelagic system modeling in relation to climate change.

Résumé:

Les effets possibles du changement climatique sur l'anchois, la principale espèce exploitée par les flottilles pélagiques du Golfe de Gascogne sont décrits par une revue de la littérature. Un modèle ISIS-Fish comportant cinq populations d'espèces marines pélagiques (Anchois, Sardine, Thon, Bar Gascogne et Bar Manche) et quatre flottilles de pêche (Chalutiers pélagiques, Bolincheurs Bretons, Bolincheurs Basques et Bolincheurs Espagnols) est construit. Il permet de faire le lien entre la dynamique des populations biologiques et la dynamique des flottilles. Cette dernière, est modélisée suite à l'analyse historique des données de logbook et de ventes sur la période 2000-2015. Le changement climatique intervient dans le modèle par la variable température et modifie l'équation de croissance de l'anchois. Plusieurs scénarios de température sont analysés, ils prédisent une augmentation des captures d'anchois avec une augmentation de la température. Ces résultats sont simplement exploratoires et le modèle doit être amélioré notamment par le possible couplage avec un modèle DEB (Diet Energy Budget).

Abstract:

Potential effects of climate change on the prominent specie harvested by the Bay of Biscay pelagic fleets are described by a literature review. An ISIS-Fish model with five marine populations (Anchovy, Sardine, Albacore Tuna, Biscay Seabass, Western channel Seabass) and four pelagic fleets (Pelagic trawlers, Bretons purse seiners, Basques purses seiners and Spanish purse seiners) is built and allow links between populations dynamics and fleets dynamics. Fleet dynamics is modeled thanks to the historical analysis of sales and logbook data over the 2000-2015 period. Climate change in the model is defined by the temperature variable and modify anchovy's growth equation. Several scenarios of temperature are analyzed. They seems to predict a rise in anchovy landings with a rise in temperature. Those results are purely exploratory and the model needs to be improved notably by the potential link with a DEB model (Diet Energy Budget).

Mots-clés : Golfe de Gascogne, Dynamique de flottille, Changement climatique, Anchois, ISIS-Fish

Key Words: Bay of Biscay, Fleet dynamic, Climate change, Anchovy, ISIS-Fish

* *Elément qui permet d'enregistrer les notices auteurs dans le catalogue des bibliothèques universitaires*