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2012

Combining fleet dynamics and population dynamics for a volatile fishery: the example of the anchovy fishery of the Bay of Biscay.

Abstract

It is increasingly recognized that fisher‟s behavior should be taken into account to understand and predict fishery dynamics, in particular in response to management. ISIS-Fish is a spatially and seasonally explicit modeling framework especially designed to couple populations and fleets dynamics and explore the impact of various management measures on mixed fisheries. It has already been set up using a static fishing effort allocation (corresponding to an average historical pattern) between the various métiers to simulate the pelagic fishery in the Bay of Biscay. We present here the integration of a fleet dynamics model. This model is derived from a Random Utility Model simulating métiers choice using as explanatory variables the past value per unit effort, the average percentage of effort spent in the different métiers and the fuel costs associated to each métier.

Simulation results while applying the dynamic effort allocation are compared with observed effort allocation over the period 2000-2004, period where no management constraints on the fishery were observed, and the period 2005-2008, period where the anchovy fishery was closed. The simulated effort allocation fits observations over the period 2000-2004 for some métiers, but not for the most variable ones. During the period 2005-2008, the dynamic effort allocation enables us to reproduce the effort reallocation from anchovy métier to métiers targeting other species. We also reproduce very well the small period where anchovy fishery was reopened in 2005.

Introduction

Fisheries in the European Union (EU) are mainly managed using single-species total allowable catch (TAC) and technical measures. This management system has repeatedly been criticized for not reaching resource conservation objectives. These critics lead managers to develop alternative or complementary management schemes building on fisheries inputs (e.g., fishing effort and/or capacity), to complement the traditional TAC-based regime (Wilen, 1979, Hilborn and Walters, 1992, Charles, 1995, Rijnsdorp et al., 2006, Hilborn, 2007). Whatever the management regime, the performance of management strategies is conditioned by population dynamics, but also by exploitation dynamics, and particularly by the response of the fleets to management measures. Thus, it is increasingly recognized that fishers‟

behavior should be taken into account to understand and predict fishery dynamics, in particular in response to management.

Depending on the fisheries, the area and the current management regimes, fishers may have yearly and seasonal flexibility in their activity both in term of location, gear choice or target species (Ulrich and Andersen, 2004, Marchal et al., 2006, Poos and Rijnsdorp, 2007). Habits, economic, biological and management are some of the factors that drive the behavior and decision of fishers during a fishing trip. In a mixed-fisheries context, bio-economic modeling tools are thus needed to simulate management scenarios. These models should take into account the adaptation of the fleet and the effort redistribution over target species, locations and métiers. Several models have already been developed to include fisher‟s behavior and stocks dynamics in Operational Models (Motos and Wilson, 2006). They predict effort allocation and fishers‟‟ reaction to management either by using decision rules (Drouineau et al., 2006) or by applying gravity models based on Value Per Unit of Effort (Pelletier et al., 2009). However, these models are not based on empirical data and fishers‟‟ behavior probably issues from a more complex integration of information. For instance, it has been shown that fishers‟‟ decisions depend on traveling costs (Caddy, 1975, Walters et al., 1993), species prices (Walters and Bonfil, 1999) and exchange of information to minimize risk (Allen and McGlade, 1986, Millischer and Gascuel, 2006). Random Utility Models have been developed to model discrete decision of individual economic agents (Wilen et al., 2002) and allow for the description of these behaviors using a set of explanatory variables. Vermard et al. (2008) developed a Random Utility Model (RUM) to describe the métier choice at a trip scale in the pelagic fishery focused on anchovy (*Engraulis encrasicolus*) in the Bay of Biscay. They evidenced the usefulness of RUM to identify variables that determine métier choice and successfully reproduced the way fishing effort reported on métiers targeting other species than anchovy during the anchovy fishery closure in 2005. However, to enable longer term prediction accounting for the impact of these choices on the populations and consequently on the future catches, this fleet dynamic model should be coupled to a biological dynamic model. To our knowledge only Andersen et al (2010), used approaches combining fleet and stock dynamics as RUM to quantify fleet dynamics, and compare *a posteriori* the predicted effort allocation and biomass levels to the observed. Indeed, interactions are complex as they occur at various time and spatial scales and imply numerous species and fleets, in several areas, consequently, analytical models could not be solved and simulation models become necessary. ISIS-Fish (Mahévas and Pelletier, 2004, Pelletier and Mahévas, 2005, Pelletier et al., 2009) is a simulation model of complex fisheries designed to model the interactions between populations and fleets in space and time. It enables the exploration of the impact of management measures on mixed fisheries. It has been used to model the anchovy (*Engraulis encrasicolus*) fishery in the Bay of Biscay. The current strategy to simulate fishers‟ reactions was to define "a priori" decision rules of effort reallocation related to each management scenario (Lehuta et al., 2010). Since no auxiliary information (based on e.g., fishers‟ interviews) were available to help defining the decision rules, these were considered to be fixed in time (i.e. equal to the mean exploitation pattern). To build in a more realistic dynamic fishers‟ behavior model, it is required to understand and model the mechanisms that drive decision-making. Based on the Bay of Biscay anchovy case study, the objective of this paper is to implement a dynamic effort allocation module, building on Random Utility Models, in the ISIS-Fish simulation model, and then to quantify the extent to which combining hypotheses relevant to both fishers‟ behavior and stock dynamics may modify the assessment of management strategies performances. As an illustration, we assess the impact of these hypotheses by simulating the implementation of Marine Protected Areas.

The paper is structured as follows:

. We first define briefly the model of population dynamics already implemented in ISIS-Fish (Lehuta et al, 2010), the different fleets and métiers involved in this study with their mean effort allocation pattern over the period 2000-2004 and the prices and costs modules.

. RUM coefficients are then estimated for each fleet using observed effort, estimated fuel costs and catch values over that period. The estimated coefficients are integrated in ISIS-Fish to predict effort allocation at each time step. Effort allocation as predicted by the model is then presented and compared with observations over the estimation period (2000-2004).

. Finally, the model is run over the period 2005-2008 to evaluate its capacity to reproduce the fishing behavior observed during the anchovy closure.

Material

Pelagic fleet description and characterization

Duhamel et al. (2004) described the French pelagic fleets and their trends in term of number of vessels and vessel characteristics between 2000 and 2004, distinguishing the trawler fleet (pelagic or mixed) from purse seiners. Most of the French anchovy pelagic trawl fleet is concentrated in the Pays de la Loire‟s region (*Saint Nazaire* and *Les Sables d'Olonne* harbors). The purse seine fleet is composed of vessels mainly coming from Bretagne/Brittany (*Le Guilvinec* and *Concarneau* are the main ports) and Aquitaine/Basque country (*Bayonne*) (Figure 1). The Spanish fleet is composed of Basque purse seiners from Santander to Fuenterrabía.

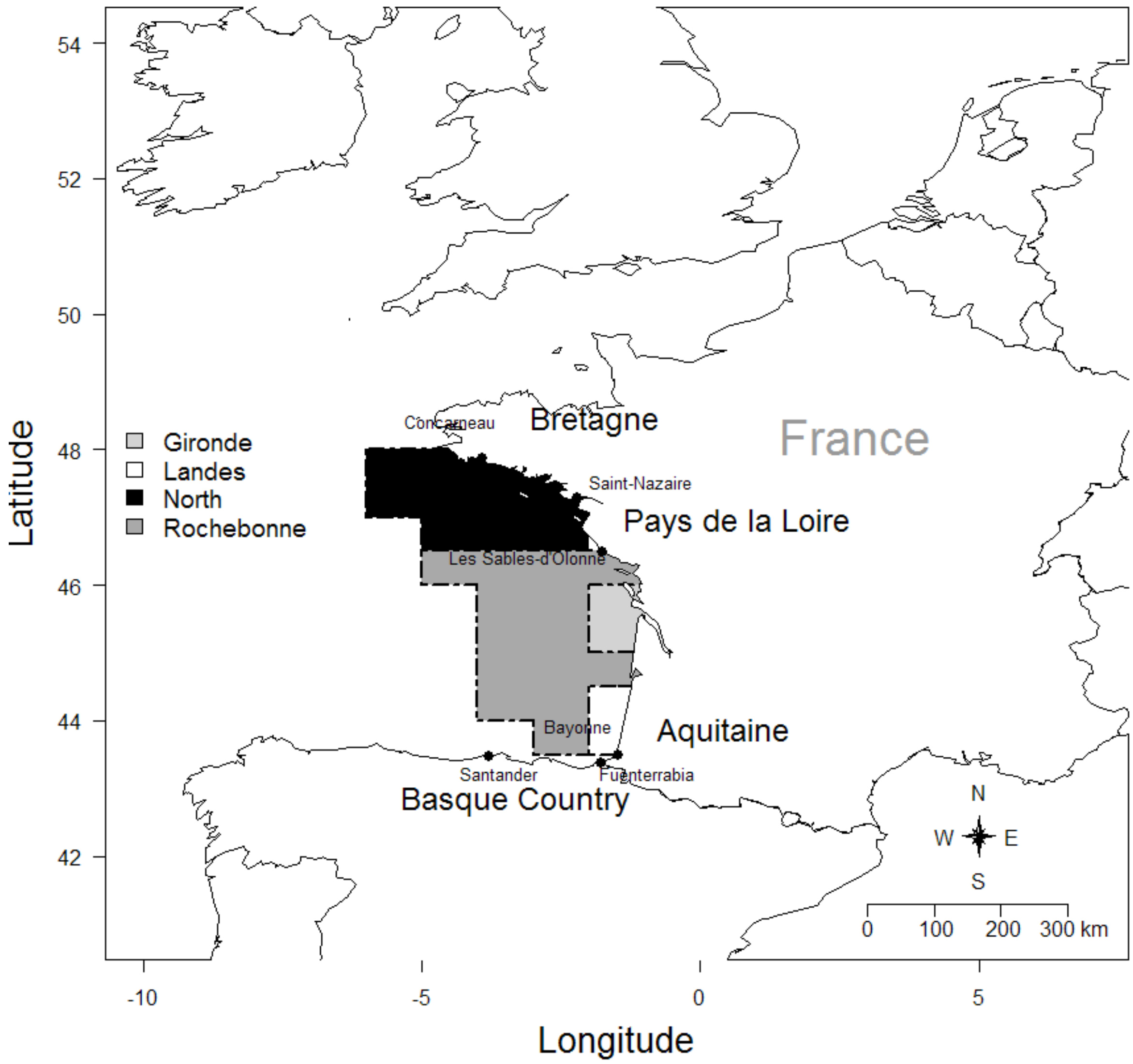


Figure 1. Main harbors and definition of the four areas of fishing.

French fleets were characterized in term of dependency on anchovy, number of vessels and strategies. Four French fleets were then defined based on their catch profiles and home harbors, two pelagic trawler fleets and two purse seiner fleets. Both pelagic trawler fleets are operating from the Pays de la Loire but can be distinguished according to their dependency on anchovy. Thus, one of these fleets is greatly dependent on anchovy ("Pelagic Trawler 1"), and the other one is less dependent on anchovy ("Pelagic Trawler 2"). Purse seiner fleets were distinguished by their home harbor and their activity areas, one being located in Aquitaine ("Basque purse seiners"), and the other in Bretagne/Brittany ("Brittany purse seiners"). Métiers are characterized by the combination of the gear used, target species and operating areas. For the French vessels, métiers were defined using landings in weight and in value and effort data by fishing trip for the whole period 2000-2008. These observations were directly available from log-books and revenue/prices from sales slips. The logbook data were registered by the French Fishery Ministry (DPMA) and extracted from "Harmonie", the database of the French Fisheries Information System managed by IFREMER.

A hierarchical ascendant clustering method based on the catch profiles in value was used to define a métier at the scale of the trip (Vermard et al 2008).

For the French vessels, 9 distinct métiers were defined according to catch profiles. Four métiers target anchovy in areas Gironde, Landes, Rochebonne and North (Fig. 1), two métiers target Sea Bass in the Channel and in the Bay of Biscay, a métier targets Tuna, a métier targets Pilchard and the last gathers all the "other" métiers. For Spanish vessels, a unique fleet and métier was considered, based on expert advice since only aggregated landings and effort data could be made available, over the period 2000-2003 (Uriarte, pers. com.).

Effort allocation and standardization in ISIS-Fish

ISIS-Fish bases the exploitation model on the description of effort distribution across métiers each month. Fishing mortality per species and area is derived from the time spent on the species by the different métiers after standardisation. Effort is standardized by gear and métier. Factors standardizing effort between gear were estimated in Lehuta et al. (2010). For each identified métier (combination of a fleet, a targeted population and an area), monthly target factors, representing the intensity of search on a species by the métier, were assessed based on logbook data, as the effect corresponding to the interaction métier-month in the following model:

$\log(\frac{CPUE}{stdF}) \approx year + métier{:}month$ with CPUE being the monthly catch per unit of effort for the species and métier and stdF the standardization factor for the gear.

At the scale of the year, the activity is specified through strategies corresponding to seasonal patterns in the exploitation. Vessels that practice the same sequence of métiers throughout the year belong to the same strategy (Laloe and Samba, 1991, Mahévas and Pelletier, 2004). Within a strategy, the number of inactivity days may change from one month to the other,

allowing for possible periods of low activity. For the anchovy fishery, each fleet, due to the homogeneity of vessel‟s exploitation pattern, is supposed to operate a unique strategy.
The nominal effort per métier of a given strategy is then computed as follows:

(1) $Effort(str,met,month) = totalEffort(str,month) * PropMetStrat(str,met,month)$

where $PropMetStrat(str,met,month)$ is the proportion of effort allocated by each vessel of the strategy (str) to a given métier (met) during a given month.

ISIS-Fish model of fish populations

Anchovy's stock dynamics

The parameterization of the anchovy‟s stock dynamics in ISIS-Fish is described in detail in Lehuta et al. (phD thesis, 2010). We will just summarize here the main components. The anchovy population is age-structured. Fish change class every month during their 15 first months, and then every year. Maximum and minimum lengths for each class were deduced from a Von Bertalanffy growth function and weight from a length-weight relationship, both derived from survey results. Natural mortality, which depends on spawning area during the larval stage, is applied monthly. Spawning occurs annually between April and August following a spatio-temporal pattern deduced from survey data. Population areas were identified according to spatial and seasonal distributions by length class observed during spring scientific surveys and deduced from commercial fishing effort distributions in autumn. Seasonal changes in distribution pattern are achieved through migrations under the assumption that these changes result from unidirectional moves. Accessibility to fishing was calibrated on the period 2000-2004.
When simulating past years (2000-2008) to test the model‟s capacity to reproduce the system‟s dynamics, anchovy‟s recruitment is constrained to fit the observed dynamics during that period and thus forced each year to the observed recruitment (ICES, 2008).

Dynamics of the other target populations

Sea bass (Dicentrarchus labrax) and yellow fin tuna (Tunnus alalunga) for the trawler fleets and Pilchard (Sardina pilchardus) for the seiner fleets are other important sources of revenue. To simulate their dynamics, simple models requiring few data were looked for. For tuna and sea bass, it was considered that the population production depends on biomass and surplus production models were used. The generic equation of such models is : $\frac{dB}{dt}=g(B)-\frac{dY}{dt}$ with B population biomass, Y yield, and g the production function that could take several forms (commonly Schaefer model, 1954 or Fox model, 1970). Two populations of sea bass were considered one in the Bay of Biscay the other in the Channel. Both forms of model, Schaeffer and Fox, were adjusted for each of the three populations using available data (biomass evaluations when available, catch and effort data) (Table 1). The best fit was retained. Hypotheses underlying surplus production models are not convenient for the dynamic of pilchard, which is a short living species with a highly variable recruitment. Consequently a population dynamics model was built with a natural mortality rate of 0.33 and the recruitment was taken from acoustic surveys estimates (Pelgas surveys 2000-2008, Ifremer) and averaged in predictions.

As other fleets than those described in the model fish on these populations, a monthly value of fishing mortality due to other fleets than the pelagic was assessed. Accessibility was sequentially calibrated to minimize discrepancies between observed and simulated monthly catches per fleet over the period 2000-2004 (Mean squared error).

Table 1. Parameters values for the biological models of Sea Bass, Tuna and Pilchard population and data used for adjustment

Population	Model assessed	Data used	Parameter values	Accessibility
Sea bass Channel	Schaeffer surplus production model	Catch per unit of effort of British trawlers 1985-2008 (ICES WGNEW, 2008)	p = 0.43 r = 0.18 K = 29000t	$4.57e^{-6}$
Sea bass Bay of Biscay	Schaeffer surplus production model	Catch per unit of effort of French pair trawlers 2000-2008 (Ifremer, SIH)	p = 0.48 r = 0.18 K = 40000t	$5.14e^{-6}$
Tuna	Fox surplus production model	Catch and biomass estimates 1975-2005 (ICCAT, 2008)	r = 3.14 K = 405282 t	$6.76e^{-5}$
Pilchard	Simple population dynamic model	Acoustic indices of recruitment (ICES WGANSA, 2009, Pelgas surveys 2000-2008)	M= 0.33	$1.21e^{-4}$

Modeling of economic variables in ISIS-Fish: fish prices and fuel costs

Given that revenues and thus métier attractivity depend on species prices, statistical models of price dynamics were assessed for each population described. Among the numerous factors that potentially drive price dynamics, ISIS-Fish model could account for quantities monthly landed by pelagic fleets and for commercial categories for anchovy. These data are available from auction sales (IFREMER, SIH). Statistical models of price formation were thus assessed for each population.

Table 2: price models used for each population and flexibility coefficient (a) obtained. P: price, c.c.: commercial category, L: landings, ε: random error.

	Model	a
Anchovy	$\log(P) = \mu + \alpha_{month} + \beta_{c.c.} + a \times \log(L) + \gamma_{month:c.c.} + b_{month:\log(L)} \times \log(L) + c_{c.c:\log(L)} \times \log(L) + \varepsilon$	-1.13
Sea bass Channel	$\log(P)=\mu+\alpha_{month}+a\times\log(L)+b_{month:\log(L)}\times\log(L)+\varepsilon$	-0.05
Sea bass Biscay	$\log(P)=\mu+\alpha_{month}+a\times\log(L)+b_{month:\log(L)}\times\log(L)+\varepsilon$	-0.038
Tuna	$\log(P)=\mu+\alpha_{month}+a\times\log(L)+\varepsilon$	-0.086
Pilchard	$\log(P)=\mu+\alpha_{month}+a\times\log(L)+b_{month:\log(L)}\times\log(L)+\varepsilon$	-0.199

Fuel costs are computed by métier. They depend on fuel price and fuel consumption. Annual average fuel prices over the period 2000-2008 were furnished by the Coopérative Maritime du Pays Bigouden. Fuel consumption was harder to approach as it depends on speed and activity (fishing or traveling), engine power... The following assumptions were made:

$$FuelC = C_{fishing} + C_{travel}$$

For seiners, fishing operations are not fuel consuming and $C_{fishing}$ was supposed negligible compared to C_{travel}.

Under the hypotheses that the engine is at full-power while trawling, that traveling speed is 9 knots, and that at 9 knots the engine use only half the power:

$C_{fishing}=\dfrac{Eff \times HP}{E\times rdt}$ with Eff: fishing time, HP: engine power, E: energy/liter of fuel (10kw.h), rdt: engine efficiency (35%, D. Priour, Ifremer, pers. comm.).

And $C_{travel}=\dfrac{Dist\times \frac{HP}{2}}{9\times E\times rdt}\times nbT$ with Dist : twice the distance in miles between harbor and fishing area, nbT: number of trips per month.

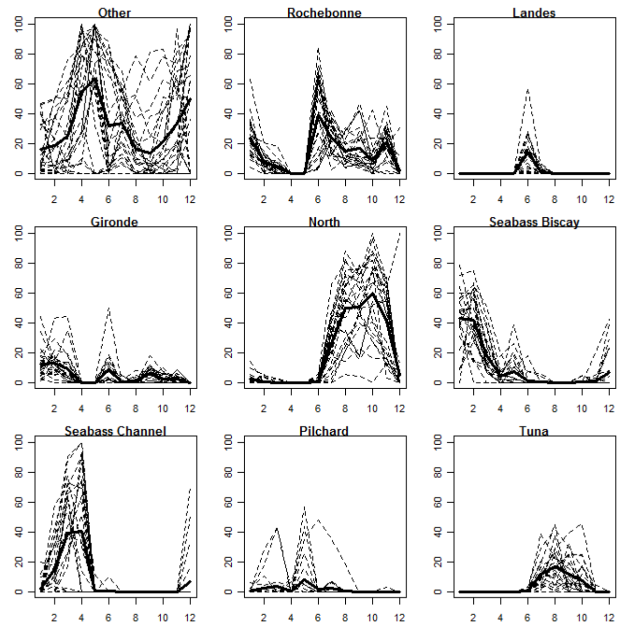
Horse powers of vessel engines were available in the national French Fisheries Information System, and were averaged by fleet. For pelagic trawlers, VMS data were available and enabled to assess average distance travelled by trip for each metier. For purse seiners, distances were assessed as the linear distance between harbour and the centre of fishing areas. Finally, the numbers of trips per month were derived from fishing time per month assuming an average fishing time per trip.

Methods

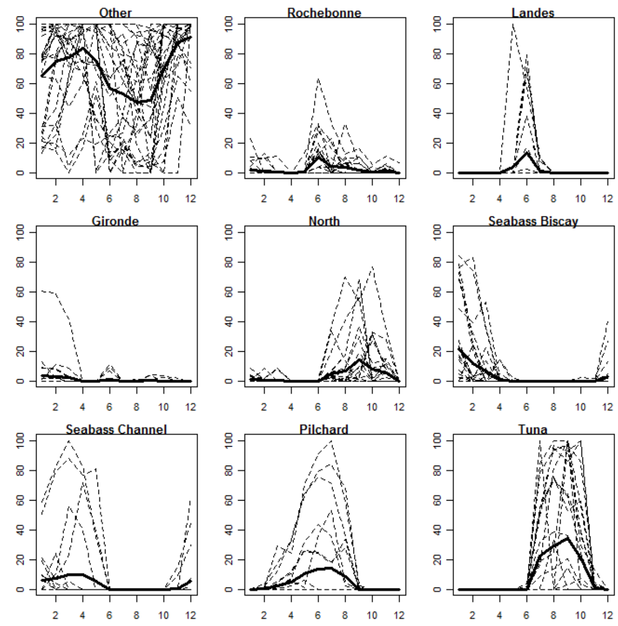
Modeling fleet dynamics

RUM definition

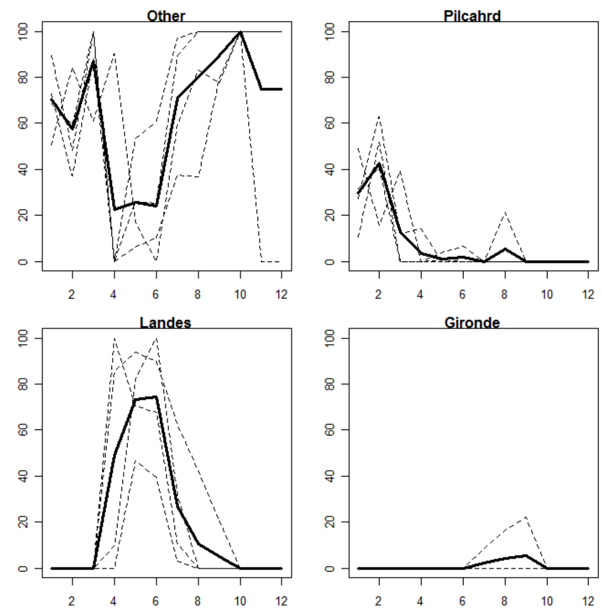
A discrete choice modeling framework was chosen to understand and forecast the underlying factors and mechanisms affecting métier choice. According to the economic theory of utility maximizing behavior, fishers confronted with a finite set of alternatives (in this case métiers) will choose the métier that provides the highest expected utility (Wilen et al., 2002). Such a framework has already been applied to a set of vessels from the fleet of Pelagic Trawlers 1 (Vermard et al., 2008). However, this study was carried out at the fishing trip level, the set of explanatory variables including the VPUE realized on each of the five main targeted species without distinguishing between fishing areas. Here, the approach is applied to the four French fleets, that present different degrees of dependency on anchovy and do not target the same species (anchovy, sea bass, tuna, sardine a set of “other species” for trawlers, anchovy, sardine and “other species” for seiners). Moreover anchovy métiers are spatially disaggregated. For inclusion in ISIS-Fish, the explanatory variables introduced in our Random Utility Model (RUM) were consistent with the scales, time period and dimensions of the simulation model. Variables were computed at the scale of the month. Explanatory variables were métier profitability, fishing habits and fuel costs. Métier profitability was approached by the mean Value Per Unit of Effort (VPUE) realized by the whole fleet the previous month. The underlying hypothesis is that in a given month, all fishers have a “perfect” knowledge of what other fishers have made the previous month in term of landings and values. This strong hypothesis was supported by the fact that they operate from the same harbor, usually fish in groups of vessels, targeting the same species and land in the same harbors. It also represents possible exchange of information between fishers. Consistent with Holland and Sutinen (1999), the percentage of effort usually spent on each métier during a given month, was considered as a proxy for fishers‟ habit. This monthly percentage was averaged over the period 2000-2004 and set constant in simulation. The assumption for using the average monthly observed effort of the fleet instead of past year observed individual effort has two incentives. First, concerning the fleet scale, as previously explained, exploratory analysis and surveys showed that all pelagic fleets operate in “groups” and have a similar behavior in term of targeted species and fishing areas over the year (Fig. 2). Second, concerning the average across years, Vermard et al. (2008) shown a relative constancy in strategies in the absence of management constraints and that after a period where the activity was constrained by management (such as the anchovy closure most of 2005) fishers have tendency to come back to their usual exploitation pattern. The implicit reason for that is that fishermen keep the knowledge of fish seasonal availability (e.g. latter aggregations or migrations) and that it is a main driver of their decisions. Fuel costs were introduced in the model, to take into account the difference in term of cost structure of fishing across the different métiers. Fuel costs while fishing do not differ across métiers, consequently, travel costs per unit of effort (the distance traveled per trip for the métier multiplied by the fuel price at that period) were used as explanatory variable in the RUM to weight métier attractivity according to potential fuel costs.



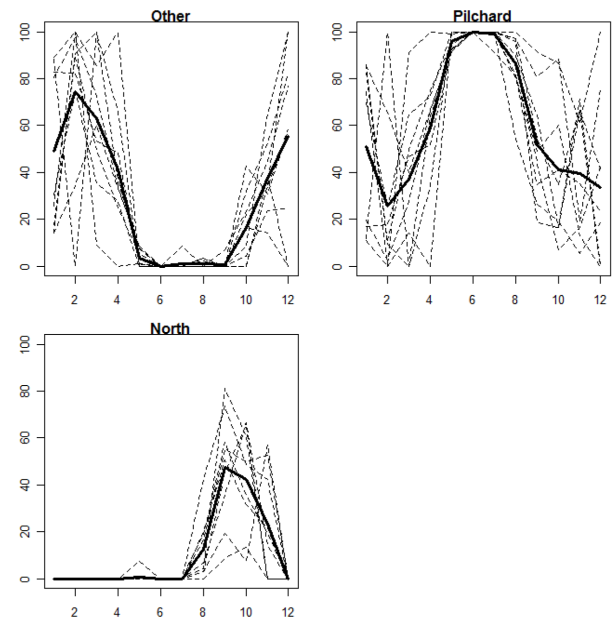
Pelagic trawlers 1



Pelagic trawlers 2



Purse seiners Basque Country



Purse seiners Brittany

Figure 2. Exploitation patterns of the French fleets. Each panel corresponds to a fleet, and displays a graph per métier. The graph shows average effort per métier per month over the period 2000-2004 for each boat of a fleet (dashed lines) compared to the average exploitation pattern over the entire fleet.

The deterministic component of the indirect utility function or the expected utility function of the conditional logit model selected is then empirically specified as follows:

(2) $V_{ij} = \alpha_1 * PercEff_{i,j} + \alpha_2 * VPUE_{i,j} + \alpha_3 * FuelCost_{i,j}$ with PercEff, the mean percentage of effort spent on métier „i‟of the fleet for the given month, VPUE the mean Value per Unit of Effort of the fleet for this métier for the given month and FuelCost, the fuel costs generated while fishing with this métier for the given month.

The dependent response variable *Vij* represents the expected utility for the jth trip choices (métier Anchovy in Gironde, Anchovy in Landes, Anchovy in North, Anchovy in Rochebonne, Sea Bass in the Channel or in the Bay of Biscay, Tuna or "Other species") for the *i*th trip. The α coefficients are estimated using a conditional logit model.

The models were adjusted externally using individual vessels‟ trip-by-trip information derived from logbooks data. Utility and resulting probability distribution of effort allocation were calculated each month using the eq.3.

(3) $\Pr oba(Choice=j)_i = \frac{\exp(V_{ij})}{\sum_{j=1}^{NumberOfChoices} \exp(V_{ij})}$

It should be noted that the detailed data required to parameterize the RUM were available for the French pelagic fleets, but not for the Spanish fleet. Consequently effort description for the Spanish purse seiners is kept static and equal to the mean effort observed during the period 2000-2003 (data for the effort allocation in 2004 were not available).

Integrating fleet dynamics into ISIS-FISH pelagic fishery model of the bay of Biscay

In our approach, effort per métier is computed every month, using a coefficient of proportion of total effort. A natural estimator of the proportion of total effort allocated to one métier is the deterministic frequencies computed each month for each choice (métier) (equation 3) by the short term behavior model described before.

From the second month of the simulation onwards (the VPUE values for first month being constrained to observed values), the estimated α coefficients, effort, values and costs per métier are used to compute the utilities and the resulting probability distribution of effort allocation for the next month.

While the anchovy, sea bass, tuna and pilchard‟s catch are computed dynamically, the "other species" catch are not modeled explicitly here, and hence can not be processed dynamically. To fill this gap, mean values per unit of effort per month were externally computed over the period 2000-2004. These VPUE are then directly used in the simulation model: Table 1 summarizes how the different values used to calculate the VPUE are computed.

Table 3. Parameters predicted dynamically in ISIS FISH (relation stock/fleet and Fishing mortality) or computed from the predicted effort and the results of linear models

Métiers	Métiers targeting Anchovy, Sea Bass, Tuna and Pilchard	Métiers targeting "Other" species
Variables	Value Anchovy, Sea Bass, Tuna and Pilchard respectively	VPUE Other
Variables computation	Dynamically	Computed as mean VPUE observed on the period 2000-2004

Capacity of the model to reproduce system's dynamics

Impact of fleet dynamics on effort allocation

Validation of effort distribution using dynamic effort allocation is obtained by comparing the predicted effort allocation with the observed allocation.

The comparison is made in two steps, we first compare the effort allocation during the period 2000-2004, where no specific management measures were in place and which is also the estimation period for the RUM. During this period the fishery was managed by TAC but these TACs were not restrictive. The total effort per month was constrained to the observed effort but the effort allocation among métiers was computed using the RUM.

In a second time, we assessed the model capacity to reproduce the anchovy closure from 2005 to 2008. The total level of effort per fleet and month is constrained to 2000-2004 averages and the proportion of effort spent on each métier computed by the RUM.

Results

Estimates of RUM coefficients

Most coefficients in the discrete choice model were statistically significant (Table 4).
A McFadden's LRI (Likelihood Ratio Index) above 0.5 indicates that the model explains a substantial proportion of variation in fisher's trip choice behavior. However, the fit of the model is lower for fleets such as Pelagic trawlers 1 and Basque purse seiners that were also the fleets presenting the highest inter annual variations.

Table 4.Parameter estimates from the discrete choice model on trip choice behavior

		Estimate	Std. Error	t-value	Pr(>|t|)	
Pelagic Trawlers 1	VPUE	1.19E-04	9.62E-06	12.332	< 2.2e-16	***
	PercEff	4.26E-02	5.69E-04	74.85	< 2.2e-16	***
	FuelCost	-3.31E-03	2.96E-04	-11.171	< 2.2e-16	***
Pelagic Trawlers 2	VPUE	1.19E-04	1.31E-05	9.0774	< 2.2e-16	***
	PercEff	4.69E-02	6.00E-04	78.0731	< 2.2e-16	***
	FuelCost	-3.19E-03	3.29E-04	-9.6936	< 2.2e-16	***
Basque purse seiners	VPUE	-1.80E-04	7.28E-05	-2.4734	0.01338	*
	PercEff	3.89E-02	2.93E-03	13.2939	< 2e-16	***
	FuelCost	-8.13E-03	4.84E-03	-1.6811	0.09274	*
Britanny purse seiners	VPUE	4.83E-05	2.16E-05	2.2379	0.02523	*
	PercEff	2.78E-02	1.69E-03	16.4352	< 2.2e-16	***
	FuelCost	-1.14E-01	2.66E-02	-4.2638	2.01E-05	***

* Statistical significance at 10% level

** Statistical significance at 5% level

*** Statistical significance at 1% level

Very logically, positive coefficients are observed in most cases for PercEff and VPUE indicating that the more effort (respectively VPUE) was spent on the métier the previous year the highest the probability to operate that métier. Alternatively, a negative coefficient is found for fuel costs, indicating that the highest the costs associated to the métier, the less likely it is to choose that métier.

Capacity of the model to reproduce system's dynamics

To assess the model validity, the observed proportions of effort spent on each métier, each month are compared with the predictions computed by ISIS-Fish using the RUM‟s coefficients over the period 2000-2008.

Figures 3 to 7 show that the model is able to reproduce the seasonality of fishing activity in terms of species choice for all the fleets. It also enables to reproduce the spatial effort allocation among the fishing areas for anchovy. The model satisfyingly reproduces the effort allocation among the different métiers before and after the anchovy closure in 2005 even the peak of effort on anchovy during the short opening periods of 2005 (Fig.3).

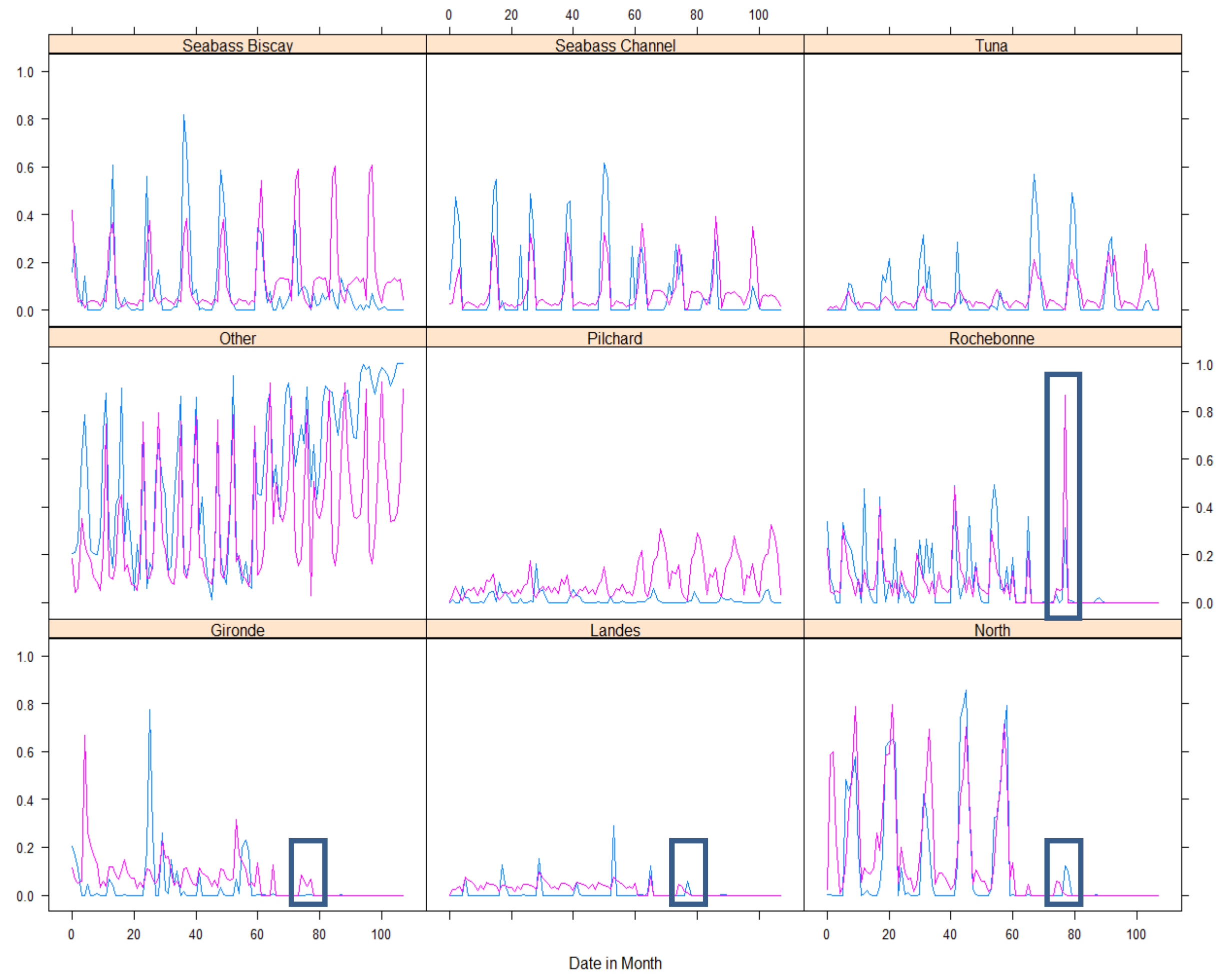


Figure 3. Observed effort proportion (blue line) spent on each métier each month (0=January 2000, 108=December 2008) compared with computed effort allocation (pink line) for Pelagic 1. Black rectangles represent the anchovy re-opening for several months during 2005.

Métiers on which pelagic trawls have reported their effort during anchovy closures, namely tuna and other species are known through enquiries. Figure 4 shows that for both trawler fleets, the model reproduces the effort reallocation and the seasonality of its allocation. However, the effort reallocation on the "Other" métier is underestimated by the model by an order of magnitude especially in the last year.

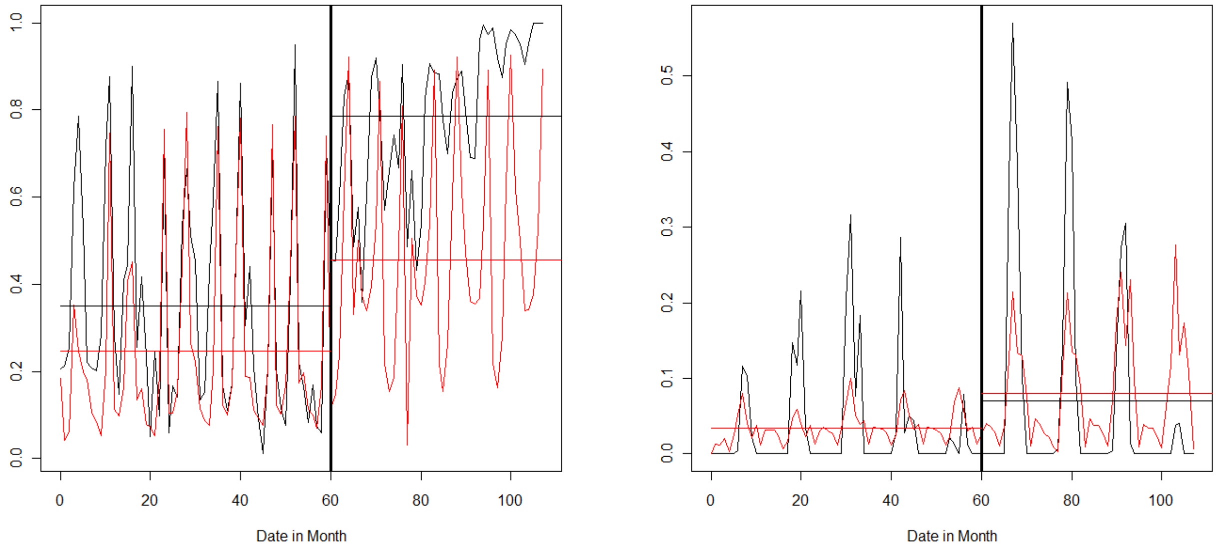


Figure 4. Comparison of observed (black line) and simulated (red line) effort proportion for Pelagic trawlers 1 each month (0=January 2000, 108=December 2008). "Other" métier (left panel) and métier targeting tuna (right panel). Vertical bolded line= Anchovy closure, horizontal lines= mean effort spent before and after the closure.

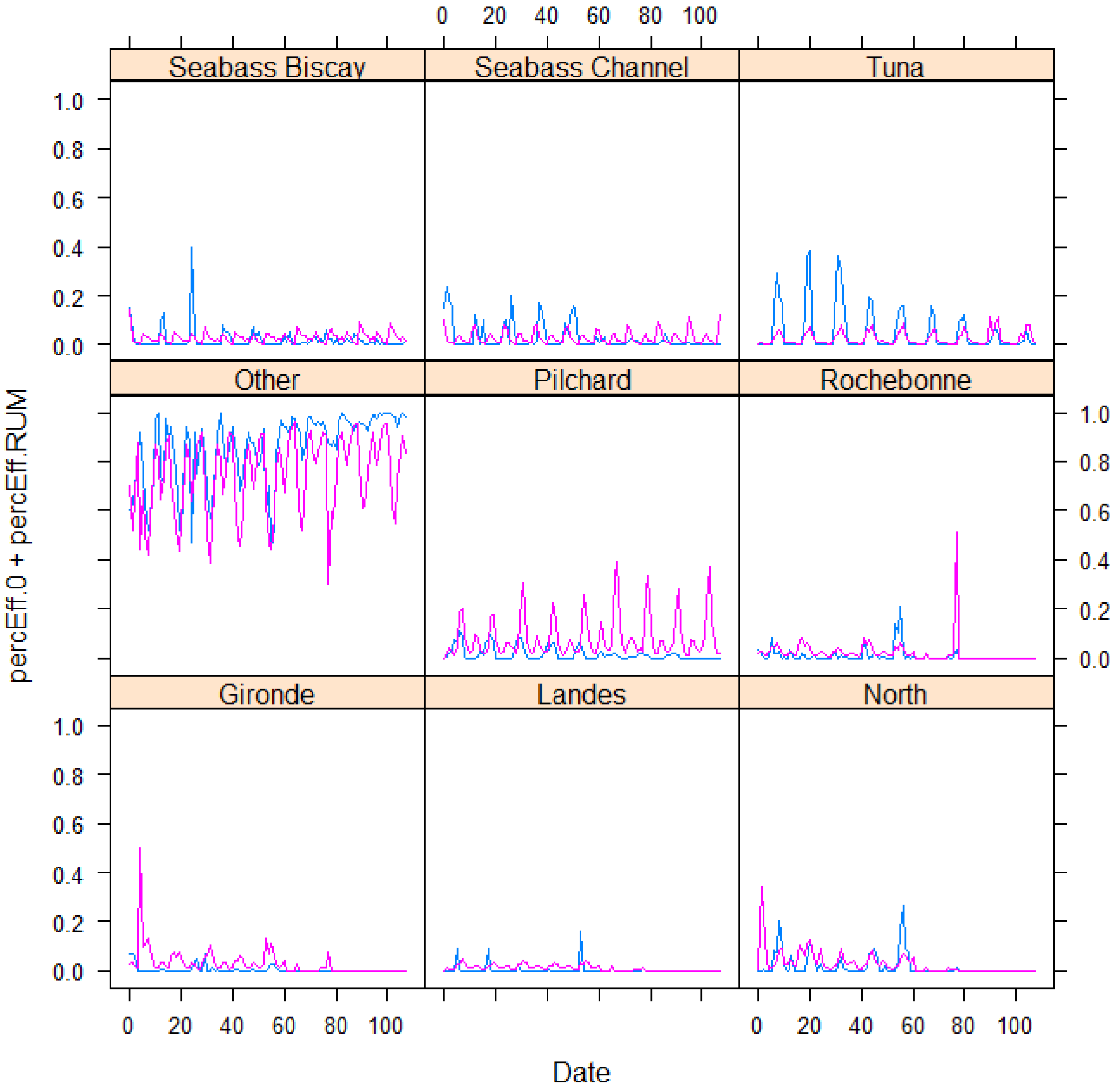


Figure 5. Observed effort proportion (blue line) spent on each métier each month (0=January 2000, 108=December 2008) compared with computed effort allocation (pink line) for Pelagic trawlers 2.

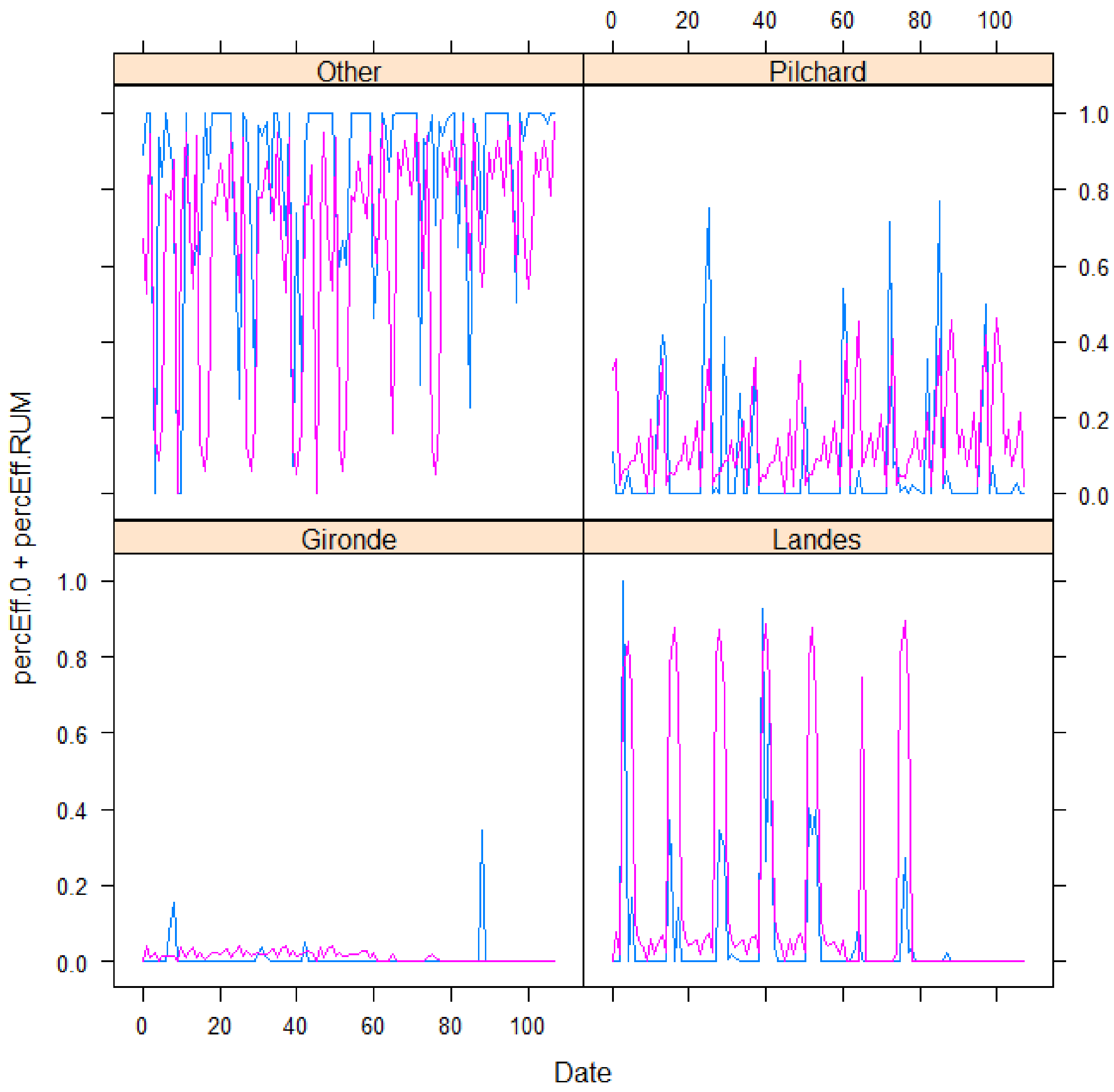


Figure 6. Observed effort proportion (blue line) spent on each métier each month (0=January 2000, 108=December 2008) compared with computed effort allocation (pink line) for Basque Country Purse Seiners.

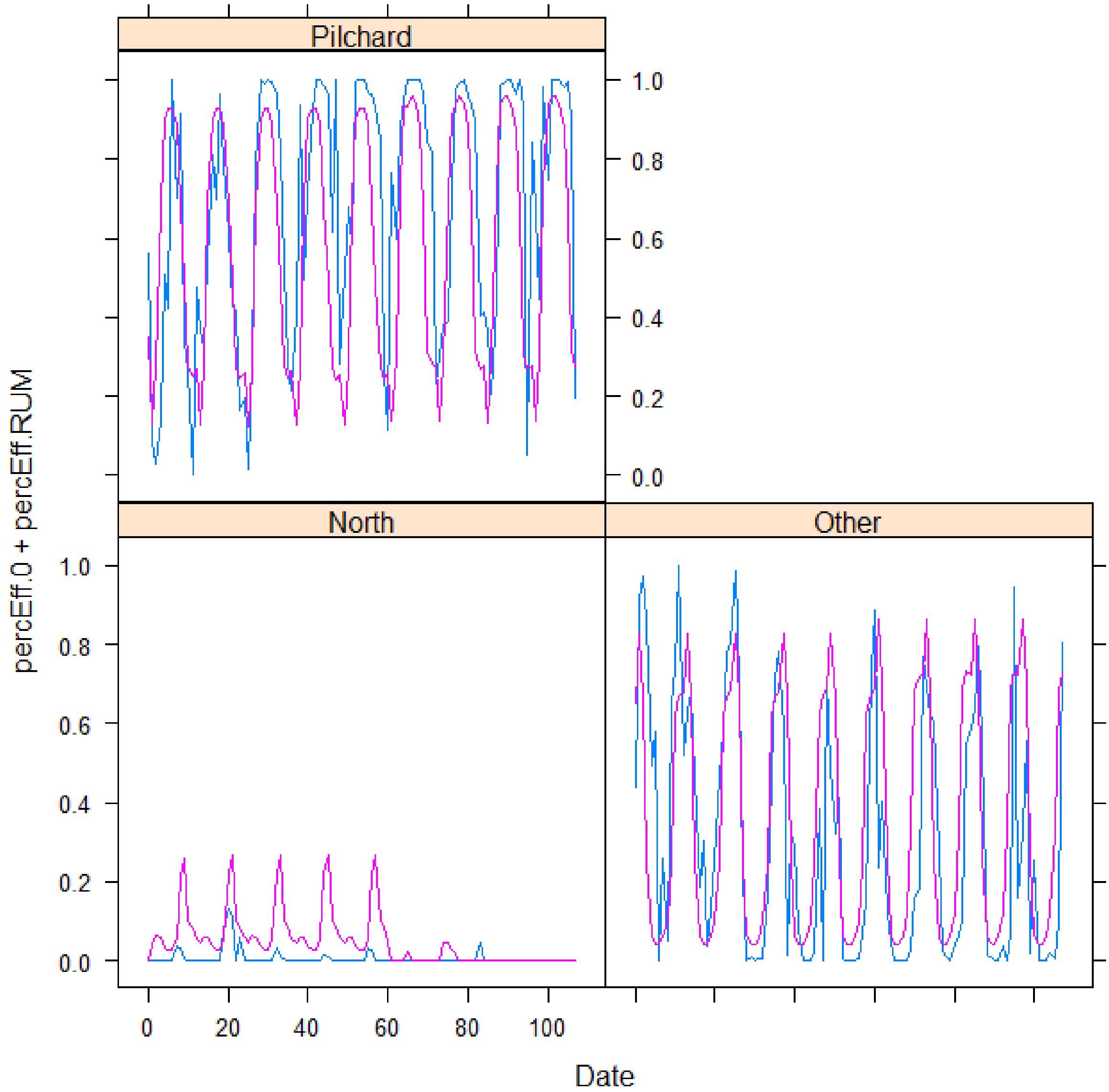


Figure 7. Observed effort proportion (blue line) spent on each métier each month (0=January 2000, 108=December 2008) compared with computed effort allocation (pink line) for Purse Seiners from Brittany.

In general, the model over estimates effort on the métier targeting sardine during the period of anchovy closure compared to what have been observed (except for the Britain Purse Seiners Fig.7 for which, sardine is the main activity). It also under-estimates effort re-allocation on the "Other" métier.

Discussion

The Bay of Biscay pelagic fishery is characterized by a vast fishery region, a variety of species targeted, a diversity of fleets and the opportunism of fishing activity in accordance with a very variable ecological context. Ecological links between the species are not well known but their harvest by the same fleets make them to some extend dependent on each other. In this context, it is difficult, but crucial, to assess how a change in the management of one species would impact the activity of the fleets and thus possibly the whole fishery. In particular as Marine Protected Areas are considered for the management of the anchovy fishery, it is necessary to determine whether effort would be reported on métiers targeting the main other species (sardine, tuna and sea bass), or on métier targeting anchovy in other areas, and which would be the ecological consequences of these options. These choices are probably highly dynamic and dependent on the health of the populations and the economic context. Consequently, the use of pre-established and time-invariant decision rules is not appropriate and the dynamic coupling of fleet and population dynamics in a spatially explicit framework is required. This is to our knowledge the first time that such a multi-species multi-fleets spatialised coupling is accomplished within a management strategy evaluation framework.

To do so, the structure of the RUM developed by Vermard et al (2008) was modify (1) to fit the scale and assumptions of the existing ISIS-Fish model of the anchovy fishery in the Bay of Biscay (Lehuta et al., Submitted), namely monthly time step and assumption of homogeneity within a fleet and, (2) to allow the use of the model for long-term predictions to evaluate the performance of Marine Protected Areas (MPAs). The seasonality and relatively good homogeneity of the fleets made the first two assumptions constraints realistic and easy to overcome without compromising the performances of the RUM. The consideration of fishing areas and high valued species (like tuna and sea bass) together with low valued high tonnage species (anchovy and sardine) however, raised the need to account for explicit fuel costs and species prices as an explanatory variables in the RUM. To allow for long term predictions the explanatory variables needed to be computable dynamically by the model which restricted the options to very few variables.

Nevertheless, the flexibility of the RUM enabled to reproduce very different fleet behaviors using the same set of explanatory variables for all the fleets. In particular, the Bay of Biscay French fishery presents two contrasted fleet strategies. The first category consists of the

French pelagic trawlers 1 that are very dependent on the anchovy fishery (41% of the total anchovy‟s catches) and can redistribute their fishing effort in the different areas of the Bay of Biscay to follow the fish spatial distribution. The second category gathers the other fleets that are less dependent on anchovy (mainly fishing on "Other" species) and more opportunistic. Part of the good results comes from the high seasonality of species availability and the large part of habits in decision making. That‟s why the traditional behavior of pelagic trawlers 1 is very well captured by the model. The more opportunistic behavior of purse seiners from the Basque Country and pelagic trawlers 2 was not as satisfying. This is mainly due to the multiplicity of species caught by these fleets. These species couldn‟t all be modeled individually. A métier "others" had thus to be created which attractivity was constant in time. This choice, although probably better than ignoring this source of revenues, explains the discrepancies observed.

Although we used some of the most recent perception of anchovy dynamics and forced recruitment for anchovy and sardine to observations, the processes underlying the strong inter-annual and spatial fluctuations in the spatial distribution of their biomass are not understood and couldn‟t be mimicked. As shown by Vermard et al. (2008), pelagic fisheries are greatly dependent on fish availability and accessibility. Any error made in the stock distribution will result in a bias in the VPUE estimates, and therefore will propagate and amplify swiftly throughout the simulated period when fishers‟ behavior is modeled in a dynamic way. This error could be amplified more quickly than in the case of some demersal fisheries, where stocks are likely to be less variable in term of spatial distribution.

Fisheries scientists are recurrently invited to develop bio-economic modeling tools to evaluate the performances of specific management measures. While a number of bio-economic modeling tools have been applied in the fisheries literature (Maury and Gascuel, 1999, Holland, 2003), it is seldom that these models have been groundtruthed against observations from the fishery system. Science advisers must not hide the multiple sources of uncertainty, but they also must conjointly explain what they are confident in with respect to their uncertainty analysis. This paper presents an informal visual validation of the bio-economic model by comparing the outputs of the dynamic effort allocation model and the observations. Given the high spatial and temporal resolution as well as the complexity and multiplicity of processes described, it is not surprising that the fit was far from perfect. However seasonal trends are reproduced as well as more punctual episodes like the short reopening of the anchovy fishery in 2005. These good performances make us confident that the model is appropriate to be used to forecast the dynamics of the fishery under new ecological and economic conditions and to assess the impact of alternative management strategies on the pelagic fishery providing that it is run within an uncertainty analysis framework.

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