

A BIO-ECONOMIC MODEL FOR THE VIABLE MANAGEMENT OF THE COASTAL FISHERY IN FRENCH GUYANA

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ABSTRACT

The coastal fishery in French Guyana is a challenging case study for the implementation of the ecosystem based fishery management. Although the current situation of this small scale fishery could be considered as satisfactory, the viability of the fishery can be questioned. Indeed according to demographic scenarios, the growth of the population will generate an increase of local food demand and therefore growing fishing pressures. Moreover, there is no direct regulation for limiting the fishing catches. Models and quantitative methods to tackle this sustainability issue are still lacking for such small-scale fisheries mainly because of the various complexities underlying the systems including the heterogeneity of the production factors, the weak selectivity of fleets and high fish biodiversity levels. In the present paper, we both use numerical simulations and a viability perspective to deal with such a problem. We first build a multi-species multi-fleets dynamic model relying on thirteen exploited species and four types of fleets. It accounts for potential trophic interactions, fishing effort and the corresponding costs and revenues. The model was fit on data collected since 2006 by Ifremer: daily production and efforts data, as well as economic data from a survey on the production costs and selling prices in 2009. The co-viability of the system under different scenarios of fishing efforts is studied through ecological and economic performances. The biological viability constraints focus on biodiversity index as species richness or trophic index while economic viability constraints intend to guarantee profitability to all the fleets.

Keywords: ecosystemic model, coviability, sustainable management, small scale fishery.

INTRODUCTION

With 350 km of coastline, French Guyana possess 130 000 Km² of exclusive economic zone with a continental shelf of 50 000 km². The area forms part of the Large Marine Ecosystem (LME) under the influence of the Amazonia River. Fishing is the third largest export sector value after gold mining and spatial activities (CCIG¹, 2008). We distinguish three kinds of fisheries: the first one is a prawn fishery with thirty industrial boats; the second one is the red snapper fishery composed by a foreign fleet (Venezuelans) under European Community License; the third fishery is a coastal one targeting “white fishes” living in littoral and estuary areas in depths up to 20 meters, mainly with drifting nets: about thirty commercial species are landed.

We focused here on the coastal fishery that concerns mainly 200 vessels which length is less than 12 meters. The coastal fishing fleet consists of wooden craft powered vessels. We can identify four kinds of vessel: “pirogues”, “canots creoles”, “canots creoles améliorés” and “tapouilles” (Bellail & Dinther, 1992). The “pirogues” are canoes with out-board motor fishing during only few hours essentially in the estuary areas. The “canots creoles” are vessels more adapted to sea navigation as compared to the

¹ “Chambre de Commerce et d’Industrie de Guyane”

“pirogues”. The “canots creoles améliorés” have cabins allowing several fishing days. The “tapouilles” are wider than the preceding, they are from Brazilian conception with cabin and in-board motor. The main fishing gear is the driftnet; it is used by 98% of the vessel (Vendeville *and al*, 2008). The “acoupa weakfish” (*Cynoscion acoupa*) is the first species in terms of landings, with 46% of the annual landing between 2006 and 2009.

Fishes are directly sailed to consumers by fishermen, or sailed to fishmongers or again sailed to factory units. High freight costs and the species ignorance in France and French West Indies make that only a small part of the landings is exported. Then Coastal fishery landings are essentially intended to satisfy the demand of the local population. During a large part of the year, local market becomes overcharged driving prices down and cooperative’s fishermen inefficiency leads to high operating costs. Indeed a main part of the coastal fleet presents some economic difficulties due to partly to the high costs of inputs and the low selling prices (Cissé, 2009). In the other side French Guyana’s population will be twice at about 2030, according to the prevision of Insee².

Then several issues appear: does the fishes supply can satisfy the local food demand with population’s growth? What about the marine biodiversity in case of rise of the fishing effort? What about the economic viability of the small fishing business? A multi-species and multi-fleet model has been built to tackle these questions. The model takes into account interactions between the thirteen main species in the landings and the four kinds of fleets.

Since 2006, daily production and efforts data for 70% of the coastal fleet are collected in the major landing points, by Ifremer³. The first economic survey for this fishery was carried out in 2009 and allowed to get information about investments, production costs and selling prices. After the description of the model and the explanations of the ways to obtain some missing parameters, we first made simulations over 30 years accounting for various scenarios.

MODEL

Presentation

The model built there is multi-fleets and multi-species, with discrete time monthly steps. It takes into account the dynamic of exploited stocks that are catch by the four fleets with contrasting selectivity, as well as the interactions between species according to the Lotka-Volterra model. Thirteen species are taken into account (table 1), representing more than 90% of the total landings.

The model allows for simulation at each step, the stock biomass and catches per specie and per vessel type. As no biomass limit exists for this species, the ICES⁴ precautionary approach⁵ cannot be used. Moreover, we look for more ecosystemic reference points. Hence, viability of the ecosystem was determined here using a biodiversity indicator: species richness, i.e. the number of species present at each time step.

² French Institute of Statistics and Economics Studies

³ French Research Institute for Exploitation of the Sea

⁴ International Council for the Exploration of the Sea

⁵ The objectives of ICES precautionary approach (PA) are to maintain spawning-stock biomass (SSB) above a limit reference point B_{lim} , while keeping fishing mortality (F) below a limit reference point F_{lim} (ICES, 2004).

Common name	Scientific name
Acoupa weakfish	Cynoscion acoupa
Crucifix sea catfish	Arius proops
Green weakfish	Cynoscion virescens
Fat snook	Centropomus parallelus, Centropomus undecimalus
Sharks	Sphyrna lewini, Carcharhinus limbatus, Mustelus higmani
Smalltooth weakfish	Cynoscion steindachneri
silver croaker	Plagioscion squamosissimus
Atlantic Tripletail	Lobotes surinamensis
Gillbacker sea catfish	Arius parkeri
Bressou sea catfish	Aspistor quadriscutis
Goliath grouper	Epinephelus itajara
Flathead grey mullet	Mugil cephalus
Parassi mullet	Mugil incilis

Table 1: The thirteen species considered

Economic dynamics

In the economic point of view, the monthly profit of the fleet is empirically defined as:

$$\Pi(t) = \sum_{i,k} \Pi_{i,k}(t) = \beta [\sum_{s,k} P_{s,k} \cdot H_{s,k,i}(t) - (C_{V_k} \cdot e_{k,i}(t))] - C_{f_{k,I}}$$

Where $\Pi_{i,k}(t)$ is the monthly profit for a ship i belonging to fleet k , β is the crew share earnings (take as 0.5), $P_{s,k}$ is the price per specie and per fleet, $H_{s,k,i}(t)$ is the monthly catches per specie, per fleet and per vessel, C_{V_k} represents the variable costs per unit effort per fleet (fuel consumption, lubricants, ice, foods), $e_{k,i}$ is the fishing efforts and $C_{f_{k,I}}$ the monthly fixed costs per fleet, per vessel (equipment depreciation, maintenance and repairs). $P_{s,k}$, C_{V_k} and $C_{f_{k,i}}$ are assumed to be same for all periods.

Ecological economics

The exploited stock dynamics have been modeled following a system of equation with the Lotka-Volterra trophic relationships:

$$B_s(t+1) = B_s(t) \cdot f_s(B(t)) - F_s(t) \cdot B_s(t)$$

Where B_s is the biomass of the specie s , $f_s(B(t))$ is the natural dynamic of specie s which depends on the density of the other populations into the trophic network, and $F_s(t)$ is the mortality of specie s , due to the activity of all the fleets.

The natural dynamic of specie s , can be expressed as following:

$$f_s(B(t)) = 1 + r_s + \sum_j S_{s,j} B_j(t)$$

Where r_s is the natural intrinsic growth rate of the specie s , $S_{s,j}$ is the trophic effect of the specie j on the specie s ($S_{s,j}$ will be positive if j is a prey of s and negative if j is a predator of s), and $B_j(t)$ is the biomass of specie j .

The trophic relationships between species ($S_{s,j}$) have been obtained from stomachal contents data (α) such as:

$$S_{s,j} = \alpha_{s,j} \mu - \alpha_{j,i}$$

Where ($\alpha_{s,j}$) is the proportion of biomass of prey j in the stomach of predator i , μ is a converse factor ($\mu = 0.125$, Doyen *and al*, 2007)

Fishing Mortality

Fishing mortality for a specie s ($F_s(t)$) is the sum of mortalities for this specie due to all the fleets:

$$F_s(t) = \sum_k q_{s,k} e_k(t)$$

Where:

- ($q_{s,k}$) is the catchability of the specie s by the fleet k , which corresponds to the catch probability of one unit of specie s by the fleet k during one unit effort.
- $e_k(t)$ is fishing effort of fleet k during the step t . The fishing efforts have been converted in hours.

Then monthly catches for each specie s by each fleet k , $h_{s,k}(t)$ and monthly total landing $H(t)$ can be write as :

$$h_{s,k}(t) = F_{s,k}(t) \cdot B_s(t)$$

$$H(t) = \sum_k \sum_s h_{s,k}(t)$$

CALIBRATION

Data used for the parameterization of the model are estimated from Ifremer's surveys. Then monthly landings per specie and per vessel ($h_{s,k}(t)$) as well as monthly fishing efforts per fleet ($e_k(t)$) have been calculated for 2006 to 2009.

Intrinsic growth rates are get from fishbase (<http://www.fishbase.org>) and qualitative trophic relationships have been estimated from Léopold (2004) and fishbase.

The value of the others parameters have been identified by optimization. The principle of the optimization algorithm is to minimize the deviations between the values of the observed catches and the simulated ones, fitting the model over 48 time steps (48 months from 2006 to 2009). Then the algorithm allows estimating missing parameters, for which the deviation is minimum, so:

$$\text{Min}_p (\sum_{2006..2009} \|H_{\text{observed}}(t) - H_{\text{fitted}}(t)\|^2)$$

Where $p = (B(t_0), \alpha, q)$ is the vector of the parameters to identify which are the initial stocks ($B(t_0)$), the matrix of stomachal contents data (α) and the catchability matrix (q).

To quantify the robustness of the missing parameters, relative error (R.E) between the observed catches and the simulated ones have been calculated as:

$$\text{R.E} = (H_{\text{simulated}}(t) - H_{\text{observed}}(t)) / H_{\text{observed}}(t)$$

With, mean (R.E) = 0.0382 and standard deviation (R.E) = 0.172.

Visual comparisons between the observed and simulated catches are presented in figure 1.

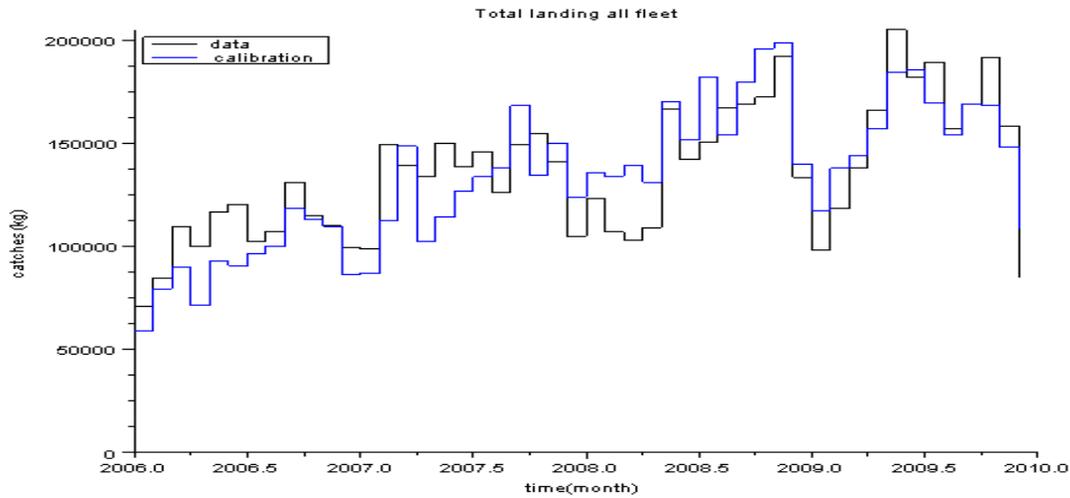


Figure 1: 2006-2009 total landings by all the vessels, observed (black line) and simulated (blue line)

SCENARIOS

Several scenarios of fishing effort have been simulated for a 30 years’ time period (360 months). The species richness and the total profit of the last year or each scenario are pointed and compared.

No fishing scenario

This scenario would correspond to the implementation of a no fishing zone on the whole Guianese area; this is the “marine protected area” scenario. For this scenario, there is no income for the fishermen. At the end of the simulation, there was no more than eight species in the ecosystem instead of the thirteen species. Indeed, the specific richness declines during the simulation (figure 2). Species as “green weakfish”, “fat snook”, “sharks”, “smalltooth weakfish”, and “flathead grey mullet” did not maintain. This situation can be explicated by the dependent relationship found through the identified stomachal matrix and/or the intrinsic growth rates of species (negative for “sharks” and “Goliath grouper”). However, no fishing allowed some species to growth until a threshold before to maintain or extinct (“atlantic tripletail” and “fat snook”, figures 3 and 4). Also no fishing scenario favored species like “crucifix sea catfish” and “gillbacker sea catfish” to grow up (figures 3 and 4). Despite a raise of the total biomass (total biomass has been multiplied by 17), there is a modification of the species proportion in the ecosystem: “gillbacker sea catfish” and “crucifix sea catfish” represent respectively 67% and 24% of the total biomass (figure 5).

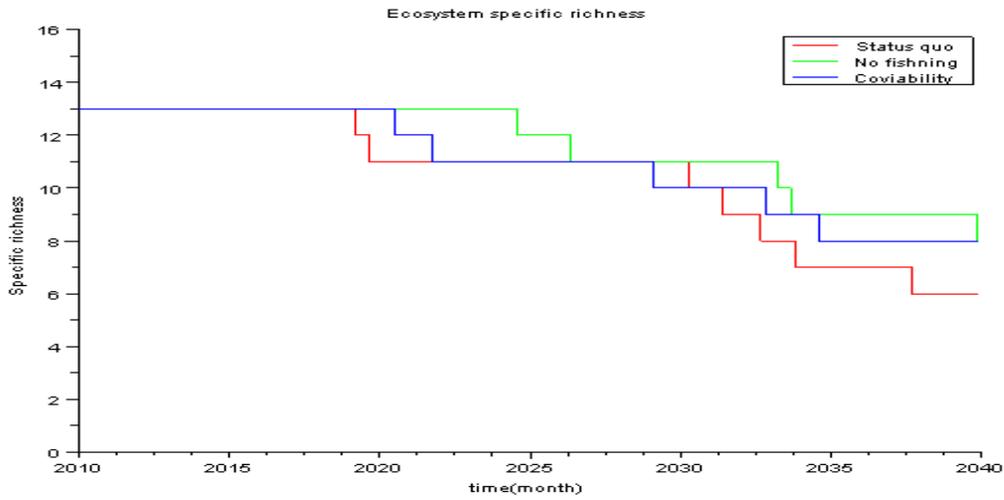


Figure 2: Simulated temporal variations of the species richness for various fishing scenarios

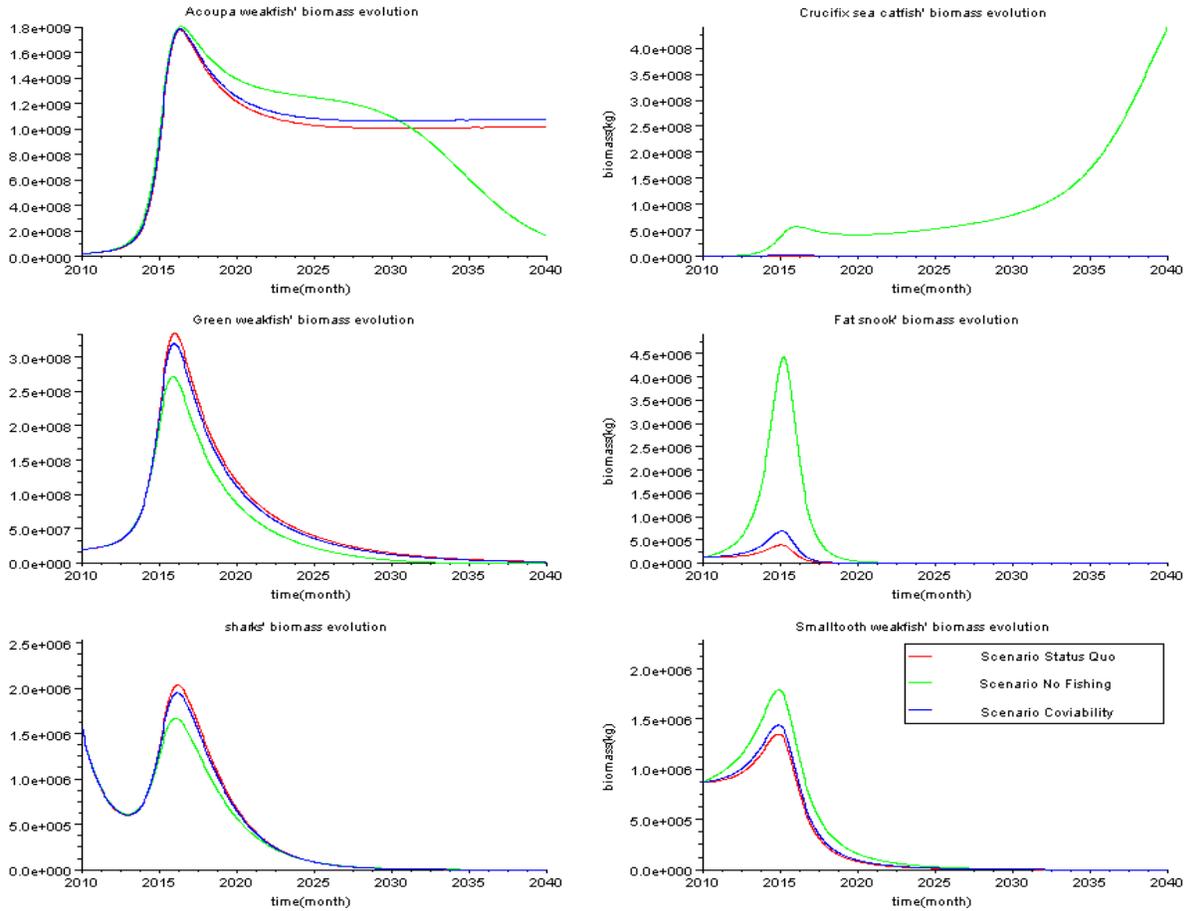


Figure 3: Simulated temporal variations of the species biomass (1)

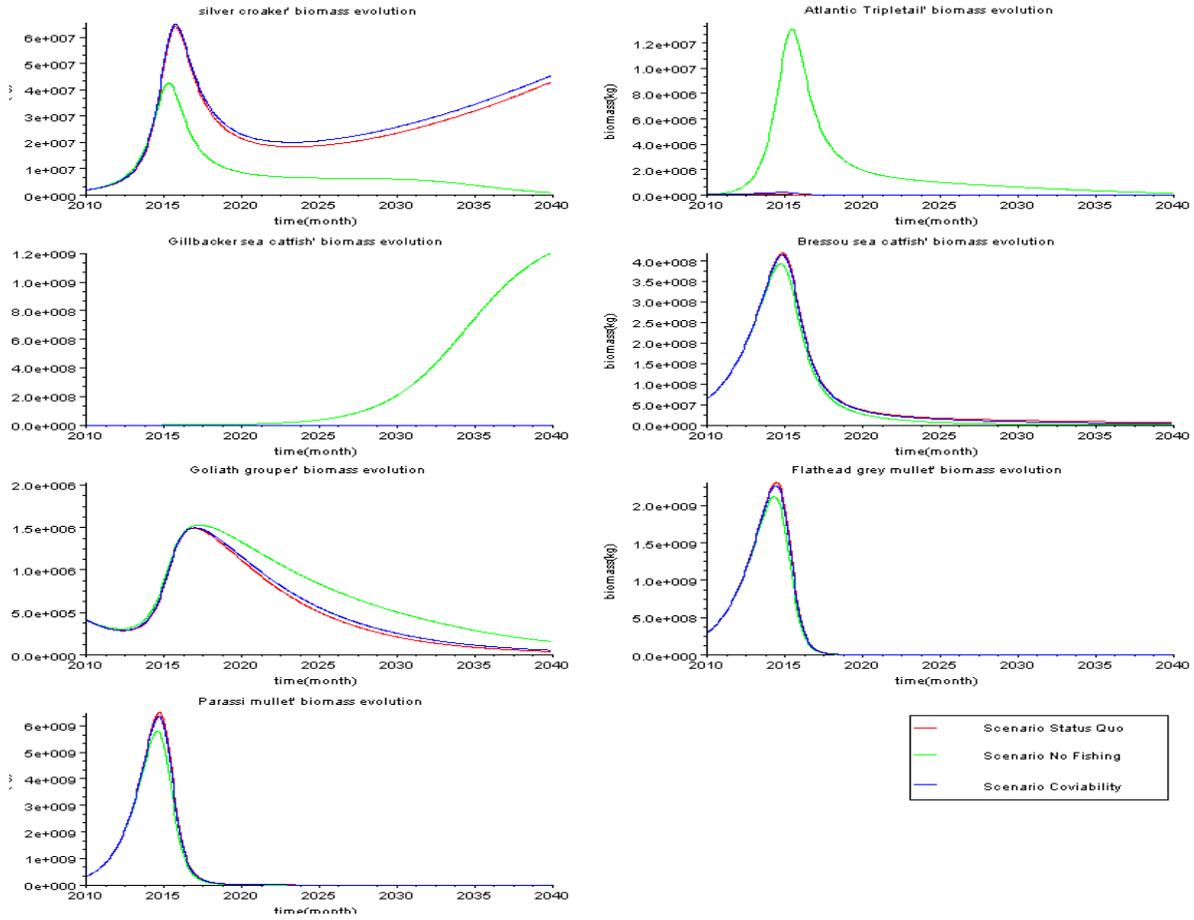


Figure 4: Simulated temporal variations of the species biomass (2)

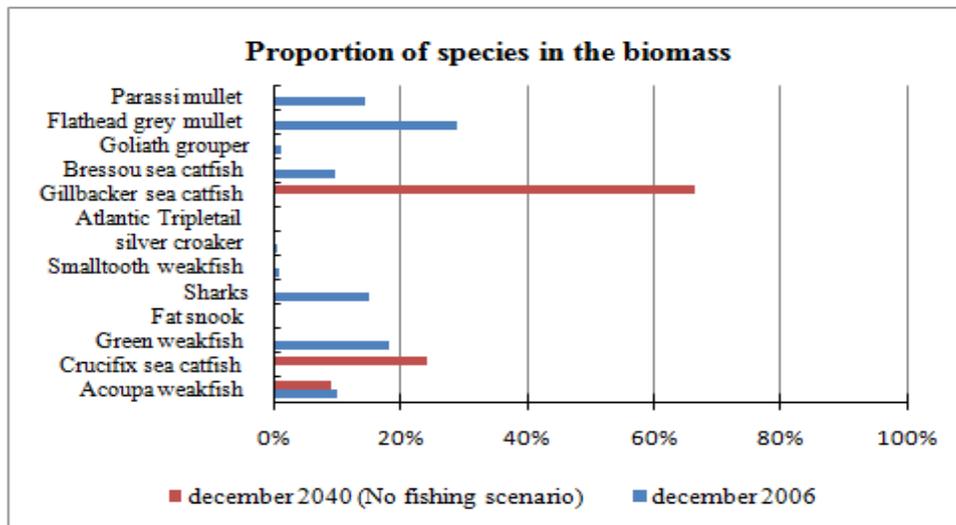


Figure 5: Compared stock biomass at the beginning and at the end of the simulation for the no fishing scenario

Status quo scenario

The status quo scenario corresponds to apply the average efforts observed between 2006 and 2009. For this scenario, the species richness declined to 6 species at the end of simulation (figure 2) although total biomass has been multiplied by 10. The seven lost species were: “crucifix sea catfish”, “fat snook”, “sharks”, “smalltooth weakfish”, “atlantic Tripletail”, “gillbacker sea catfish”, “Flathead grey mullet”. Some species reached a very high biomass level during the simulation (“green weakfish”, “sharks”, “flathead grey mullet” and “parassi mullet”, figures 3 and 4). There is a specialization of the ecosystem, with ‘acoupa weakfish’ representing 95% of the total biomass at the end of the simulation (figure 6). The total profit of all the fleets was negative during the first two years (figure 7) and the local food demand was not satisfied during the first year of simulation (figure 8). This scenario is not an optimal solution considering the objective of marine biodiversity preservation.

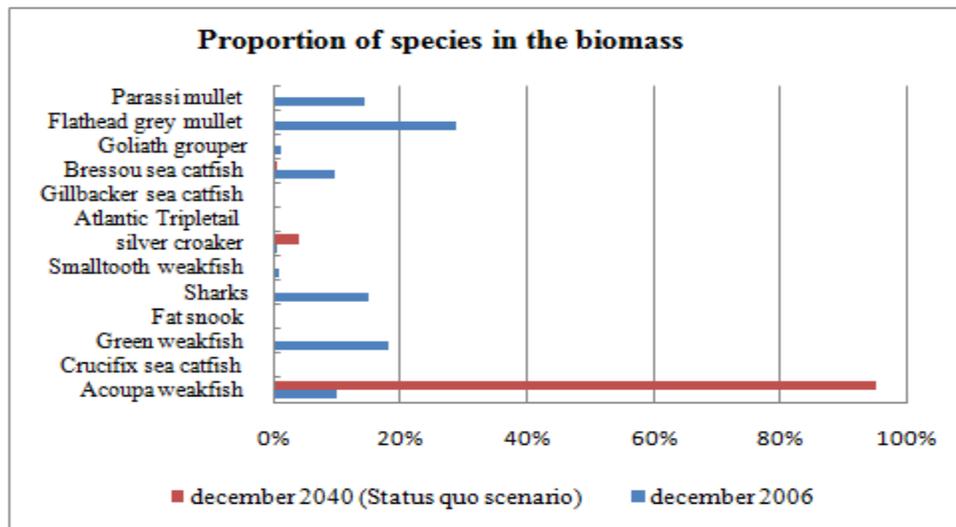


Figure 6: Compared stock biomass at the beginning and at the end of the simulation for the Status quo scenario

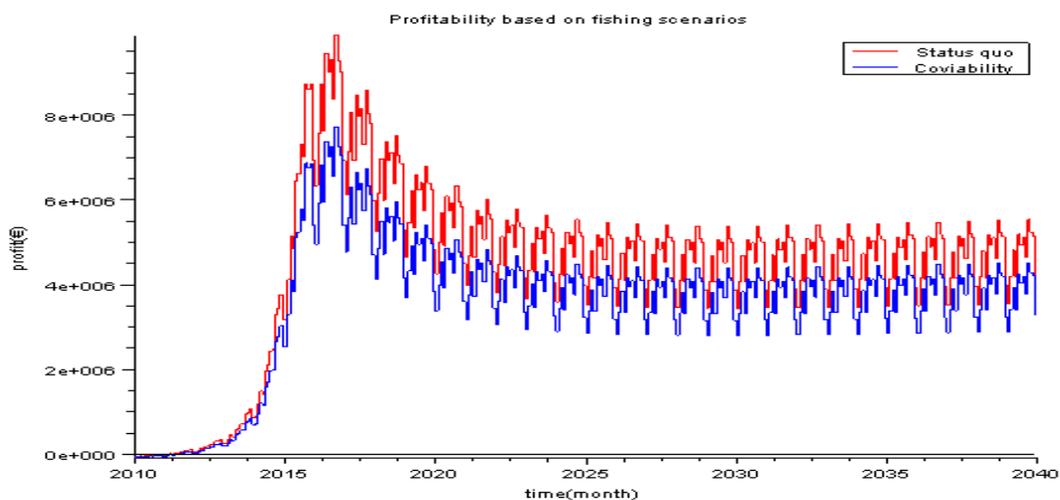


Figure 7: Simulated temporal variations of the profit

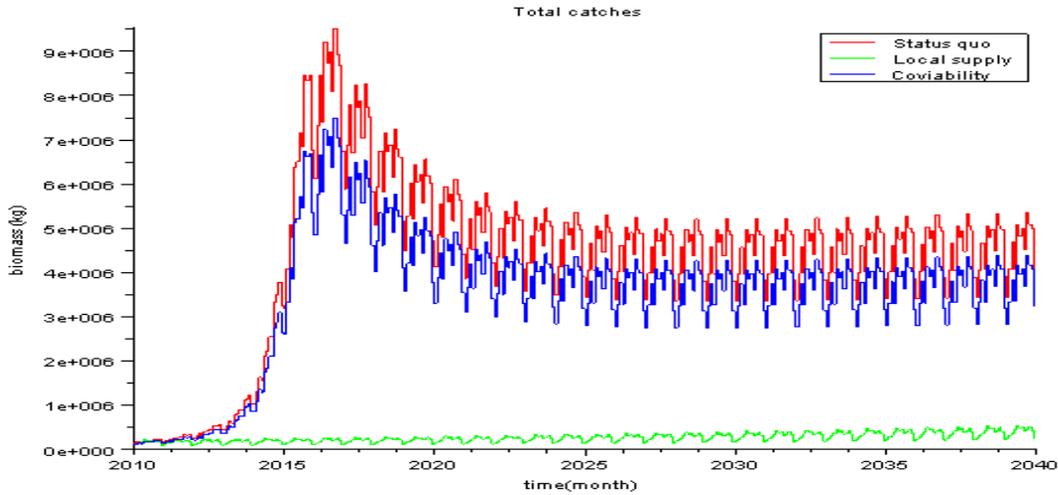


Figure 8: Simulated temporal variations of the total catches and of the local demand

Co-viability scenario

Let u a parameter⁶ used to change the fishing pressure compared with a standard period (2006-2009) according to:

$$F_s(t) = \sum_k u q_{s,k} e_k(t)$$

We try to find a level of fishing effort (u) such as the 3 constraints below are satisfied for all the steps of the simulation:

- $\forall t, \Pi(t) > 0$ (profitability constraint)
- $\forall t, SR(t) = 13$; where $SR(t)$ mean species richness at t time (biodiversity constraint)
- $\forall t, H(t) \geq H_{2009} * (1+\beta)^t$; (Demand constraint) where H_{2009} represents the landings in 2009 and β correspond to population growth rate ($\beta = 0.03^7$).

The first constraint imposes fleet profitability; the second allows maintaining the species richness and the third one allows local food demand satisfaction. For the last constraint we first assumed that local fish demand will grow directly proportionally to the population growth. Secondly we assumed the substitutability of the species regarding the demand for fish consumption, then the extinction of one species can be counteracted by the raise of consumption of the others species.

Using numerical optimization, solution satisfying all constraints hasn't been found. The best solution found ($u = 0.7740905$) corresponded to:

- Negative profit during the first two years (figure 7).
- Insufficient catches to face to the local demand for the first two years (figure 8).
- 8 species at the end of the simulation (figure 2 and 9).

⁶ The status quo scenario correspond to $u=1$.

⁷ Calculated according the intermediate Insee's scenario (doubling of local population at about 2030)

The species richness obtained for the last simulation step was the same as for the no fishing scenario. The five lost species were: “fat snook”, “sharks”, “smalltooth weakfish”, “atlantic tripletail”, “flathead grey mullet”. We note some differences with the other scenarios: “Green weakfish” remained stable and “atlantic Tripletail” disappeared in the coviability scenario. At final step, the total biomass was multiplied by 10 with a specialized ecosystem, ‘acoupa weakfish’ representing 96% of the total biomass, as for the status quo scenario (figure 10). The species biomass temporal trajectory was the same as for the status quo scenario, except that some species subsisted at the end of the simulation (figures 3 and 4).

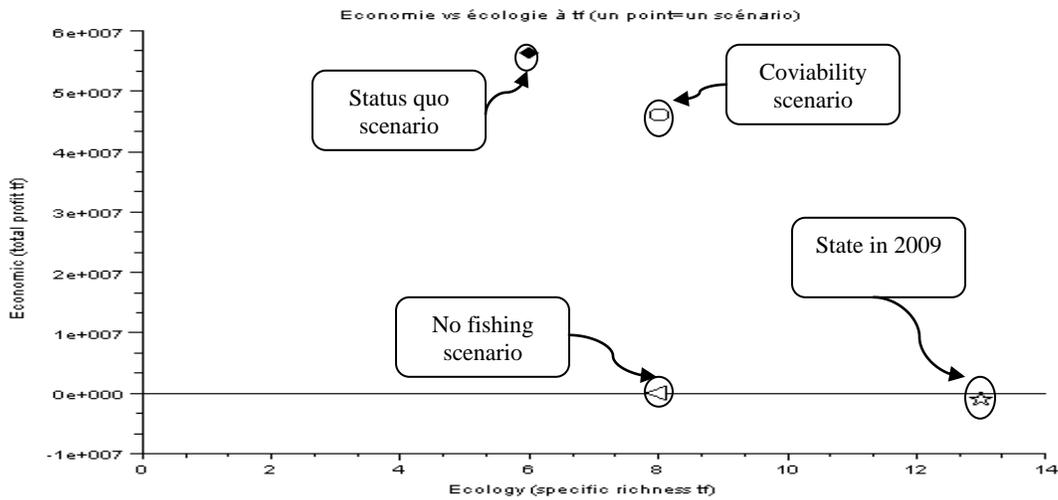


Figure 9: Species richness and profit obtained at the end of the simulations for each scenario

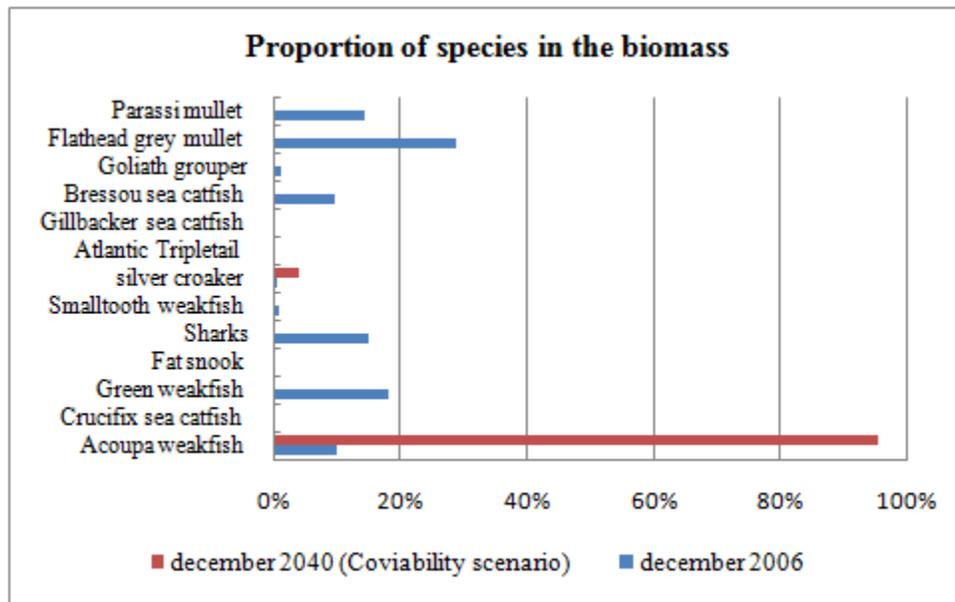


Figure 10: Species richness and profit obtained at the end of the simulations for each scenario

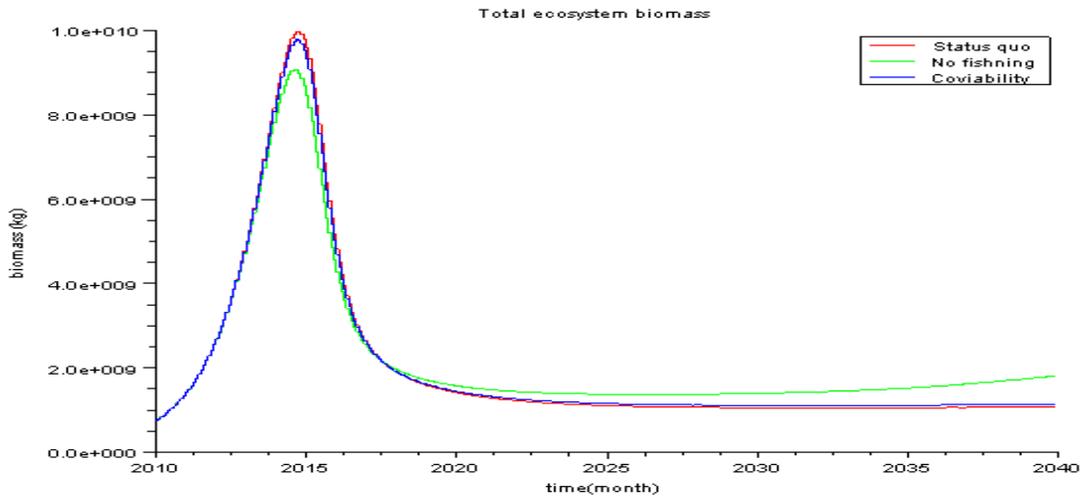


Figure 11: Simulated temporal variations of the total biomass

DISCUSSION

Viability of different scenarios of fishing has been investigated both for the biodiversity (species richness) and the fishery (profit), but also for the local population (local food demand). Projections over 30 years pointed out the complexity of the mechanisms involved, in particular their non-linearity. The trend of the total biomass was the same for the three scenarios: a period of relatively rapid growth during the first five years of simulation; a period of decline during the five following years; and finally a relative stagnation period until the end of the simulations (figure 11). Between the three scenarios identified, the no fishing scenario and the coviability one provided the greatest species richness. The no fishing scenario was the one which the loss of species richness was the slowest (figure 2). Indeed the system had not greater species richness without fishing, and the same result in term of species richness was obtained by reducing the fishing effort by 22.6%. Stop fishing is not a viable solution, either economically of course, or biologically. Nevertheless maintain constant the fishing effort is not a solution, regarding the objective biodiversity preservation.

To satisfy the future local food demand, conserve a maximum of species in the ecosystem and ensure a profit for the fleets, the fishing effort corresponding to the coviability scenario is the best solution. This scenario corresponds to a decrease of about 23% the fishing effort as compared to the reference period (2006 -2009) fishing effort. However, constraints of profitability and local food demand are not satisfied for the first two years. Then, subsidiaries and fish imports could be introduced during this period and for the following years fish exports can be planned.

However these results must be moderated for four main reasons: i) the model is based on simplified theoretical ecosystem dynamics, ii) some parameters of the model were estimated from fishbase or literature, iii) discards and illegal fishing by foreign vessels, which are common, are not taken into account, and iv) many other species are present in the ecosystem that may avoid the extinctions observed in the simulations (probably often due to trophic interactions). The sensitivity of the results to some of these problems was tested but not reported here. It allowed to argue that for example, the use of growth rates and stomach contents values from studies carried out on this ecosystem should improve the model. Moreover, an estimate of discards (some data are yet available) and additional fishing mortality should be integrated in the model. Finally, a fourteenth species could be added to represent the remaining biomass of the ecosystem constituted of many species that may be preys as well as predators of the first thirteen ones. Hence extinctions would be probably less observed in the simulations. Addition of uncertainties in growth rates, and demographic and environmental stochasticity may be considered too.

This work is a preliminary analysis which may contribute to the establishment of sustainable development framework, taking into account the ecosystemic interactions between several species and the economic system, the fisheries, exploiting them.

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