Simulating a fishery exploitation: Application to the small-scale fishery in Senegal.

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Abstract: *The artisanal fishery in Senegal is characterized by composite biological, technological, economical dynamics in interaction. A computer model of the exploitation is presented to study the relationships existing between resources, production, trading, consumption (dynamic approach). The model is developed using a systemic approach. The computer transcription utilizes a multi-agent formalism (artificial intelligence) based on representation of the actors choices, actions and interactions.*
The model of the exploitation is composed of 11 categories or types: fisherman, fish-trader, consumer, factory, fishing zone, port, market, fish stock, species, fishing gear and vehicle. Each object is autonomous, able to receive and send information to other objects. These information induce for fishermen and fish-traders multiple criteria choices and actions (moving, fishing, selling, buying). Transactions between actors modify the species prices in the various ports and markets. Combination of the different actions produces fluxes of fishes, currencies, human actors and work. Several variable types, local or global can be traced. The global dynamics (fluxes) is obtained from a local representation (objects). This approach permit to observe and analyze some complex behaviors of the exploitation.

Résumé: ***Simulation d'une exploitation halieutique: application à la pêche artisanale maritime au Sénégal:*** *La pêche artisanale sénégalaise se caractérise par de multiples dynamiques (biologiques, technologiques, économiques) en interaction. Un modèle informatique de l'exploitation est présenté afin d'étudier les relations existant entre la production, la commercialisation, la consommation (approche dynamique). Le modèle a été développé en adoptant une approche systémique. Sa transcription informatique utilise un formalisme multi-agent issu de l'intelligence artificielle qui est basé sur la représentation des choix et des actions des acteurs.*
L'exploitation modélisée se compose de 11 catégories ou types: pêcheur, mareyeur, consommateur, usine, zone de pêche, port, marché, stock, espèce, engin et véhicule. Chaque objet est autonome, capable de recevoir et d'envoyer des informations à d'autres objets. Ces informations induisent chez les agents pêcheurs et mareyeurs des choix multi-critères et des actions (déplacement, pêche, vente, achat).
Les transactions entre acteurs modifient les prix des espèces dans les différents ports ou marchés. Les diverses actions combinées produisent des flux de poisson, de devise, d'acteur ainsi que du travail. Plusieurs types de variable, local ou global, peuvent être tracés. La dynamique globale (flux) est obtenue à partir d'une représentation à un niveau local (objets). Cette approche permet d'obsrver et d'analyser certains comportements complexes de l'exploitation.

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Introduction

The artisanal fishery exploitation in Senegal is a complex system of fishermen and fish traders acting in close interaction (Laloë et Samba, 1990, Chaboud, 1985). Indeed, in the global marine fishery, several ethnic groups with different behaviors targets more than a hundred of species using 19 types of fishing gear. On the other side, when fishermen land their catches, an other complex set of fish traders is in charge of the food product distribution. Seafood can be sold on the beach, carried to the various markets of the country, brought to Dakar for exportation or processed.

Historical review of this fishery exploitation pointed out that management changes introduced in the small-scale exploitation always led to unexpected effects (Chauveau et Samba, 1990). Indeed, one management measure introduced for a given purpose may often lead to consequences on other part of the exploitation that were not concerned by the given measure. On an other side, the need for management may simultaneously involve several objectives. For example, one may simultaneously aims at a better resource conservation, economical profit, employment, or food supply.

In a management purpose, one may look for scientific representation that could account for these multiple objectives and investigate the relationships existing between the different components (technology, biology, economy, fishing, trading) of the exploitation.

A computer model has been developed for this purpose. Even if it is clearly not possible to reproduce exactly the real exploitation, the project aims at providing some advice on the way the exploitation could possibly react to a natural or management change.

Model

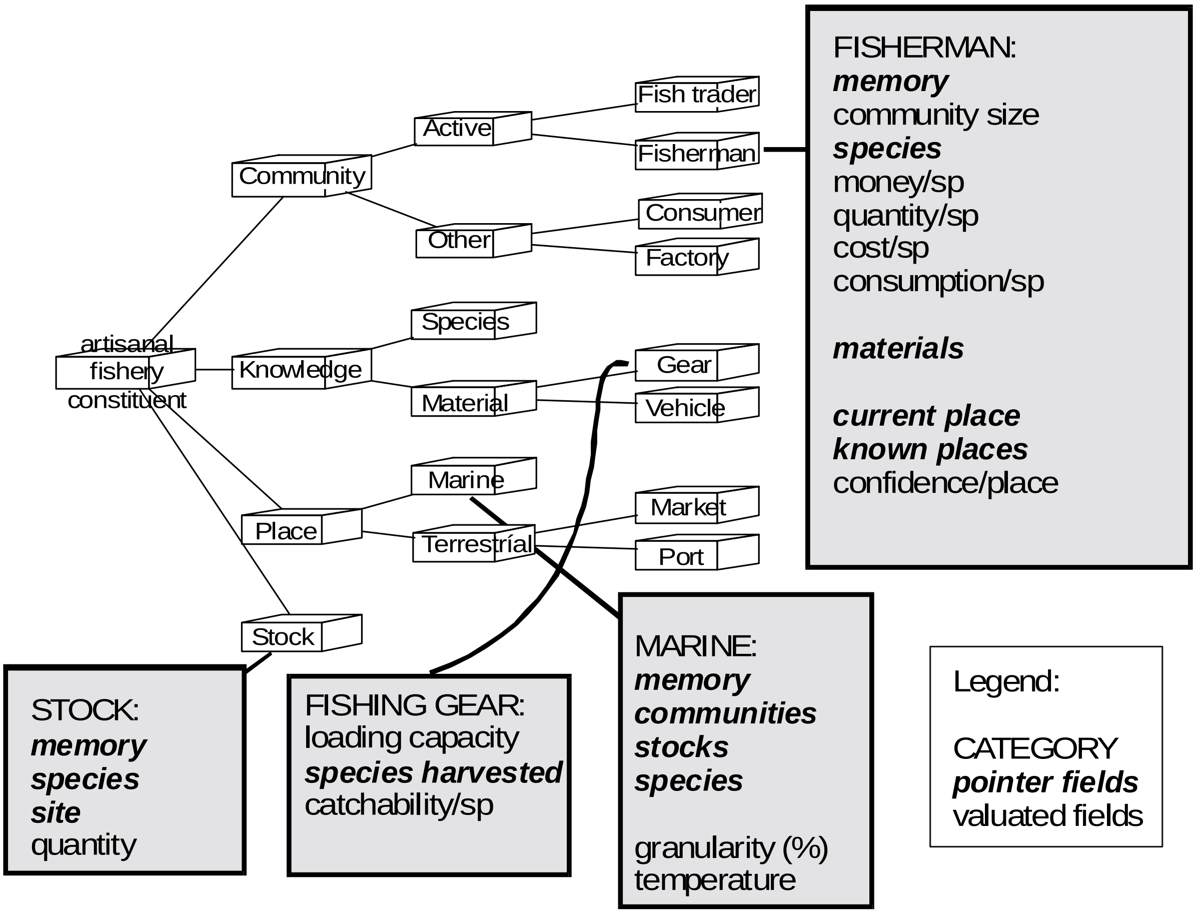
The model is based on a systemic perception of the exploitation (Bertalanffy, 1968, Le Gallou et Bouchon Meunier, 1992). In this approach, the exploitation is considered as a set of four interconnected networks where circulates money, fishes, human actors and information. These fluxes may be interconnected at some points where matter can be exchanged (e.g., money exchanged into fishes, work into money). Each constituent of the exploitation (site, actor, material, stock, etc.) is involved in realization and interconnection of these fluxes. The constituent activity and their interactions produce the global dynamics (production, richness) of the exploitation. From this point view, looking for a sustainable exploitation of Senegalese resources may consist in maintaining these fluxes.

The human groups in charge of the exploitation (fishermen, fish traders) may constitute the concrete link between biological, technical, economical and social dynamics. For these actors, the ability to respond to changes in their environment may be dependent from their ability to choose from one alternative to the other, ability to negotiate with other actors, ability to act in a proper way.

Structure representation

To get into this composite problematic, the computer model is build using an object oriented representation (Masini et al., 1989). Using this formalism, each constituent of the exploitation is considered as an autonomous object belonging to a specific category. The categories that have been retained in the model of the Senegalese exploitation are described on Figure 1.

Figure 1: Computer constituents (categories) of the exploitation and examples of the objects characterization.



The global fishery exploitation is composed of four main categories: the *communities* realizing the various fluxes, the *knowledge* they can access for this purpose, the *places* in which they stand and the *stocks* they harvest. These major classes are divided into more specialized categories to get a sufficient (parsimonious) description of what composes the fishery exploitation. In each category, several objects are differentiated. Every object on a given category is given a set of attributes that are defined by its belonging category. The value of these object's attributes document either the relationships with other objects (pointer fields) or specific characteristics (valuated fields).

Functional representation

Upon this structure a multi-agent formalism (Ferber, 1989) has been developed. The *Active-Community* category relates to the active agents (fishermen and fish traders) of the exploitation. These objects are endowed with various behaviors allowing them to get information from their environment, make choices about it and produce several actions:

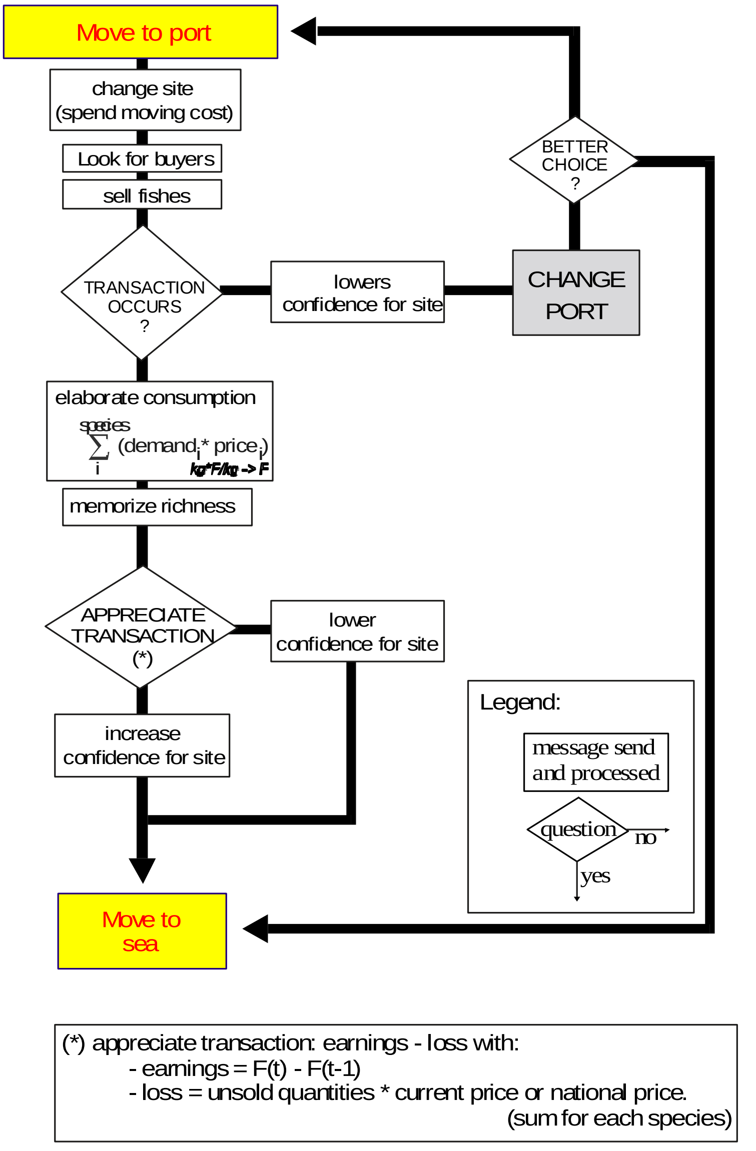
The only action a computer agent can perform is to send messages to other agents, receive messages from other agents and produce "back-answers" by means of new messages (messages are small computer routines). For example, if a fisherman community needs to know the traders' demand for a given species in a given port, it sends the corresponding message to the port's agent. The port looks for the fish-traders currently at this place and sends to each of them the message "species' needs ". Each fish trader then proceed to an inner evaluation of its needs and owning. It replies by sending a message back to the port. The port cumulates the answers and after a compilation can reply back to the fisherman community.

Through successive nesting of this message sending and replying mechanism one can formalize sophisticated behaviors. For example, the interest of a fisherman for a given port is a combination of traders' demand, species prices, moving costs, confidence in the ports. Each of these information are obtained through combination of the appropriate messages.

At a higher level of combination it is possible to model some basic activity of the various agents in the exploitation. The example in Figure 2 represents fishermen action once they have gone fishing and come back to land their catches.

Each fisherman agent arriving in a port tries to sell its fishes. If it succeeds, it memorizes the results of its action and then stands by. The next time it will have to act it will choose to go at sea. If transaction does not succeed, whether there is no fish traders for its fishes or negotiation did not succeed, fisherman look for another port (action *change port*) through a decision process sub-model (Le Fur, 1995). Depending on the information it can gather from other agents the community elaborates a set of alternatives where it can goes. For each of these places, it evaluates the opportunity related to several criteria. In this case, the opportunity to go to one port or the other will depend on traders' demand, species prices, moving costs, confidence for one or the other place. After comparing the opportunity for each of the alternative, whether it finds a better place to sold its fishes and then goes to the new port where the whole process starts again, or it does not find a better place, and stands by for a sea ride. If, during its standby, fish trader agents happen to arrive in this port, selling may occur.

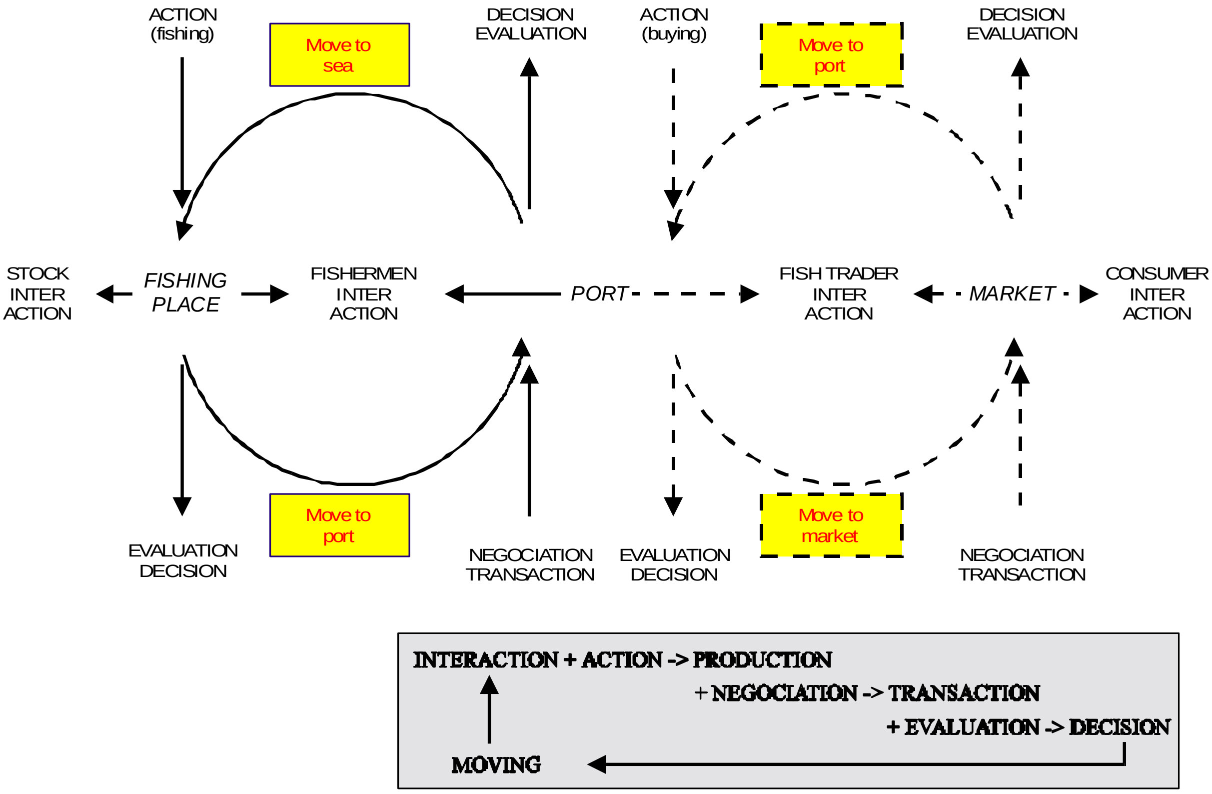
Figure 2: Decomposition of the action proceeded by a fisherman to move to a port (e.g. after fishing). Each box reflects a set of messages send by the fishermen community to itself.



To account for the whole exploitation activity, four similar processes have been formalized: two for the fishermen agents: " move to sea " and the " move to port " just described, and two for the fish traders agents: " move to port " and " move to market ". In an other step, these four meta-processes are organized through a global activity cycle described on Figure 3.

At each time step, each active agent, fisherman or fish-trader has to choose from one of its two

Figure 3: dynamics principle of the model



moves. Moving to the same place is allowed as a stand-by. Depending on its owning (fishes, money) and the result of its preceding choices, it moves to a given place whom characteristics conduct it to a specific *action*. For example, a fisherman arriving at a fishing zone fishes, a fish-trader in a port tries to buy fishes, etc. Any action proceeded lead to a subsequent *evaluation* of its result. This evaluation may lead to change or no change in the next action aimed at by the active agent (*decision*). Again, action and evaluation are sets of messages exchanges between the various types of agents described in Figure 1.

When two communities, a buyer's and a seller's, happen to meet in a given place, a *negotiation* may occur, followed or not by a *transaction*. A particular sub-model has been developed to formalize this mechanism.

Transaction sub-model

Since in Senegal, bargaining is the rule for exchange, the transaction sub-model represents selling by private contract between the different communities: at the beginning of the transaction, the selling community (fisherman, fish trader) gets information from its surroundings, evaluates the cost caused by the previous activity (moving, fishing) and proposes its price. The buyer (fish trader, customer) considers its previous costs or needs and put forth its own proposition. The final price of the transaction will be a value between the seller's lowest price and the buyer highest price. In decision theory, given *A* a set of acts, *E* the possible states of an environment, the possible consequences (*C*) can be described through a probability distribution. A thumb rule (Charreton and Bourdaire, 1985) establishes the possible mean of this distribution (i.e., final price) as: *1/3 * [maximum of the distribution + minimum of the distribution + mode]*. Following this scheme, the transaction price will be, for example in a port: *1/3 *[fishermen's price + traders' price + final price in the port during the last transaction concerning this species]*. If the final price is convenient to both of the partners, the transaction occurs and the price changes in the port. In a given time step, the evolution of the traders' arrival in the port and their successive transactions makes the port's fish prices evolve. These fluctuations will again intervene in the agents' choices. This procedure is duplicated in the market places where transactions occur between fish traders and consumers.

Since the agents may carry fishes, currencies, their moves lead to the activation of the various fluxes constituting the exploitation. Moreover, depending on the place where one agent stands, it can come into interaction with other agents and proceed to an exchange of matter (e.g., work into fishes, fishes into currency, etc.). In this sense, the various moves lead to interactions between agents of different kinds. The accuracy of the interactions will be a condition for an accurate subsequent action.

Simulation process

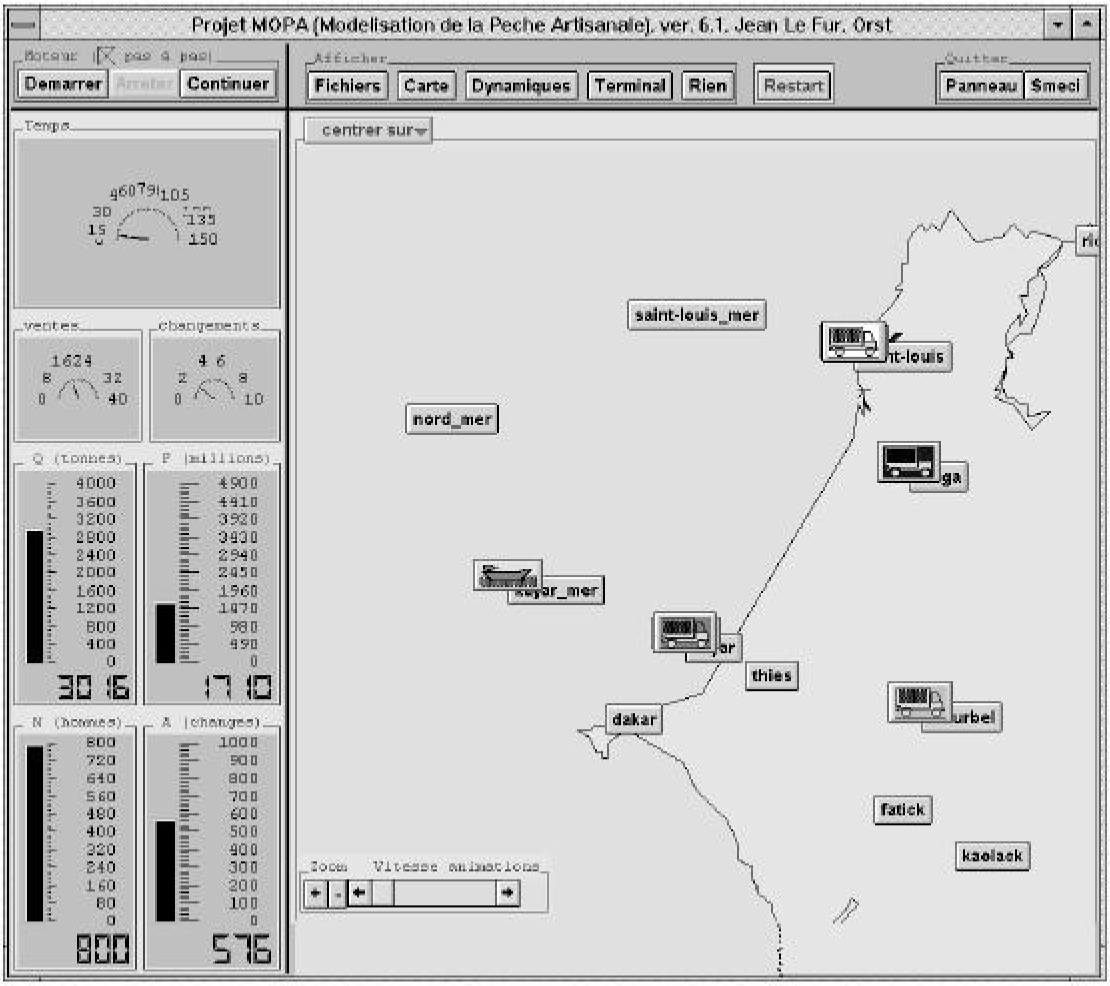
The exploitation's model is composed of these structural and functional frameworks. Building a simulation consists in creating various objects of each category according to the real system studied. The whole Senegalese exploitation has been formalized using some available data (Chaboud, 1985, Chaboud et Kébé, 1990, CRODT, 1989, 1990) and led to a scenario where the whole system is composed of 3193 fishing teams, 1278 traders vehicles, 75479 customers, 1 factory (standing for the whole exportation fluxes), 14 markets, 9 ports, 13 fishing zones, 5 fishing gears, 6 vehicle types and 21 types of fish species. This scenario is too large to be practically utilized and the simulations are carried on with subsets of this configuration. In this study, the exploitation simulated refers to the North coast of Senegal with only gillnets and lines, two ports and 8 markets.

Once the objects constituting the exploitation are introduced in the model. The simulation proceeds step by step: At each time step the external sources of fluctuation are documented. This consist in making natural resource produce fish on one side of the system and providing consumers with money and consumption rate on the other side. Each active community is then allowed to produce an action. Depending on their environment, their preceding choices and results, fishermen and fish traders move to one or another type of site, port or market and try to fish, sell or buy.

From the computer standpoint, an interface has been elaborated where the exploitation evolves (Fig. 4). The main screen is a reproduction of the map of the studied area (the north coast of Senegal) where the objects are represented.

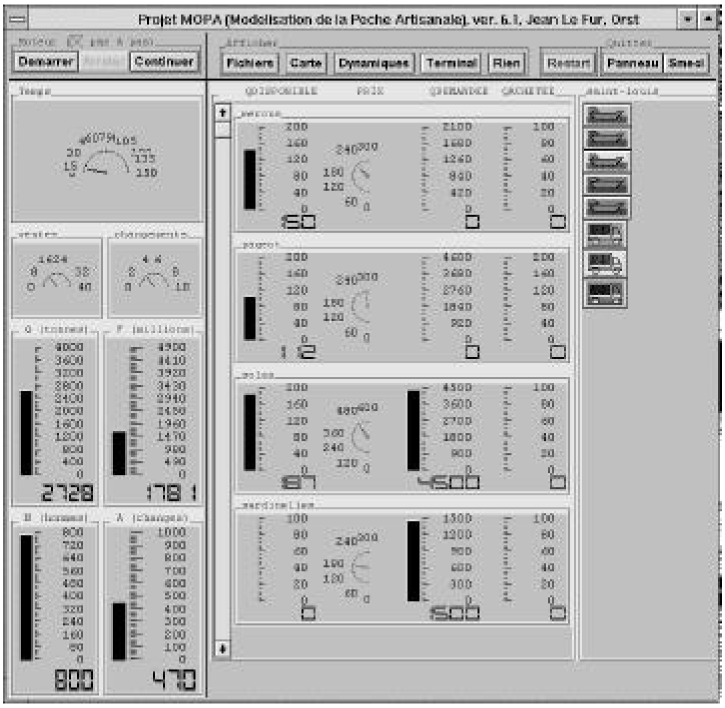
On the map, the active fish traders (trucks) and fishermen (canoes) are positioned on their current sites. Through time, their position changes depending on the action they chose. At the left of the screen, the four gauges trace the resulting fluctuations of the exploitation's fluxes:

Figure 4: Screen copy of the simulated exploitation general interface.



quantity of fish, richness of the exploitation, active population size and amount of work done. The two small chronometers visualize the number of succeeding transactions and the number of changes during the elapsed time step. Time is traced on the upper meter. By clicking on one or the other button on the map one can reach a more complete description of the object concerned. For example, a mouse click on a port (Figure 5) will present a screen with, for each species, the landings, the demand, the quantity bought by fish traders, the prices fluctuation and, on the right, the arrival and leaving of communities.

Figure 5: Screen copy of the objects interface. Example: the port of Saint-Louis.



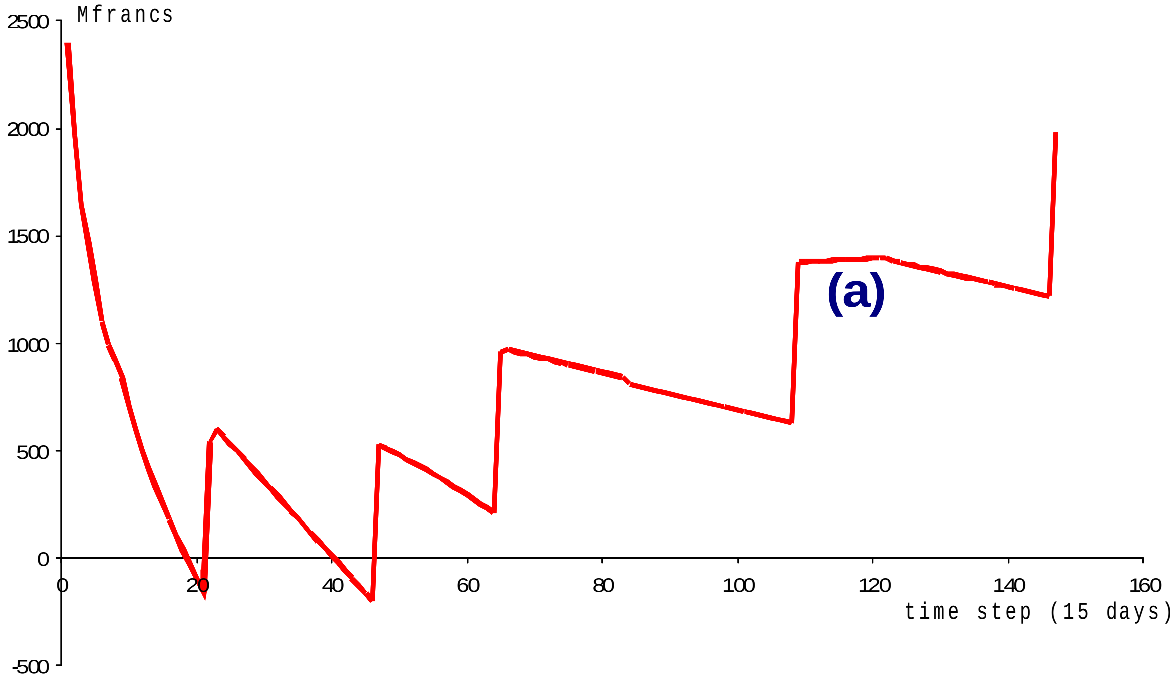
For each and every object, one may trace the time dynamics of the four fluxes (fish quantity, richness, population size and activity). On an other screen the various types of activity (moves, choices, transactions, selling's) or activities can be followed on a scrolling list (see example on Figure 7).

At the start of a simulation, each community agent is given 200 kFcfa/day for 15 days.

Simulation results

In the beginning of a simulation and depending on the initial scenario, the communities introduced in the "virtual exploitation" may not be fitted to the particular environment simulated. For example, a fisherman with bad information will not go where fish traders stand by, an other will look for unavailable species, a fish traders will go in far markets and will get high moving costs, etc. Depending on their action some community may thus loose money. If a community happens to loose more than 106 Francs/Ind. in the 15 preceding steps, it leaves the fishery. The dynamics on Figure 6 expresses the global richness of the simulated exploitation. It correspond to the sum of the net richness of each active (fisherman and fish trader) community present in the exploitation.

Figure 6: global net richness of the simulated exploitation (fishermen and fish traders).



The most indebted, i.e., unfitted, agents disappear first. At the start of the simulation, the total richness of the exploitation decreases, the whole exploitation looses money. Each time an misfit community disappears its debts also leave the system and the total richness reaches a step up. The richness then continues to decrease. From time to time, only the best fitted communities remains in the exploitation. As time goes by in the simulation, communities get more information from this new environment and build confidences in the available alternatives. The slope then gets less and less negative until it becomes positive (see phase a).

Negotiations and transactions between agents can be studied precisely: the listing on Figure 7 presents a snapshot of a fisherman community during this phase their activity.

Figure 7: An example of transactions. This listing is automatically produced by the computer. It reflects the actions proceeded by the agents. In this example, information has been filtered on the selling tasks. . . .

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* 5 pml-ky-2 leave kayar_sea and [transport:2kFcfa] arrive at kayar
Price given for rays    by pml-ky-2:           220.
Price given for pagrus  by pml-ky-2:           130.
                        by kayar-40:           43.
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                        after negotiation:      97.
               5 pml-ky-2 sell (each) 200kg/d. of pagrus to 3 kayar-40 and earn 20
                                                                      kFcfa/pers/d
Price given for pageot  by pml-ky-2:            177.
Price given for grouper by pml-ky-2:            488.
                        by kayar-75:            14.
                        after negotiation:      315.
                                             , kayar-75 refuses transaction.
                        by kayar-40:            399.
                        after negotiation:      444.
       5 pml-ky-2 sell (each) 41kg/d. of groupers to 3 kayar-40 and earn 18
                                                                 kFcfa/pers/d.
pml-ky-2 has no cuttlefish to sell.

* 5 pml-ky-3 leave kayar_sea and [transport:2kFcfa] arrive at kayar
 ...
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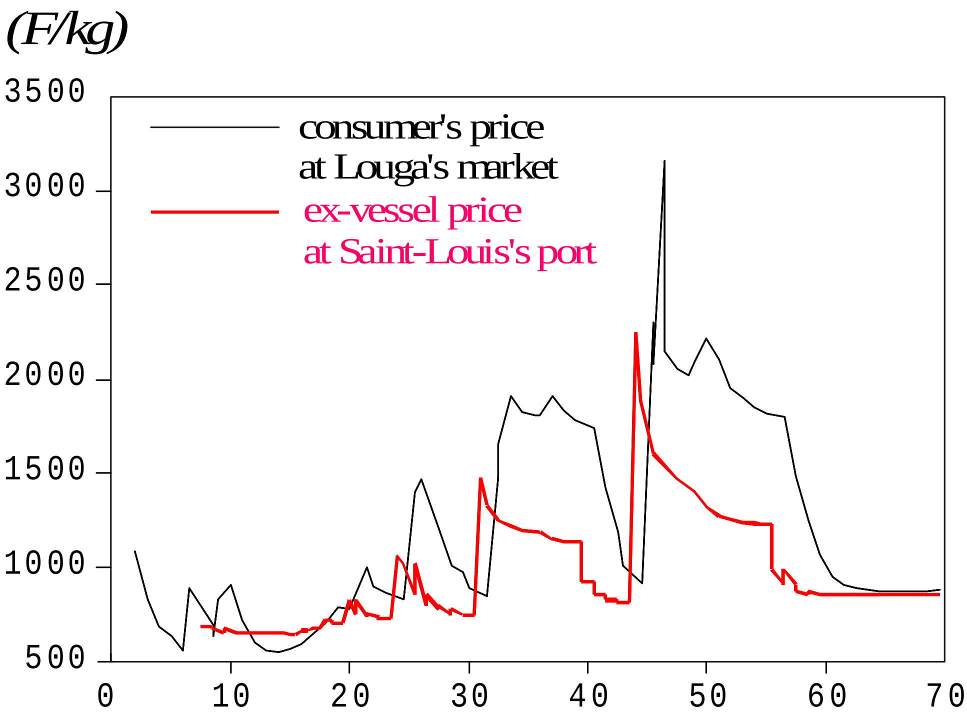
In this example, The fishermen community *pml-ky-2* come back to *kayar* after having fished in *kayar_sea*. It tries to sell its *rays* but no fish trader is interested by this species. Nothing thus happen. The fishermen community then tries to sell its *pagrus*. From its previous costs, the quantity owned and the port's price, it proposes a price (130.). The fish traders *kayar-40* are interested in buying and make an offer. After " bargaining " the price is negotiated to 97. and the two communities proceed to the transaction. For the *pageot* species, fishermen do not find any traders. For the groupers species, The *kayar-75* traders agent proposes a very low price (14.). The negotiated price remains too high and the trader refuses the exchange. The former trader's community *kayar-40* is also interested by the *groupers* species and here, the negotiation succeed. At the end of the negotiations, fish traders ask for *cuttlefish* species but the fishermen community did not target this species. Nevertheless, this may conduct the community to later choose a fishing place to catch this species. Thereafter an other fishermen community *pml-ky-3* arrive at *kayar* and the process goes on.

From time to time and depending on the moves of the various communities, the supply and demand fluctuate and, through negotiations, the species prices change. The example on Figure 8 presents the co-evolution of the groupers species prices dynamics resulting from a simulation in a port and its nearest market. Dependencies appear between the two places. The compared evolution lead greater prices in the market than in the port. Moreover, fluctuations in the port propagate with a delay in the market. A cyclic dynamic appear (t_{20}-t_{60}) with an amplification of the fluctuations followed by a decrease around t_{60}.

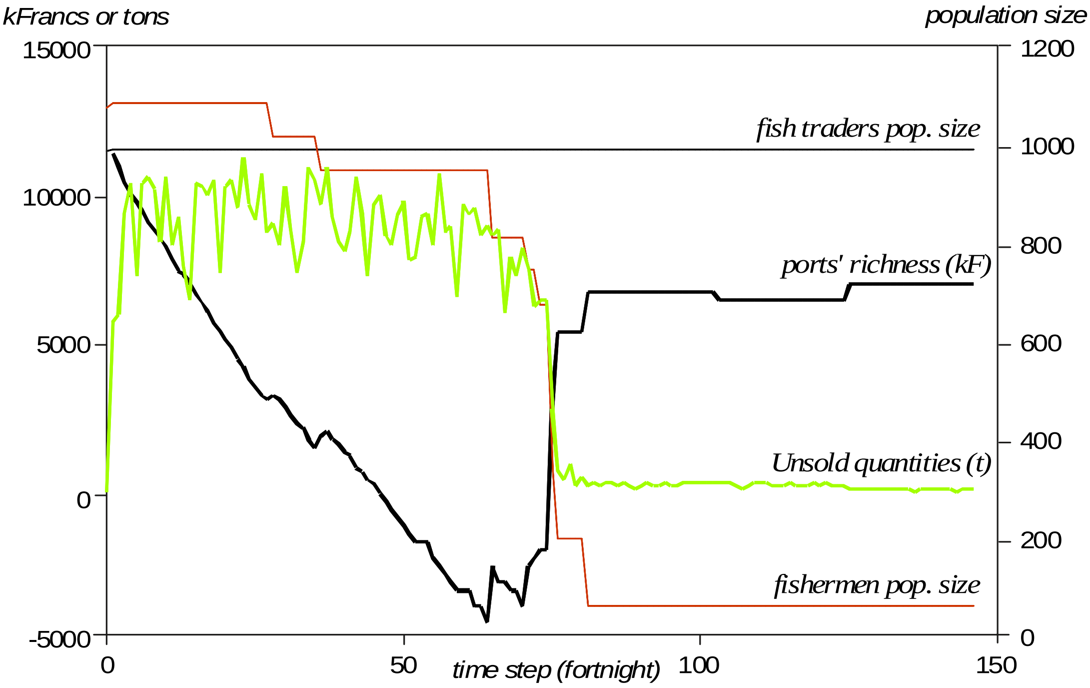
Figure 8: prices evolution of the groupers species in two related places (a port and a market). Results from a simulation.



Various fluxes may be followed in the simulation. The example on Figure 9 presents a possible evolution of the simulated fishery.

At the beginning of the simulation, fish landings are greater than the buying capacity of the fish traders. The unsold quantities are too high and fishermen loose money. The exploitation is globally indebted (*port's richness*). Through time, fishermen which are not able to support the loss leave the fishery (*fishermen population size*). The fish traders number remains stable. In the middle of the simulation, fisherman number reaches a low level until it is fitted to the trading capacity of the fish traders. Then the unsold quantities tend to zero, the exploitation richness becomes positive. The exploitation is then composed of numerous fish traders with small buying capacities and a few fishermen providing the exact demand. The four dynamics becomes stationary.

Figure 9: Auto-adaptation of the virtual exploitation (North coast and markets of Senegal with only gillnets, lines and seines).



Discussion - Conclusion

During a simulation, the communities' objectives change depending on the phase where they stand in the activity cycle (fishing, selling, moving, buying, consuming). From one objective to the other, from one type of community to the other and from one environment to the other, the decision processes lead to different choices. The resulting sum of the activities modify the contexts (i.e., environments) through time and, by feed-back, influence the various evaluations processed by the agents.

Model's validation first comes from the observed activity of the exploitation. Fishermen go fishing , fish traders arrive in the right market at the right time. Coherence is observed in the virtual exploitation behavior compared to what is known in the Senegalese small-scale fishery.

Some simulations pointed out the model's sensitivity to the agents' choice criterion, the order in which the agents act or the initial conditions of the simulations. These factors modify a lot the dynamics shapes. The interactions woven between the various types of agents make it difficult to separate the effect of one process from the others. Sensitivity analysis are thus difficult to conduct with this multi-agent model.

When using observed data for the scenarios, it is possible, through successive trials, to get reasonable values for the fluctuations (e.g., prices on Fig.8). By combining various types of information the model provides a practical mean to observe some behaviors of a simulated fishery (with respect to multiple criteria needed in fisheries management). Possible studies could then concern the condition within which the exploitation can be sustainable or what could be the various consequences of a given change.

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