Modeling Fishery Activity Facing Change: Application to the Senegalese Artisanal Exploitation System

JEAN LE FUR

ORSTOM
Laboratoire Halieutique et Ecosystèmes Aquatiques
BP 5045
34032 Montpellier cedex 1
FRANCE

ABSTRACT

A computer model is presented which formalizes the responses of the Senegalese artisanal fishery to changes in its environment. The problem of a fishery's response to change is first considered at a global system level. There, adaptive processes are defined as the major determinant of the fishery's response to change. The system's structure and function are then formalized at the most local possible level (that of communities) and related, through successive embedded schemes, to the global level. An artificial intelligence formalism is used to generate this progression. In a third part, some simulation results of the fishery model response to change are discussed in support of the adequacy of this approach.

RÉSUMÉ

Un modèle informatique est décrit qui représente les réactions d'une exploitation halieutique artisanale à des changements de son environnement. Le problème du changement

1.2. Local constraints to representation

1.2.1- Human activity

If the fishery exploitation system as a whole can present adaptive characteristics, it is mainly due to the human actors within this system. Indeed, through the past half century, most of the major changes observed in the Senegalese system have been 'processed' by human communities (see the examples above). It therefore appears necessary to take into account the various modalities of actions and reactions of the actors. This however, is best done at the local level.

1.2.2- Monitoring

In the case of resource exploitation, after a change whatever becomes of a fishery exploitation, its basic functionality remains such as providing seafood, a positive currency balance, employment, etc. (Fonteneau and Champagnat, 1977; Chauveau, 1984; Chaboud and Kébé, 1989). The means society at large has to impact the system dynamics may belong to the macro scale (e.g., the recent currency devaluation in Senegal; Kébé and Dème, 1994). These means are often local such as fishing quotas, defining fishing zones, etc.

To take these local aspects into account, the adaptive properties of an exploitation system must be understood as a result of the interactions of lower-level elements of this system. This 'neo-systemic' approach of dynamics is presently developed in several different fields such as physiology (Bagley and Farmer, 1991), ethology (Drogoul and Ferber, 1993), sociology (Nowak and Latané, 1992), or fisheries sciences (Bousquet *et al.*, 1992).

1.3. Choosing a 'granularity'

Several levels can be selected for describing a system's behavior, ranging from the global, systemic view to the most local mechanisms (i.e., individual behavior). It thus appears necessary to select the level or 'granularity' that is best adapted to the objectives at hand.

The individual level appears computationally difficult, since it implies too many little-known processes to consider. On the other hand, if a more global level is chosen (e.g., trading, fishing, consuming), important lower-scale mechanisms will be missed. Moreover, it will prevent the study of the means that can be used to bear on global dynamics.

The granularity retained here is the community level, which is intermediate between the two above extremes. A community is here defined as a set of human actors whose individual behavior can be considered equivalent. For example, every trader in a given landing site can be assumed to sell fishes at the same market places, while fishers owning the same type of gear will be considered to display the same behavior when faced to a change in their environment. In this sense, they belong to the same community.

2. THE COMPUTER MODEL

The growing power of computer simulations leads to increasing investigations of complex systems in the modeling field. It now appears that most of the major concepts to be manipulated in this field (e.g., interaction, diversity, organization, memory, evolution, catastrophe, emergence) can be depicted fairly well. Scientists working on artificial intelligence have provided new, powerful formalisms to represent these concepts. From this new panel of techniques, distributed artificial intelligence (DAI) and multi-agents' formalism are being used more and more for complex systems and artificial life modeling and simulation. This technique is based on communication between objects and their environment (Ferber, 1994; Erceau, 1994). It has also been here retained for it allows the fine granularity that suits our purpose.

Using DAI, a model was structured through different embedded levels. This chapter describes the different levels modeled, from the most local (components) to the most global (exploitation system). Here, the first steps of the modeling effort is to represent how the different components of the fishery system are organized and how they get information from their environment.

2.1. Structure representation

Structurally, the fishery exploitation system is formalized as a few set of meaningful components (i.e., communities, stocks, markets, fishing zones, etc.). In the model these components are translated in a class hierarchy. For the Senegalese exploitation system, the model class hierarchy is presented in Figure 2, which identifies the limits within which the investigated system is defined.

A given class is defined by a set of fields and may contain several different objects or agents. For example, the agent described in Figure 3 belongs to the 'fisher-active-community' class. It is defined by several fields whose value characterize it. These fields are for example its size (number of fishers belonging to this community), the equipment it owns (fishing gears, canoe), the species it can harvest, the sites where it can go (landing sites, fishing zones), or the fishing tactics[1] it may use. The set of fields is given by the class, the field proper values define each particular instance (e.g., particular fishing community). The field values can change depending on context.

Other type of agents are related to this community agent. The Kayarland current site for instance refers to another agent belonging to the 'landing site' class. It is characterized by the different communities that are currently acting in it, the species that are exchanged or eaten in this site, and the last price at which these species have been sold (to the customers) or bought (by the fish traders).

By defining several agents in each of the various classes, one may obtain a global representation of the exploitation system thus modeled.

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[1] *A tactic corresponds to the practice of a given fishing gear in a given fishing zone, used for targeting given fish species. This notion has been extended and also corresponds to a particular landing site.*

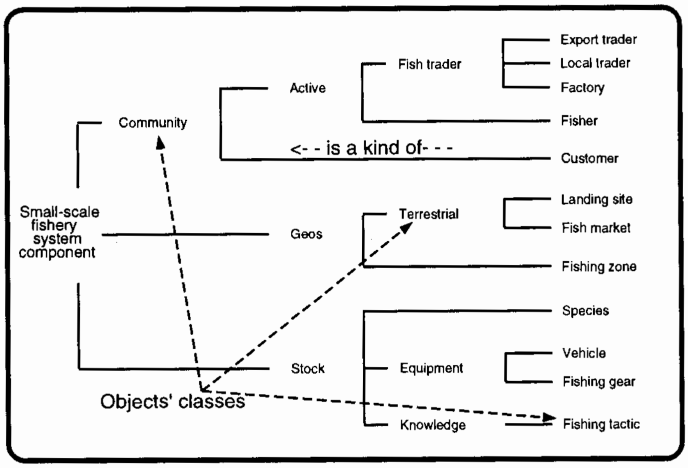

Fig. 2: Structural limits defined for the Senegalese artisanal fishery exploitation system (multi-agent class hierarchy).

2.2. The communication step

The only actions a computer agent can perform are sending messages to other agents, receiving messages from other agents and providing 'back-answers' by means of new messages[2]. The arrows on Figure 3 present an example of the relations constructed is this fashion. In this example, the *st-ky-2* fishing community needs to know the traders' demand for its species of jacks (Carangidae) in its current landing site. *st-ky-2* sends to the landing site Kayarland the message: "what is the trader's demand for jacks?" (messages 2+2'). The 'landing sites' specific behavior to this message is to send itself a message to know which traders are currently acting in it *(3,4)*. The 'site' agent then sends the same message to all of these known fish trading communities *(5,5',5'')*. Each trading community receiving this message is then able to answer it after an internal evaluation (step 6 stands for another combination of messages taking into account information about vehicles' maximum capacity, room available in vehicles, the market as demand for fish, the species preferred, the money available). The landing site then processes all the traders' answers and returns the answer back to the fishing community *(7,8,9)*.

This process can be perceived as communication between agents (e.g., community *st-ky-2*) and their environment (e.g., landing site, known traders)[3]. In the sense of the model presented here, this corresponds to communities gathering information from their environment.

Almost all the functional representations of the fishery exploitation system are governed by this message-sending formalism: by successive nesting, sets of messages such as those just described can be gathered for more global tasks (e.g., 'knowing the traders' demand') which can in turn become part of an upper-level behavior (e.g., 'comparing different traders' demand at different, known landing sites'). Thus, sophisticated tasks and global behaviors can be represented.

[2] *The messages are small computer routines;*

[3] *The filtering protocol enables the representation of uncomplete information. For example, in this case community C is not allowed to know about traders which are not at their usual landing place.*

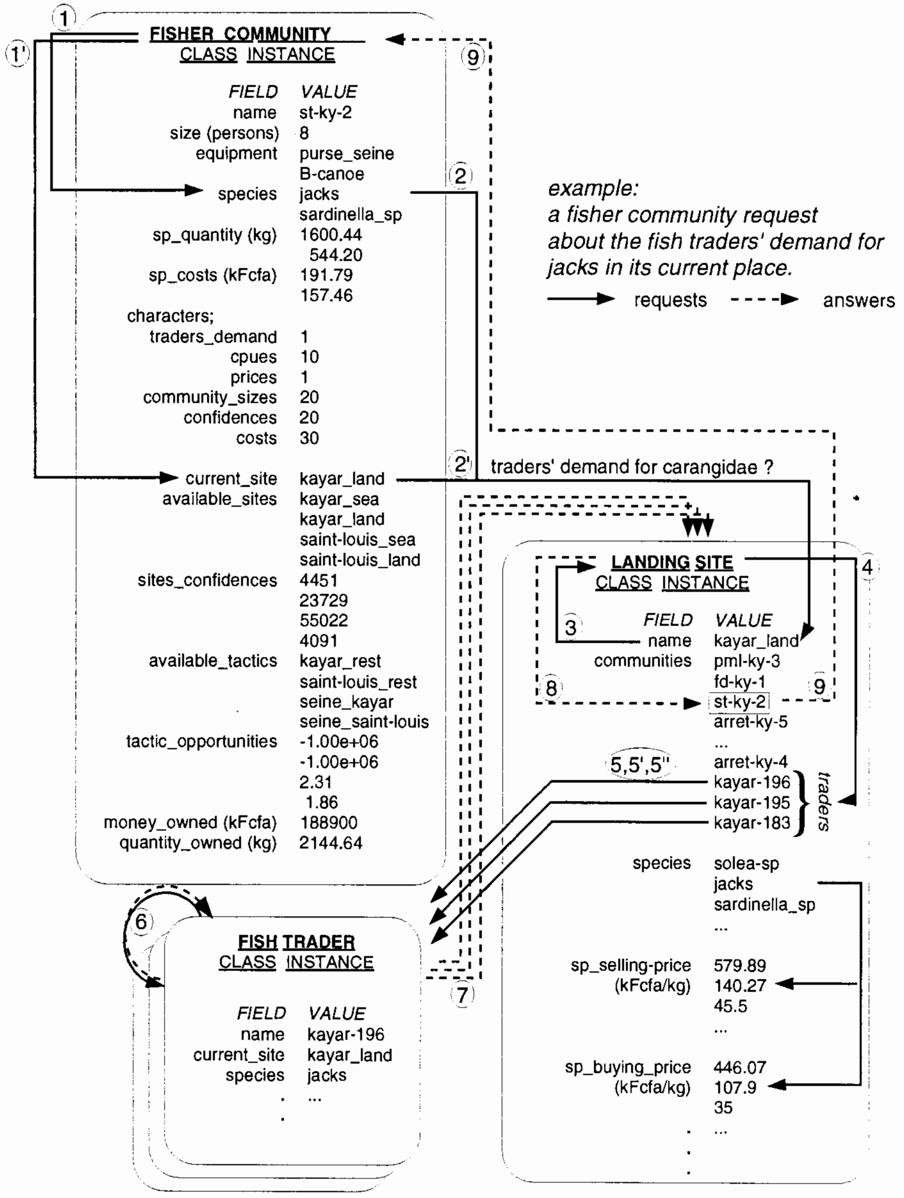

Fig. 3: Structure and communication between (computer) agents in the Senegalese artisanal exploitation system.

2.3. The decision step

When communities gather information of different kinds about their environment, they must decide what to do with this information (this need for choice is probably more acute when change occurs in the communities' environment). Under this hypothesis, decision processes must be paid particular attention.

Using previous works on communities' behaviors, common sense rules and *in situ* interviews, several criteria have been selected that may be involved in the communities decision processes. The conceptual scheme retained and represented undertakes three classes of criteria: the objectives to reach (e.g., fishing, earning money) at the time of the decision process, the information gathered from the environment, and the communities' character and habits.

Using the representation described in the communication step, local tasks can be represented. The example in Figure 4 represents the decision process of a fishing community agent. In this example, the community already sold its fish, needs to go back to fishing (objective) and must decide which kind of fishing tactic it will use (from the different behaviors it can exhibit).

The process follows the circular path. The community objective is assumed to be already defined (here: 'going fishing') and not represented here. The process begins with an 'information step' divided in three main parts: the community first considers what equipment it owns related to its objective, in this case, a canoe, gillnets and lines (a,b). The community can then obtain information from the corresponding fishing tactics (here, gillnet fishing tactic or line fishing tactic 's agents). Thus, it gets connected to a new information flux constructed by the particular tactics[4]. In this case the community may know about the species potentially targeted , their fishing yields, their prices at the different landing sites (c,d,e). Also, these communities are related to other contexts such as fish traders' demand for the species they can target or the moves needed to practice a given tactic. Each time they practice the tactic, the fishing communities' own confidence for this tactic will change: when, at preceding time steps, fishers 'succeed' or 'fail' in practicing a given tactic, they gain or lose confidence in their action. This implementation, partly based on confidence theory (Le Cardinal and Guyonnet, 1994), provides an evaluation criterion for the corresponding decision processes: the communities become experienced and take into account this experience during the decision processes.

Each of the evaluation criterion can be given a priority depending on the 'social characters' of the community. For example, depending on the fishery investigated, a community can be more influenced by the cost implied by its choice than by the benefit it can gain from it. In this example, the 'moving costs' choice criterion will be given more weight than the selling price of species or fishing yields. The character field described in Figure 3 accounts for this balance between each evaluation criterion. The weight given to each criterion (e.g., *confidence* 0.20) will lead each community to different choices when faced to a given situation. By combining these weights, it is possible to represent different types of communities (e.g., communities of young men preferring yields and prices or of old men to whom confidence or community size may be more important). This quantitative transcription can be used to input qualitative or fuzzy knowledge about the system's actors. An example is provided for the community size's criterion in the simulation results (first simulation, t_{26}).

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[4] *In the computer model, fishing tactic are agents in the strictly same way the communities are. They are able to send and receive message depending on the value of their differents defining fields. They can therefore communicate with other types of agents.*

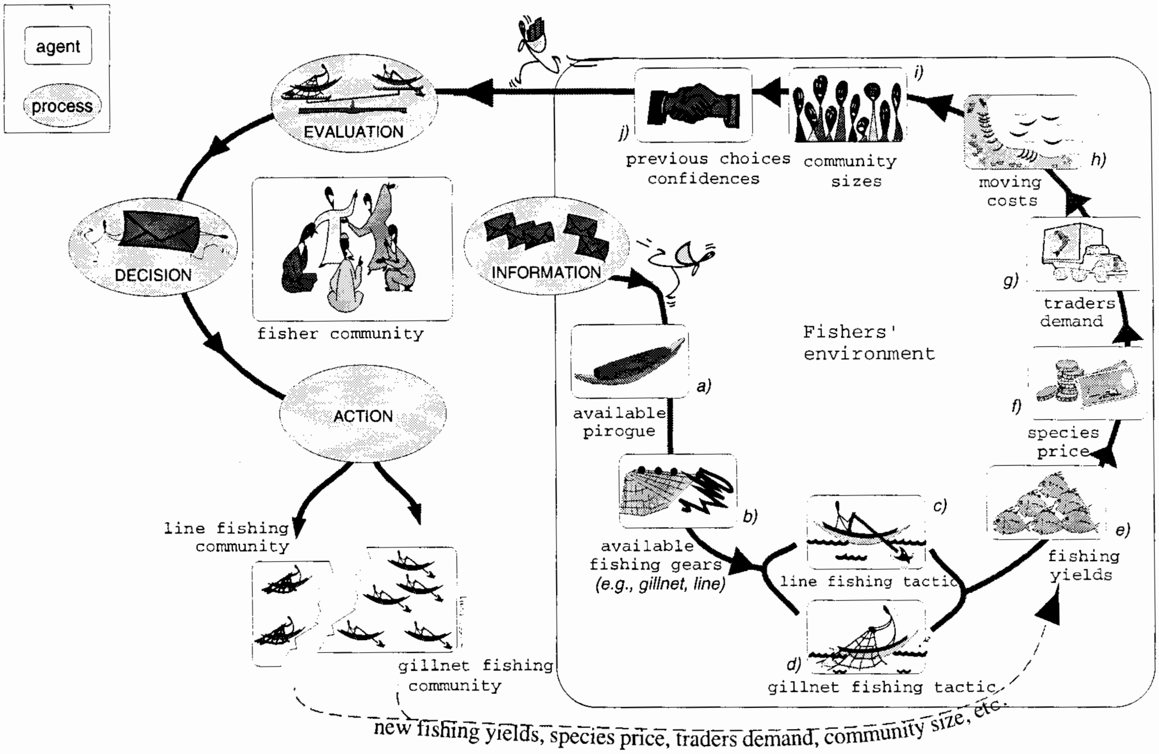

Fig. 4: Schematic representation of a community agent decision process.

In the following step (*evaluation*), the communities weigh each of these information, depending on their experience and character and produce a decision. This decision leads one part of the fisher community to choose line fishing and the other one gillnet fishing (given *VL* the expected value of line fishing and *VG* the expected value of gillnet fishing, the community percentage choosing gillnet will be $VG/VL+VG$). The resulting action leads to dividing the community agent into two community agents, one practicing gillnet fishing, the other one going on with line fishing. This partition induces changes in the fishery system. For instance, the distribution of fishing effort will be different from before; it will lead to new fishing yields, new species prices, new traders demand, new community sizes, different confidences for each of the new communities and, therefore, changes in all further evaluations and decisions (i.e., the next simulation's time step).

Since 'good' or 'bad' choices may govern adaptation to change, this decision-process level constitutes an important step to represent whole system's dynamics. Observed dynamics of Senegalese artisanal fisheries were thus simulated using a simplified version of this model (Le Fur, 1995). Good agreement was obtained between *in situ* observations and model simulation. It was concluded that this decision process model would be reliable in simple cases.

2.4. The activity step

Apart from choosing, fishers also move, practice fishing, sell or give their catches. Through change, performance and results of these activities can also determine communities' dynamics. A decision process sub-model was completed to account for these processes. These tasks have been implemented and organized through an 'activity cycle' in which the decision process model is included.

The resulting activity cycle of this third modeling step is presented on Fig. 5 for the case of the fisher communities. The whole cycle accounts for one time step. It arbitrarily begins when the fishers at a landing site decide what would be the best fishing behavior. The decision process first occurs (the DP symbol locates the decision process model that was previously described). Once the fishers have chosen what fishing tactic they want to practice, they split into two communities and with one sailing towards the selected fishing site. This task performs the removing unsold fishes, spending money for the journey depending on the available equipment, informing related agents concerned by this move (e.g., traders at the landing site left, arrival in the fishing zone). When fishers arrive at a fishing zone, they actually fish[5] and, depending on their success, change their confidence for the particular fishing zone and tactic choice selected. The

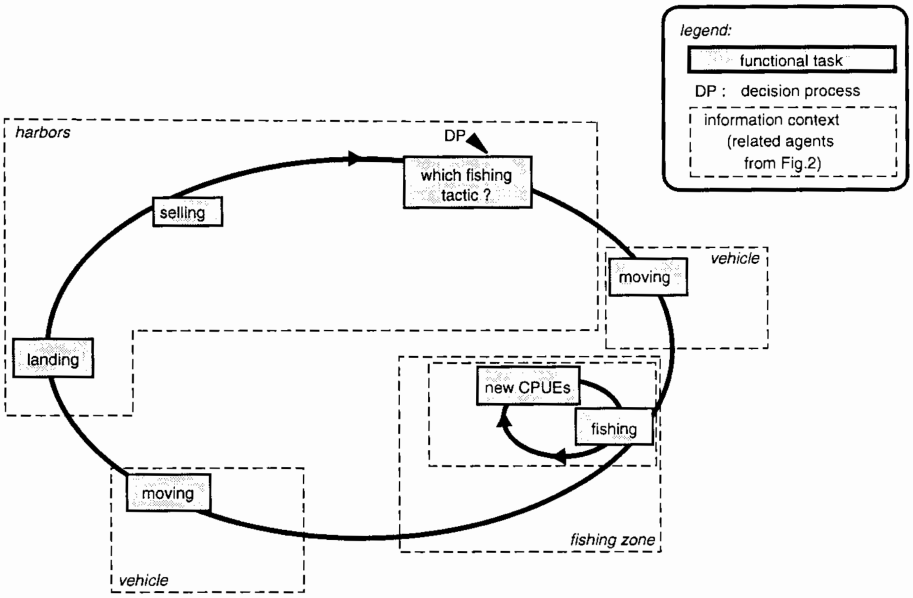

Fig. 5: Fishermen communities' activity cycle.

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[5] *In this step, fishing yields can be generated through various means such as observed data files or multispecies and multi-gears production model (Laloë and Samba, 1991). Response curves can also be introduced to simulate any event affecting fish stocks (e.g., stationery yields, catastrophe-like decrease/increase, sudden appearance of new species, etc.). The DAI formalism can be also used to make this task dependent on the gear the fishers own and choose, the species availability in this fishing zone and the number of fishers from other communities currently acting in this fishing zone.*

next task makes them go back to the landing site (given by the chosen tactic, see decision process step). Selling occurs, money and fishes are exchanged, new confidences and new information are gained. The results of this activity will lead to new choices in the next time step.

In Senegal, fish-traders play as an important role as fishermen in the artisanal exploitation system's dynamic (Chaboud and Kébé, 1989). A second cycle accounts for fish-traders' choices and activity. It has been formalized in the same way as the fishers' (Fig. 6). The traders' cycle starts when the fish traders have sold their fishes in a given market place. They then have to choose a harbor where they will supply for new fishes. Another task makes them move towards a given landing place. There, money and fishes are being exchanged.

To account globally of the exploitation system's dynamics, these two cycles have been connected and organized in an upper level 'interaction step'.

2.5. The interaction step

Exchanges of fish and money are the main links between traders and fishers, and thus, transactions play an important role in the dynamics of the system. In Senegal fish prices may change fourfold during the same day (Chaboud and Kébé, 1989). Moreover in Senegal, bargaining is an important social phenomenon; almost a social duty. Price setting was formalized to account for this through a 'bargaining' sub-model which represents selling as private contracts between different communities. At the beginning of the 'transaction task' (Fig. 6), each selling community gets information from its surroundings (i.e., send messages). It 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.

In particular game theory applications (i.e., in cases where information is incomplete), the Bayes equilibrium states that, in an auction, the best choice for an actor is to propose a third of its maximum price (Guerrien, 1993). As bargaining may appear functionally close to auctions, we adapted this hypothesis for the selling transaction: sellers propose three times their lowest price, buyers propose a third of their maximum buying price. The final price of the transactions will be values between the sellers' lowest price and the buyers' 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 rule of thumb (Charreton and Bourdaire, 1985) establishes the possible mean of this distribution (i.e., final price) as:

$$\frac{\begin{array}{c}\text{maximum of the distribution } (\textit{i.e., fishers' price proposal}) \\ +\text{ minimum of the distribution } (\textit{i.e., traders' price proposal}) \\ +\text{ mode } (\textit{i.e., final price in this port for the last transaction concerning this species})\end{array}}{3}$$

In a given time step, the evolution of the traders' arrival in the port and their successive transactions cause the harbor's fish prices to evolve. These fluctuations will again intervene in the agents' choices.

Once the fish traders have bought their fishes, they proceed to another decision process, choose a selling market place and move towards it. To obtain an equilibrated presentation of the interaction's cycle and a controlled input/output for the fish and money fluxes, two more simple cycles have been provided. The first accounts for the local consumers in the country — fish is the major source of protein in Senegal (Chaboud and Kébé, 1989). The other cycle accounts for the

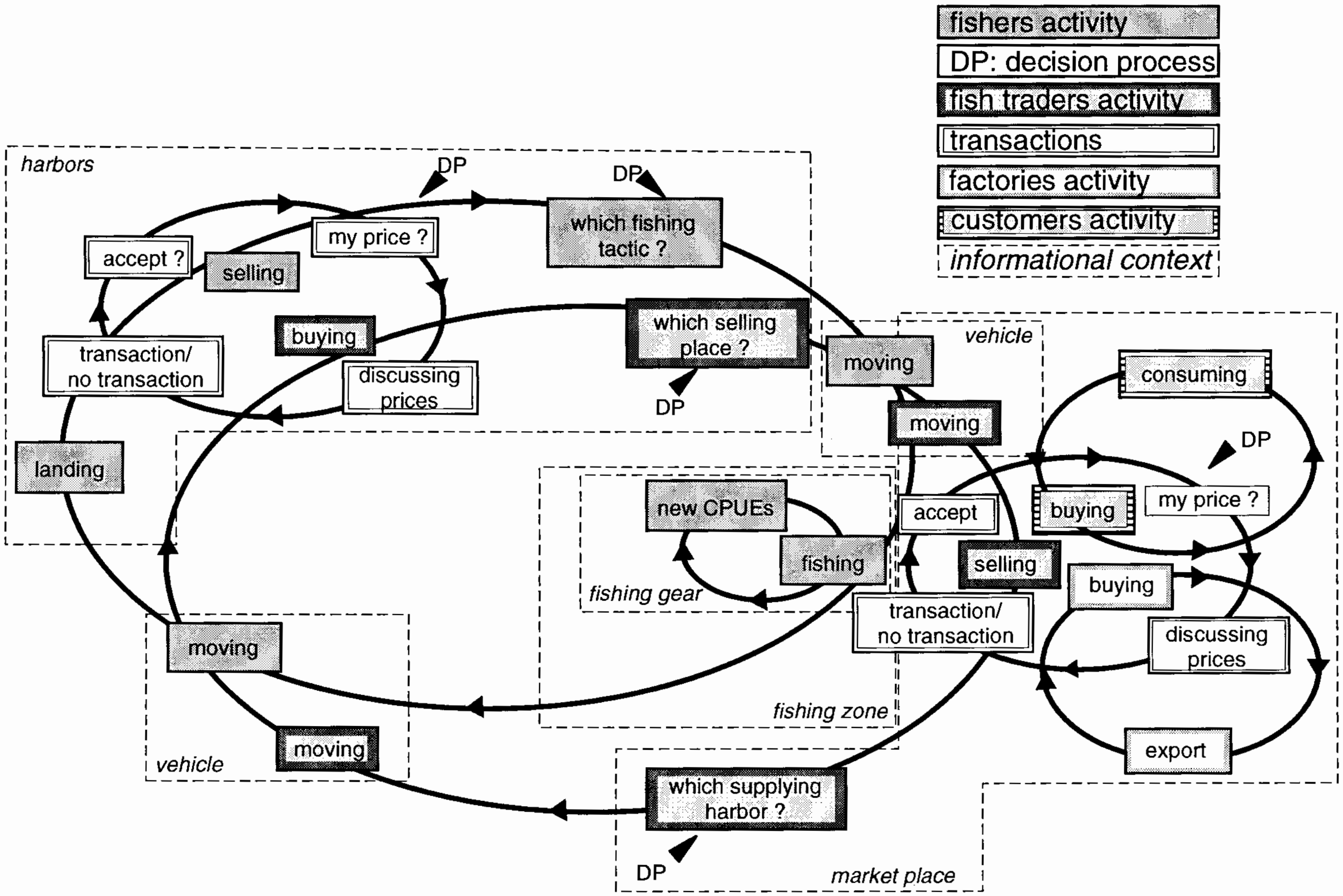

Fig. 6: Dynamics of the fishery system interaction model.

plants involved in fish exports — exports represent 40% of the Senegalese artisanal fishery production (Dème, 1988). Bargaining was duplicated to account for interactions between consumption requirements and supply fluctuations and was modeled as part of the fish traders' activity cycle. This bargaining generates the market prices. This also allows to take into account the fish market as another factor of change in the exploitation system.

At the end of this step, the exploitation model is a reliable functional system of interconnected levels. The external sources of fluctuations can be generated by the dynamics of the resource, by changes in national consumption, by international market prices, or by equipment and fuel costs. From the dynamics point of view, during a simulation, the communities' objectives will change depending on the phase where they stand in the activity cycle (fishing, selling, moving, buying, consuming). Then, from one objective to the other, from one type of community to another and from one environment to the other, the decision process will lead to different (adaptative?) choices. The resulting activities will modify the contexts through time and, by feed-back, influence the various evaluations processed by the human communities.

3. SIMULATION RESULTS

Using this model, we attempted to simulate the observed Senegalese fishery exploitation. For this purpose, available observed data were selected and formatted. Several quantitative data sets were used: artisanal fleet monitoring data, by fishing gears and fishing places (CRODT, 1990), fishery yields for several species and types of engine, monitored daily at the various landing sites in Senegal (Ferraris *et al.*, 1993; Laloë, 1992), species composition for each fishing tactic (Laloë and Samba, 1990; Ferraris and Samba, 1992; Périnel, 1992), markets and fish traders characteristics and distributions of traded species (Chaboud et Kébé, 1990), geographical information on the different sites, technical information such as vehicle costs, capacities and abilities (Chaboud, 1985), fish consumption rates in the different cities of Senegal (Chaboud and Kébé, 1990) etc. Most of the data selected for the simulations refer to 1986-1987, where the largest set of markets and consumption data was available. The communities simulated are distributed through the different fishing and trading communities, markets and harbor places, tactics and habits. In the initial conditions of the experiment (t_0), the whole system communities represent 3 193 fishing teams, 1 278 traders, 75 479 customers, 1 factory (standing for all exportation fluxes). 14 market places, 9 landing-sites, 13 fishing zones, 5 fishing gears and 6 vehicle types; 21 types of fish species and 43 fishing tactics are also described. Each community agent is given 200 000 FCFA/day (1 US \$ ≅ 280 FCFA in 1986/87) for the first step of the simulation and allowed to act for several time steps. Fishing yields are tactic-specific and remain constant throughout the simulations.

Global activity indicator: The initial issue is defined as the fishery's response to change. For feed-back at this level, we developed an indicator of global system's response: in the multi-agent simulation model, each time a message is sent or received by an agent, information can be obtained from the computer (in one simulation time step, million messages are sent). Depending on the aspects of the system, that are studied (e.g., productivity, strategies, distributions), printed messages can be filtered to keep only the ones corresponding to the investigated fields (e.g., moving, selling, fishing, choosing, bargaining). Depending on the intensity of the activity, the amount of messages at a given time step will fluctuate. The procedure thus saves, at each time step, all printed messages onto the hard disk. Depending on communication intensity, these messages' files can contain from several hundreds to several hundreds of thousands lines. The evolution of the file sizes was traced from the beginning to the end of the simulations as an indicator of the 'system's activity' (when no messages are produced, that the system is 'inactive' or 'dead').

Some results obtained from these simulations are described below[6].

In the first simulation, only the fishers' activity cycle (Fig. 5) is considered. The total number of fishers in the system is kept constant throughout the simulation as are the selling prices at the different harbors. Moreover, fishers' communities are allowed to sell their entire catch every time they proceed to the selling task.

The curve on Figure 7 provides the evolution of the system's activity indicator for these simulation. System's activity quickly expands at the start of the experiment, producing diversity in the communities[7]. Activity then decreases through time. The system was allowed to run for 60 time steps (one step equals 15 days in this example). During the simulation, three kinds of change have been introduced; a 'biological' change at t_{11}, a 'behavioral change' at t_{16} and a 'technical change' at t_{45}. The resulting reactions of the system were studied.

A) For perturbation introduced at time t_{11}, the catches of sardinella species was lowered by a factor of 10 (from 300 kg per trip for a purse seine to 30 kg/trip). This resulted to no reaction of the whole system (Fig. 7, point A). In the simulated fishery, sardinella is mainly caught by purse seine; analysis of the simulation results (not shown) revealed that at that time, a purse seine tactic would have survived this change, by switching to jacks (carangidae) (in the model, purse seine fishing tactic allows fishers' communities to target both sardinella and jacks species; this type of behavior is observed in the artisanal Senegalese purse seine fisheries (CRODT, 1989)).

As the ports' prices were maintained constant throughout the simulation, the price of jack could have remained sufficiently high to maintain interest in seine fishing.

B) The second change consisted in giving more weight to the 'community-size' criterion. During the decision processes, this criterion provides a mean for fishers to take into account the size of the other communities as a confidence indicator for the practice of their tactic (see 'decision step', Fig. 4): the more people practice a given tactic, the safest it will be to choose it, and vice versa. Previous studies, for instance, in economics (Lesourne, 1990) and in fisheries (Allen and McGlade, 1986) have pointed out the role of risk-aversion in dynamics where both 'followers' and 'risk takers' coexist. The change introduced here consisted in accentuating this character, e.g., more old fishers in the fishery, or more uncertainty in the input dynamics.

When this change was introduced (t_{26}, point B), the systems' activity dropped, while the number of agents remained constant. The modeled system lost activity because of this change. Nevertheless, it did not collapse, but reached a new, and lower stationary state. After the period of change, the system remained at this low level, but with a slightly descending slope.

C) To investigate the absence of the systems' reaction to the change in sardinella purse seine fishing yields at t_{11}, a final perturbation was induced at t_{42}. This consisted of allowing purse seine fishers to practice line fishing (i.e., 'providing suitable canoes for practicing both types of fishing'). The effect of this change on the whole system results in an 'electric potential' type response (Figure 7, point C). The fishers activity suddenly dropped a new, higher level (it 'benefited' from the change). The system's activity thereafter went on with a slightly decreasing slope.

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[6] *At the time of this paper's writing, the results were work in progress: from the technical point of view the coherence of the system was entirely validated and some of the basic sub-tasks not represented in satisfactory fashion (e.g., the task for evaluating the costs involved by the community activities only takes moving costs into account).*

[7] *At the start of the experiment, some choices are forbidden until the community agents gather all available information. After the agents get more information, their range of choices enlarges. As these choices are considered, these very new possibilities create new communities, which increase the systems' activity.*

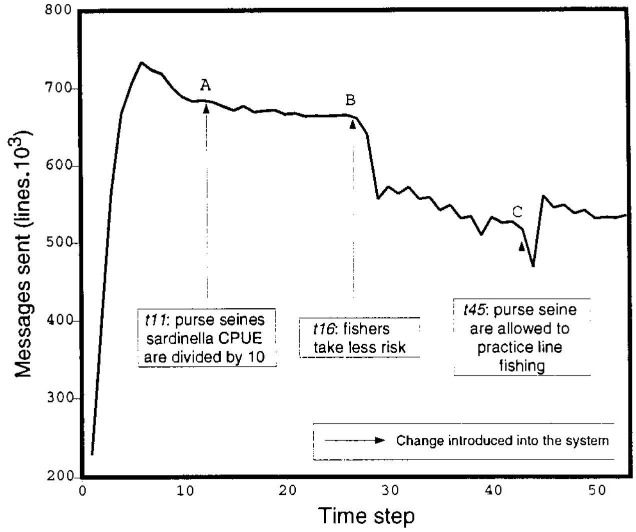

Fig. 7: Change of the 'system's activity' indicator during the first simulation (see text).

In a second simulation, the extended exploitation system described in Figure 6 was investigated in some details. The model was allowed to simulate traders' activity cycle, bargaining and transaction processes and the dynamics of other, related agents (markets, factories, customers, vehicles). This simulation was first run during 50 time steps, with the total number of individuals in the system kept constant. However, economically unadapted communities were rejected: when, through successive activity cycles, a given community comes to the point where it is in debt by more than 1500 kFcfa/person, it is ruled out of the system (the agent is removed). During the simulation, two changes were introduced in the system.

* at t_{11}, a sudden increase in the 'fish demand' was simulated. This was realized at the local level (communication step) by multiplying the size of each consuming community agent in the different market places by ten;
* at t17, the past experience of the fishery was removed (i.e., the confidence fields described in the communication step of all communities have been set to zero);
* Finally, a test simulation was run with the same initial conditions, but with no change introduced in the system.

The results, in Figure 8, present two evolutions of 'system's activity'. The first curve accounts for the simulation with changes introduced in the system and the other one without change (control). As in the first experiment, the system's activity first explodes when the fishery model becomes 'accustomed' to its new environment. The activity then starts to decrease.

Unexpectedly, the first perturbation at t_{11} has no effect on the system. Two selected generic variables were plotted on Figure 9: the total size of agents (whole community size) in each active type (fish-traders and fishers) and the amount of money earned by each agent from the start of the experiment (money/agent). It appears from the figure that multiplying fishing consumption (first change) provided more possibilities for traders to sell their fishes. This resulted in an increase of traders' incomes but no change on the fishers' earnings. Nevertheless, the systems' activity did not benefit from this change and went on decreasing (the reference curve on Figure 8 presents another possible scenario for the system's evolution).

The second perturbation, at t_{17}, relates to the loss of the experiences by the agents. System's activity drastically declines but the system does not collapse. The activity goes on in another slowly decreasing dynamics. The community size's slopes did not change nor did the money earnings.

The simulation was run, finally through 400 steps with no more change introduced. The results are presented on Figure 10. Some of the variables clearly fluctuate when others remain similar. Moreover, in several parts of the simulation, the monetary benefit of one of the two types of community (fishers, traders) occurs to the prejudice of the others (see arrows 'inverted evolution'). Finally, for the whole range of the simulation, activity constantly declines. However, the system does not collapse but becomes a very small, undiversified system (48 fishers only practicing in 3 harbors, 189 fish traders with small vehicles selling in 2 markets). At the same time, the agents' personal benefit increases. It can be here noticed that this configuration of a small fishery exploitation is similar to that described earlier by McGlade and Allen (1984).

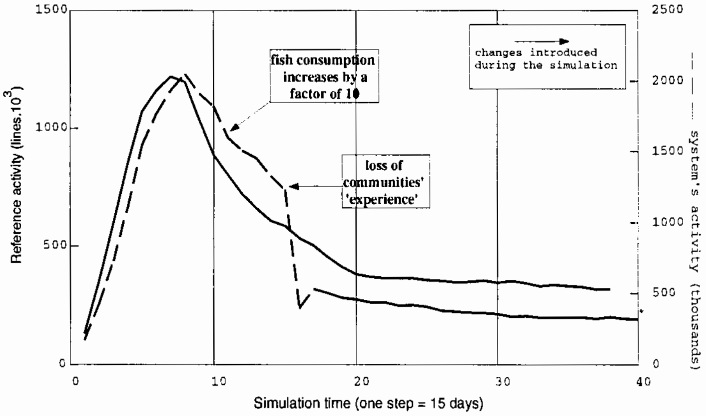

Fig. 8: Activity observed during extended system's simulation (with and without changes).

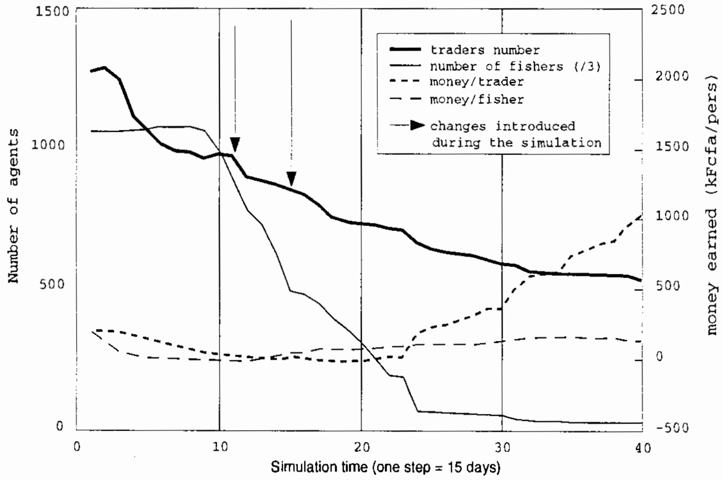

Fig. 9: Sizes and earnings of communities during the extended system's simulation.

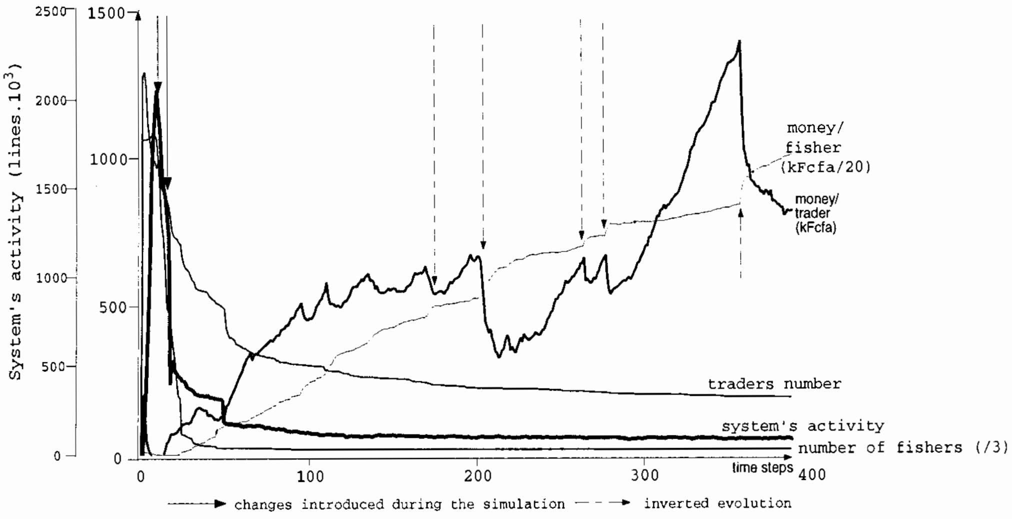

Fig. 10: Long term simulation of the extended system (extension of Figures 8 and 9).

4. DISCUSSION

Some parts of our modeling approach are discussed, notably: the modeling tools and limits of the hypotheses, the results of the simulations and the possible use of the approach.

4.1. Modeling tool and hypotheses limits

The choice of a thin 'granularity' implies that a large set of information must be introduced at the beginning of the simulations. The model structure then generates a huge amount of intermediate and final results, which makes such a system hard to validate.

The 'systems activity' indicator closely depends on the filter chosen for the messages. In this case, the indicator was mostly composed of choices, and bargaining messages (offer a price, refuse, etc.). It was therefore closely dependent on the number of communities (i.e., behavior diversity). More objective methods (e.g., statistics) should make this indicator more robust.

The communication step may not be viewed as occurring at the same conceptual level as the other steps of decision, action, interaction, etc. Indeed, message sending between agents are computer processes that intervene at each level or cycles where reality is simulated (Treuil, pers. comm.). Information therefore appears to create the ability of the exploitation system to adapt, but this may be a bias of the multi-agent formalism that was used.

4.2. Results

At a global level, a given change can produce unexpected effects as well as expected effects or no effect at all. In the first simulation example, the increase of communities' aversion to risk produced a large modification of the systems' dynamics, whereas a drastic lowering of sardinella fishing yields did not. Sensitivity analysis seems necessary, therefore, to better understand the results.

In the second simulation, an increase of fish consumption led to an increase of traders' earnings, but this monetary effect did not propagate all the way towards the fishers. A similar example was recently encountered in the Senegalese exploitation system: just after the currency devaluation at the beginning of 1994, artisanal fish exports increased. The fish traders interviewed in Kayar felt satisfied with the new situation whereas the fishers were negatively affected by the change. It appeared that the fishers went on selling their fishes at the same price, while fish traders were selling theirs at the new international price (without telling the fishers). The problem was finally partly solved by the fishers 'syndicate' which ruled on the prices (Le Fur, pers. obs.).

In each of the reported simulations the systems' activity slope is always descending. It therefore looks as if the system tends to collapse (other simulations not shown here confirm this result). From the processes represented in the model, it appeared that the agents' possibilities are too restricted to fully explore their environment. Indeed, if a fisher community can get information about two possible tactics, if a drastic change occurs in the environment that greatly affect both of the tactics, the community will not have the mean to adapt[8]. This case occurred for the purse seine in the first simulation: when the sardinella catches were lowered at t_{11}, no change occurred since the communities went on fishing for jacks. When these purse seine fishing communities were allowed to practice another fishing tactic (line fishing at t_{42}), most of them changed to the new tactic, as if they were unsatisfied with their current earnings (poor catches of sardinella). It will be noticed that this also resulted in a higher level of activity in the system (and thus, to better adaptation of the system).

4.3. Extension of the model

The communities fish, sell, move, they become experienced through several decision processes. Nevertheless, they still are only concerned with one activity objective. For example, the fisher communities can only decide which fishing

[8] *At the computer level, this phenomenon seems to come from unexploited possibilities: since the agents' fields are defined at once, a fisher community with its usual species or a fish trader with its potential selling markets will be unable to change if their knowledge remains static. These field values define the information networks available to each agent. The problem there appears to give the ability for the agents to change their sources of information (see adaptation step, next paragraph).*

behavior to go on with. To better model change, it would be interesting to complete the adaptation scheme with new 'reality-like' choices such as 'am I satisfied with my current situation?', 'do I get the best context to work?', 'is it profitable to invest?' or 'am I happy to be a trader?'.

To represent these processes, the model could formalize a new adaptation step embedding the interaction step. This 'adaptation step' is tentatively described in Figure 11. The whole model described is here considered as one global task, part of an upper level system's cycle where a generic decision task concerns every agent. In the DAI formalism, the previous cycle is considered as a one unique task corresponding to producing (i.e., working). In the same way two other cycles (i.e., tasks) can be produced. In each of these new cycles, communities can decide not to produce, fish, sell, move, but also to adopt new fishing tactics (buying gillnet for example will acknowledge new available information on species, traders, etc.), to buy bigger vehicles or new fishing gears. In the computer model, this gives the possibility for the agents to obtain more information from other agents in the system. The community can even decide to change more drastically ('mutate' in Fig. 11). This last task can express, for instance, changing jobs (fishers becoming traders), leaving the fishery, becoming industrial workers, etc. At this upper level, communities can adapt through several goals and not only through their producing activity (they have more choices and possibilities to adapt). These three upper cycles are driven by another upper level cycle. In this 'adapt' cycle, the community agents evaluate their current state and, using the same decision process model, choose the best from the three activity cycles.

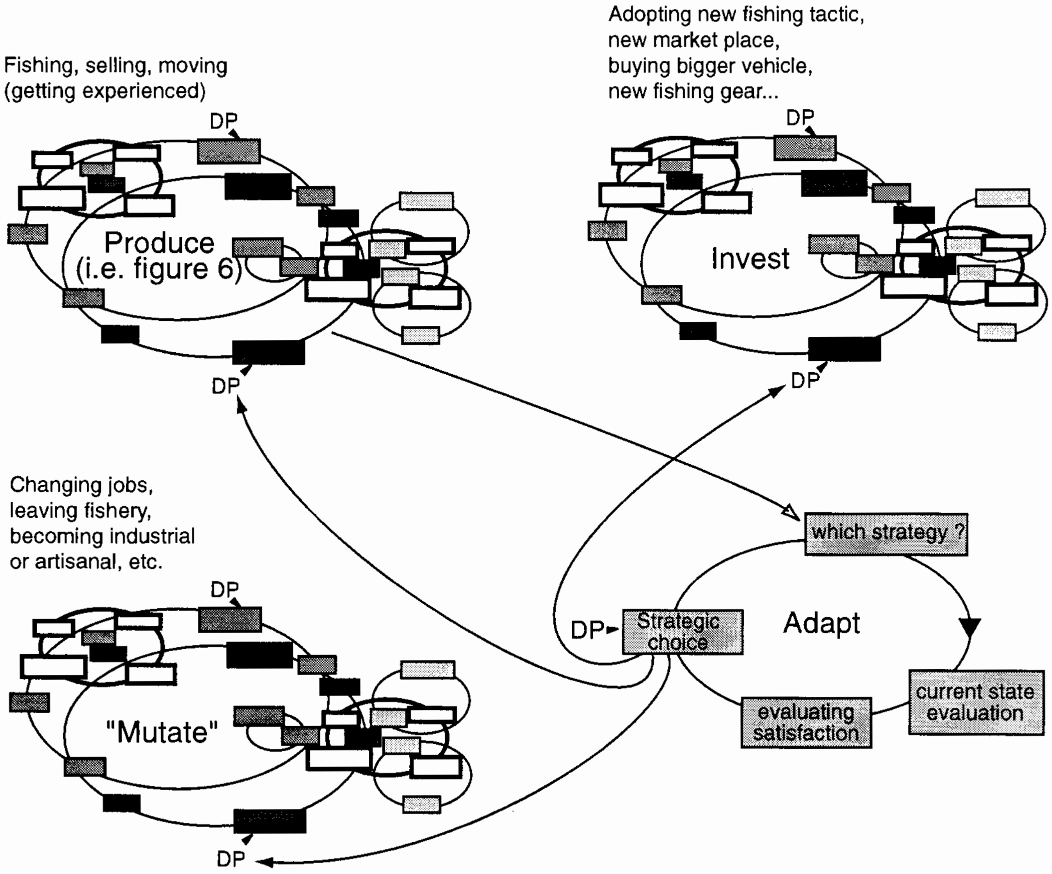

Fig. 11: Towards an adaptation step?

CONCLUSION

The initial issue was founded on a global perception within which the reactions of fisheries to change can be studied as a reduced set of global response curves. This approach is as a simple way to study and understand change and its possible effects on a complex fishery exploitation system.

The hypothesis of a global system, and multi-agent formalism makes it possible to represent a system's global behavior based on local mechanisms. Moreover, through successive modeling steps, we can successively deal with *communication*, *decision*, *activity* and *interaction* steps. We finally proposed a new *adaptation* step. This modeling scheme, 'from global to global through local processes', may be proposed as a generic mean to model and investigate the dynamics of exploitation systems in general.

Some of the simulation examples provided unexpected results and may require the current 'reality' transcription to be improved (this was discussed as a possible bias of the approach). Despite this, it proved possible to simulate different local changes in the same system, and to simultaneously analyze a global systems' behavior[9]. The fine 'granularity' selected for the model also made it possible to study a large array of local indicators (species fluctuations, community confidences, prices' evolution, distributions of tactics, etc.). Thus, if change occurs in real systems, it appears possible to better identify that part of the system from which good or bad consequences may be expected.

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[9] *The simulations presented here are only concerned with static, punctual change. It would be interesting to study the effect of dynamical changes such as trends, inflations, continuous depletion, etc.*

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