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INDIVIDUAL BASED MODELING OF FISHING TACTICS.

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Abstract :

A fish aggregation pattern implies, from a fisherman point of view, an heterogeneous distribution of catch probabilities. We can then consider the fishing tactic developed by ships as an adaptation to this local and short-term uncertainty, within a given fishing strategy, defined for a longer period.

The present study aims to measure the impact of this abundance spatial heterogeneity on the efficiency of different kinds of fishing tactics. In this goal, a multi-agent simulator is implemented, in which the harvesting activity of a fleet is simulated and coupled to the spatial dynamics of a virtual fish population, in a bi-dimensional spatially explicit environment. Simulations, as an exploratory tool, lead us to experiment different scenarii, in which different fishing tactics are applied by the fleet to a given resource distribution.

First results of this study deal with the informative component of fishing behaviors, and its impact on the efficiency. Two kinds of informative exchanges among ships are studied, which corresponds respectively to an accurate but hardly diffusive information, and to a widely diffusive but more inaccurate one. We examine the impact of both informative exchanges on the global fishing efficiency of the fleet, which is to be considered as a result emerging from the interactions between the individual fishing tactics developed by ships. The way this impact occur depends clearly on the degree of aggregation of the catch probabilities, as the efficiency of each type of information appears to be related to aggregation pattern simulated.

Key-words : catchability, fishery model, fishing efficiency, fishing tactics, individual-based modeling, multi-agent systems, spatial heterogeneity.

Introduction

An important implication of fish aggregation patterns lies in the uncertainty fishermen have to face, relatively to the heterogeneous distribution of their catch probabilities. This uncertainty appears at different scales, in correlation with the different scales of fish aggregation (schools, clusters, population). We focus here on a meso-scale, between individuals (relationship between individuals among a school) and population. This meso-scale refers to collecting patterns of fish aggregations gathered into clusters. At this scale, the uncertainty can be theoretically related to the mean probability for a fisherman to find a school (a fish aggregation) into a given spatio-temporal unit. In terms of fishing strategy, this meso-scale implies individual choices from fishermen, which intend to answer the question « where to go to maximize my instantaneous fishing expectation?».

The ability to answer this question is an important part of the constitution of the global fishing power Pg of a fisherman, which measures the efficiency of his fishing effort. The study of this term Pg led to a large literature (Robson, 1966 ; Laurec, 1977 ; Laurec & LeGuen, 1981 ; Hilborn & Walters, 1992 ; Gascuel et al., 1993 ; Millischer et *al.*, 1998). An important problem in the measure of the real efficiency of the fishing activity resides in the fact that many qualitative factors are involved in its constitution, like experience and learning ability of fishermen, incomplete knowledge, competition or cooperation phenomenon within a fleet, information exchange which defines the desirability of a particular fishing zone. An associate problem is the fact that these qualitative factors operate at an individual scale, making an analytical approach even more difficult. The present work wishes to be a contribution for the generic understanding of the nature and the impact of the processes involved in the constitution of fishing-boats' fishing power, which constitutes a key-point for fisheries management (Hilborn & Walters, 1992).

Objectives

Our work is based on two general assumptions. Firstly, a fleet's fishing efficiency is the emergent result of interactions among individual fishing behaviors. Secondly, these individual behaviors arise from three constraint components : an informative component, which traduces the information transfer among ships ; a « cognitive » component, which refers to partial knowledge and learning capacity of the fisherman ; a directive component, which covers the individual behavior facing the fishing activity legislation and any collective organization. These three components refer to the relationships nature among the different actors of a fishery system (Breton & Diaw, 1992) : among fishermen (first component), between one single fisherman and the resource (second component), and between one single fisherman and the authority structure (third component). As a first step of investigation, we present here a theoretical study of the informative component.

Thus, the objective of this work is, first, to propose a relevant formalism for information transfers within fleets, and, second, to measure the impact of these transfers on fleet's fishing efficiency, for a given spatial organization of the resource. In regard to the scale involved, the spatial organization is to be seen as a distribution of the probability to find one fish aggregation, likely to be captured, into a spatio-temporal unit - 10 miles/hour for example.

In this goal, a generic multi-agent simulator is implemented using the object-oriented language JAVA (*fig.1*). This simulator leads us to experiment different scenarii of information transfer process among a virtual fleet, explicitly modeled by its individual components.

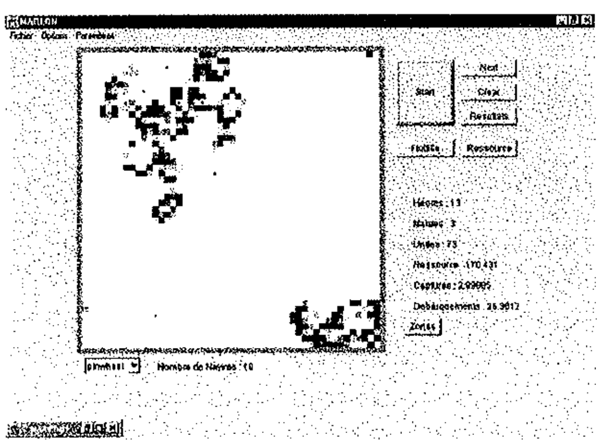

Fig.1 - *The simulator interface.*

Multi-Agent System methodology in fishery modeling context

The Multi-Agent System (MAS) methodology is based on a discrete representation of a system in space and time, by individual elements - the « agents » of the system - in interaction which compose this system (Ferber, 1995 ; Coquillard & Hill ; 1997). This kind of methodology thus appears quiet suitable for an approach of located and individual scaled phenomenon.

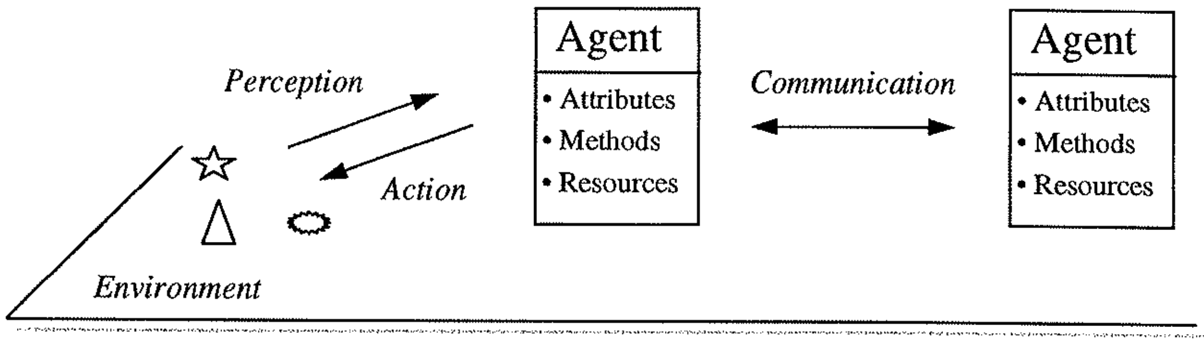

Fig.2 - *Schematic running of a Multi-Agent System.*

Each agent is defined by its methods, or functions, which lead its actions in and on the environment, and by its attributes , which allow him to carry out these actions (*fig.2*). An agent appears then as an autonomous computer process, able to perceive and react to its environment's variations, and whose behavior is defined for each step of its evolution (Ferber, 1997).

Previous models for fishery simulation (Allen & MacGlade, 1986 ; Hilborn & Walters, 1987 ; MacGlade 1989 ; Allen, 1991) dealt with fleets composed of interchangeable individuals, only defined by a global state. They don't directly take into account individual interactions and decision making. MAS methodology allows such a direct modeling of individual processes. Furthermore, one of the main qualities of this type of modeling is the easy coupling of both quantitative and qualitative assumptions in the model implemented. Now the representation of individual choices, and their determinism, can't avoid qualitative assumptions on the structure and social organization of a fleet. More, this kind of methodology allows a quantitative approach (which means a modeling approach) of essentially qualitative phenomena. In our case, this approach of modeling resides in the formalism we wish to give to the information transfers among ships, which leads the impact these transfers should have on the fleet efficiency.

The virtual fishery system implemented here is composed of singular and autonomous agents evolving in a bi-dimensional spatially explicit environment. This spatial environment consists in an 8-neighboring cells network (each cell being directly neighbored by eight cells), and characterized by a local and instantaneous fish density (mean catch probability) *fig.3*).

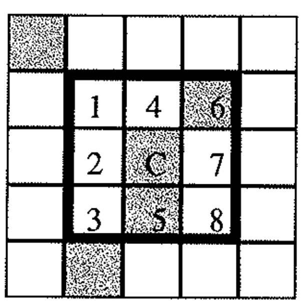

Fig.3 - *8-neighboring cell network of the simulator. Here figures a cell "c" and its 8 neighbors. Color gray indicates cells with a positive mean catch probability Ec ; white indicates null Ec.*

Working on qualitative determinants of the fishing efficiency, choice has been made to simulate the fishing activity with a constant fishing effort, equal for each virtual ship, applied on a single target distributed in the whole spatial grid (« fishing zone ») . The number of agents within the virtual fleet remains constant all along the simulation. The duration of one simulation reproduces a fishing season. It is thus divided into N trips, each trip being divided into n steps of time (« fishing hours »). The space is itself divided into z sub-zones, which correspond to the representation the agents have of their environment. This cutting out doesn't affect the resource distribution, but may influence the way the agents spatially allocate their fishing effort.

Distribution of resource density

As a first step, simulations are led with a static environment : a global fish density is distributed at the beginning of the simulation among the cells of the spatial grid. Two kinds of initialization are then possible. The first one consists in a pseudo-random distribution of clusters in space, following the uniform probabilistic law. The second one distributes aggregated clusters in the spatial grid. This latter initialization is led by the mean of a cellular automata algorithm (Phipps, 1989), which organizes spatial arrangements of clusters until it shares an appointed level of aggregation (*fig.4*).

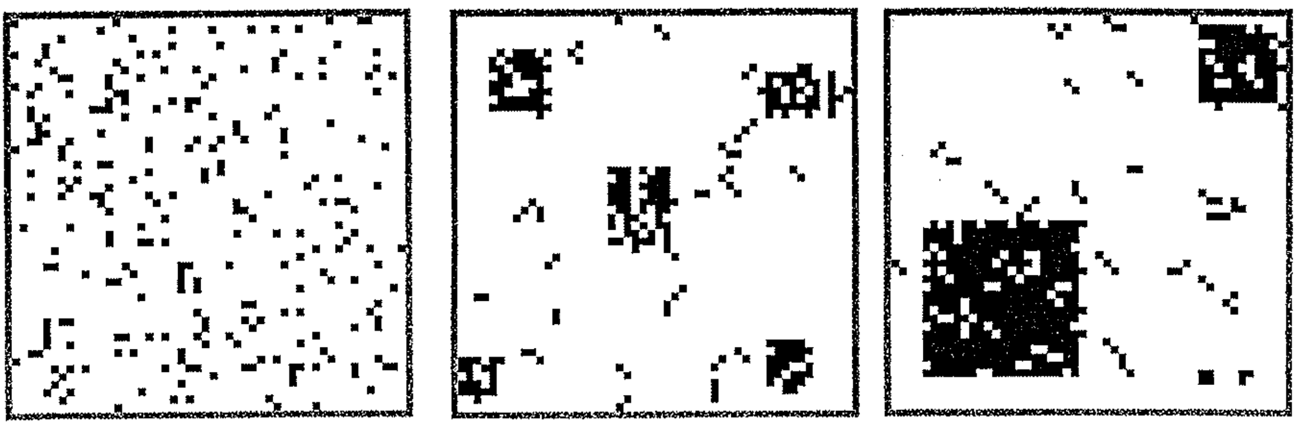

Fig.4 *-Distribution of clusters for three levels of aggregation : Ca = 0.01 (random), Ca = 0.56 (weakly clumped), Ca = 0.88 (strongly clumped).*

We use an aggregation coefficient (Ca) as a measure of aggregation level of the mean catch probabilities Ec (two types of cells are considered, where Ec=0 (type 0) and where Ec>0 (type 1)) :

$$Ca = \frac{\sum_{i=4}^{8} N[1][i]}{N[1]}$$

with :

N[1][i], the number of cells of type 1 that are adjacent to i cells of type 1;
N[1], the total number of cells of type 1 in the whole grid.

As a second step, we simulate a dynamic « resource » (to be considered here as a dynamic landscape of mean catch probabilities) by the mean of a fuzzy cellular automata process, denoted Real Life (Mar & St.Denis, 1996), constructed upon fuzzy transition rules which calculate at each time step t the value Ec[t][x,y] as a function of the sum of Ecs in the nine adjacent cells (cell (x,y) plus its 8-neighborhood) :

$$\begin{cases} Ec[t][x,y] = Max(0, Min(1, \mathrm{E})); \\ \mathrm{E} = 1 + 0.5 \bullet Ec[t-1][x,y] - \left| 3 + 0.5 \bullet Ec[t-1][x,y] - \sum_{i=-1}^{+1} \sum_{j=-1}^{+1} Ec[t-1][(x+i),(y+j)] \right|; \end{cases}$$

Synchronization between the virtual environment dynamics and the virtual fleet dynamics is insured by the mean of a coefficient δ : if t is a time step of the fleet system, and t' a time step of the environment system, we have : $t = \delta \bullet t'$, with $\delta > 1$.

Individual Model of the fishing activity

Each ship of the fleet is modeled as a singular agent of the fishery system. Different kinds of attributes give their autonomy to the agents : moving rules, local fishing power, investigation rules, communication ability, local knowledge, choice rules. Each agent is located at each time step *t* by its Cartesian coordinates *(x,y)* in the spatial grid, and has a local perception of its immediate environment, composed by the 8-neighboring cells of *(x,y)* (*fig.5*).

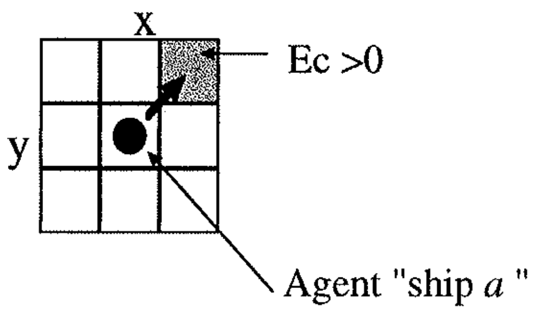

Fig.5 - *Schematic representation of agents location in the spatial grid of a simulator. In this example, the agent "a" knows the Ec of the 8-neighboring cells which compose it's immediate environment, and can direct its moving in this environment.*

The basic behavior of an agent « fisherman » is divided into two types of activity : fishing within the present cell, or moving to a neighboring cell of the spatial grid. On the one hand, the fishing behavior is here reduced to its simplest expression : it is a sample of a fixed percentage, corresponding to the local catch power Pl, of the resource located in the cell. On the other hand, the moving behavior is led by a research model, which intend to maximize the mean instantaneous catch probability Ec. This research model gives to the agents a strategic capacity which quantify the ability to find the available fish (Laurec, 1977). In this model, the instantaneous catches C are directly function of this ability, the fishing effort being remained constant and equal for all ships :

$$C[t][x,y][s] = Pl[s]*Ec[t][x,y]$$

with :

C[t][x,y][s], the catches of ship s, at step t, on cell (x,y);
Pl[s], the local fishing power of ship s, fixed for the whole duration of the simulation;
Ec[t][x,y], the mean instantaneous catch probability of cell (x,y) at step t.

A basic reference agent, which can be seen as a « reactive » type of agent, is defined by a random model of research (*fig.6*). From this basic behavior, « cognitive » agents are implemented by adding several attributes and methods which allows them to exchange information with their partner-ships in the fleet.

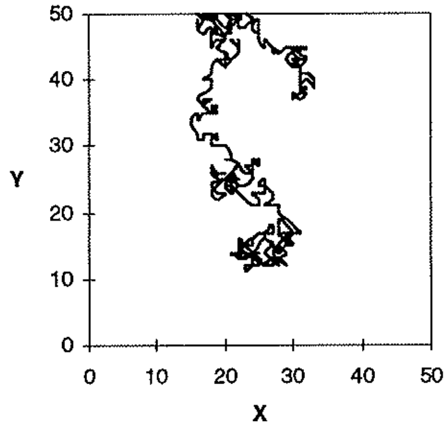

Fig.6 - *Example of a random research trajectory.*

Information transfer between ships

Two kinds of information, corresponding to two degrees of accuracy, can be exchanged among ships, reproducing the network structure of informative relationships that can be found within a real fleet (Pichon, 1992). Information transfers within the fleet occur by the mean of two lists of relations, which are attributes defined for each agent. The first list, denoted « restricted list », corresponds to a small but strong relations network. It gives to the agent ***a*** which owns this list, at each time step ***t***, the instantaneous catch of each other agent strongly related to ***a***, and the cell ***(x,y)*** where these catches occurred at time ***t-1***. On the contrary, the second list, denoted « large list », corresponds to a large but inaccurate relations network. It gives to the same agent ***a***, at each step of time ***t***, the instantaneous catches of one agent weakly related to ***a***, randomly chosen in the list, and the sub-zone *z* where these catches occurred at time ***t-1***. A third kind of information, corresponding to the largest degree of spreading and inaccuracy, interfere at the end of each trip ***T***. At that time, each agent makes available for the whole fleet its own global resulting yield for ***T***, and the sub-zone where its major effort were allocated. The results presented here aren't concerned by this latter medium of information transfer since they correspond to simulations of one trip fishing season ***N=1***).

We have presented the structure of informative exchanges among the agents of our virtual fishery. But the real point of the informative model resides in the thresholds which define the way the agent should use the received information. In others terms, these thresholds determine which information agents should consider as a « good » or usable one, i.e. an information that would conduct their research. This kind of judgment, resulting from subjective decision making, depends clearly of fisherman's own history, and can't be simulated by a fixed parameter. Each fisherman has, at a certain time step, a representation of what is a « good » catch, a « good information », or a « good » zone desirability, which should defer according to the time step and the fisherman. These decision thresholds are thus calculated in the model as functions of agents' past results during the considered trip, and functions of the distance of emission of the information.

Let us consider an agent ***a*** at step ***t*** $(1 \leq t \leq n)$ of trip ***T*** $(1 \leq T \leq N)$, located in the cell (x,y) of sub-zone *z*, receiving an information from an agent ***b*** located in the cell (x',y') of sub-zone *z'*. We assume that the cell (x,y) exhibits a mean catch probability Ec[t][x,y]. In the case of strongly related agents (restricted list), ***a*** knows C[t-1][x',y'][b] ; in the case of weakly related agents, ***a*** knows C[t-1][z'][b]. Let ***d*** be the distance between (x,y) and (x',y'), or the center cell of z' ; σ the last step of T when ***a*** followed an information ; Y[T-1][a] the yield of ***a*** at trip T-1. Agent ***a*** will follow this information (i.e. will give (x',y') in the first case, the center of zone z' in the second one, for direction of its research until it finds a cell exhibiting a positive Ec) if and only if C[t-1][x',y'][b] >α, or C[t-1][z'][b] > β, with :

$$\alpha = \begin{cases} 1 & if \quad t < 0.1 \bullet n \quad or \quad d > n - t; \\ \dfrac{\sum_{i=\sigma}^{t-1} C[i][a]}{(t-1) - \sigma} & else; \end{cases}$$

$$\beta = \begin{cases} 1 & if \quad t < 0.1 \bullet n \text{ and } T < 1, \text{ or if } d > n - t; \\ \dfrac{Y[T-1][a]}{n} & else; \end{cases}$$

The threshold β, corresponding to weakly relationships, appears quite more restrictive than α, giving a higher degree of confidence to the information coming from the restricted list.

First results

The results presented here show simulations of a 10 ships homogeneous fleet, evolving in a 50*50 cells grid. Three types of agent are implemented : "Random research" agent, "Restricted List" agent, and "Large List" agent, in order to compare effects of each type of informative exchanges within the fleet. We will focus here on simulations led with a static environment, for which we laid down three different aggregation levels : Ca = 0.01 ; Ca = 0.56 ; Ca = 0.88.

For each simulation, cumulated catches and relative efficiency of each type of fleet are calculated (*fig.7*). Instantaneous catches can be here considered as Catches Per Unit of Effort (C.P.U.E.). Furthermore, comparison is done with similar initial conditions. Thus, the relative efficiency (denoted Cs for "Strategic Capacity") is given by the ratio of instantaneous cumulated catches of the considered fleet by the sum of instantaneous catches of the three fleets at the same time step.

In the case of randomly initialized Ecs, the informative ability appears logically useless, as the relative efficiency of the three types of fleet are similar. This is a known result that a random behavior is the most accurate one facing a randomly distributed resource.

The real point here is that information doesn't become useful until aggregation has grown over a threshold level. In the second set of simulations, corresponding to a middle aggregation degree, the random research tactic appears to be more efficient than the informative ones. This can be explained by the fact that at this aggregation level, no sub-zone appears clearly richer than others. In this case, information has a "deceit" effect, which confine ships in sub-zone, whereas random agents explore the whole space. This "deceit" effect is quite more sensible for "Large List" type of agents which point for a longer time a given sub-zone. Their behavior of systematic exploration of sub-zones clearly appears by the examination of cumulated catches of the four sub-zones(*fig.8*).

Finally, at the largest level of aggregation, the most efficient tactic becomes the "Large list" one, because of its ability to quickly discover and occupy the richest zone. The "Restricted

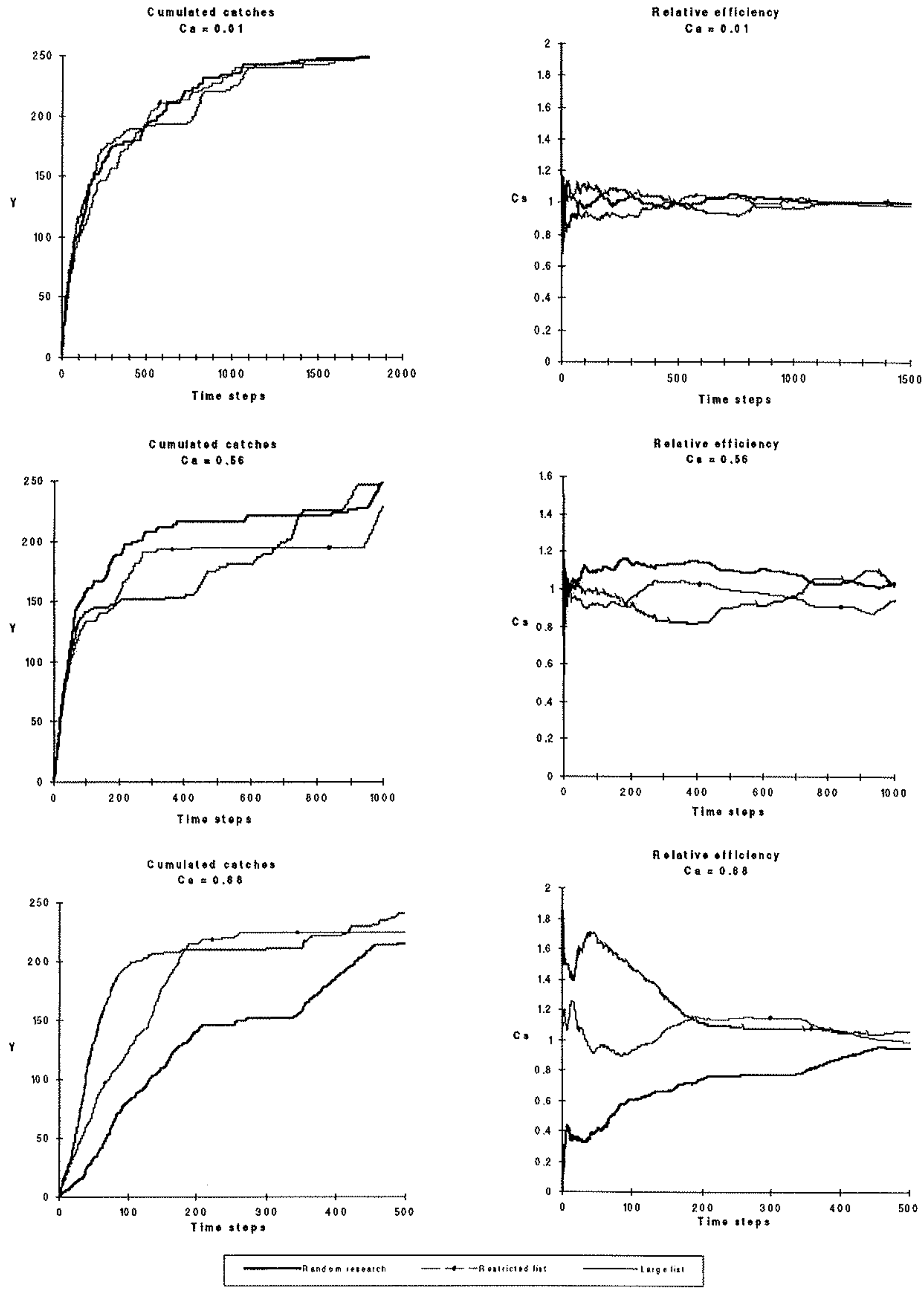

Fig.7 - *Simulation results for three different levels of aggregation Ca : 0.01, 0.56, 0.88.*

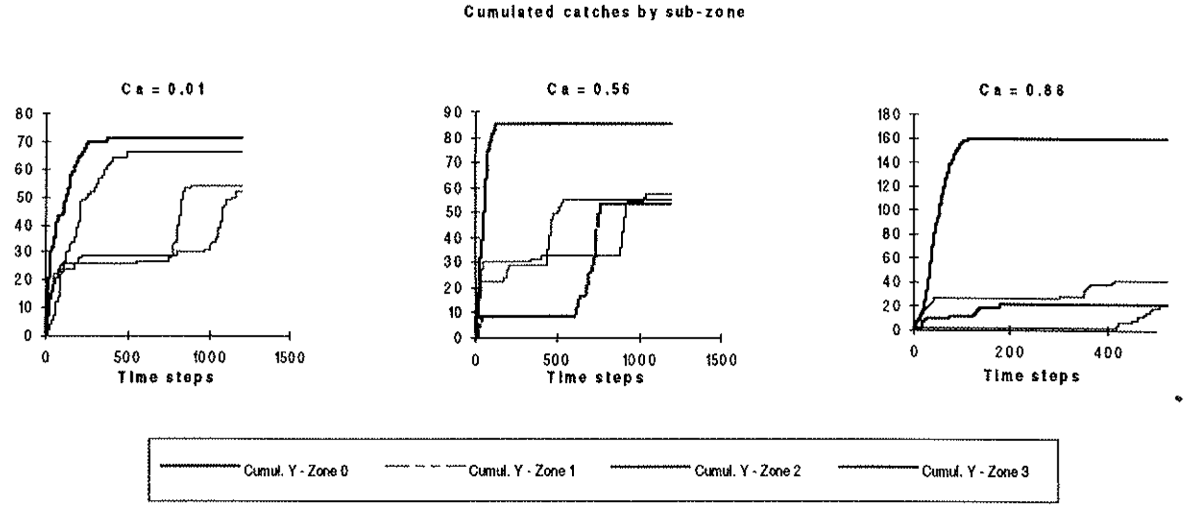

Fig.8 - *Cumulated catches by sub-zone, in the case of weakly related agents. Results are given for the three levels of aggregation Ca : 0.01, 0.56, 0.88. Information exchanges within the fleet deal with four sub-zones, denoted 0, 1, 2, 3.*

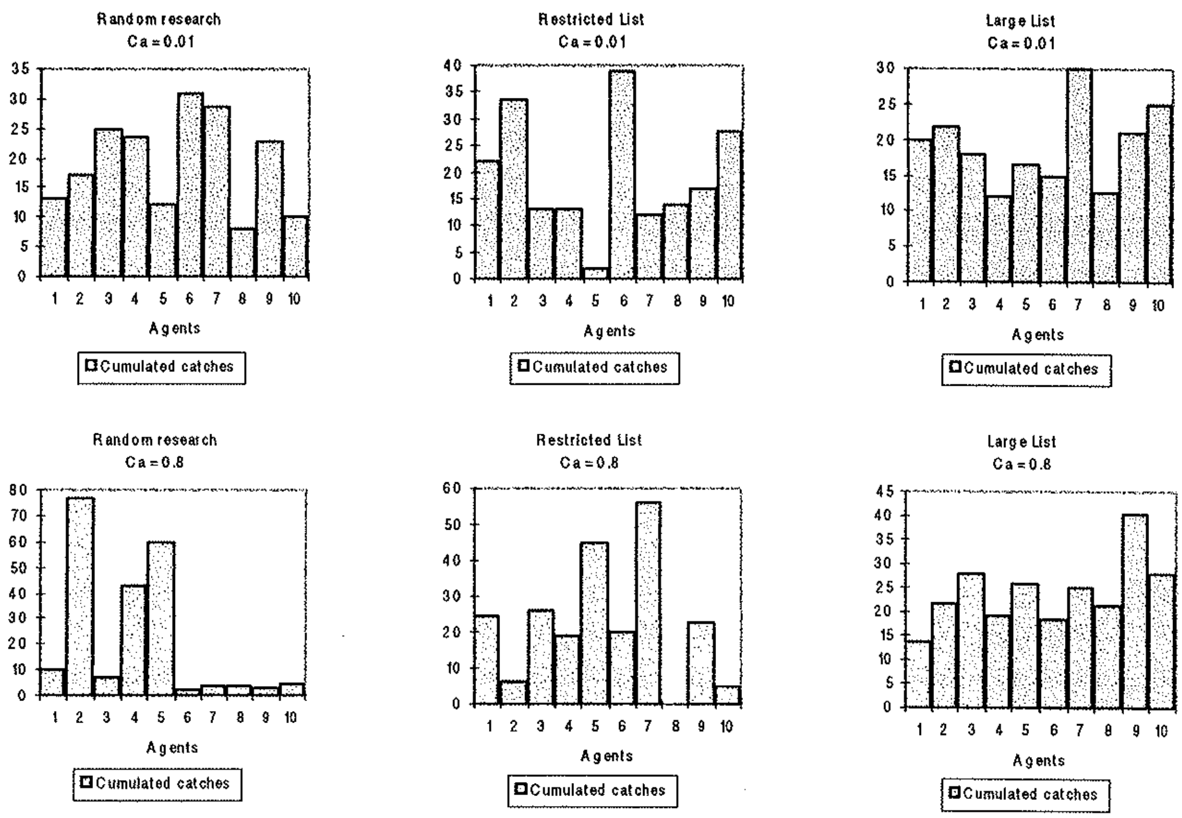

Fig.9 - *Cumulated catches of each simulated virtual fleet agent, for two levels of aggregation : Ca=0.01, Ca=0.88. The three cases correspond respectively to a random type, a "restricted list" type and a "Large list" type of agents.*

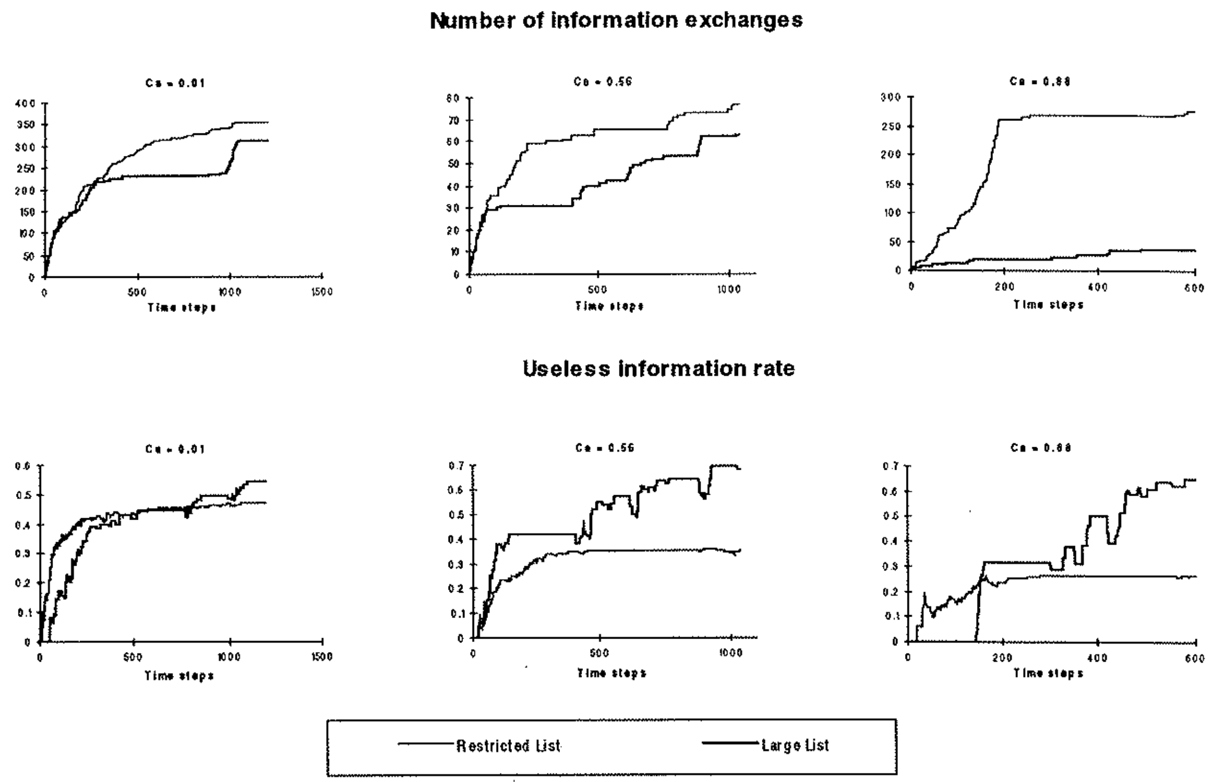

Fig.10 - *Number of information exchanges and useless information rate along the simulations, for the two types of informative fleet.*

List" appears to be relatively inefficient in this case. This apparent inefficiency, in comparison with the "Large List" results, can be explained by an insufficient resource rarity. This informative tactic should be more adequate in the case of "extremely rare events" type of distribution.

Examination of cumulated catches of each agent underlines an important point (*fig.9*). The "Large List" results are the most balanced ones for the three sets of simulations. Thus, in the case of strong aggregation of Ecs, the "distributed" tactic is the most suitable one, with a largely lower informative intensity (*fig.10*).

Concluding remarks

The study presented here show the preliminary results of a larger and in process work. Many aspects are not yet taken into account in these simulations. In particular, the dynamic aspect of cluster's aggregation has to be included in this type of simulating study. In this goal, a fuzzy cellular automata, described previously, has been added to the simulator, which allows to test fishing tactics in a dynamic context. Other coupling of our model with fish population models are also planned, which will manage a generic approach of fishing tactics in this simulator.

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