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Reflection on the determinism and the modelling of the fishing practices of an inshore marine ecosystem

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Abstract: The goal of this paper is to contribute to the development of a theoretical framework for the structure, operation and evolution of inshore fishing practices. This type of research presents many difficulties given the size of the occupied area, the intense biodiversity of the inshore marine ecosystem, and the wide diversity of fishing practices. The general theoretical approach underlying this research is the ecosystems theory and that of self-organization. Its object is to describe and to understand the succession of practices used by each fishing unit during one year. A typological study of these practices can be conducted by using factorial analysis methods and classification techniques. In these typologies the fishing units are gathered in fleets that have, by definition, homogeneous cost functions and practice similar métiers. Therefore, the basic element of the system is the métier. It is considered structurally stable, evolutionary, adaptive and self-organized, and thus represents the main hypothesis of the model used. The main difficulty that can be encountered in these classifications is finding the discontinuities that allow for a proper discrimination among fishing activities. To distinguish too few métiers is to integrate some activities at a level which denatures them. On the other hand, a typology which is too thorough brings in too many details in the characterisation of the different métiers and presents only little interest for their management. Once the structure has been described, a functioning model can be created in order to measure the changes of the fishing unit's size by métier over time. The conclusion shows how such a representation of fishing activities can have an impact upon its organisation and how it can cause it to evolve, thus demonstrating the consequences of such research on fishing management.

Eléments de réflexion sur le déterminisme et la modélisation des pratiques de pêche d'un écosystème marin côtier

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Résumé : Ce papier a pour objectif de contribuer à la conception d'un cadre théorique d'étude de la structure, du fonctionnement et de l'évolution des pratiques de pêche côtière. Cette recherche est difficile à appréhender à cause de l'étendue de l'espace occupé, de l'intense biodiversité du milieu et de la grande diversité des pêches pratiquées. Elle utilise comme théorie générale la théorie des écosystèmes et de l'auto-organisation. Son objet est de décrire et surtout de comprendre la succession des métiers pratiqués par chaque unité de pêche au cours d'une année. Une typologie des pratiques peut ensuite être menée à l'aide des méthodes d'analyses factorielles et des techniques de classification. Dans ces typologies les unités de pêche sont regroupés en flottilles qui sont définies comme des ensembles ayant des fonctions de coûts homogènes et exerçant des pratiques similaires. L'élément de base du système étudié est donc le métier. Il est considéré comme structurellement stable, évolutif, adaptatif et auto-organisé. C'est du moins l'hypothèse principale du modèle utilisé. La difficulté principale que l'on rencontre dans la détermination des métiers est de trouver les discontinuités qui permettent de discriminer à bon escient les activités de pêche. Distinguer trop peu de métiers a pour effet d'intégrer les activités à un niveau qui les dénature. Au contraire, c'est le cas le plus fréquemment rencontré, une typologie trop fine apporte trop de détails pour déterminer les différents métiers, et ne présente que peu d'intérêt pour leur gestion. Une fois la structure décrite, son fonctionnement peut être modélisé de façon à mesurer l'évolution au cours du temps des effectifs d'unités de pêche par métier. La conclusion montre comment une telle représentation des activités de pêche peut agir sur son organisation et la faire évoluer, montrant les retombées organisationnelles d'une telle recherche.

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1. Introduction: The large diversity of inshore fishing practices

Fishing is a varied activity encompassing everything from on land fishing to industrial fishing involving significant capital investment. This multi-activity is generated by three main sources: a natural habitat that offers a proliferation of species which are all exploitable, the spatial immensity and the mosaic distribution of the fishing grounds, and finally, the multitude of fishing gears used simultaneously to exploit the same resource.

The marine environment is the most varied insofar as the ecological distribution of species in the animal kingdom is concerned: It has 28 branches of which 13 are endemic, while only one in 14 can be counted as fresh water species. There are 11 in the terrestrial environment (of which only one is endemic) and 15 in symbiotic life style (Barbault, 1994). Thus, with the exception of insects, 90% of animal species come from the marine environment (Raup, 1991). The coral reef provides us with a remarkable example of this fact as it only takes a glance by the observer to see the entirety of the animal kingdom represented. The inshore ecosystem is the only ecosystem that presents such a large specific diversity. And practically all marine species are potentially exploitable, from the shellfish species buried in the sediment to the large pelagic species located at top of the food chain.

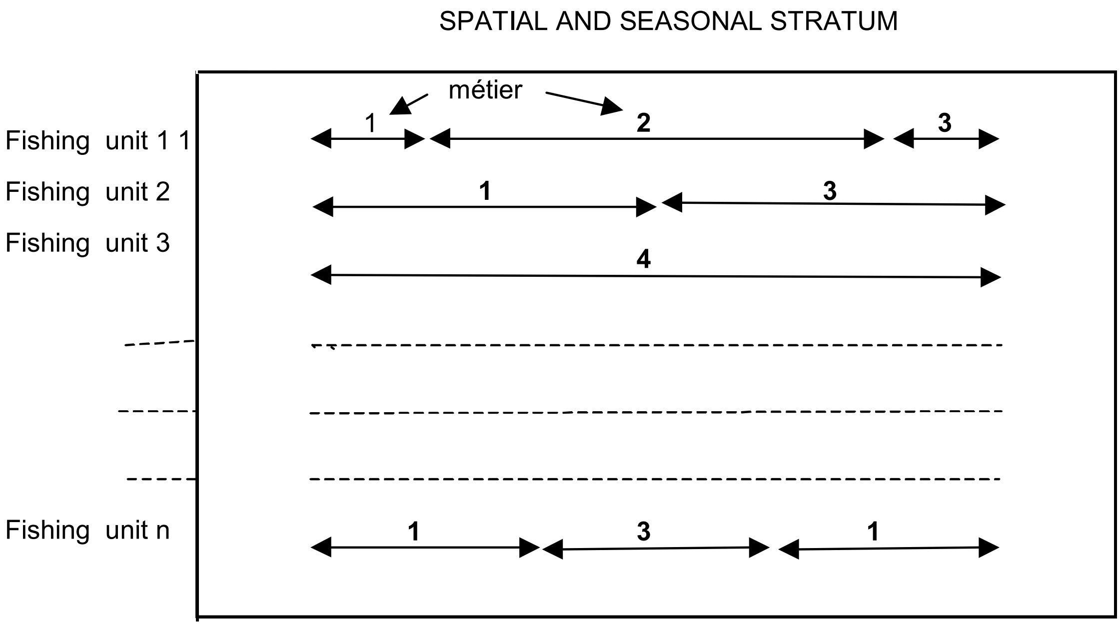
The inshore ecosystem presents a large diversity in the nature of sea bottoms, which can be either hard, sandy or muddy. This leads to the multiplication and the dispersion of species. In addition, the coastline is a hydrodynamically discontinuous zone where there exists a spatial and seasonal gradient of auxiliary energy, called ergocline (Frontier and al., 1998), which serves to mix the elements that condition biological productivity (nutritive salts, sunlight, primary production, secondary production, etc.). These inshore areas are thus « oases of abundance in a desert of ocean » and are more productive than the surrounding ocean. The spatial and seasonal parameters' fluctuations of the inshore environment lead to the spatial and seasonal fluctuations of biological resources. The inshore fishermen adapt to these environmental modifications by changing target species, fishing areas and gear. Therefore, we can explain why the diversity of the métiers practised in an inshore sector is notably greater.

When compared to agrarian resources, fishing resources are mobile, available in limited quantities and freely accessible. The exploitation of such a resource, which is shared among all fisherman, generates a high degree of interaction whether this interaction is direct or differed. It engenders the following paradox which is a well-known characteristic of fishing: profit decreases when investment increases, whereas in the other economic activities the opposite dynamic pertains as long as the market is not saturated. This situation produces conflicts between short term interests and those of the long term. These conflicts concern the occupation of space, as well as the exploitation of the resource, and they affect the fishermen practising the same métier as well as those practising different métiers. The level of observation considered here is regional (approximately 1000 km) and includes individual exploitations all the while integrating the ecological, economic and social environments. Fisheries management consists, therefore, in putting in place the levels of management in order to take into account the external effects generated by the fishing units. This explains why, here, we are not interested in the microeconomic analysis of one fishing unit which relies on the law of supply and demand on the one hand, and on the law of decreasing yields on the other. This microeconomic analysis informs the fisherman directly, models his activity and predicts what he should do, to what extent, and with what production factors.

In fishing practices research, one searches for a resemblance between what is happening now and what happens at another moment. One tries to explain these similarities and demonstrate an evolutionary change process. The internal organisation of a fishing activity is described at one specific moment in time. Rather than to continue to accumulate isolated details of fishing anatomy, we elaborated a kind of « fishing genetic» and a «fishing physiology» that we have summarised with the expression « fishing determinism ». It is a fundamental change in our conception of research. We have passed from a descriptive and empirical approach to a more rational approach that looks for the regularities in fishing activities. This change has occurred gradually over the last twenty years (for example see Biseau and Gondeau, 1988, Rochet and Durand, 1993) and the evolution is probably not complete (Pech et al., 2001), etc. Its objective is not to describe, but rather to understand how to run the fishing system according to an interdisciplinary approach. If the exploited population dynamic is adapted to the simultaneous management of some stocks and some métiers, it becomes inadequate in the management of a whole that is composed of several dozen stocks and several dozen métiers, and forces us to widen the scope of the research object (Le Gay, 1997).

2. Redefinition of the research object

The fishing practices of a fishery are defined by the succession of métiers practised during one year. A métier is defined as the association of fishing gear, a group of target species and a fishing ground at a given time (Anon., 1987, Laurec and al., 1991). Such combinations have also been termed “fishing tactics” by Laloë and Samba (1991) and by Pelletier and Ferraris (2000), and also “fishery/zone combination” by Holland and Sutinen (1999). We study fishing practices implemented by fishing units. The fishing unit represents the elementary unit of decision. In general, it represents a vessel piloted by a skipper. But other cases are possible, from on land fishing to fishing with several vessels, such as, for example, tandem trawling or the association of several vessels in the catching of pelagic fishes. These métiers form a series of interdependent technical operations whose previous description allows for the determination of the factors which influence the implementation of such or such a métier, which is evidenced by the creation of a fishing calendar or fishing card for each fishing unit as is shown in the diagram below :



<u>Fig. 1</u> : Calendar of fishing activity or fishing card.

Determinism in a fishing activity operates like a computer program, an « open program» that relies on a learning factor and the acquisition of new information for the passage from one métier to another.

These studies encompass those fishing units that exploit the fishing resources of one area at any given time. A typology of the practices gathers the fishing units in homogeneous groups, and then compares each operation to its group of reference. Therefore, the methodology consists in ignoring special characteristics observed in order to retain the regularities that can be observed in space-time. In this description of fishing practices, it can be useful to dissociate the action of determination from that of classification (Conruyt, 1994). Classification or typology defines the distinctive characters of the practised métiers. Determination is concerned with the names of the métiers practised by a fishing unit.

The fishing units are gathered in fleets that are defined as follows: « a fleet is defined as a set of fishing units that have the same physical characteristics (length, power, tonnage), the same equipment, the same cost functions and those that exercise similar métiers”. It is important to note that if two fleets have the same fishing practises, they differ in their exploitation costs.

Thus our research object is defined by the diagram below which represents the distribution of the activity according to the fishing practices on one hand, and to the fleets on the other hand.

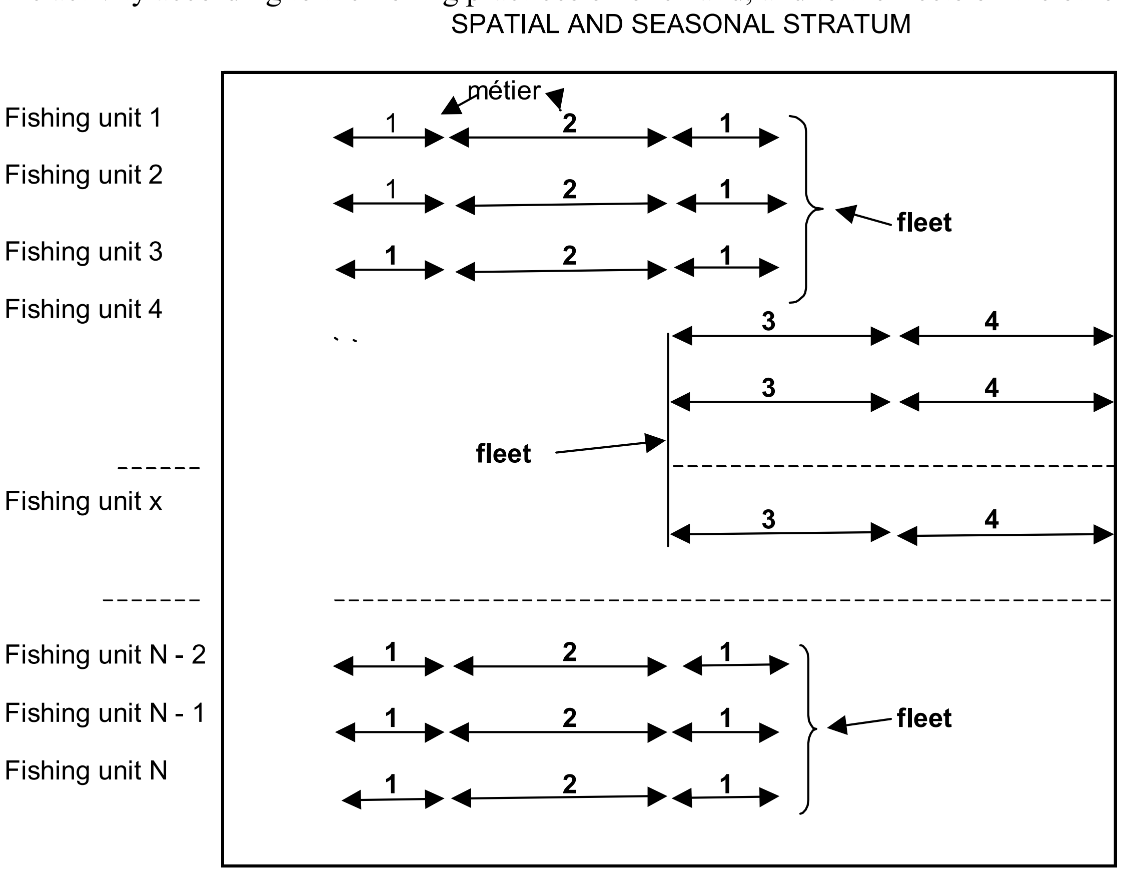


Fig. 2 : Descriptive diagram of the fishing activity according to the fishing practices and fleets.

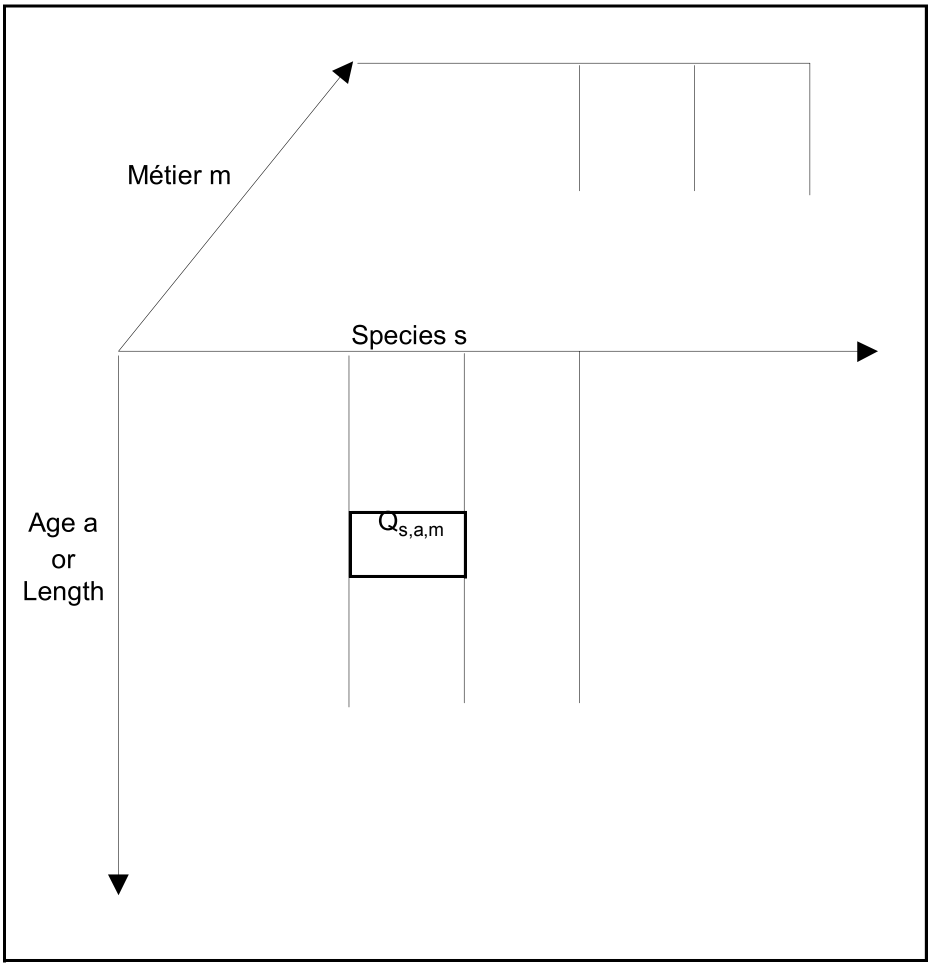
3. The key notion of métier

The systemic approach that we have just presented is not reductionist as are lists of species, gears or fishing areas, nor is it holistic as are global indicators of fisheries monitoring. It falls between the two and uses a theoretical approach like the theory of systems (Brossier et al., 1990, Le Moigne, 1990, Simon, 1991, Sebillote, 1994, Le Gallou et al., 1992, Frontier et al., 1998). A system is, by definition, a group of interactive elements – here, the métiers - as the functioning of every element is conditioned by its neighbours. The métiers show a high level of interactivity, and are a perfect example of the classic expression which states that “the whole is greater that the sum of its parts.” The basic element of the ecosystem approach to fisheries is therefore the métier, indivisible by definition without alteration. The results of one fishing action – the practice of a métier by a fishing unit at one moment in time – are reentered into the system in a recursive manner in order to determine whether or not to continue the action, the result of the action acting on its cause. This feedback can have a positive or negative influence on the choice to continue the practise of a métier. The interaction between boats practising the same métier demonstrates the dual aspects of competition and co-operation. Indeed, if fishermen from a same fleet put co-operative strategies in place in order to search for fish, they are in open competition with each other to capture that fish. Interaction between boats practising different métiers can be direct when it concerns the competition for the occupation of a fishing area, but also indirect with a delayed effect when the métiers exploit successive age groups. The indirect and invisible effects are generally more important than direct effects.

The consequence of this management using interaction and feedback is that it produces an autonomous system. This autonomy can be considered as an emergent property of the system, generated by a composition effect. The basic element of the ecosystem approach to fisheries, the métier, is structurally stable, evolutionary, adaptive and self-organised. It is the main hypothesis of the model used. Métiers are historic entities that are invariable over time. Indeed, the relative stability of circumstances over time and the ignorance of the intermediate métiers when they exist, incite us to postulate that the métiers are unchanging. But, we know by experience that the constraints exercised by the social, economic and biological environments can transform a métier into a new one over the space of several years. A métier has a life that spans from its appearance to its disappearance due to extinction or transformation, whether or not the original métier persists. Every métier has a degree of mutability that characterises its faculty to change.

The characteristics of each métier can be distributed in a discontinuous or in a continuous manner. In the first case the characteristics have a corpuscular distribution. In the second case, the characteristics have an individual gradation. The difficulty in defining some métiers, therefore, stems from the discontinuities that allow for the determination of a fishing activity. To distinguish too few métiers is to integrate an activity at a level that denatures it. On the contrary, a typology which is too thorough brings in too many details in the characterisation of the different métiers and presents only little interest for their management. Though in practice it is possible to encounter a limited number of cases that make the determination of the métier problematic in the absolute, it should not be a pretext to reject the métier entity as the basic element of the studied system.

The métier corresponds to an observable fact in the field. It makes reference to an operational activity of fishing, and, at the theoretical level, to an abstract entity linked to a catchability matrix, perfectly defined in mathematical terms, and used to quantify the impact of fishing on the resource, using the theory of exploited population dynamics: every métier is characterised by a matrix of constant catchability coefficients Q by species and by age (fig.3).



<u>Fig. 3 :</u> Matrix of catchability Q_{sam} by species, age and métier.

In practice the determination of the Q coefficients are not necessary to determine the practised métiers. Observations of activity criteria are generally sufficient. From a conceptual point of view, it is important to add that what interests us is not so much the description of the activity of fishing units, but rather the decisions led to the activity. As this "fishing program" is not observable, we are obliged to learn about fishermen's plans from fishing activity criteria such as:

- Surveys among fishermen or their representatives;
- Archival research;
- Indirect investigations such as the observation of gear loaded on board;
- The proportions of species landed by every fishing unit;
- Etc.

In order to eliminate any ambiguity in the description of fishing plans, it is necessary to use at least two activity criteria that are mutually independent for a rigorous analysis.

Finally one obtains a technical organisation (fleets and métiers) that is predictable and verifiable. But, from a social point of view, the experimental verification implicitly supposes that the fishermen of every fleet represent a social group united around interests that were constituted themselves in the past. In reality, this social identity is not acquired straightaway and can pose problems. And yet, no hypothesis is made as to their identity. It is difficult to distinguish the production of technical knowledge from the production of social identity says Callon (1986): knowledge and social identities are inseparable. Thus, our research object contains both some observations on the society and on the nature and it is the reason why there is not a definitive border separating natural facts from societal facts.

Once the structure of the fishing system is established, and fishing units and fishers numbers counted by métier, it remains to replace this fishing diversity in the functioning of the fishing system.

4. Modelling of the fishing practices diversity and interpretation of their dynamics

In reasoning by analogy, one can apply to ecology the methods used to study bio-diversity. Thus, every métier occupies a bio-economic niche that is a generalisation of the ecological niche in ecology. It represents a domain of tolerance concerning the main factors, these last being represented in a hyper space with as many dimensions as there are considered factors.

The diversity of métiers practised by a fleet covers two aspects : the number of métiers, and the regularity that is the distribution of boats among the métiers, as the diagram below shows in cases of weak and large diversity, borrowed from Frontier and al. (1998) :

This fishing diversity can be measured by the same index that is used in ecology, for example

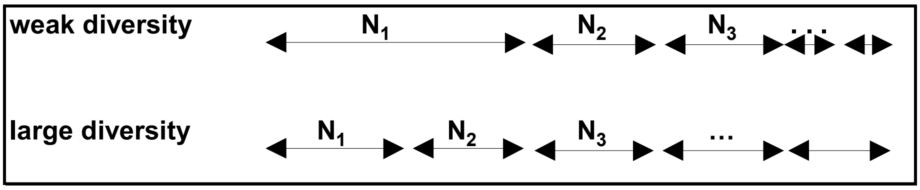


Fig. 4 : Représentation of the distribution of boats in métiers, for a same number of métiers, in a case of weak diversity and a case of large diversity.

the Gleason index, that is founded, once transposed to fisheries research, on the logarithmic growth of the S number of métiers according to the logarithm of the N number of boats. We can measure the diversity I by the slope of the straight $I = (S-1)/Ln(N)$. The Shannon index measures the mean quantity of information given by the boat practising a métier in the population of métiers. The maximal diversity is obtained by the equifrequency of the métiers and we call the regularity R the ratio between the observed diversity and the maximal diversity. We can also study the distribution of the activity of boats in Frequency Diagram Rank (FDR), etc.

The analysis of the structural diversity is completed by an analysis of the functional diversity, that is defined as the set of bioeconomic functions that emanate from the exploited ecosystem. From a functional viewpoint one can easily distinguish the key métiers, the secondary métiers, the occasional and seasonal métiers, the métiers which are ecological indicators, the emblematic métiers, the confidential métiers, etc. This assignment of function is linked to a global functioning concept. We operate the explanation of the practised métiers in terms of function and we show the orientation centred on a project, a program. This oriented organisation must appear from the etiological analysis of the métiers, because the causes of practised métiers must be their tendency to produce a certain result (Duchesneau, 1997).

To continue this analysis, the implicit hypothesis is to say, even though it is not often clarified, that there is an order in the distribution of boats in different practised métiers. It is an order that spontaneously emerges by differentiation and by selection. This order doesn't correspond to the one that could be obtained through optimisation. It is an order of limited rationality or procedural (H.S. Simon in Kourilsky, 2002) by reference to an order of substantial rationality. It means that possibilities of improvement for the observed situation exist. The fleet has the possibility to do better than it does spontaneously as long as the different decision-makers – the fishermen and the administrators mainly – use a better knowledge of the distribution of the resource in spatial and seasonal strata and the distribution of other fishermen in these spatial and seasonal strata. This hypothesis is confirmed by a great deal of scientific work, in particular by that of Holland and Sutinen (1999) : "the tendency of fishers to follow their own historical patterns may be due to factors such as family tradition and simple inertia ".

Once the structural and functional analysis achieved, it remains to understand the evolution, generally per year, of the fishing unit's number N by métier. The whole can be modelled by a model in discrete time of the form $N_{(t+1)} = f\left[N_{(t)}\right]$. Two types of variables are considered: the state variables (N) and the flux variables (k). The first represent the variations of fishing unit's number that take place through the flux variables. The flux variables represent the factors on which it is possible to act on the system. One generally uses a Leslie's matrix that passes from the state vector $[N]_{t-1}$ at the time t-1 to the state vector$[N]_t$ at the time t.

$$\begin{bmatrix} N_0 \\ \cdot \\ \cdot \\ \cdot \\ N_n \end{bmatrix}_t = \begin{bmatrix} k_0 & \cdot & \cdot & \cdot & k_{0n} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ k_{n0} & \cdot & \cdot & \cdot & k_n \end{bmatrix} * \begin{bmatrix} N_0 \\ \cdot \\ \cdot \\ \cdot \\ N_n \end{bmatrix}_{t-1}$$

The main hypothesis concerns the speeds of transfer. The simplest model is the model with a constant coefficient: during a very short time interval, the fishing unit's number crossing from one compartment to another is proportional to the fishing unit's number, the proportionality coefficient being k.

Moreover if the fishing units have the possibility of choosing a métier between several at once – each choice at one time is equivalent to the "strategy "term employed by Pech and al. (2001)-, we have to study the distribution of probability of métiers practised by these fishing units. It can be used to predict the relative probabilities of individuals' choices among the alternatives open to them.

Two ways of forecasting are possible. One, of a quantitative nature, on the dynamics of the fishing unit's number by métier and their transfer from one métier to another. The other, of a qualitative nature, on the determinism of métiers and allows us to understand the observed bioeconomic mutations, often subject to surprises and new events. It is therefore important to know and to formalise the historic evolution of the studied system. Nowadays theoretical work privileges the concepts of irreversibility, of non linearity, of threshold effect and bifurcation, causing the change of one equilibrium to another. Thus we will be in a position to replace the symmetrical and reversible functions by some more complex and irreversible trajectories of the fishing system. The irreversible evolution of the marine exploited ecosystem is nowadays well known (Cury, 2003).

5. Conclusion : organization of the fishing system

The knowledge on the structure and functioning of fishing practices is indispensable to fisheries management. Indeed, it is interesting to look for the factors responsible for the practice of métiers in order to have the possibility to act on them, the objective being to simulate changes in regulation and to see their impact on such or such component of the fishery.

This research on fishing practices requires a mobilisation of other thematic research, in particular that which concerns ecology, economics and social sciences. This different kinds of thematic research are necessary to the running of the ecosystem approach to fisheries and can be represented of the following way :

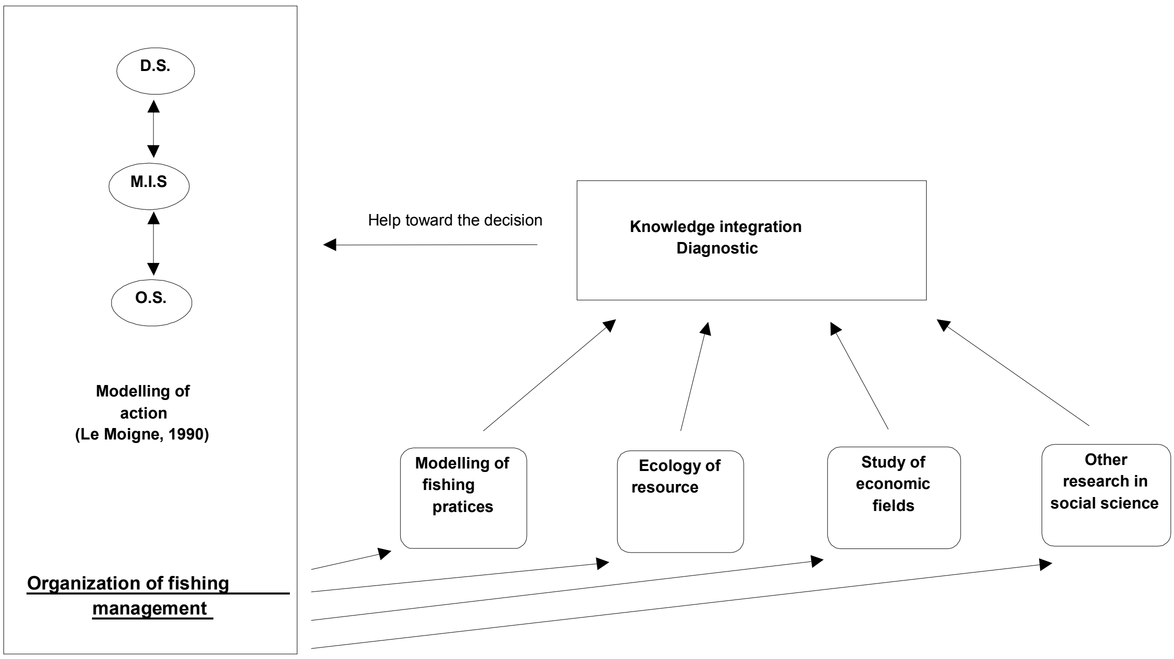


Fig. 7 : Assembly of the different thematic researches necessary to the organization of fishing management.

The thematic level that corresponds to the integration of knowledge and diagnosis analyses information acquired by the different thematic research forms a link to management's organisation. It is research centred on the recursive relationship between information and organisation. It is by definition an interdisciplinary domain that is based on a theory of the organisation, that is otherwise in development. This phase of research, when it is eluded, characterises a fishing management in the process of constitution as Vallerand shows it (Brossier in and al., 1994) in describing the different organisation degrees of an agrarian system.

What is the degree of organisation of ours fisheries ? It is necessary to understand that we work with the data that we have on hand. This is not the best strategy to solve the fishing management problem. The real stumbling block toward improvement of our diagnoses is the quality of data, more precisely our ignorance of fishing practices and imprecision in the measuring of commercial fishing yields. It is necessary to collect the detailed data to from the fishing operation. This is the main factor limiting the improvement of our diagnoses. It is necessary to find an innovative artefact, to promote a cooperation between scientists and fishermen. In our analyses, fishermen are in fact auxiliary scientists that cannot be ignored. Now is the time to have them participate in the management of their own resource and to encourage the setting-up of a decentralised management system. Finally, it is an opportunity to take in account fishermens' knowledge, to formalise it and to integrate it into the modelling of fisheries. It is also represents the opportunity to develop the degree of confidence that the fishermen can have toward scientists.

Research on fishing practices leans toward complexity, as it is comprised of both social science and natural science. The scientists' partners in this research - fishermen - are the objects of the research but also the subjects because they are the first people concerned by the results. The main objective is not to produce absolute solutions ready for use, but to help fishermen and organisers to the development of their organisation capacity and to implement technical, institutional and political solutions. It is research that organises fisheries in a recursive manner. The scientific objectivity criteria is then replaced by the inter-subjective communication that recognises the self-regulation of fishermen. Organisation generates information which potentially transforms itself, as it is written by Morin and Le Moigne (1999). It is the spiral of self–organization (Benkirane, 2002). But the beginning of such an self- organisation is the longest and most delicate phase to implement. Let's hope that it occurs before the ecological modifications caused on the ecosystem become irreversible.

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