School of Economics and Management

TECHNICAL UNIVERSITY OF LISBON

Department of Economics

José A. Filipe, Manuel A. Ferreira and Manuel Coelho

The Relevance of Chaos Theory to Explain Problems of Overexploitation in Fisheries in Japanese Seaports

WP 24/2008/DE/SOCIUS

WORKING PAPERS

ISSN Nº 0874-4548

The Relevance of Chaos Theory to Explain Problems of Overexploitation in Fisheries

José António C. Bonito Filipe
ISCTE - Portugal
Edificio ISCTE
Av. das Forças Armadas, 1649-026
LISBOA, Portugal
Phone: +(351) 966058963, +(351) 217903411.
Fax: +(351) 217903941.
Email: jose.filipe@iscte.pt

Manuel Alberto M. Ferreira
ISCTE - Portugal
Edificio ISCTE
Av. das Forças Armadas, 1649-026
LISBOA, Portugal
Phone: +(351) 914970560, +(351) 217903240.
Fax: +(351) 217903941.
Email: manuel.ferreira@iscte.pt

Manuel Coelho
ISEG - Portugal
Rua do Quelhas, 6, 1200-781
LISBOA, Portugal
Phone: +(351) 213925800.
Fax: +(351) 213922808.
Email: coelho@iseg.utl.pt

Introduction

The Mankind's oldest concern inhabits necessarily on its survival. For thousands of years the Humanity always lived with an almost steady level in the way of living. Production followed the growth of the population. To the generality of the times and to the generality of the people, the historical rule was a life with the strictly necessary for the populations' day-to-day.

The development is an exception in the history of the Humanity that exists just for a period not longer than 250 years. The Humanity had never had a so significant, consistent and intense transformation in its History. In this period, a complete revolution in the life style of the world-wide population happened to the countries currently appointed as developed countries. However, its effects were not bordered to these zones. Its presence has been extensive to the whole world. In particular, with what it is assigned as external aid, the rich countries changed the stages of development of a great part of the globe, shortening the development stages of many countries and provoking several kinds of unbalances and disturbs (see, for example, what happened with vaccines on the field of health, with the pollution, with all the problems emerged on the feeding area and with other many forms of intrusion, with visible effects and heavy direct impacts).

This development represents a large step for the Humanity. The comfort, the best levels of health and the best standards of life correspond to a set of advantages which medal reverse represents so big costs that their effects we are not able to study yet.

It is not the progress and the development that may be contested but the way the societies do not find ways to get a supported and balanced development, respecting the principles of equity that must exist among our specie and the others.

Throughout the 20th century the extreme exploitation of resources brought out very big concerns about their preservation. Along the time the immoderation has shown the necessity of measures to avoid the depletion of many resources. That is why common resources become studied worldwide. Nowadays, they are an important subject to analyze resources problems. In the last few decades, international organizations have successively

looked for balances to the problem of fragile resources preservation and environmental questions, searching for solutions. The international agents and the private interests are numerous and the convergences seem to be traditionally very difficult. National and international organizations and States have seen the balances of life and resources on Earth to be frequently broken.

It is on the basis of the existence of this type of position divergences that we intend to analyze the framings and this idea relative to the Earth resources. Our study intends to conjugate the need of resources preservation (specially the common resources) with the perception of the way the involved agents face the subjects studied.

We intend to answer to the necessity of finding solutions that aim the preservation and the improvement of the conditions of life in society compatible with the environment.

The existing risks to the Humanity and to all the live resources require that some theoretical contexts are posed in a way that allow investigators to develop possible solutions and to find out the best ways to achieve them.

Many live resources, particularly many marine resources have suffered drastic reductions motivated by their overexploitation. Populations of many species have been led to the rupture and close to the extinction. How can Humanity modify this state of things? Is there a line of evolution that helps to explain this kind of events? How can we shape these facts in this perspective? Is there any ways to invert these trends? Or simply to find the principles that underline the facts? The main agents in this process may be questioned? The supranational institutions just emit simple indicative rules?

Dynamic systems and Chaos

The theories of dynamic systems have been applied to numerous areas of knowledge.

In the 80's, several exact sciences (physics, chemistry or biology, for example) and some social sciences (economics or management or even the sociology) still had their own objects of study and their own methods of analysis and each one of them was different from the others. The Science has been branched and specialized, so that each one uses to

have its own world. Recently new forms of analysis, looking for an integrated study have emerged (Filipe, 2006).

The theory of chaos and complexity theory itself reflect the phenomena that in many activities (such as fisheries) are translated into dynamic forms of analysis and reflect a very complex and widespread reality, specific of complex systems. That reality falls within a range of situations integrated in a broader context, which is expressed in the theory itself but also in terms of their own realities (fisheries, for example), dynamic, complex and often chaotic features in its essence.

The theory of chaos stresses that the world does not necessarily work as a linear relationship with perfectly defined or with direct relations in terms of expected proportions between causes and effects. The chaos occurs when a system is very sensitive to the initial conditions. These initial conditions are the measured values for a given initial time. The presence of chaotic systems in nature seems to place a limit on our ability to apply physical deterministic laws to predict movements with any degree of certainty. Indeed, one of the most interesting subjects in the study of chaotic systems is the question of whether the presence of chaos may or may not produce ordered structures and patterns on a wider scale. In the past, the dynamic systems showed up completely unpredictable and the only ones who could aspire to be understood were those that were represented by linear relationships, which are not the rule. On the contrary, there are some situations clearly isolated.

Today, with the help of computers, it is possible to make extremely complex calculations and to understand better the occurrence of chaos.

Many scientists see today, with particular interest, the theory of chaos as a way to explain the environment. Therefore, the theory of chaos stresses the fundamental laws of nature and natural processes and requires a course for a constant evolution and recreation of nature. The theory of chaos allows realizing the endless alternative ways leading to a new form or new ways that will be disclosed and that eventually emerge from the chaos as a new structure. The reality is a process in which structure and chaos rotate between form and deformation in an eternal cycle of death and renewal. Conditions of instability seem to be the rule and, in fact, a small inaccuracy in the conditions of departure tends to grow

to a huge scale. Basically, two insignificant changes in the initial conditions for the same system tend to end in two situations completely different. The ecology where many things are random and uncertain, in which everything interacts with everything at the same time is, itself, a fertile area for a cross search to the world explanations (Filipe *et al*, 2005).

Lansing (2003) states that the initial phase of the research of nonlinear systems was based on the deterministic chaos, and it was later redirected to new outbreaks of research focusing on the systems properties, which are self-organizing. What is called anti-chaos. It also says that the study of complex adaptive systems, discussed in the context of non-linear dynamic systems, has become a major focus of interest resulting from the interdisciplinary research in the social sciences and the natural sciences.

The theory of systems in general represents the natural world as a series of reservoirs and streams governed by various feedback processes. However, the mathematical representations were ignoring the role of these adjustment processes.

The theory of complex adaptive systems part of the theory of systems, although it has in specific account the diversity and heterogeneity of systems rather than representing them only by reservoirs. It explicitly considers the role of adaptation on the control of the dynamics and of the responses of these heterogeneous reservoirs. This theory allows ecologists to analyze the reasons inherent to the process at the lower levels of the organization that lead to patterns at higher levels of organization and ecosystems. The adaptive systems represent one of the means to understand how the organization is produced to a large scale and how it is controlled by processes that operate at lower levels of organization. According to Lansing (2003), came to be a general idea involving physical and mathematical complexity that is hidden behind systems very simple.

Considering a system composed by many interactive parts, if it is sufficiently complex, it may not be practical or even not be possible to know the details of each interaction place. Moreover, the interactions can generate local non-linear effects that often it becomes impossible to find a solution even for simple systems. However, diverting us from causal forces that move the individual elements, if we focus on the system behavior as a whole we can highlight certain global behavior standards. However, these behavior standards

may hide an associated cost: it can not be expected to understand the causes at the level of individual behavior.

Indeed, the systems do not match the simple decomposition of the whole into parts and therefore do not correspond to the mere sum of the parts, as living systems are not the juxtaposition of molecules and atoms. Since the molecule to the biosphere, the whole is organized and each level of integration leads to properties that can not be analyzed only from mechanisms that have explanatory value in the lower levels of integration. This corresponds to the appearance of new features to the level of the set that does not exist at the level of the constituent elements. Lansing (2003) believes that the adoption in the social sciences of the idea that complex global patterns can emerge with new properties from local interactions had a huge impact here.

The ecological systems are comparable to systems self-organized as they are open systems which arise far from thermodynamic equilibrium. On self-organized and self-regulated systems, the reciprocal interactions within the system between the structures and the processes contribute to the regulation of its dynamics and the maintenance of its organization; partly due to the phenomena of feedback (see Lévêque, 2002). These systems seem to develop themselves in accordance with the properties referred to the anti-chaotic systems. Indeed, we have auto-regulated systems that channel different initial conditions for the same stage, instead of what is happening with chaotic systems, which are very sensitive to initial conditions (see Kauffman, 1993). These systems would be relatively robust for a particular type of disturbance, to which the components of the system fit, creating a meta-stability that depends not only on the internal interactions within the system but also on external forces that can regulate and strengthen the internal factors of cohesion (see Lévêque, 2002).

Scoones (1999) argues that should be concluded a new commitment in research on the ecological new thinking and he develops its search precisely in the area of ecology around the concepts of chaotic dynamics and systems of non-equilibrium. In turn, Levin (2003) shows that in the study of complex adaptive systems anti-chaos involves the understanding of how the cooperation, alliances and networks of interactions emerge from individual behaviors and how it generates a feed-back effect to influence these behaviors within the spontaneous order and self-organization of ecosystems.

Chaos Theory and Fisheries

In order to frame some methodological developments, it must be mentioned, first of all, that some characteristics associated with some species support strategic survival features that are exploited by the present theory. Its aim is to find the reasons and the way in which these strategies are developed and the resulting consequences. The species use their biological characteristics resulting from evolutionary ancient processes to establish defense strategies.

However, given the emergence of new forms of predation, species got weaker because they are not prepared with mechanisms for effective protection for such situations. In fisheries there is a predator, man, with new fishing technologies who can completely destabilize the ecosystem. By using certain fisheries technologies, such as networks of siege, allowing the capture of all individuals of the population who are in a particular area of fishing, the fishers cause the breakdown of certain species, particularly the pelagic ones, normally designated by schooling species.

To that extent, with small changes in ecosystems, this may cause the complete deterioration of stocks and the final collapse of ecosystems, which in extreme cases can lead to extinction. These species are concentrated in high density areas in small space. These are species that tend to live in large schools.

Usually, large schools allow the protection against large predators. The mathematical theory, which examines the relationship between schools and predators, due to Brock and Riffenburgh (see Clark, 1974), indicates that the effectiveness of predators is a reverse function of the size of the school. Since the amount of fish that a predator can consume has a maximum average value, overcoming this limit, the growth of school means a reduction in the rate of consumption by the predator. Other aspects defensive for the school such as intimidation or confusing predators are also an evidence of greater effectiveness of schools.

However this type of behavior has allowed the development of very effective fishing techniques. With modern equipment for detecting schools (sonar, satellites, etc.) and with modern artificial fibers' networks (strong, easy to handle and quick placement), fishing can keep up advantageous for small stocks (Bjorndal, 1987; Mangel and Clark, 1983).

As soon as schools become scarce, stocks become less protected. Moreover, the existence of these modern techniques prevents an effect of stock in the costs of businesses, as opposed to the so-called search fisheries, for which a fishery involves an action of demand and slow detection. Therefore, the existence of larger populations is essential for fishermen because it reduces the cost of their detection (Neher, 1990). However, the easy detection by new technologies means that the costs are not more sensitive to the size of the stock (Bjorndal and Conrad, 1987).

This can be extremely dangerous due to poor biotic potential of the species subject to this kind of pressure. The reproductive capacity requires a minimum value below which the extinction is inevitable. Since the efficiency of the school is proportional to its size, the losses due to the effects of predation are relatively high for low levels of stocks. This implies non-feedback in the relation stock-recruitment, which causes a break in the curves of income-effort, so that an infinitesimal increase on fishing effort leads to an unstable condition that can lead to its extinction.

Considering however the fishing as a broader issue, we may consider the modeling of the stocks of fish on the basis of an approach associated with the theory of chaos instead considering the usual prospect based on classical models. Indeed, the issue can be placed within this framework from two different prisms: the traditional vision and the vision resulting from theories of non-equilibrium. Around the traditional Newtonian view, the facts can be modeled in terms of linear relationships: involving the definition of parameters, identifying relevant variables and using differential equations to describe the processes that change slowly over time. For a given system, it should then carry out measurements in a context that remains stable during various periods. Moreover, we may have models based on the theory of chaos. These models are based on non-linear relationships and are very close to several disciplines, particularly in the branch of mathematics that study the invariant processes of scale, the fractals, and in a huge range of other subjects in the area of self spontaneous creation of order: the theory of disasters or complex systems, for example.

The first way is largely used by the majority of biologists, economists and environmentalists, scientists and technical experts that conduct studies in marine search and senior technicians from state and transnational agencies in the area of fisheries. It

treats nature as a system, which has a regular order. But today there are many responsible for fisheries management who also base their decisions on models of chaos. The classical models center on a particular system and depend on a local analysis, studying several species, age, class, sub-regions of the marine eco-niche, the various ports and their discharges, depending on the account of an even wider range of other factors. Probably, the classic expression of linearity on the dynamics of the population (the principle that nature is orderly, balanced and that has a dynamic balance) is due to Maynard Smith (1968), which argues that the populations either remain relatively constant or regularly vary around an alleged point of balance. In the specific case of commercial fisheries, biologists believe that the fishing effort is often relevant to explain the deviations of actual populations' values for the model. They say that, specially based on studies made in the last decade, fish stocks sustainability should be ensured by the control made through fisheries regulation.

Moreover, some people see nature as not casual and unpredictable. The natural processes are complex and dynamic, and the causal relations and sequential patterns may extend so much in time that may seem to be non-periodical. The data appear as selected random works, disorderly, not causal in their connections and chaotic. The vision provided by nature leads to consider the fish stocks, time, the market and the various processes of fisheries management as likely to be continuously in imbalance rather than behave in a linear fashion and in a constant search for internal balance. It is this perspective that opens the way for the adoption of the theory of chaos in fisheries. However, the models of chaos do not deny, for themselves, some of the linearity resulting from the application of usual bionomic models. What is considered is that there are no conditions to implement all significant variables in a predictive model. Moreover, in finding that a slight change in initial conditions caused by a component of the system may cause major changes and deep consequences in the system itself. So, the application of the theory of chaos to fishing is considered essential, by many researchers. The theory of chaos depends on a multitude of factors, all major (and in the prospect of this theory all very important at the outset) on the basis of the wide range of unpredictable effects that they can cause.

Conclusions

Chaos Theory got its own space among sciences and has become itself an outstanding science. However there is much left to be discovered. Anyway, many scientists consider that Chaos Theory is one of the most important developed sciences on the twentieth century.

Aspects of chaos are shown up everywhere around the world and Chaos theory has changed the direction of science, studying chaotic systems and the way they work.

We can not say yet if chaos theory may give us solutions to problems that are posed by complex systems. Nevertheless, understanding the way chaos discusses the characteristics of complexity and analyzes open and closed systems and structures is an important matter of present discussion.

REFERENCES

BJORNDAL, T. (1987), «Production economics and optimal stock size in a North Atlantic fishery», *Scandinavian Journal of Economics*, 89(2).

BJORNDAL, T. and CONRAD, J. (1987), «The dynamics of an open access fishery», *Canadian Journal of Economics*, 20(1).

CLARK, C. W. (1974), «Possible effects of schooling on the dynamics of exploited fish populations», *Journal du Conseil Internatinal pour L'Exploration de la Mer*, 36(1).

FILIPE, J. A. (2006), *O Drama dos Recursos Comuns. Um caso de aplicação da Teoria dos Jogos aos comuns da pesca*, PhD thesis, ISCTE.

FILIPE, J. A., COELHO, M. e FERREIRA, M. A. M. (2005), «Sistemas Dinâmicos, Caos e os Comuns da Pesca»**.** *Revista de Economia Global e Gestão*. N.º 2/2005. ISCTE. Lisboa.

KAUFFMAN, S. (1993), «*The origins of order: self-organization and selection in evolution»*, Oxford Univ. Press, New York.

LANSING, J. S. (2003), «Complex adaptive systems», *Annual Review Anthropology*. http://www.ic.arizona.edu/lansing/GompAdSys.pdf.

LÉVÊQUE, G. (2002), «*Ecologia: do ecossistema à biosfera»*, Instituto Piaget.

LEVIN, S. (2003), «Complex adaptive systems: exploring the known, the unknown and the unknowable», *Bulletin of the American Mathematical Society*, 40.

MANCEL, M. e CLARK, G. (1983), «Uncertainty, search and information in fisheries», *Journal du Conseil International pour L'Exploration de la Mer*, 41.

MAYNARD SMITH, J. (1968), «*Mathematical Ideas in Biology»*, Cambridge University Press, Cambridge.

NEHER, P. (1990), «*Natural Resource Economics: Conservation and Exploitation»*, Cambridge University Press.

SCONES, I. (1999), «New ecology and the social sciences: what prospects for a fruitful engagement? », *Annual Review of Anthropology*, 28.