NON-LINEAR BEHAVIOR OF SOCIAL-ECOLOGICAL SYSTEMS

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ABSTRACT. – Non-linear behavior of social-ecological systems. Social-ecological systems are featured by a high complexity which to the non-linear dynamic, mutual feed-back cycles, lags, resilience, heterogeneity and surprises. These properties raise numerous puzzling aspects for the substantiation of decisions in ecological policies, in general, and in nature conservation, in special. From this topic, the paper addresses the non-linear behavior based on several case studies that pursue to relief the human made precursors for abrupt changes and ecosystem functioning. The practicality of information regarding social-ecological systems necessitate to acknowledge the change potential in terms of chaos or catastrophic model and to anticipate the results of system interaction with different model of changes.

Keywords: complexity, social-ecological systems, ecological thresholds, predictability

1. INTRODUCTION

Complex systems are characterized by an internal structure which is built up due to numerous and different processes, subsystems, and interconnections. The system theory, as a science of parts' integration evolved within the context of post-normal sciences emergence aiming to approach issues that have little predictability, are uncertain and lead to abrupt changes (surprises).

Complexity is determined a number of elements and interactions that are beyond the comprehension possibility of scientific methodology. Systems featured by complexity display a number of properties such as uncertainty, non-linear feedback, interactions among processes deployed at different scale, self-organization and emergence. Both ecological and social systems behave like complex systems, and this feature is recognizable at the next level, made up by the social-ecological systems. Two models describe these systems' change potential: chaos behavior and catastrophic model. The paper explains these behavior types and provide several examples of nonlinearities for social-ecological systems.

2. THEORY OF SOCIAL-ECOLOGICAL SYSTEMS

Human-nature relationship is represented by numerous and diverse conceptual models that express contradictory vision. The human-nature relation is featured by much scientific uncertainty even after several decades of research focus

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in this direction. Consequently, this relation subjected to wide and intense debates that led to the formulation of more conceptual models in the attempt to make a clear representation of key elements and relations occurring among them.

The theory of socio-ecological systems departs from the premise that accomplishing the objective of sustainability supposes the understanding of integrated socio-ecological systems' functioning. This model represents the human, social and natural dynamic as part of an integrated system in which there are obvious social-ecological interconnections and in which the limit between social and natural systems are artificial and arbitrary.

The model envisages shading light on the sources of changes that have the power to transform adaptive systems. The analysis targets economic, social, and ecological changes that undergo with different paths and at different spatial and temporal scales.

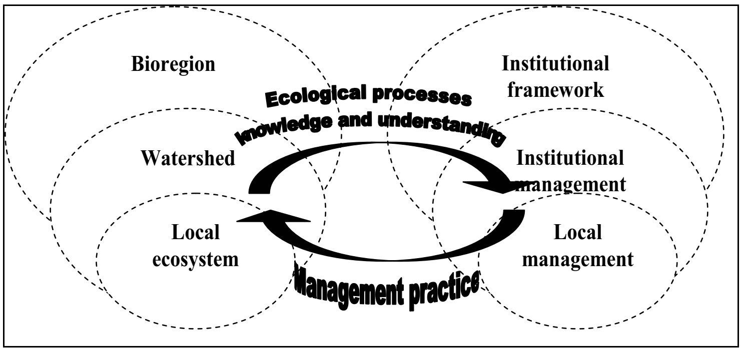

Fig.1. ***Socio-ecological systems*** ***(by Berkes and Folke, 2002)***

In fig.1 there is a visual representation of the socio-ecological system concept. There could be noticed the focus on the role of social learning. The components of the system's hierarchical structure are connected through the knowledge and understanding of ecological processes that are further translated in managerial practice. Meanwhile, there is not excluded the possibility of other change determinants to come into action.

The core concept of the socio-ecological systems model is the adaptive cycle of renewal. This was developed in order to explain the biological dynamic in ecosystems, being than used for the explanation of change in socio-ecological systems. According to this concept, ecological, economical, and social changes are produced through four successive phases of cycle, as follows:

- rapid increase and exploitation (the r phase);
- accumulation, monopolization and structure preservation (the K phase);
- rapid decrease or release (omega phase); and
- renewal and reorganization (alpha phase).

Through the theory of adaptive cycles the socio-ecological systems model proposes a dynamic concept that transcend spatial and temporal scales and allow the explanation of non linear changes. The purpose is to integrate the real ecological dynamic in the human anticipative behavior.

The concept of adaptive cycle of renewal were also used for explaining evolutionary change in ecology, economic change and business cycles in economy and for the cycles of development and fall of civilizations in history. The concept is criticized for its limited capacity to predict abrupt changes. The driving force of adaptive cycle is competition and it stems from the ideas of Charles Darwin, for nature, and of Adam Smith, for economy, and of Herbert Spencer for the evolution of human societies. The focus on competition could reduce the attention given to other factors and this ignores the power of cooperation, self-sacrifice, and reflection on values. Thus, it could be said that the model denies the human option for choosing values and priorities, others than the ones dictated by competition.

3. BEHAVIOR OF COMPLEX SYSTEMS

The traditional science paradigm relies on reductionism, meaning that phenomena, processes, and components are analyzed and reduced to simple elements in that will be studied in order to explain their behavior and also the behavior of the whole. This approach is dominant and underpinned the modern knowledge of the world. The complexity approach entered the science area and it applies a complementary view. This science of complexity envisage systems composed by many and varied parts that interact, typically in complex and non-linear ways.

Complexity means a system feature that does not allow a proper explanation by the analysis of its parts. The interactions among parts and the consequences of these interactions are equally significant. Therefore, traditional science is not able to provide the information needed for understanding the behavior of such system.

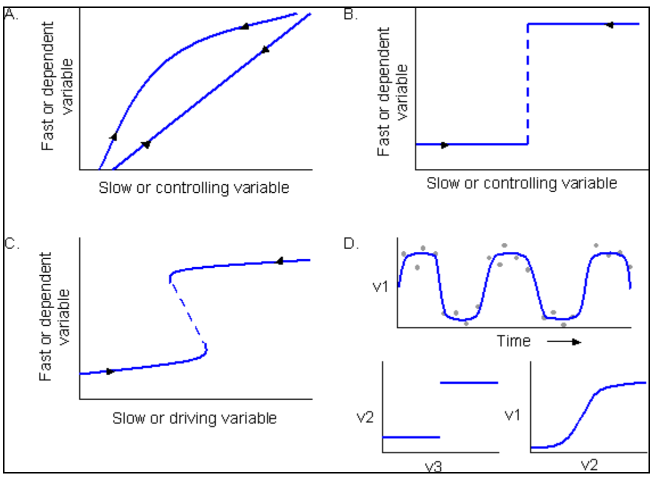

Fig.2. ***Kinds of changes that are possible in complex systems (by Walker and Meyers, 2004)***

The nonlinear behavior of complex systems was conceptualized in various forms (fig.2). It is noticeable that some changes are smooth (A), while others record thresholds in one (B,C) or more variables.

Although there are a number of characteristics of complex systems, such as uncertainty, hysteresis, interactions among processes deployed at different scale, self-organization and emergence, the non-linearity of their behavior poses most of the challenges for management. Rosser (2000) distinguishes two types of non-linear behavior: systems with chaos type behavior and systems with dynamic discontinuities or catastrophic behavior. In fact, the author puts these types in antithesis as long as sustainability implications are regarded. Chaotic systems are sustainable although there is little understanding about the mechanisms that provide this feature, while systems with catastrophic behavior present the threat of loosing this feature with no warning for their managers.

Another important aspect is the interchangeability of behavior types. Thus, systems with chaotic behavior could shift to the catastrophic one. Such shift could occur then more chaotic systems are coupled. Although individually they are sustainable, the coupled system they made up is no longer sustainable and has a catastrophic behavior. Social-ecological systems are coupled complex systems and therefore we could infer a catastrophic behavior with abrupt changes for them.

4. EXAMPLES OF NON-LINEAR BEHAVIOR

The existence of multiple stable states in complex systems was recognized long ago, especially by research done in the field of ecology. Muradian (2001) made a survey regarding ecological thresholds and made descriptions for five types: population harvesting, pollution, habitat fragmentation, ecosystem management and biological invasions.

Population harvesting is the most common direct intervention that trigger changes in ecosystem components. Meanwhile those involved in harvesting of natural ecosystems are keen to predict the evolution of target populations. Multiple stable populations are predicted using the predator-prey model. By applying this model the outcomes are in the shape presented in fig.3.

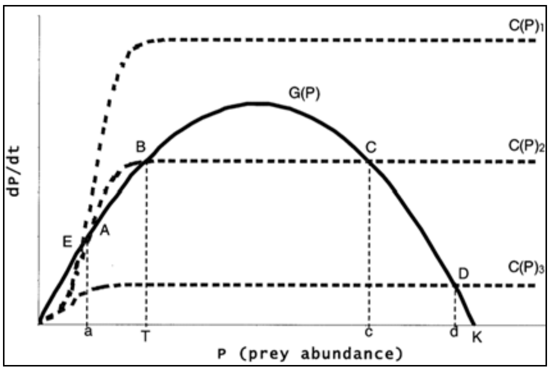

Fig.3. ***Multiple states in predator-prey interactions (by Muradian, 2001)***

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Pollution is an environmental change that could bring in discontinuities in ecological processes. The perturbation of nutrient cycling in relation with algal blooming is quite well documented in case of shallow lakes in temperate climate. Thus, these lakes have two stable states: one with clear water, dominated by vascular aquatic vegetation and a turbid states then algae (phytoplankton and cyanobacteria) is high. The shift from one state to another occurs than a certain level of nutrient concentration is reached. It was demonstrated that the recovery from turbid state necessitates a much lower concentration of nutrients than the value recorded in initial clear lake state. Although this evolution is demonstrated, research outcomes cannot bring in much to establish the actual value of the nutrient threshold. The complexity of interactions and the occurrence of stochastic events (e.g. hurricanes) are the main barriers for a better understanding of this ecological threshold.

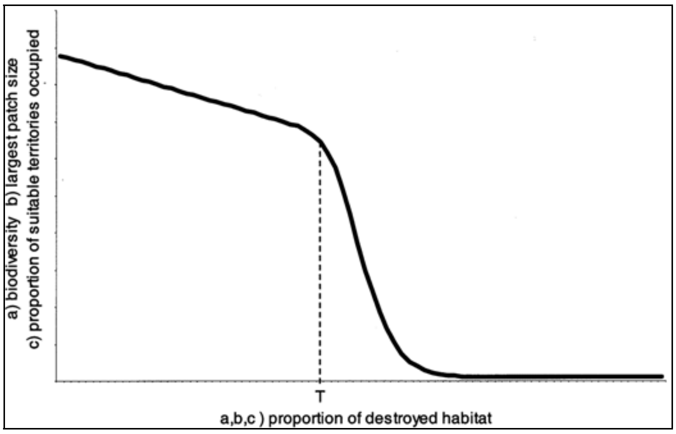

Fig.4. ***Habitat fragmentation and ecological threshold*** **(by Muradian, 2001)**

Habitat fragmentation is currently acknowledged as the most important driver of biodiversity loss (Ioan et al., 2010). The effect of habitat loss and/or fragmentation on populations could be described by an ecological threshold curve. The model of this relation is presented in fig.4.

The model relies on two theoretical developments about the ecological consequences of habitat fragmentation:

- Qualitative and quantitative changes of habitat along a gradient of fragmentation. Discontinuities occur than quantitative changes in the habitat size lead to qualitative shifts in the properties of the patches.

After a certain fragmentation threshold the effect of destroying another portion of the habitat is not longer quantitative, but qualitative since the original habitat starts to be broken in smaller patches. Further, the isolation and border effect strengthen the impact of habitat loss resulting in a faster reduction in population size;

- Meta-population dynamic. The ecological threshold is the minimum proportion of suitable habitat that is necessary for population persistence.

Nonlinearities and alternative stable states could be described in case of ecosystem management. For example in grassland ecosystems human intervention may favor the invasion of woody plants. It was documented (Perrings and Walker, 1997) that even in the case of reversing the favoring factors the change in species composition is not following. Once the woody plants have substituted grass cover, some positive feedback loops make their dominance very robust.

5. CONCLUSIONS

Predictability is an important feature that allows humans to interact among them and within the natural world. Enhancing our capacity to associate between drivers and effects, between causes and effects is the core challenge for science. Traditional approaches attempted to resolve it by analyzing components and inferring the behavior of their assemblage. At a certain point scientists recognized the limited explanatory power of this approach. Consequently, predictability was addressed from another perspective that acknowledges complexity.

Social-ecological systems are considered complex systems featured by a number of characteristics that hinder predictability. One of these is the nonlinear behavior that was explained and exemplified in this paper.

The social-ecological interactions could be described as nonlinear with thresholds in many cases. Nevertheless, the ecological science is now able to provide more information on the magnitude of change and much less on the threshold value. Although this drawback could be addressed by further research, it is likely that large uncertainties will remain due to the high complexity and the influence of stochastic variables.

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