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The management of complex sociobiophysical systems: Ecosystem-based management and the Chesapeake Bay Program

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The Management of Complex Sociobiophysical Systems:

Ecosystem-Based Management and the Chesapeake Bay Program

by

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Abstract

There are an entire class of entities for which conventional scientific understanding is necessary but not sufficient to comprehend. These entities are too complex for analysis and yet too organized for statistics. They exist in a dynamic balance between the ordered and the disordered. They are ecosystems and human institutions. They are complex systems. There is an emerging body of theory that is providing insight into the structures and dynamics that underlie such entities. Under the rubric of complex systems theory, catastrophe theory, chaos theory, hierarchy theory and the interrelated theories of self-organization have profound implications for the way understand the world around us.

The field of environmental planning and management exists along the boundary between two complex systems: the ecological and the human socio-economic. Until recently efforts to conserve, restore or even understand such complex sociobiophysical systems have been limited on a theoretical or even epistemological level. Complex systems theory is providing powerful heuristics for the management of human activities within such systems.

Current environmental management literature points to three themes or requirements for a systems-based or ecosystem-based approach to planning and management within complex sociobiophysical systems: systems-based science, ethical governance and adaptive management. These themes provide a framework for the integration of some of the most recent complexity theory-based planning and management heuristics in order to produce a new conceptual ideal for ecosystem-based management. This conceptual ideal is compared to an existing case example of adaptive, ecosystem-based management so that insights can be drawn.

The Chesapeake Bay Program (CBP), one of North-America's most studied and well-recognized examples of ecosystem-based management is examined and compared to the conceptual ideal developed. The program's officially mandated and operational scientific, governance and management perspectives are described. Strengths and limitations of the CBP are drawn from the comparison with the ideal ecosystem-based management perspective and conclusions and general recommendations for the further development of the approach are presented.

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Introduction, Methods and Outline

Introduction

> Science always evolves, responding to its leading challenges as they change through history. After centuries of triumph and optimism, science is now called on to remedy the pathologies of the global industrial systems of which it forms the basis. Whereas science was previously understood as steadily advancing in the certainty of our knowledge and control of the natural world, now science is seen as coping with many uncertainties in policy issues of risk and the environment. In response, new styles of scientific activity are being developed. The reductionist, analytical worldview which divides systems into ever smaller elements, studied by ever more esoteric specialism, is being replaced by a systemic, synthetic and humanistic approach
>
> - Funtowicz and Ravetz, 1993:739.

The power of the mechanistic, reductionist approach and claims of objective scientific 'truth' are being met with less and less confidence in the realm of environmental policy and decision-making. The traditional, mechanistic, dualistic Cartesian worldview, some have argued, has "contributed more to our lack of understanding than it has to useful understanding of the complexities and uncertainties of the interaction between modern human societies and their natural environment" (Slocombe, 1990:5). "It is not that the method is a poor one; rather, it has been argued that an analytic approach is simply not appropriate in dealing with an important class of entities" (Phillips, 1976:6).

More synthetic and systemic environmental planning and management perspectives are slowly becoming accepted as legitimate alternatives to the traditional analytical planning models. Adaptive and ecosystem-based management approaches, developed in recent decades, are examples of such an epistemological shift. However, more recently, analogies and heuristics borrowed from the literature on complex, self-organizing systems have been utilized to explicate emergent phenomena in social and biophysical systems. Conceptual models and planning methods or protocols are being developed to explicitly identify and analyze such macro-level spontaneous orders especially those that are manifest as human socio-economic systems and ecological systems interact (Slocombe, 1990; Rosser et al., 1994; Boyle et al., 1996; Kay et al., 1999).

Purpose and Goals

Purpose

- To study the scientific and organizational requirements of ecosystem-based management from a complex systems theory-based perspective

Goals

- Derive and summarize key requirements of ecosystem-based management from the relevant literature

- Augment these requirements with complexity theory-based heuristics and utilize these to provide a framework for an analysis of an existing, regional-scale case example of ecosystem-based management

It is the purpose of this thesis to study the scientific and organizational requirements of an archetype of ecosystem-based management from a complex systems theory-based perspective so as to demonstrate the heuristic potential of this perspective in the realm of environmental planning and management. In order to work towards this purpose it was first necessary to derive several key themes or requirements of ecosystem-based management from the current environmental management literature, these included:

- holistic systems-based scientific perspective
- inclusive, equitable, democratic governance framework
- an adaptive management approach

The other main goal of this thesis is to augment these themes or requirements with complexity theory-based heuristics and then apply them to an existing, regional-scale case example of ecosystem-based management. In order to do this, it is first necessary to clarify a philosophical/epistemological foundation for this new perspective on ecosystem-based management and ultimately describe the congruent scientific, governance and management approach. Running parallel to this, it is also important to gain appreciation of the historical and current sociobiophysical context of the case study. With this conceptual and general empirical foundation, the application of the complexity theory-based themes of ecosystem-based management can be utilized to analyze the Chesapeake Bay Program as a case example and ultimately to provide some insight into how the conceptual ideal can be translated into an operational reality.

Epistemological Foundations

Magorah Maruyama (1977, 1994) created a loose classification of epistemological types based on four general metatypes of causality. In this work he argued that as science has evolved over the last several decades a new type of epistemology has emerged based on what he called "morphogenetic causal-loop models, in which probabilistic or deterministic causal loops can increase heterogeneity, generate patterns of mutually beneficial relations (i.e. positive feed-back) among heterogeneous elements, and raise the level of sophistication of the system" (Maruyama, 1977: 75). This he contrasted with three more traditional epistemological types, these included: the H (Hierarchical) mindscape, Newtonian based, mechanistic, reductionist epistemology; the I (Individualistic) mindscape, an independent event epistemology having its basis in statistical mechanics and thermodynamics, that assumes the most probable state of the universe is random, unstructured, homogeneous states; and the S mindscape or homeostatic epistemological type which "developed during World War II with the use of error-correcting feedback systems in such devices as antiaircraft artillery connected with radar by computer" (Maruyama, 1994:3).

An analytical framework adapted from Maruyama (1977 and 1994) and Berman (1981) and Slocombe (1990) will be presented to compare and contrast these epistemological types and their implications for the practice of science. The ramifications of these mindscapes specific to environmental management will also be explored. For now, it is posited that the morphogenetic mindscape is the most appropriate for understanding many of the complex interactions between human socio-economic and biophysical systems and also for understanding the context that allows for the interplay of epistemological types in order to develop effective management and governance institutions.

Systems-Based Science: Complex Systems, Ecology and Environmental Management

More recent and perhaps less conventional heuristics and metaphors that have their basis in the morphogenetic worldview come from a wide variety of disciplines and subdisciplines; taken together they have been loosely grouped under the rubric complex systems theory or have even been dubbed the New Science. With diffuse origins in physiology and natural philosophy and organic holism, later crystalizing with Kohler's work in the nineteen-twenties and Ludwig von Bertalanffy's 'general systems theory' (GST) in the nineteen-sixties, a more synthetic, holistic, and systemic scientific gestalt has begun to emerge in response to the limitations of the analytical, reductionist, mechanistic scientific paradigm.

At the heart of this new scientific gestalt is a greater appreciation of complex, adapting, self-organizing wholes and their processes as well as their individual parts. This study of complexity or New Science refers to several interrelated theories including general systems theory, chaos theory, catastrophe theory, hierarchy theory, information theory and self-organization theory. It is the implications of these theories, and especially the last, for environmental planning and management that is the focus of this thesis.

The theories of complexity have implications beyond the disciplines in which they were developed (mainly physics, chemistry and biology). Several authors have explored the implications of these theories for socio-cultural and biophysical systems including, Jantsch (1978), Ulrich and Probst (1984), Zeleny (1985), Grzybowski and Slocombe (1988), Slocombe (1990, 1993), Zeleny and Hufford (1992), Hollick (1993), Kay (1984), Kay and Schneider (1994), Kay (1994), Boyle, Kay and Pond (1996), Kay and Regier (1999), Kay, Regier, Boyle and Francis (1999), Hwang (1996) and Bella (1997). Gryzbowski and Slocombe (1988:467) argued that "it is not hard to find analogues of these characteristics in human and natural systems". In fact, Jantsch (1979:19) contended that, "self-organization is the dynamic principle underlying the emergence of a rich world of forms manifest in biological, ecological, social and cultural structures".

Zeleny (1985:118) noted that social systems are "mixtures of deliberate arrangements of man-planner-designer, interacting with complex, spontaneously emerging orders, increasingly complex and important, made by no one, preconceived by no one, foreseen by no one". He asserted that, "both aspects - artificial and natural, man-made and spontaneous, designed and self-produced, simple and complex - should be studied in their interaction and mutual co-determination" (Zeleny, 1985:118).

C. S. Holling in his introduction to the book *Barriers and Bridges to the Renewal of Ecosystems and Institutions* (Holling, 1995: 3) noted that recent advances in understanding the way ecological systems are structured and function are changing our view of resource and environmental 'management'. He stated, "some of the attributes of ecological systems are really attributes of any complex, evolving system, so that they might also structure the functioning of the economies and institutions that interact, often in hidden ways, with ecosystems" (Holling, 1995:3).

Developed within a morphogenetic epistemology, these works, and many more to be explored in the literature review, highlight the notion that,

> complex, regional problems at the intersection of the biophysical and socioeconomic environments (i.e. in sociobiophysical systems) are underlain by nonequilibrium system dynamics; and . . . this has implications for understanding, planning, and management of these systems.
>
> - Slocombe, 1990: 1.

These concepts and heuristics not only provide us with new insights into the dynamics of complex sociobiophysical systems but also can provide guidance for the development of effective management and governance institutions.

Ethical Governance

As a result of the inherent uncertainty of such complex, self-organizing systems as well as the high decision stakes associated with planning and management within large-scale sociobiophysical systems many argue (Funtowicz and Ravetz, 1992, 1993, 1994; Oxley, 1997; Dempster, 1998; and Kay et al., 1999) that traditional expert-oriented decision-making can no longer be considered effective or, arguably, ethical. "The scientific process now encompasses the management of irreducible uncertainties in knowledge and ethics, and the recognition of complexity, implying the legitimacy of a plurality of perspectives and ways of knowing (Funtowicz and Ravetz, 1994: 1885). Developing decision-making and governance structures to accommodate such an 'extended peer community' will not be an easy task but should be considered a normative goal.

Towards this end, the relationship between science and policy-making within environmental management and planning regimes needs to begin to shift towards a less-technocratic more ethically responsible, inclusive perspective. Decision-makers need to take more responsibility for their policy-choices rather than forcing scientists into 'hyperobjective' technocratic or 'moral compass' roles. Scientists rather, should simply provide descriptions of system possibilities and allow governance bodies to make policy decisions based on this information as well as other stakeholder perspectives. Systems-based heuristics and concepts such as Ecological Integrity acknowledge the inherent complexity of ecological systems as well as allowing for multiple perspectives and should be considered valid management and governance criteria.

Adaptive Management

Given the complexity and uncertainty associated with sociobiophysical systems, traditional comprehensive, anticipatory management can no longer be considered a valid approach to environmental management and planning as science cannot provide adequate information to allow for the predictions upon which this approach is based. An alternative approach to management with complex systems is a recursive planning perspective, in which the management organization does not attempt to reduce the inherent uncertainty but simply acknowledges it and learns, as an organization, based on experience and experimentation. Adaptive management (Holling, 1978) is "learning by doing ... by treating program measures as experiments, it is possible to proceed more effectively in the future" (Lee and Lawrence, 1986:439). An adaptive management regime views systems as complex and uncertain in that, "projects are inevitably experiments ... given the current state of knowledge, no measure can be guaranteed to perform as intended" (Lee and Lawrence, 1986: 442). As well adaptive management acts "with the expectation of surprise" acknowledging that change "is a way to produce new knowledge" (Lee and Lawrence, 1986: 442). Finally, acknowledging the hierarchic (spatial and especially temporal) and evolutionary nature of systems, adaptive management often focuses on the long-term recognizing that "short-run human interests are often poorly aligned with the needs of the natural system" and that "measures may be limited in time, but management is forever" (Lee and Lawrence, 1986: 443).

Adaptive management not only requires a management institution to adopt a new scientific perspective but also a new organizational/management structure. Traditional bureaucratic, top-down management is not conducive to the organizational learning required for an adaptive management approach. However, on the other hand, this is not meant to imply that flexibility and adaptability are to be emphasized at the expense of organizational efficiency. In fact, much of the complexity theory-based organizational behavior literature implies that organizations exhibit a set of dynamics similar to that of ecosystems. As such, it would be most effective to synchronize these dynamics so as to provide the most appropriate management given the level of ecosystemic uncertainty.

Requirements of Ecosystem-Based Management

Ecosystem-based management models have set a precedent for, and have provided legitimation for, less conventional integrative, systemic perspective in environmental management. The recent environmental management and planning literature describes such management models in a variety of ways, referring to them as integrative resource management, adaptive management, an ecosystem approach to environmental planning or simply, ecosystem-based management. All however, have three common themes or requirements, systems-based science which explicitly acknowledges the inherent complexity and uncertainty of sociobiophysical systems; a recognition of the need for a new form of ethical governance, involving a new relationship between science and policy-making; and lastly, an experimental form of management involving continual organizational learning and managerial adjustment.

Estuarine Ecosystems: Managing Complex Sociobiophysical Systems

Estuarine ecosystems are highly complex, dynamic, and subject to many internal and external relationships that are subject to change over time. This creates conditions of extreme uncertainty and presents unique challenges for the design and management of governance systems

- Imperial and Hennessey, 1996: 116.

Estuarine ecosystems provide an excellent example of inextricably linked socio-economic and biophysical systems or sociobiophysical systems. These incredibly productive and beautiful ecosystems can provide almost limitless natural resources and attract increasingly intensive human settlement. One such sociobiophysical system that has been studied in great detail is the Chesapeake Bay ecosystem.

> The Chesapeake watershed comprises an ecological system whose beauty and productivity have led to high rates of human population growth and settlement. These high population growth rates have in turn, directly and indirectly, caused a troublesome infirmity, including declining fisheries, receding wetlands, vanishing seagrasses, and a devastated oyster industry. These trends have also led to a decline in the quality of human life . . . Because of the special characteristics of the Chesapeake Bay and its watershed, it is, at one and the same time, extremely productive, unpredictable, resilient, sensitive to stress, and hard to understand and manage with traditional methods
>
> - Costanza and Greer, 1995: 169-170.

Boynton (1997: 71) has noted that, "a key question, which includes both economic and ecological concerns, is how to manage these systems for sustainable outputs of inextricably coupled economic and environmental products and characteristics." Hennessey, (1997:201) would respond that, "given these characteristics of complexity and uncertainty, the management program design must incorporate the capacity to learn in order to adjust to new information as this becomes available". In 1976 the EPA established the Chesapeake Bay Program; during its two decades of existence the program has become a well-known and much studied example of adaptive, ecosystem-based estuarine management. The Chesapeake Bay Program provides an excellent case-study of adaptive, ecosystem-based management of a complex sociobiophysical system.

Methods

This thesis work began with an in-depth review of the relevant systems literature, along several themes, including: general systems theory and the epistemology of systems thinking; complexity and self-organization; systems ecology; and ecosystem-based methods of planning and management. This investigation, along with input from my advisor, led me to focus my exploration of a complex systems theory-based perspective on the much-heralded concept of adaptive, ecosystem-based management. Much of the recent environmental planning/management literature referred directly or at least indirectly to this concept, which is pervading main-stream environmental management institutions and organizations at various scales, including the International Joint Commission; the United States Environmental Protection Agency; the Maryland Department of Natural Resources; Environment Canada; and the Ontario Ministry of Natural Resources.

In order to effectively explore the heuristic potential of a complex systems theory-based perspective in the context of adaptive, ecosystem-based management, it was necessary to select an existing case example. Such an organization or institution should have most effectively and completely operationalized the concept ecosystem-based management. Aside from this more academic criterion, the case-study selection was also based upon the more pragmatic issues of access to information and travel expenses. Therefore, the selection was limited to North American case-studies.

The literature revealed several distinctive North American case-examples of adaptive, ecosystem-based management, the most obvious and most thoroughly documented of these were at the regional scale or larger (including, the Florida Everglades, the Chesapeake Bay, the Greater Yellowstone Ecosystem, the Great Lakes). While a comparative study of two or more of these would perhaps have been fruitful, time and logistic constraints limited this investigation to a single case study. Perhaps, such a comparative analysis could be explored in the context of a PhD program.

Of these case examples, the most recognized and well-documented were the Great Lakes and the Chesapeake Bay Program. The latter was chosen for its originality (less studied in this region than the near-by Great Lakes) and for its manageability (only involves local, state and federal governance levels not international as with the Great Lakes Initiative). Once the Chesapeake Bay Program was chosen as the primary case-study, a review of the relevant literature was undertaken (including paleo-ecology of the region, ecology of the region, human historical, socio-economic, socio-political, history and recent work of the Chesapeake Bay Program or CBP as well as recent analyses of the CBP as an adaptive, ecosystem-based management organization). With this complete, a field excursion to the Chesapeake area (Maryland) was organized for mid-May (1998) in order to attend a conference on Biodiversity Management in the Chesapeake Bay watershed; interview contacts in the Maryland Department of Natural Resources, the Chesapeake Bay Program, and the University of Maryland's Chesapeake Bay Biological Laboratories; and for general field reconnaissance and information gathering purposes.

This was an informative and rewarding experience. The interviews and informal meetings conducted provided this author with a more concrete perspective on the issues and problems associated with the practice of environmental management, especially in the context of

Chesapeake Bay ecosystem. More recently, follow-up interviews with several environmental management professionals in, and associated with, the CBP were conducted to obtain a more detailed organizational perspective of the program (i.e., the relationship between governance, management and monitoring). I was very fortunate to be able to acquire a very balanced view of the program, with several interviewees offering very positive, optimistic opinions of the CBP as well as several more candid, somewhat negative, even jaded views of the inadequacies of the program. All interviewees were very professional and offered invaluable insights.

Derived from the literature, the literature review and subsequent analysis of the CBP from a complex systems theory-based perspective were organized along three main themes (also the three requirements of adaptive, ecosystem-based management), systems-based science, the changing relationship between fact and values (ethical governance), and adaptive management. The analysis involved describing how the CBP had demonstrated the operationalization of these three requirements and how a complex systems theory-based perspective could provide greater insight into the dynamics of the ecological system, the socio-political or organizational system, and the complex relationship between these two systems. Recommendations for ecological study, environmental management initiatives and organizational changes and conclusions were drawn out of the analysis.

Outline

In order to set the context for an evaluation of the Chesapeake Bay Program (CBP) as a case example of adaptive, ecosystem-based management from a complex systems theory-based, post-normal perspective, the following literature review will begin with a description of the epistemological foundations of this perspective as it is compared to other, more traditional scientific world views. The remainder of the chapter will be structured along the three central themes or requirement of ecosystem-based management including, Systems-Based Science, Ethical Governance and Adaptive Management.

Chapter three will provide a description of the case example: the Chesapeake Bay Program. Not only will it provide a detailed history of the development of the CBP itself but it will also provide a general description of the area as well as many of the main environmental issues the Bay program was developed to address. Also included in this chapter will be an example of one of the many positive feed-back loops involved in this complex, self-organizing sociobiophysical system.

The actual evaluation of the CBP as an example of adaptive ecosystem-based management from a complex systems theory-based, post-normal perspective will be presented in chapter four. This chapter has also structured along the three requirements of adaptive, ecosystem-based management (systems-based science, ethical governance and adaptive management). After a brief introduction describing how the Bay program demonstrates aspects of all three requirements, the main limitations of the CBP's scientific perspective, barriers to organizational learning and ethical governance will be identified based on some of the latest complex systems-based ecological, governance and organizational behaviour literature available. Finally, chapter five will provide a short overview of the thesis followed by a concluding statement which will offer some insight into how the conceptual ideal presented might be operationalized in the context of the CBP and beyond.

Literature Review

Introduction

In recent decades, the fields of natural resource and environmental management and planning have grown and evolved with the advent of new approaches and procedures to more appropriately deal with the complexity and uncertainty inherent in environmental issues. Despite the various labels (environmental assessment, integrated resource management, adaptive management, an ecosystem approach, ecosystem-based management, to name just a few) an examination of these approaches reveals three main requirements for environmental planning and management: systems-based science, ethical governance and adaptive management.

Reflecting the irreducible and uncertain nature of environmental issues, management and planning within turbulent, interconnected ecological and socio-economic environments must be systems-based, ethical and adaptive. Systems-based in this sense refers to an acknowledgment of macro-level organization (the not just micro-level as implied in an atomistic perspective) inherent in complex, self-organizing systems such as ecosystems as a result the approach must be holistic as well as reductionist, focusing on structure as well as process, and thus, must be integrative and trans-disciplinary. Secondly, the relationship between facts and values must change to reflect the complexity, uncertainty and wide-spread repercussions of environmental issues. A new relationship between science and decision-making must emerge to acknowledge this complexity, resulting in a new form of ethical governance. And finally environmental management must be adaptive. Management organizations must experiment, learn and adjust to a dynamic sociobiophysical context. That is, due to the great uncertainty inherent in ecological and socio-economic systems the approach must be iterative, recursive or adaptive.

The following literature review is structured to first guide the reader through the philosophical groundings of a complex systems theory-based approach to environmental planning/management and then ultimately to describe the implications of such an approach for the science, governance and management of sociobiophysical systems. The first section is an in-depth discussion of the philosophical/epistemological/scientific foundations of this thesis work, describing the epistemological and theoretical bases and heuristic potential of a complex-systems theory-based perspective relative to other more traditional scientific world views. Three subsequent sections address the main themes or requirements of adaptive, ecosystem-based management previously mentioned (systems-based science, ethical governance and adaptive management). And finally, a concluding section is devoted to the concept of ecosystem-based management itself.

Epistemological Foundations: Systems, Complexity and the Philosophy of Science

> The true method of philosophical construction is to frame a scheme of ideas, the best that one can, and unflinchingly to explore the interpretation of experience in terms of that scheme ... all constructive thought, on the various topics of scientific interest, is dominated by some such scheme, unacknowledged, but no less influential in guiding the imagination. The importance of philosophy lies in its sustained effort to make such schemes explicit, and thereby capable of criticism and improvement
>
> - Whitehead, A., 1972.

In chapter 3 of his book *Life Itself*, Robert Rosen apologizes to his readers for taking them down to what he calls the 'basement' of the 'temple' or 'monument' of science. He notes that, "scientists, especially, are impatient with their basement of epistemology and ontology ... why take the time and trouble to descend and contemplate anew uncongenial things that were settled long ago" (Rosen, 1991: 39). However, he goes on to reassure his readers that "what we will do there will be of importance" (Rosen, 1991:39). In the context of this work, a visit to the 'basement' is especially important as the purpose of this thesis is to explore the implications of an unconventional scientific perspective for environmental planning and management. In this case I will be contrasting a complex systems theory-based world view with more conventional scientific philosophies. So as Rosen did, I too apologize for taking you down to the 'basement' of science but I also assure you it is very important, not only to the continuity of this thesis but in a more general sense, I am attempting to make explicit and legitimize the foundation of my work, something that is often taken for granted.

C. S. Lewis (1964: 222), in the epilogue of his book, *The Discarded Image* discussed the shifting of scientific models over the centuries. He suggested that we should, "regard all models in the right way, respecting each and idolising none ... no model is a catalogue of ultimate realities, and none is a mere fantasy". The purpose of this section is two-fold: to make explicit the philosophical (ontological and epistemological) underpinnings of this work to allow for criticism and improvement; as well as to acknowledge that the complex systems-based perspective investigated herein is not offered as a 'catalogue of ultimate realities', nor is it presented as a replacement paradigm, in the Kuhnian sense, to more conventional mechanistic, stochastic or cybernetic approaches, but merely as a complementary set of heuristics necessary, but not sufficient to comprehend the whole of reality. If we are to explore the implications of a complex systems theory-based worldview for environmental science and management and contrast this with current understanding and practice we must first look at the underpinnings of conventional scientific wisdom.

Modern, Normal Science

> The story of the modern epoch, at least on the level of mind, is one of progressive disenchantment. Form the sixteenth century on, mind has been progressively expunged from the phenomenal world. At least in theory, the reference points for all scientific explanation are matter and motion - what historians of science refer to as the 'mechanical philosophy'
>
> - Berman, 1984: 2.

> The world lies before us to be acted upon not merely contemplated
>
> - Bacon.

The ideas of men such as Bacon, Descartes, Galileo and, of course, Newton changed the way the human race understands and interacts with its physical environment. Changed forever was the way in which we as humans acquired knowledge of, and more fundamentally, how we view our relationship with the world around us. The modern, western scientific tradition rests on the twin epistemological poles of rationalism and empiricism, embodied in the works of Bacon and Descartes respectively. While Decartes' emphasis on the role of reason in obtaining knowledge is in sharp contrast to Bacon's emphasis on 'vexing nature' through experimentation, it was the union of these two epistemological perspectives in the works of Galileo and later Newton that formed the basis for modern, western science.

It was first the work of Galileo, and later Newton that clearly demonstrated the power of the synthesis of rationalism and empiricism. Galileo, although constrained by his social (mostly socio-religious) context, applied the twin tests of measurement and experimentation. His work demonstrated the heuristic power of distinguishing between fact and value. That is, not asking the often teleological and ontologically complicated question of 'why' but rather simply asking 'how'. For Galileo, his method was not "merely useful, or heuristically valuable but uniquely true" (Berman, 1984:28). His experiments with gravity and motion removed from scientific thought the notion of 'telos' or ultimate (divine) purpose ultimately resulted in his conflict with the Catholic church and conflict within himself.

Perhaps, mostly due to the changing social context brought about in no small part by Galileo's work, it is the name Newton with which most would associate the creation and development of the modern scientific world view. "Like Galileo, Newton combined rationalism and empiricism into a new method; but unlike Galileo, he was hailed by Europe as a hero rather than having to recant his views and spend his mature years under house arrest" (Berman, 1984:29). Despite Newton's attacks on the work of Descartes, one of Newton's main contributions, his laws of planetary motion are the result of the application of Cartesian atomism and mechanical philosophy. The notion of the universe as a 'machine' which can only ever be fully understood by objectively decomposing it into ever smaller parts is the essence of the modern, western scientific world view. However,

> the mechanistic world view, taking the play of physical particles as ultimate reality, found its expression in a civilization which glorifies physical technology that has led eventually to the catastrophes of our time. Possibly the model of the world as a great organization can help to reinforce the sense of reverence for life which we have almost lost in the last sanguinary decades of human history
> - Bertalanffy, 1972: 19.

Mechanisms, Aggregates and Systems

> It is not understatement to say that the mechanical analog has a particularly widespread and firm hold over how we view and practice science. Describing phenomena through the metaphor of the machine is the accepted (and to most the only) way of doing business.
>
> - Ulanowicz, 1997:3.

Many authors (including Weinberg, Berman, Rosen, Ulanowicz, Phillips etc.) have addressed the 'disenchantment', as Berman termed it, that has resulted from our Western culture's co-evolution with modern, 'normal' (reductionist, mechanistic) science. These authors have argued that while the pursuit of the modern mechanistic world view has yielded great success, its singular pursuit has limited our ability to fully understand an entire class of phenomena, systems.

Weinberg, in his book, *An Introduction to General Systems Theory*, provides a useful framework for discussing different types of phenomena and their relation to methods of thinking. Figure 1 provides us with a framework with which to discuss the need to expand (not simply deconstruct in the post-modern sense) our scientific world view to allow us to effectively explore the domain of 'organized complexity' or the realm of systems. Often described as the middle-number problem, Weinberg's notion of 'organized complexity' represents "the region too complex for analysis and too organized for statistics. This

Figure 1: Mechanisms, Aggregates and Systems

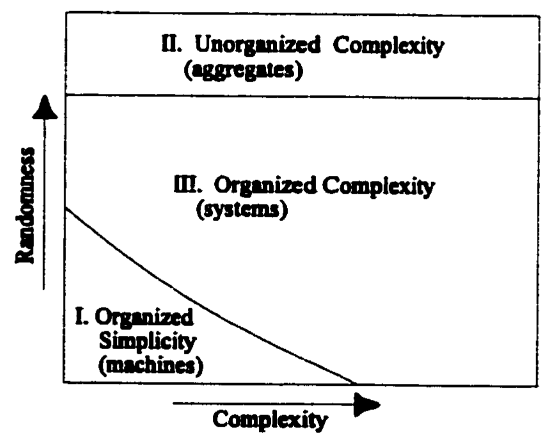


Figure 1
Region I is the region that might be called 'organized simplicity' - the region of machines, or mechanisms. Region II is the region of 'unorganized complexity' -the region of populations, or aggregates, as we shall call them. Region III, the yawning gap in he middle, is the region of 'organized complexity' - the region too complex for analysis and too organized for statistics. This is the region of systems - (Weinberg, 1975, pg. 18).

is the region of systems" (Weinberg, 1975: 19). Living systems, organisms, ecosystems, economies and even cultures are examples of such systems. To this point science has attempted to study these as mechanisms, by simplifying them (describing them as simple systems, machines) or by aggregating and averaging through statistical analysis (describing them as unorganized complex systems). However, both of these approaches, for the sake of mathematical tractability, remove the very complexity and macro-level organization which characterize this class of phenomena. Such entities often exist at a threshold between order and chaos, too complex to be treated as machines and too organized to be assumed random and averaged.

Since the Second World War, the concept of systems and systems thinking has developed and pervaded many fields of expertise and study. Along with structural-functional analysis in sociology and structuralism in the humanities, systems approaches, "sprang from the critique of some classical concepts and are in fact an attempt to find a way out of the crisis of classical science by formulating new guiding principles of scientific investigation" (Blauberg , et al., 1977: 15). These new principles of knowledge were in reaction to several of the main tenets of classical science, especially atomism, mechanism and scientific objectivity.

> There is a certain realm of phenomena where the analytic method is not successful - phenomena involving what they variously describe as 'wholes', 'organized complexities', or systems
>
> - Phillips, 1976:47.
>
> Although predominant forms of scientific thinking have, until now, been associated mostly with the elementalist doctrine, scientific knowledge as a whole has developed within the elementalism vs. integratism dichotomy, and the possibilities in this dichotomy have been far from exhausted
>
> - Blauberg, et al., 1977:18.

One fault of modern science has been its tendency to favor the analytical approach while neglecting the final stage of synthesis. Blauberg, et al. indicated three reasons for the dominance of the elementalist approach. First, they indicated that it is "the simplest and most natural method of investigation of an unknown object" (Blauberg, et al., 1977:16), that is decomposing the object, and studying its components in isolation, followed by a synthesis of the components. Secondly, the authors noted that the "realization of the elementalist principle brings about the discovery of fundamental unity of essentially different objects" (Blauberg, et al., 1977:17). They pointed to the laws of mechanics as being a dominant stimulant for all of classical science. Finally, they noted that "elementalism uses the logic of reasoning inherited from antiquity and based to a considerable extent on the Aristotelean schema of genus-to-species relationships" (Blauberg, et al., 1977:17). In spite of these factors and the success of the Cartesian method, Laszlo (1972:7) stated that on its own "reductionism generates a multiplicity of limited-range theories, each of which applies to a small domain of highly specific events, but says nothing about the rest".

Systems thinking or a systems approach can be seen as an attempt to reintegrate holism into scientific inquiry to acknowledge that these entities known as systems exhibit what have been termed 'emergent' properties, i.e. properties that emerge only when components are connected or interacting within a given context or whole. Blauberg , et al. (1977:18) indicated that "however sophisticated the analysis of the object under investigation may be, however important the reduction of reality being cognized to the primary, elementary-level units, the synthesis of these elements can never been complete, and it never is, unless some 'non-elementary' considerations are brought into play".

Systems Thinking, Holism and the Biological Sciences

The philosophy of holism, especially in the realm of the biological sciences, has often been associated, to its detriment, with the concept of 'vitalism' (the doctrine that life originates from an almost spiritual influence beyond physical forces). Any reference to macro-level organization within the biological sciences has been either met with ardent denial or at the very least strong skepticism. Rosen, in his book *Life Itself* (1991), discussed the concept of entailment (systemic or upper-level order or constraint) in evolutionary processes, noting the current biological world view's absolute denial of such macro-level processes. He (1991:256) noted that, "if we did admit entailment into the evolutionary realm, then only two alternatives seem visible: (1) these entailments are themselves mechanistic, in which case biology disappears back into mechanism again, and loses forever its distinguished character, or (2) these entailments are not mechanistic, which seems to mean they must be vitalistic". Rosen indicated that neither of these explanations were acceptable. Thus, the notion of entailment has been all but expunged from the evolutionary biologist's vocabulary, "not on any intrinsic scientific grounds, but because of the psychological requirements of biologists" (Rosen: 257).

Here Rosen referred to what Ulanowicz (1997) has called the 'schizophrenic' nature of the biological sciences. Though they attempt to study the holistic, systemic characteristics of the natural world biological scientists can not allow themselves to slip into the non-scientific, even mystical realm of vitalism. As a result, biologists and ecologists "are continually forced to shift perspectives abruptly from the stochastic world of Ludwig Boltzmann, where new genetic combinations arise, to the deterministic arena of Isaac Newton, where only those organisms with the fittest genes can be counted on to survive" (Ulanowicz, 1997: 4). However, an holistic perspective need not be considered mystical or non-scientific. Phillips, in his discourse on holistic thought in science (1976), differentiated three types of holism:

Holism 1 (organicism):

- analytical approach inadequate when applied to certain cases, example, biological systems.
- the whole is more than the sum of its parts
- the whole determines the nature of its parts
- the parts cannot be understood if considered in isolation from the whole the parts are dynamically interrelated or interdependent
- opposed by supporters of the analytic/mechanistic method

Holism 2:

- the whole, even after it is studied, cannot be explained in terms of its parts
- opposed by reductionism

Holism 3:

- it is necessary to have terms of reference to wholes and their properties
- acceptable to supporters of the analytic method and reductionism

It is not vitalism, but rather Phillip's third definition that best represents the conception of holism associated with a systems approach. Systems thinking is holistic in that it requires the practitioner to not discard the reductionist approach but to acknowledge that the components may behave and interact differently in different contexts, that is, they may exhibit emergent properties. Machines do not exhibit emergent behaviors. "The belief in reductionism, buttressed precisely by the machine metaphor, extrapolates these facts back to the entire universe; there is always a set of parts, into which any material system (and in particular, any organism) can be resolved, without loss of information" (Rosen, 1991:21). Systems thinking offers science an alternative to the machine analogue. The concept of a system offers the scientist an heuristic device, an analogy appropriate to Weinberg's realm of organized complexity, the realm too complicated to be a machine yet too organized to be aggregated and averaged.

The New Science

There exists an emerging and interrelated body of theory often referred to collectively as, the 'New Science' or complex systems theory including, chaos theory, catastrophe theory, hierarchy theory, and self-organization theories which are allowing scientists to begin describing the behaviour and dynamics of phenomena in Weinberg's realm of organized complexity.

Chaos theory (many contributors) attempts to account for the complex and unpredictable results that can occur in systems that are sensitive to their initial conditions. A common example of this is known as the Butterfly Effect. It states that, in theory, the flutter of a butterfly's wings in China could, in fact, actually effect weather patterns in New York City, thousands of miles away. In other words, it is possible that a very small phenomenon can produce unpredictable and often significant impacts at larger spatial and temporal scales as its effects concatenate (ripple up) through a system. Chaos theory reveals that complex systems are only predictable over a limited range as there are an infinite amount of small interactions and variations in initial conditions which lead to high uncertainty at large scales. However, based on knowledge of the history of the system, general trends can be predicted.

Catastrophe theory (Thom, R. and Husseyin) generally states that in complex systems the relationships between state variables are not always continuous, rather, some are often discontinuous. As a result, this theory reveals that the relationships between state variables often involve thresholds between the domains of different attractors. The movement around or between these states can be characterized as follows: there can be movement back or down a thermodynamic branch, there can be bifurcations along branches, or there can be flips to totally new thermodynamic branches (Kay, 1991a: 53). Catastrophe theory also implies that a system's current state depends on its history. Consequently, the qualitative prediction of potential future states becomes impossible without knowledge of the system's history (Kay, 1997 and Kay et al. 1999). Involved in this qualitative prediction are the concepts of divergence and multiple paths. Divergence refers to the fact that "two points in state space may be very close, but the system may diverge quite dramatically later on in its development" (Kay, 1991a: 53). Thus, even our ability to qualitatively predict the future direction of systems is limited.

Hierarchy theory (Herbert Simon, T.F.H. Allen) states that systems are composed of sub-systems, either in terms of the dynamic cycles which occur, or in terms of the physical structures involved, or in a mixture of the two. Upper levels of physical structures can be composed of the lower structures in the hierarchy. The upper levels may also have larger and/or slower processes, which act as the control or context of smaller and/or faster cycles below. This tells us that the behaviour of a system depends both on the interactions of its components as well as on its context within a larger system. Hierarchy theory also states that as one moves up or down hierarchical levels or as a system becomes more complex, properties can emerge that were not anticipated. Thus focusing on a particular level will miss phenomena at other levels which are important to the understanding of the whole.

The interrelated theories of self-organization (Prigogine, I., Haken, H.Eigen and Schuster, and Varela) "while employing different words and mathematical techniques, the elements and processes are similar: thermodynamic openness and organizational closure, feedbacks and cycles, nonlinear dynamics, complex internal structure, random fluctuations in system elements, and periods of macroscopic instability" (Grzybowski and Slocombe, 1988:465). The work probably most often associated with the term self-organization is that of Ilya Prigogine. Prigogine's work characterizes such open, non-linear systems as 'dissapative structures' revealing that complex systems work at an optimum level of exergy (quality of energy) dissipation. Systems dissipate exergy at a rate that will help them break down incoming exergy and increase entropy (in accordance with the second law of thermodynamics). The higher the exergy gradient imposed on the open system, the greater the level of organization developed by the system to break down the exergy, and increase its own internal order (Kay, 1984). As a system becomes more organized, the more exergy is required to move it further away from thermodynamic equilibrium. Consequently, attempts to maximize or minimize within systems tend to imbalance the trade-offs established by the system, and may cause the self-organizing phenomena to degrade and collapse, or to be pushed into the domain of another attractor (Kay, 1994: 10).

Hollick (1993:622) has provided a concise overview of the characteristics essential for systems to be self-organizing and highlights three main properties of self-organizing systems.

- It must be far from equilibrium.
- It must be governed by recursive application of internal rules. In other words, its state in the next time interval must be determined by the application of fixed rules to its state now. This is the basis for computer simulations of dynamic processes.
- At least some of its rules must be non-linear.
- It must have some positive feedback loops so that there is the potential for small changes to be amplified.
- It must be able to exchange energy with its surroundings in order to maintain its structure against the natural increase of entropy.

Properties of Self-Organizing Systems

- The whole is greater than the sum of the parts. The behaviour of a self-organizing system cannot be deduced from that of its constituent parts and the rules by which they interact.
- They are self-controlled within larger constraints. The term holon is used to describe certain types of systems. A holon is an independent, autonomous entity when viewed from the perspective of its constituent subsystems, such as

an animal from the viewpoint of an organ. However, the same holon viewed from a larger scale appears as simply a component of the larger system, e.g., an animal in an ecosystem.

- They evolve. A self-organizing system evolves in the sense that the system's structure and relationships change with time so that its behaviour changes irreversibly. Evolution is caused by random fluctuations originating in the environment or internally.

Complex systems theory taken as a whole has important implications for the philosophy of science, and for the practice of science itself.

Characteristics of Complex Systems

- Non-Linear: Behave as a whole, a system. Cannot be decomposed into pieces which are summed together to give system.
- Hierarchical: Cannot be understood by focusing on one hierarchical level (holon) alone.
- Multiple Steady States: There is not necessarily a unique preferred system state.
- Catastrophic Behaviour: The norm,
  Bifurcations: unpredictable behaviour
  Flips: sudden discontinuity
- Chaotic Behaviour: our ability to forecast and predict is always limited, for example to about five days for weather forecasts, regardless of how sophisticated our computers are and how much information we have
- Self-Organizing: characterized by phases of rapid organization to a steady-state level followed by a period during which the systems maintains itself at the new steady-state

- (Kay et al. 1999).

Complex systems theory provides the basis for a new and evolving scientific world view which is providing powerful insights into these entities too complex to be analyzed as machines and too ordered to be assumed completely chaotic and statistically aggregated. The following section describes this new scientific world view by juxtaposing it with three more traditional scientific perspectives.

Scientific Worldviews

In his work on causality in science Maruyama described four of what he terms 'mindscapes' or philosophies of science. While this set of epistemological types is by no means exhaustive or absolute this framework does provide the reader with a distinction between a complex systems world view and more traditional scientific mindscapes.

Maruyama's 'H' mindscape can logically be linked to a 'Cartesian' (atomistic, mechanistic) scientific approach. It is the worldview most appropriate for Weinberg's realm of 'organized simplicity'. It is the view of the universe as a machine which can be understood simply by dismantling it and studying its components in detail. Maruyama's second mindscape is the 'I' which can be linked to a more 'stochastic' scientific perspective which views the world through a nominalist lense. This is the scientific approach that gave birth to the statistical analysis appropriate to Weinberg's second realm of 'unorganized complexity'. The final two of Maruyama's mindscapes ('S' and 'G') describe two related scientific perspectives applicable to Weinberg's third realm of organized complexity. Both are systems-based, however the 'S' or cybernetic worldview is limited as it only describes a subset of the phenomena (negative feedback) described by the 'G' or complex systems worldview. Figure 2 compares these four epistemological types in terms of several characteristics including their basic philosophy, metatype of causality, fundamental structure of nature and perspective on change.

Figure 2: Mindscapes

Characteristic				
Mindscape	**H**	**I**	**S**	**G**
Worldview	**Cartesian**	**Stochastic**	**Cybernetic Worldview**	**Complex Systems Worldview**
Philosophy	Universalism: Abstraction has higher reality than concrete things Organismic: The parts are subordinated to the whole.	Nominalism: Only the individual elements are real. Society is merely an aggregate of individuals	Equilibrium or cycle: Elements interact in such a way as to maintain equilibrium or go in cycles.	Hetergenization, Symbiotization and Evolution: Symbiosis thanks to diversity. Generate new diversity and patterns of symbiosis.
Metatype of Causality	Nonreciprocal causal model - two things cannot cause each other. Cause-effect relations may be deterministic or probabilistic - 1978	Independent events are most natural, each having its own probability. Non-random patterns and structures are improbable, and tend to decay.	Homeostatic causal-loop model - structures and patterns of heterogeneity are maintained by homeostatic causal loops -1980	Morphogenetic causal loop model - Morphogenetic causal loops generate patterns of mutually beneficial relations among heterogeneous elements, and raise level of sophistication of the system - 1980
Fundamental Dynamics	deterministic and causal	acausal, stochastic	nondeterministic with multiple causation, characterized by equilibrating -ve feedback	fundamentally stochastic; nonlinear interactions creating uncertainty and instability or creative self-organization and order at macroscale, characterized by self-organization and +ve feedback

Characteristic				
Mindscape	**H**	**I**	**S**	**G**
Worldview	**Cartesian**	**Stochastic**	**Cybernetic Worldview**	**Complex Systems Worldview**
Cosmology	Causal Chains. Hierarchy of categories, supercategories and subcategories. "one-ness" with the universe. Processes are repeatable if conditions are the same.	The most probable state is random distribution of events with independent probability. Structures decay.	Equilibrium by means of mutual corrections, or cycles due to mutual balancing. Structures maintain.	Generate new patterns by means of mutual interaction. Structures grow. Heterogeneity, differentiation, symbiotization and further Hetergenization increase.
Reductionist	Yes	Yes	No	Both: analysis and synthesis upper and lower constraints
Certainty	sought and expected; use of experts	none	sought but not expected? use of generalists	neither sought nor expected; specialized generalists
Fundamental Structure of Nature	Atomic - separable into fundamental smallest parts	Stochastic	Holistic - focus on process not structure	Holistic - structure and process; connections create self-organization
Information	The more specified, the more information. Past and future inferrable from present probabilistically or deterministically	Information decays and gets lost. Blueprint must contain more information than finished product. Embryo must contain more information than adult.	Loss of information can be counteracted by means of redundancy or by means of feedback devices.	Complex patterns can be generated by means of simple rules of interaction. The amount of information needed to describe the generated pattern may be greater then the amount of information to describe the rules of interaction. Thus amount of information can increase.

Characteristic				
Mindscape	**H**	**I**	**S**	**G**
Worldview	**Cartesian**	**Stochastic**	**Cybernetic Worldview**	**Complex Systems Worldview**
Emergence	No	No; possibly statistical, even so any emergent structure will inevitably degrade	Yes	Yes
Perspective on Change	avoided through abstraction	inevitable	change recognized through process focus	change central and characteristic
Types of Change	incremental, linear change	stochastic change, random variability	linear and stochastic change, however, random variability corrected by -ve feedback loops	linear, stochastic and non-linear change, random fluctuations can be amplified by +ve feedback loops
Implications for Conceptual Models	Hierarchic structure, linear change, reductionist epistemology, one right or true model - goal: prediction	Independent events, order decays, stochastic change - goal: maintain individual autonomy	Homeostatic system models "nature in delicate balance", linear and stochastic change -goal: maintain balance	Non-equilibrium system models, linear, stochastic and non-linear change, nature is dynamic and evolving - goal: maintain context for self-organization

- after Maruyama, 1977, 1994 and Slocombe 1990.

It is important to note that the presentation of this framework is not meant to represent paradigms evolving from the left column over to the right, instead it is posited that each of these mindscapes is necessary but not sufficient to comprehend reality. This framework does provide a structure for the discussion of the implications of these epistemological types for the science of ecology and the practice of environmental management. Following this, will be a discussion of the implications of a complex systems worldview for the practice of science in general and its role in decision-making and policy development.

Systems-Based Science:
Complex Systems, Ecology and Environmental Management

The science of ecology is approaching a cross-road. "Present-day ecology, including modeling, is failing to produce an adequate science of large-scale, unbounded and interconnected complexity that exists as a fundamental property of the world's ecosystems. These systems cannot be reduced to component mechanisms without losing the essence of their holism. The challenge of irreducible complexity and breaking the riddle of wholeness cannot be met by the mechanistic reductionism of traditional science" (Jorgensen , et al., 1992: 3).

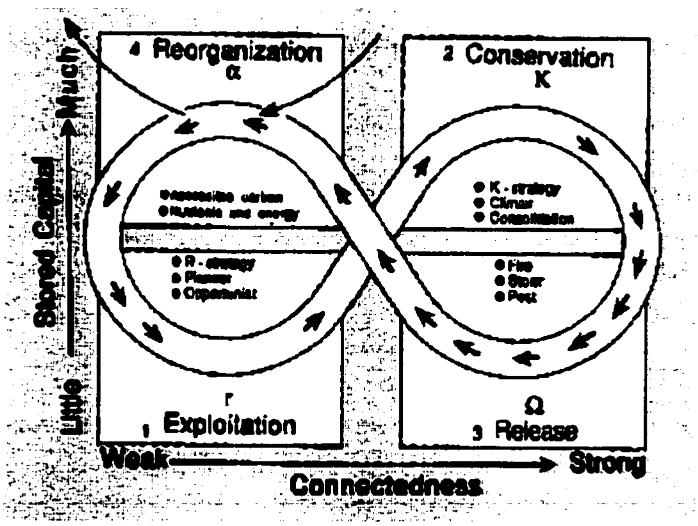
There has, almost since its beginnings, existed a deep schism in the science of ecology, between the Gleasonian ecologists (reductionist, species or population-based) and Clementsian ecologists (holistic, stable ecosystem-based). These ecological doctrines can be linked to two of Maruyama's mindscapes. The Gleasonian ecological doctrine, having its basis in a nominalist philosophy (i.e. macro-level order does not exist; only individual behaviour is of consequence), can be linked to an 'I' mindscape. By contrast, the more organismic, cybernetic, Clementsian ecological worldview can be said to exemplify an 'S' mindscape. Even the mechanistic 'H' mindscape has been utilized in ecology, in the work of Howard Odum. However, "stimulated by recent demands on ecology to provide more effective bases for resource management and attacking environmental problems, many ecologists have seized upon systems analysis as the wave of the future" (McIntosh, 1976: 364).

Using the idea of a system in ecology has its roots in the organismic Clementsian ecological worldview (e.g. an 'ecosystem'; coined by Sir Arthur Tansley in 1935). However, systems thinking and more recently complex systems theory are moving the science of ecology beyond the cybernetic organism analogy, approaching the study of ecosystems from a 'G' mindscape. This view of ecosystems as complex systems is providing new insight into the dynamics of ecological systems, drawing upon recent theoretical developments and offering a new context for more traditional thinking.

The work of C. S. Holling, as well as other systems ecologists including, Kay, Ulanowicz, Conrad and Allen and others represent a new ecological worldview. They document the macro-order which results from micro-level interactions using community systems ecology, thermodynamic/self-organization, hierarchic and information theoretic perspectives respectively. All of these stem from an understanding of ecosystems as complex systems. Obviously, it is not possible to summarize the works of these authors in a single section or even in a single thesis, however an attempt has been made to capture the one or more key element(s) of their works deemed integral to this work.

Holling has developed a conceptual model of ecosystems which is based on the notions of complexity. His four-box or figure-eight model of ecosystem dynamics requires understanding gleaned from all four of Maruyama's mindscapes (see Figure 3). It incorporates the Clementsian theory of linear succession ('S' mindscape) to a highly ordered climax state (Phase 1 Exploitation to Phase 2 Conservation). As well, it allows for Gleasonian independent, species-level and below, disordered behaviour (I_H

Figure 3: Holling Figure-Eight



mindscape) to influence ecosystem function (esp. between the Reorganization and Exploitation phases and throughout the Exploitation phase). This conceptual model has profoundly changed how ecologists and environmental managers view the dynamics of ecosystems. Instead of viewing events such as fire, storm or pest outbreaks as 'natural disasters' they are simply seen as another phase in the cycling of nutrients and carbon through an ecosystem.

Holling's four-phase dynamic can be seen as an example of self-organization within an ecosystem. Based on the work of Ilya Prigogine, James Kay (1984, 1991a, 1991b, 1994, 1999) has described ecosystems as large 'dissipative structures' similar to, but obviously more complex than the vortex that appears in any bathtub as it empties. Ecosystems dissipate or degrade energy gradients with the spontaneous emergence of macro-level organization exemplified by the Holling Figure-Eight model. These self-organizing systems are also characterized by abrupt changes or 'flips' between the domains of 'attractors'. That is, if the context of the ecosystem is altered in any way (e.g. change in the amount or quality of energy, nutrients etc. entering the system), the system may 'flip' into the domain of another attractor, in this case another Holling loop. Qualitative and even limited quantitative predictions about the behaviour of a system around a single attractor are possible and very useful. However, as Schneider and Kay (1994) indicate,

> the form of expression this self-organization takes on is not predictable in advance because the very process of self-organization is by catastrophic (in the catastrophe theory sense) change ... (that is) systems may have several possible behavioural pathways available at a catastrophe threshold.

Although quantitative predictions are possible over a very limited range, long-term quantitative predictions about the behaviour of ecological systems are impossible. Ecosystems in this sense can be seen as self-organizing entities, existing at 'the edge of chaos', "in a middle ground of enough, but not too much" order (Schneider and Kay, 1994: 35) or in a dynamic tension between order and disorder.

In his book, *Ecology, the Ascendent Perspective* (1997) Dr. Robert Ulanowicz has described this tension between order and disorder within ecosystems using his notion of 'ascendency'. He has argued that ecosystems require a unique balance between 'ascendency' (ordered, mutually reenforcing elements of a system, species that maintain normal operations, processes in an ecosystem) and 'overhead' (disordered residual, species less involved in normal operations). Ulanowicz (1997) stated, "there is a fundamental incompatibility between ordered and disordered fractions - yet they are complementary aspects of what is essential to sustaining the operation and persistence of the system". The ascendent fraction of an ecosystem at a given scale maintains the system's health under normal conditions whereas the overhead provides for adaptability in the face of change and it is the dynamic tension between the two that allow the system to continue to self-organize and evolve.

With its philosophical groundings in the later work of Karl Popper and integrating aspects of Newtonian science, Ulanowicz's notion of ascendency represents a 'G' mindscape ecological tool that even the most ardent 'H' mindscape thinker could accept. Dr. Ulanowicz has used Popper's notion of 'propensity' as alternative to the notion of a Newtonian 'force'. Viewing ecosystems as causally 'open' Ulanowicz (1997: 8) quoted Popper (1990) stating, "the deterministic realm where forces and laws prevail is but a small, almost vanishing subset of all real phenomena ... Popper's is not the schizoid world of strict forces and stochastic probabilities, but rather a more encompassing one of conditional probabilities that are always influenced by their context or environment". The truly exciting aspect of Ulanowicz's work with Ascendency is the ability to quantify (using information theory) the ascendency, overhead and capacity of a given ecosystem allowing the ecologist or resource manager an understanding of the 'developmental status' and integrity of the system not possible with conventional ecological tools (discussed further in the case study analysis).

Also addressing the relationship between order and disorder in ecological systems is Conrad's (1983) seminal volume *Adaptability*. The main idea behind Conrad's adaptability theory is that,

> for every biological system there is an ensemble of modes of allowable behaviour which is consistent with its functional integrity and which underlies fundamental biological phenomena: reliability, transformability, stability and instability, and, in different disguises, all the different modes of genetic, phenotypic, populational and community adaptability. The larger the ensemble, the greater the adaptability
> - Conrad, 1983:236.

Conrad (1983: 56) notes that adaptability has three main components:

1. Behavioural uncertainty - represents the potential behavioural uncertainty because it is a measure of ensemble of possible modes of behaviour of the biota.
2. Ability to anticipate - is the potential tolerance for decorrelation of the biota from the environment, i.e., the biota's inability to anticipate the state of the environment
3. Indifference - is the potential tolerance for decorrelation of the environment from the biota, i.e., the biota's potential for insensitivity or *indifference* to the environment. This indifference may be either selective , in which case the system avoids harmful features of the environment, or nonselective, in which case it misses out on useful features. Nonselective indifference is error.

This parallels Ulanowicz's four elements of 'overhead' (or disordered elements which allow for adaptability). Ulanowicz (1997) identifies four flows which generate overhead in systems:

1. Inputs - exogenous imports modulated both by the magnitudes of the inputs and their multiplicity
2. Dissipations -the more dissipative loss (i.e., dissipation of energy) the less efficient the system, the more overhead.
3. Exports - if some dissipations represent necessary encumbrances at lower hierarchical levels, it could be expected that exports of usable currency generate overhead that is demanded by higher levels.

4. Internal Transfers - this involves the redundancy of intrasystem flows, the more redundancy the more overhead.

Ulanowicz's 'internal transfers' is an obvious parallel for Conrad's 'behavioural uncertainty', both represent a system's internal redundancy of flows or possible modes of behaviour. The other components or flows which generate adaptability represent the elements of adaptability that are generated as a result of the relationship between the system and its environment. Conrad's 'ability to anticipate' and 'indifference' measures characterize or describe the nature of the relationship across the system/environment boundary, whereas, Ulanowicz's 'imports', 'exports' and 'dissipations' are descriptions of the actual flows across the boundary.

Both of these descriptions of the elements of adaptability provide ecologists and resource managers with valuable information on what aspects of a system to monitor in order to maintain and perhaps alter the adaptability of an ecosystem. It could also provide practitioners of adaptive management keys to maintain the adaptability of their institution/organization.

T. F. H. Allen's (1982, 1992) work relating insights from hierarchy theory to dynamics of ecosystems highlights the holistic, irreducible nature of ecological systems. One of the major themes of this work is the concepts of scale and type. Scale refers to the notion that larger, and in general slower elements of a system constrain smaller, faster elements; essentially that the parts do not determine the whole. While elements lower in a hierarchy may provide the potential of a system, the higher components in a hierarchy constrain this potential. Again, we see elements of order and disorder in dynamic tension in ecological systems. Allen used Koestler's (1967) concept of a 'holon' to describe such systems.

> Every holon has a dual tendency to preserve and assert its individuality as a quasi autonomous whole; and to function as an integrated part of (an existing or evolving) larger whole. This polarity between self-assertive and integrative tendencies is inherent in the concept of hierarchic order; and a universal characteristic of life. The

self-assertive tendencies are the dynamic expression of holon wholeness, the integrative tendencies of its partness - Koestler, 1967: 343.

Complementary to the notions of scale and nested holons, Allen's work also provides us with the concept of type. A systems related concept, type refers to the different varieties of systems that can exist simultaneously in a given situation or context. Allen , et al. have provided a simple example in the 1993 report to the Great Lakes Science Advisory Board, entitled "The Ecosystem Approach: Theory and Ecosystem Integrity". The authors described the same town from four different perspectives, the material system (buildings and people), the sewage system, the economic system, and as a sparrow habitat. All are valid descriptions of the town and all require separate boundaries and analyses. However, as with the scalar considerations, dynamics across types are not simple and an analysis of these can provide powerful insight into a situation. Cross-type communication is often hampered by disciplinary and institutional boundaries (Kay, 1993; Slocombe, 1993).

This is the science appropriate to complex ecological systems. More so than the other three mindscapes, Maruyama's 'G' perspective provides new and fresh insight into the dynamics of complex ecosystems. More complex than machines yet too organized to be considered completely stochastic, ecosystems exhibit the characteristics of complex systems. They are non-linear, hierarchic, self-organizing systems that exhibit multiple steady states, catastrophic and even chaotic behaviour.

Complex Sociobiophysical Systems

Ecological systems are not the only systems that tend to exhibit such complex behavior. In fact, Jantsch (1979:19) contended that, "self-organization is the dynamic principle underlying the emergence of a rich world of forms manifest in biological, ecological, social and cultural structures". Holling (1995: 3) furthered this argument when he noted that,"some of the attributes of ecological systems are really attributes of any complex, evolving system, so that they might also structure the functioning of the economies and institutions that interact, often in hidden ways, with ecosystems". In the opening chapter of his book *At Home in the Universe* Stuart Kauffman (1995:15) affirmed Holling's notions when he stated,

> from ecosystems to economic systems undergoing technological evolution, in which avalanches of new goods and technologies emerge and drive old ones extinct. Similar small and large avalanches even occur in evolving cultural systems. The natural history of life may harbour a new and unifying intellectual underpinning for our economic, cultural, and social life.

Kauffman asserted that all 'living systems' (ecosystems, economies, socio-cultural systems) are complex, self-organizing, non-equilibrium, adapting systems and act as what Ilya Prigogine called dissipative structures, dissipating energy and matter to maintain their structure.

Isomorphic insights are emerging in literature on the complex dynamics of human social and organizational systems. Human socio-economic systems can be seen as complex, self-organizing systems exhibiting a tension between order and disorder (esp. Bella, 1996, 1997a, 1997b; Holling 1978, 1995; Zeleny, 1985, 1992). Holling's four-box or figure-eight conceptual model of ecosystem dynamics has implications beyond the ecological. "It is this view of alternative phases in a cycle of birth, growth, death, and renewal that seems to underlie any complex adaptive system - ecological certainly, but human, institutional, and societal as well" (Holling, 1995: 25). Therefore, it is "those institutions that have developed policies that induced a rhythm of change, with periods of innovation followed by consolidation and back again, maintain a flexible and adaptive response" (Holling, 1978:36).

Milan Zeleny, in his work on 'spontaneous social orders' described human social systems as "mixtures of deliberate arrangements of man-planner-designer, interacting with complex, spontaneously emerging orders" (Zeleny, 1985:118). He argued that, "both aspects - artificial and natural, man-made and spontaneous, designed and self-produced, simple and complex - should be studied in their interaction and mutual co-determination" (Zeleny, 1985:118). His thesis argued against the overuse of a static, reductionist approach in the study of social and economic phenomena. His argument, similar to that of the 'G' mindscape ecologists above, was that there are self-creating macro-level orders which act to constrain individual choices and actions. These 'spontaneous social orders' cannot be fully understood by a thorough examination of individuals or individuals' genes. Zeleny (1985: 121) provided several examples of such macro-level orders from the animal kingdom, the arrow formation of flying geese, the defensive ring of the buffalos, and the sophisticated division of labour in bee, ant and termite colonies. Using several other examples, including the human family, he examines social orders as autopoietic or self-producing systems. He noted that,

> the individuals in a society, a social order, spontaneously assume the sort of conduct which assures their existence within the whole. Of course this conduct must also be compatible with the preservation of the whole. Neither society not the individuals could exist if they did not behave in this manner. The overall order is not the 'purpose' or 'plan of the individuals"
>
> - Zeleny, 1992: 154.

David Bella, in his work on human organizational systems, has a similar perspective on social systems but used a slightly different approach, perhaps reflecting Bella's training as an engineer versus Zeleny's business and social science background. Bella (1996, 1997a, 1997b) described large human organizational systems such as NASA, the tobacco industry and universities as CANL (complex, adapting, and nonlinear) systems. These systems "display emergent behaviors that cannot be reduced to the intentions and values of individuals" (Bella, 1997a: 617). Bella has developed a conceptual model of these CANL systems based on an attractor analysis. He described two general propensities or attractors within organizational systems. The 'R' attractor is a pattern of behaviour which draws order out of disorder. In this sense order refers to "coherent patterns, arrangements that draw activities into coordinated wholes" (Bella, 1997b: 979). The other tendency, the 'S' attractor represents 'disordered commotion' this tendency is characterized by disruptive activities that disturb the overall order in the system. His thesis was that organizations will tend toward the 'R' attractor, tending to suppress 'disruptive' activities while reinforcing those behaviours that preserve the whole.

However, if taken to an extreme either attractor can lead to what he called 'systemic imbalance' which can have disastrous implications. For instance, Bella described the 1986 shuttle Challenger disaster as an example of systemic imbalance and not simply the failure of an 'O-ring'. The disaster, he argued was the result of the loss of program funding and NASA's drive to do more with less. The organization shifted behavior to dampen disorders (i.e., unfavorable safety assessments) and reinforce activities that served to meet schedules and cost requirements. The result, Bella concluded was systemic imbalance toward the 'R' attractor and a reversal of the burden of proof (i.e. safety inspectors had to prove beyond any doubt that the shuttle was <u>not</u> safe to fly).

From this analysis Bella described the behavior of CANL systems as exhibiting five main tendencies. These included:

<u>Tendency 1:</u> Adaptive change leading to organized complexity involves the emergence of reinforcing relational patterns that tend to dampen disorders to nondisruptive levels

<u>Tendency 2:</u> The emergent behaviors of organized complexity reflect the history of

experienced disorders that the adaptive process was forced to accommodate.

Tendency 3: As organizational systems shift to dampen disorders over time, they tend toward systemic imbalance, reinforcing some activities while suppressing others, sometimes to destructive extremes

Tendency 4: As organizational systems adaptively shift in their normal manner, they tend toward the reinforcement of some premises and the suppression of others.

Tendency 5: The degree of systemic imbalance that merges within modern society and its consequences are inversely proportional to the credible disorders that organizational systems experience through the continuing activities of independent checks, which ultimately depend on an alert and responsible citizenry.

Paralleling the 'G' mindscape ecological literature, the work of Holling, Zeleny and Bella underscoreS the relevance of the complex systems-perspective to understanding the dynamics of human social systems.

Conceptual Models and Implications for Environmental Management

The view of ecological and human social systems as interacting complex systems appears to be a very powerful heuristic for addressing the complex social and especially environmental crises of the late twentieth century. These heuristics not only provide us with new insights into the dynamics of complex sociobiophysical systems but also can provide guidance for the development of effective management and governance institutions. Holling (1995) has referred to what he calls 'the paradox of resource management'. He has suggested that "any attempt to manage ecological variables inexorably lead to less resilient ecosystems, more rigid management institutions, and more dependent societies" (Holling, 1995: 25).

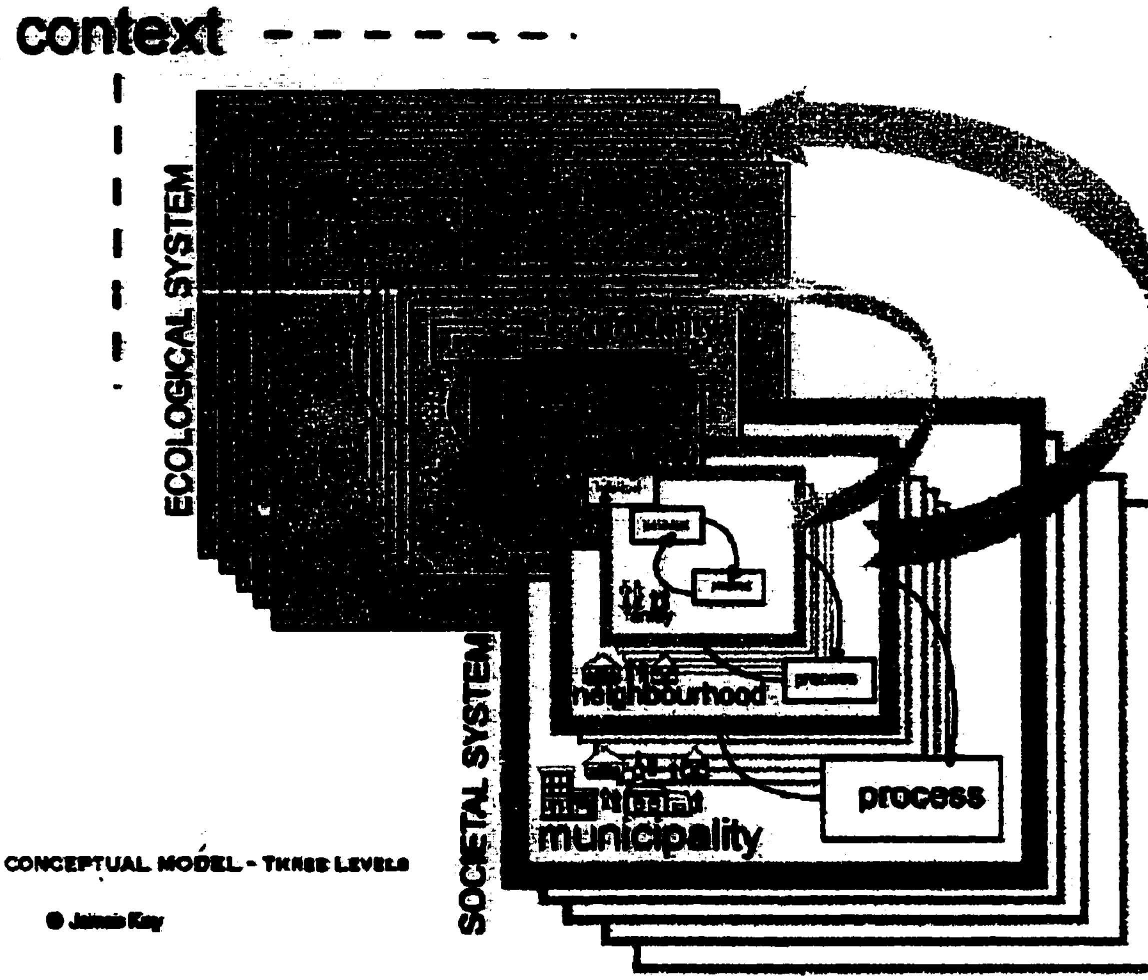
It was this paradox, he noted, that provided the impetus for the recent book, *Barriers and*

Bridges to the Renewal of Ecosystems and Institutions. In this volume six regional case studies were described highlighting the problem of over-managing ecosystems. In these case studies management decisions were based on a stable, homoeostatic conceptual model (Maruyama's 'S' mindscape) of the ecosystem. Efforts were made to maximize whatever 'product' the ecosystem was expected to provide. This entailed essentially holding the ecosystem in stasis in the 'conservation' phase of Holling's 'figure-eight' model of ecosystem dynamics. This lead to, in the forestry case, for example, the massive outbreak of spruce-budworm (a release phase on a very large spatial scale), which in turn lead to a long-term timber supply problem (see Baskerville, 1995). All of the case studies in this important volume highlight the need to understand the complex dynamics that underlie the function and evolution of ecosystems. There have, however, been few attempts to operationalize this perspective by creating conceptual models of complex, self-organizing sociobiophysical systems (Boyle , et al., 1996 and Rosser , et al., 1994) and identifying the implications of these in an environmental management context (Dempster, 1997; Hollick, 1993; Gryzbowski and Slocombe, 1988; Kay, et al., 1999; Slocombe, 1990, 1993, 1996).

The conceptual models developed by Boyle, et al. and Rosser, et al. of interconnected ecological and socio-economic complex, self-organizing systems, provide insight into the way in which these hierarchic systems co-evolve and interrelate. Both are essentially models of two interacting hierarchies or 'bi-hierarchies' (Rosser, et al., 1994). While the Boyle, et al. model illustrates the dynamics of the interacting, nested levels, Rosser, et al. focused on the genesis of new upper levels within these hierarchies.

Used in the development of indicators for State of the Landscape Reporting (Ontario Ministry of Natural Resources), Boyle , et al. (1996) have created a model depicting the self-

Figure 4: Boyle et al. (1996) Conceptual Model



Conceptual model of 'bi-hierarchic' social and ecological systems. Arrows inside holon level boxes represent relationship between structure and process. Larger arrows denote the influence of the social system on the context of the ecological system.

organizing, hierarchic nature of sociobiophysical systems. This conceptual model (see Figure 4) illustrates the dynamics within and between levels of the twin hierarchies (ecological, socio-economic) as well as the nested character of these systems. The authors characterized the relationship between ecological and societal systems in the following three key points:

1. Ecological systems provide the context for societal systems. That is, they provide the biophysical surroundings and flows of exergy, material and information that are required by the self-organizing processes of the societal systems (dashed lines from the structure box).
2. Societal systems can alter the structures in ecological systems (lower arrow). For example, cutting down a woodlot, removing a beaver from a watershed. Changes in the ecological structure can then, of course, alter the context for the societal systems themselves (dashed lines from the 'structure landscape' box).
3. Societal systems can alter the context (upper arrow) for the self-organizing processes of ecological systems (dashed lines on the left). For example, a change in the drainage patterns into a wetland or a change in the local micro-climate, such as heat island effect, for a woodlot. Changes in the ecological processes can alter ecological structure and consequently the context for societal systems (dashed lines from the 'structure landscape' box). - Boyle , et al., 1996:27.

The authors noted that structural changes induced by societal systems generally have obvious repercussions, e.g., cutting down a woodlot will change the ecological context for the social system in detectable ways, and thus involve more tractable management issues. On the other hand, when societal systems change their ecological context, repercussions for human communities are less direct and more difficult to assess and monitor. It is, however, this type of change that may be most detrimental to the continued integrity of the life-sustaining ecological systems.

Boyle, et al. then went on to describe the hierarchic structure of the model. Using Koestler's notion, they described the whole system as a set of 'nested holons'. The larger (spatially) and slower (temporally) levels provide the context for the smaller, faster levels with the system as a whole, with the societal system always dependent on the ecological one for exergy, material and information. Ultimately, this model is bound by the biosphere and the exergy received from the sun. One of the key points this model highlights is the fact that societal systems are now linked on a global scale and so are able to alter the ecological context for the entire biosphere which has potential worldwide implications. Rosser , et al. (1994) in their work described the process by which human social systems have created new levels of organization such that they are able influence ecological systems on a global scale.

In their article "Discontinuous Change in Multilevel Hierarchical Systems" Rosser, et al. described the process of 'anagenesis' or the creation of a new macro level of organization within a 'bi-hierarchic' sociobiophysical system. This is the result of discontinuous change at lower levels 'concatenating' or rippling up through a hierarchy or as the authors called it 'the revolt of the slave variables'. The emergence of a new dissipative structure or the creation of a new level of organization in the ecological, socio-economic bi-hierarchy has the perhaps undesirable effect of the creation of a global economy. Undesirable in that, as Boyle, et al. indicated and as the authors here stressed, we as humans are ultimately constrained by the global biosphere and as such are now in revolt against the very system that maintains our existence. We are in revolt against Gaia and changing the ecological context at this level will ultimately result in, as the authors put it "the punishment of the slaves" (Rosser, et al. 1994: 81).

Both of these models illustrate that "complex, regional problems at the intersection of the biophysical and socioeconomic environments (i.e. in sociobiophysical systems) are underlain by nonequilibrium system dynamics" (Slocombe, 1990:1). And as Slocombe (1990: 1) indicated "this has implications for understanding, planning, and management of these systems". Several authors including, Gryzbowski and Slocombe (1988), Hollick (1993), Dempster (1997), Kay, et al. (1999) have explicitly examined the implications of a complex systems, self-organization theory-based perspective for environmental planning and management.

Using the example of the South Moresby area of the Queen Charlotte Islands, British

Columbia, Canada, Gryzbowski and Slocombe described the region as a self-organizing entity. After investigating the historical and then current influences (both social and biophysical) the authors created a conceptual model of the complex, evolving sociobiophysical system of the South Moresby region. Using this model Gryzbowski and Slocombe provided five examples of transformations or discontinuities within the South Moresby sociobiophysical system that "reflect the dynamic complexity of the area and illustrate the appropriateness of a self-organizational perspective for understanding the region's evolution" (Gryzbowski and Slocombe,1988: 468).

One of the transformations described was the eradication of the sea otter. The authors noted that, "the sea otter played a fundamental role in determining the structure of subtidal ecosystems ... by controlling populations of invertebrate herbivores such as Abalone and sea urchin" (Gryzbowski and Slocombe,1988: 472). With the fur trade of the late 18th and early 19th century the eradication and subsequent extirpation of the sea otter in the Queen Charlotte islands lead to a great increase in abalone and sea urchin populations. This resulted in a dramatic change in the ecology of the subtidal areas of the islands as well as the increased consumption of abalone and sea urchin by the Haida living on the islands.

More recently, the authors indicated recolonization by, and proposed reintroduction of, the sea otter will have not only drastic ecological but socio-economic impacts as well. Gryzbowski and Slocombe (1988: 472) indicated that the dynamics of this and other examples "are illustrative of the self-organizing responses of ecosystems to stress, expressed at a macroscale by changes in community structure: increased energy dissipation, greater nutrient turnover, changes in lifestyle strategies, species diversity, and functional properties". The examples used by the authors underscore the value and appropriateness of a complex systems theory-based perspective for environmental management and planning. The authors also concluded that,

> the 'big' plans, at the regional scale and larger, over longer time periods, must be changed - not abolished, but remade to incorporate uncertainty and the likelihood of discontinuous change, to recognize the nonlinear processes that generate change and new opportunities for choice , and to build in the monitoring functions necessary to track the process of change and to anticipate the new.
>
> - Gryzbowski and Slocombe, 1988: 475.

Through a review of the theory, Hollick (1993) provided his readers with lists of essential characteristics for a system to self-organize as well as properties of self-organizing systems (listed in a previous section). These he applied to ecological and economic systems and drew out implications for environmental management. Noting that it is perhaps intuitively obvious that ecosystems are self-organizing, Hollick went on to demonstrate that they fulfill his criteria. "They are clearly far from thermodynamic equilibrium, and use natural energy flows to maintain themselves. They are governed by many recursive rules, many of which are nonlinear (and) ... examples of positive feedback are not hard to identify" (Hollick, 1993: 623). As well ecosystems exhibit the three properties of self-organizing systems, "ecosystem behavior cannot be deduced from that of component parts ... it is significantly determined by internal processes within regional climatic and geological constraints (and) ... system evolution occurs due to both human and natural disturbances" (Hollick, 1993: 623).

Hollick also described human economic systems as self-organizing noting that they too meet his criteria as far from equilibrium, non-linear, open systems. Where these two self-organizing systems interact is the realm of environmental management. Exploring the implications of this self-organization theory-based perspective for environmental managers under three themes, "Sustainability and the Evolutionary Paradigm", "Unpredictability, Planning and Control", and "Management Structures and Roles", Hollick offered the following list of recommendations for managers:

- View ecosystems as part of a larger sociobiophyscial system which may be the source of external stimuli with the capacity to trigger major system changes
- View themselves as parts of the system they manage, and other participants in the system as managers as well
- Recognize and cultivate the capacity of the system they manage for self-organization rather then trying to control them
- Learn to live with change and uncertainty ready "to engage with full ambition and without any reserve in the structure of the present, and yet to let go and flow into a new structure when the time has come" (Jantsch, 1980)

More Pragmatically, managers should:

- Seek to understand the process of change, and identify key variables and processes that may amplify fluctuations
- Explore possible alternative futures rather than seek to predict the future
- Monitor key variables and processes in order to detect potential discontinuities
- Maximize the flexibility of plans, programs, infrastructure systems, and organizations
- Maximize the number of options available at all times
- Prolong processes which seem to run in creative directions, stop those which appear unpromising and eliminate those deemed uncreative
- Make frequent incremental adjustments to the system rather than major changes
- Use technologies that harmonize with the surrounding natural and social systems rather than being imposed upon them

Making explicit use of the science of complexity, specifically self-organization theory, Hollick's work provides practitioners of ecosystem-based management a perspective on sociobiophysical systems appropriate to the characteristics of such complex systems (i.e. exhibiting catastrophic and chaotic behavior and multiple steady-states, they are also non-linear, hierarchical, and of course self-organizing).

In their recent paper, "An Ecosystem Approach for Sustainability: Addressing the Challenge of Complexity", Kay, Regier, Boyle and Francis (1999) also explored the implications of a self-organization theory-based perspective but in this case specifically for ecosystem management and an ecosystem approach. In this work the authors described ecosystems and human systems as "Self-organizing, Holarchic, Open (SOHO) systems and interpret their behaviours and structures with reference to non-equilibrium thermodynamics; holons propensities and canons; and information and attractors" (Kay, et al., 1999:1). Of great relevance to this work, they discussed what they considered an appropriate relationship between governance, management and monitoring in an adaptive management framework in light of the dynamics of SOHO systems. They characterized this relationship in the following:

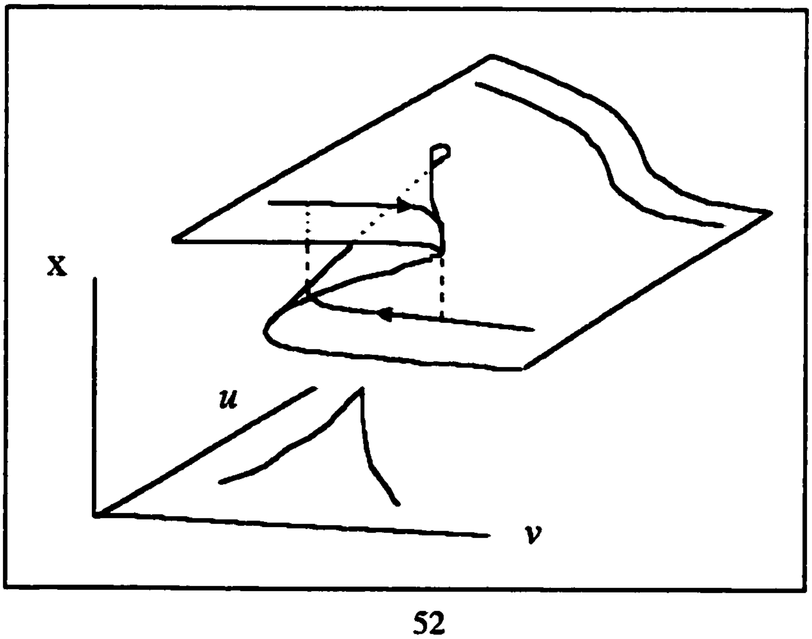
> governance is an activity that focuses on the SOHO systems and adjusts the vision based on how the self-organization process is unfolding. Management seeks to translate the vision into reality by maintaining the context for self-organizing systems rather than intervening in the system in a mechanical way as is done under an H-type mindset. ... Monitoring is the activity of observing the human and natural self-organizing systems and synthesizing the situation into a narrative of how the situation is actually unfolding
>
> - Kay, et al., 1999:18.

Put differently, governance is about where the system 'ought to be going' (based on what those involved in the decision-making want). Management is all about 'getting there' that is, altering or reinforcing feedbacks loops to change or maintain the context of the SOHO system. And finally, monitoring is about where the system is 'actually going'. If the system is not reflecting the vision, monitoring should create what Bella (1997) called 'credible disorders'. That is, actions which directly question the status quo. This should, ideally feed back into governance and decision-making, and would ultimately alter management initiatives which would in turn need to be monitored .... This recursive relationship between governance, management and monitoring is at the core of adaptive management.

Kay et al. (1999) used the example of Lake Erie describing it as a SOHO or Self-Organizing, Holarchic, Open system. SOHO systems, as the authors referred to them, not only exhibit homeostatic behaviour (and hence, the health analogue and the cybernetic scientific perspective of Maruyama's 'S' mindscape) in the domain of a single attractor, but also catastrophic systemic evolution (such as when an ecosystem flips to the domain of another attractor). The authors noted that, "as SOHO systems evolve they shift between attractors within the SOHO system's overall state space. The re-organization that these shifts entail is not smooth and continuous but rather is step-wise. The system flips its organizational state in often dramatic ways" (Kay et al., 1999:11). In the case of the Lake Erie ecosystem, there are two main system attractors, the pelagic and the benthic. "When and where the benthic association as an attractor was dominant, oligotrophic features were manifest. If the pelagic association was the more powerful, then eutrophic features occured" (Kay et al., 1999:18). The authors, using a fold catastrophe model (see Figure 5), identified two main drivers of this dynamic system, turbidity and nutrient availability.

> Assume that the benthic attractor is currently dominant. As nutrients are made available in the water column, the amount of solar energy which can be captured, in principle, by photosynthesis increases thus effectively increasing the exergy in the water column. As this exergy increases a critical threshold is passed which allows the pelagic system to self-organize to coherence. Once this occurs the exergy at the bottom decreases rapidly due to shading (turbidity) thus catastrophically de-energizing the benthic system.

Figure 5: Fold Catastrophe Model



Dempster has also applied 'an emergent systems perspective' to the discipline of urban and regional planning. In her work, Dempster characterized both physical and social systems as self-organizing for the purposes of addressing some very fundamental questions regarding the purpose and methods of the discipline of planning, i.e. how can we plan? How can we not plan? And how should we plan? But the most innovative and exciting facet of this work is her useful distinction between two types of self-organizing systems. Based on Maturana and Varela's concept of an Autopoietic system (bounded, self-producing entity), Dempster has developed the related but distinct concept of Synpoiesis (unbounded, self-producing). The following chart taken from a recent 1997 article illustrates the compares and contrasts these two types of self-organizing systems:

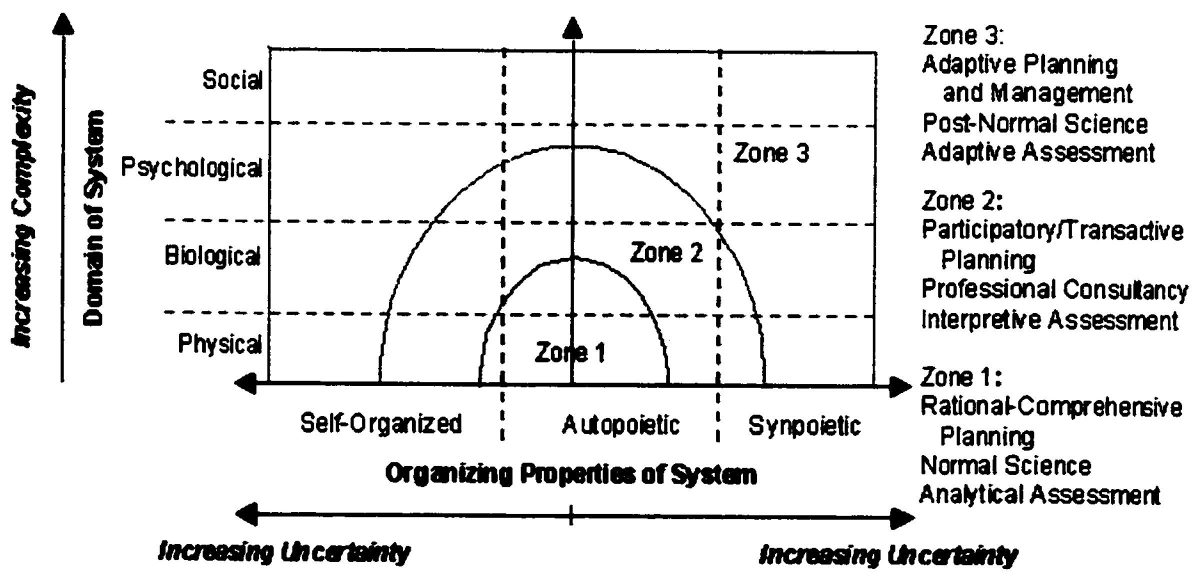
Autopoietic Systems	**Synpoietic Systems**
self-produced	self-produced
bounded	unbounded
autonomous	cooperative, synergistic
eg. cell, organism	eg. ecosystem, cultural system
transmitted self-organization	creative self-organization
negative feedback	negative and positive feedback
equilibrium centered	potential for surprising change
finite trajectories	potentially infinite trajectories
developmental	evolutionary
predictable	unpredictable

With this distinction Dempster clarified and operationalized Maruyama's 'G' mindscape for planners. As other authors have, she underscored the potential pitfalls of extending the organismic analogue (autopoietic) inappropriately to, for instance, ecological or human socio-cultural systems which exhibit the characteristics of Synpoietic systems. Her distinction between Auto- and Synpoietic systems highlights the relationship between order and disorder within complex self-organizing systems.

Autopoietic systems exhibit a very different compromise between their ordered and disordered elements than do Synpoietic systems. They are, to use Ulanowicz' term, more Ascendent, more connected systems, whereas Synpoietic systems are more 'organizationally ajar' and are more adaptive with more systemic 'overhead'. Dempster did note that, "this typology is offered as a heuristic. Both system types should be understood as perceptions - or perhaps more accurately - perceptual lenses".

Dempster went on to note that an adaptive management approach is most appropriate for synpoietic systems, versus the more traditional rational-comprehensive planning (an autopoietic approach suitable for autopoietic systems). She provided planning practitioners a useful 'conceptual map for matching system type with various planning approaches'. The figure (see Figure 6), based on Funtowicz and Ravetz' 'post-normal science' problem-solving strategies diagram, uses different axes, 'system domain' and 'organizing properties' to illustrate the

Figure 6: Conceptual Map of Planning Approaches



appropriateness of various planning approaches to various system scales and types. She noted the relevance and truth of a statement by Hudson (1979: 393) "where planning for the future is feasible...then planning is unnecessary. Conversely, where planning is most needed planning is least feasible". She described this as one of the fundamental paradoxes of the discipline of planning, that is, "we cannot plan, yet we must" (Dempster, 1997: 15). She concluded with yet another paradox. In light of the characteristics of synpoietic systems such as ecological and human socio-economic systems, "we must encourage planning that is, in essence, non-planning" (Dempster, 1997: 16). By this she meant, "the surface will only change by altering the self-organizing elements that govern their creations" thus, she advocated what she called 'serendipitous planning' (essentially non-planning) to cope with the emergent complexity of intractable social-environmental systems.

Ethical Governance:
Ethics, Integrity and Post-Normal Science

Despite the fruitful insights these works provide, operationalizing this complex systems perspective in the context of ecosystem-based management has met many conceptual and practical barriers. Slocombe (1998) has noted that the two greatest barriers to ecosystem-based management are 'institutional territoriality' and 'complacency/weak goals'. As such, he described and compared several normative (normative in that they are "compatible with some 'higher' ethical principles and rules" Slocombe, 1998:2) conservation goals including biodiversity, ecosystem health, ecological integrity and sustainability. He concluded that of these current attempts at normative conservation goals, "no single one encompasses enough to be independent and complete" (Slocombe, 1998: 10). Instead, he suggested that a suite of goals is required to deal with the complexity of ecosystem-based management issues as well as the many perspectives involved. Grumbine (1994) provided an example of such a goal set with his five goals for ecosystem management (maintaining viable populations, ecosystem representation, ecological processes, and evolutionary processes, and accommodating human use in light of the first four).

Ecological Integrity

It can, however, be argued that the concept of ecological integrity (as defined by Kay, 1991b, 1994) is a comprehensive, flexible and theoretically grounded normative goal that can be seen to provide a conceptual framework for several if not all of these other goals, addressing the need for a goal set under the conceptual umbrella of a single principle. Kay defined the concept of integrity as follows: the maintenance of system components, interactions among them and the resultant behavior of the whole system in the face of change (Kay, 1994: 37). The strength of the concept lies in the integration of many of the principle elements of contemporary environmental management goals. Integrity incorporates the following concepts and characteristics:

- ecosystem health or ability to maintain normal operations under normal conditions;
- ability to cope with change (slow and/or sudden) or stress (resilience);
- ability to continue the process of self-organization (i.e. to evolve, develop and go through Holling loops over time)

- (Kay, 1994: 37).

Ecosystem health alone, as Kay (1993: 205) pointed out is not sufficient. "An ecosystem must be able to cope with changes in environmental conditions, that is, stress" as well it, "must be able to continue evolving and developing, that is, continue the process of self-organization on an ongoing basis" (Kay, 1993: 205). As such, integrity requires the maintenance of the unique dynamic balance between the ordered and disordered elements of an ecosystem which allows for its continued self-organization. In fact, the three elements of integrity can be seen to parallel Ulanowicz' (1997) notions of ascendency (ecosystem health, the ability to maintain normal operations under normal conditions), overhead (resilience, the ability to cope with stress) and the dynamic tension between the two which allows for the continued self-organization.

As noted previously the balance between the ordered and disordered elements of an ecosystem that Ulanowicz (1997) referred to, depends to an extent on the history of disturbance within the system. However, this balance can be struck in a number of equally valid ways and it is often human activities that influence how the system will ultimately self-organize (refer to Boyle, et al.'s conceptual model of sociobiophysical systems). As complex systems, ecosystems exhibit multiple steady states in a given spatio-temporal context, that is equally viable system states each with its own structures and processes, no one any more legitimate than another. How the system is influenced by its context, including human activities, (within a given historical context) dictates which steady-state will result. Thus, as Kay (1993: 204) pointed out, "the challenge facing us is to discover what rules, if any, govern the overall direction of ecosystem development and ecosystem organization induced by environmental change". Kay (1993: 203) highlighted the nature of the dilemma with an example from the work of Serafin and Steedman (1991).

> Did the Mount St. Helen or the Krakatoa events cause an impairment of ecological integrity? If we say no, implying that nature can do no wrong, we have made a definite value judgement. Conversely, arguing that the biotic aspect of the ecosystem was degraded invites a rebuttal built around forest fires, floods, or other dramatic stochastic events. Again we have made a value judgement. Therefore, it seems apparent that we can measure and analyze CHANGES in an ecosystem, but we can only make JUDGEMENTS about the integrity of that system.

Ultimately, Kay (1993 pg. 208) concluded, "an evaluation of the ecological acceptability of a human activity will depend on a value judgement about whether the resulting changes in the effected ecosystem are acceptable to the human participants".

Regier (1993), in his characterization of integrity also addressed this issue of human values and integrity. "The notion of ecosystem integrity is rooted in certain ecological concepts combined with certain sets of human values" (Regier, 1993: 3). His description of integrity highlighted "the features which characterize the self-organization of ecosystems" as well as "the particular set of human values associated with maintaining or enhancing these features of ecosystems". As such, he defined what he calls cultural integrity as, "the human capability individually and through institutions to complement the integrity of modified natural ecosystems in an overall context that is inevitably turbulent, socially and ecologically" (Regier, 1993: 3).

Questions leading from these characterizations of integrity require considerations of perspective and scale. Allen, Bandurski and King, (1993) in their work on the ecosystem approach, highlighted these two factors when attempting to utilize the normative goal of ecological integrity in an ecosystem approach. "Changes in a system defined by one criterion may have little impact on the observations of that same system defined by other criteria" (Allen, Bandurski and King, 1993:26). They used the example of the conservation of rare species. The authors noted that from an ecological community perspective the rarity of a species "may be a consequence of declining populations in response to stress, and rare species may be more at risk" (Allen, Bandurski and King, 1993: 27). From a human aesthetic perspective humans are generally attracted to those things that are rare or unique (Allen, Bandurski and King, 1993). However, from an ecosystem function-based criterion a rare species has little effect on the system's integrity precisely because it is rare (Allen, Bandurski and King, 1993). They did add, however, that "some species with small biomass or rare occurrence can sometimes play a crucial role in larger ecosystem function ... we must therefore remain always open to alternative conceptions of the ecosystem" (Allen, Bandurski and King, 1993: 27).

Scale is also a critical issue when attempting to employ the concept of ecological integrity. "Observations over one hectare and one year will lead to a different system description than observations over thousands of hectares and tens of years. Consequently, those characteristics of ecosystem integrity which may be observed or inferred are importantly determined by the scale chosen for observation" (Allen, Bandurski and King, 1993:31).

Thus, as Kay (1993: 202) reemphasized, "one of the lessons of systems theory is that there is no preferred observer". Therefore, "we must be careful to explicitly specify the system (i.e. identify scale, hierarchy, boundaries, system environment, etc.) because part of this process is the identification of the issues of importance, that is the contextual perspective for the integrity evaluation" (Kay, 1993: 202). However, one issue that results from many of these discourses on the concept of integrity is who decides what the issues of importance are? Who decides 'what changes are acceptable to the human participants'? Addressing these issues is far beyond the scope of this thesis, but they are currently being addressed in the work of such authors as Kay, Westra, Funtowicz and Ravetz etc.. These questions take us full circle back to the relationship between science and policy, to the difference between traditional, 'normal' science and 'post-normal' science. Thus the concept of integrity, acknowledging the complexity and high decision-stakes associated with sociobiophysical systems, is a post-normal concept requiring the inclusion of multiple perspectives.

Aside from being a theoretically grounded and flexible concept, integrity can also be seen as a comprehensive concept capable of providing a conceptual framework for several other normative conservation goals such as ecosystem health, biodiversity and even elements of sustainability. Ecological health as originally advanced by Rapport and Regier, and further developed by Rapport and others, has evolved over time to include such concepts as resilience (the ability to cope with stress), however the concept is hampered by links to the original human health analogue, (i.e. emphasizing current well-being and a possibly inappropriate equation of health assessment to diagnosis and cure) (Slocombe, 1998: 8). As noted previously, the concept of integrity explicitly acknowledges the need to maintain normal operations under normal conditions, vis-a-vis, ecosystem health.

The concept of integrity can also be seen to provide an appropriate context for biodiversity conservation. Several works including Kay (1984), Schneider and Kay (1994), and more recent works Ulanowicz, (1997), Lister (1998) and McCarthy and Slocombe (in press) provide a fresh perspective on the concept of biodiversity based on a complex systems theory-based perspective. Based on insights gleaned from information theory Lister (1998) described biodiversity as 'information'. That is, the 'information' ("anything that causes a change in probability assignment" Ulanowicz, 1997, e.g. genetic make-up of particular species, species content in the ecosystem etc.) determines whether an ecosystem will reset itself during the reorganization phase of Holling's figure-eight conceptual model of ecosystem dynamics, or whether it will 'flip' to the domain of another attractor. McCarthy and Slocombe (in press) used this perspective on biodiversity to provide a new conceptual framework for the conservation of biological diversity. Using Ulanowicz' concepts of 'ascendency' and 'overhead' the authors highlighted the need to maintain the dynamic balance between these ordered and disordered elements within an ecosystem. By viewing biodiversity as 'information', the 'ascendent' and 'overhead' elements of an ecosystem, at various scales (spatial and temporal), conservation efforts can be refocused. Instead of maintaining diversity simply for diversity's sake, or for more anthropocentric utilitarian purposes, biodiversity conservation efforts should be based on the notion of sustaining the balance between species that maintain normal operations of the ecosystem and those that provide the ecosystem with the ability to cope with stress thus, maintaining the system's ability to continue the process of self-organization, vis-a-vis ecological integrity.

Westra (1994) reemphasized the preceding when she noted that the concept of integrity "includes the value of health in a nonanthropocentric sense", "encompasses the value of biodiversity, and (a) the life-support functions and (b) information/communication it supports" and "subsumes the value of sustainability". Equating the principle of sustainability with that of maintaining 'stability', Westra (1994: 52) noted that, "from the practical standpoint, the instrumental value of the undiminished system is evident in the necessary role it plays in supporting sustainability in all other systems ('used' and 'manipulated'), such as those supporting forestry or agriculture". Restating Regier's (1993:3) notion of 'cultural integrity', "the human capability individually and through institutions to complement the integrity of modified natural ecosystems in an overall context that is inevitably turbulent, socially and ecologically", integrity can be seen to subsume the value of sustainability, that of meeting the needs of the present generation without compromising the ability of future generations to do the same. Thus, the concept of integrity can be seen to be a theoretically grounded, flexible and comprehensive normative conservation goal, that acknowledges the uncertainty and high decision-stakes of environmental management within complex sociobiophysical systems. As such it makes an appropriate normative goal for ecosystem-based management providing a framework for several interrelated goals, meeting Slocombe's requirement for a suite of goals under the conceptual umbrella of a single concept.

The concept of integrity provides an example of the operationalization of the philosophy of systems science and more specifically a complex systems perspective in the context of environmental management. An holistic, integrative perspective highlighting the complexity and macro-level organization characteristic of entities called systems, this perspective also emphasizes the fact that for entities such as systems, there is no 'objective' observer. Thus, it underscores the need to include multiple perspectives not only due to the uncertainty associated with complex systems but also in light of the extreme decision-stakes associated with complex systems at the scale of sociobiophysical systems. "The science appropriate to this new condition will be based on the assumptions of unpredictability, incomplete control, and a plurality of perspectives" (Funtowicz and Ravetz, 1993:739). Authors such as Funtowicz and Ravetz have termed this new scientific perspective, 'post-normal' science.

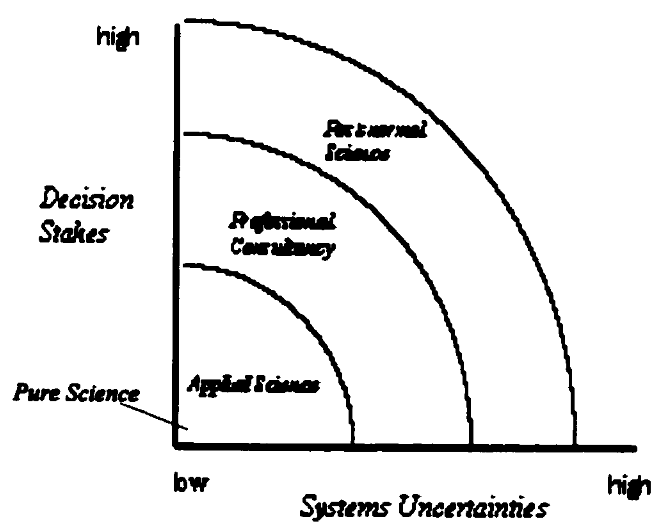
Post-Normal Science

Referring to the Kuhnian concept of 'normal science' which Funtowicz and Ravetz (1993: 740) referred to as "the unexciting, indeed anti-intellectual routine puzzle solving by which science advances steadily between its conceptual revolutions. In this 'normal' state of science, uncertainties are managed automatically, values are unspoken, and foundational problems unheard of". The post-modern perspective, they note can be seen as a response to the failures of this normality in science. Offering post-normal science as an alternative to the post-modernist, deconstructionist doctrine which Funtowicz and Ravetz (1992: 964) described as "an approach of unrestricted criticism of the assumptions underlying our dominant culture, and it flirts with nihilism and despair". Their approach makes explicit the need to deal with, and not reduce uncertainty; as well it requires that values be reintegrated into science and be made explicit in decision- and policy-making.

In a number of their works Funtowicz and Ravetz (including 1992, 1993, 1994) described the concept of post-normal science by juxtaposing it with more conventional scientific perspectives, i.e. pure science, applied science and professional consultancy. They used two attributes of systems, level of uncertainty and decision stakes to distinguish among these methods of inquiry (see Figure 7).

To begin, the authors described the most familiar problem-solving strategies, what they call 'pure' and 'applied' science. 'Pure' science they refer to as 'curiosity-driven' or 'investigator-chosen'. Here there are no 'external interests', so decision-stakes are very low and there is very low uncertainty as research is not normally undertaken unless the problem is believed to be solvable (Funtowicz and Ravetz, 1994: 1882). In applied science, by contrast, "the value of a positive outcome of the research can compensate for strong uncertainty about its prospects for success" (Funtowicz and Ravetz, 1994: 1882). That is, the outcomes of the research may become useful for some external problem or function. When this happens the relevant peer community is extended beyond

Figure 7: Problem Solving Stragtegies



the usual academic peer-review process into the public domain and may include for example users and managers. However, the authors pointed out that the results of the research, despite being applied in a public domain, remain the 'intellectual property rights' of the researcher or become corporate policy or 'know-how'. In both the pure and applied sciences the goals are reproducibility and prediction.

This differs from the goal of the next region, professional consultancy, which is serving the client. Here the decision stakes are higher as the science leaves the lab and moves into the public realm and error-costs take on new meaning. The work of the scientist is placed in a new context, a specific social context, in which the burden of proof will reflect societal or community values. As well, in the region labeled professional consultancy, "uncertainties cannot be managed at the routine, technical level, because more complex aspects of the problem, such as reliability of theories and information, are relevant. Then personal judgements depending on higher level skills are required, and uncertainty is at the methodological level" (Funtowicz and Ravetz, 1993: 747). The authors noted that in the realm of professional consultancy, 'the peer-community' is extended beyond the specific scientific discipline, beyond the scientific community, to include the client and relevant members of the community.

The next region in their diagram is the natural extension of this for situations of high decision-stakes and extreme uncertainty. "Post-normal science occurs when uncertainties are either of the epistemological or the ethical kind ... the traditional fact-value distinction has not merely been inverted; in post-normal science the two categories cannot be realistically separated" (Funtowicz and Ravetz, 1993: 751). Expert-oriented decision-making in which scientists offer decision-makers so-called 'objective' answers, in this realm is no longer ethically viable. This is due to the high level of uncertainty associated with the dynamics of complex systems often, as the authors point out approaching 'sheer ignorance'. Thus,

> the dynamic resolution of policy issues in post-normal science involves the inclusion of an ever-growing set of legitimate participants in the process of quality assurance of the scientific inputs ... In this way, its practice (science) is becoming more akin to the workings of a democratic society, characterized by extensive participation and toleration of diversity. As the political process now recognizes our obligations to future generations (sustainability), to other species, and indeed to the global environment science also expands the scope of its concerns
>
> - Funtowicz and Ravetz, 1993: 751.

The role of science in policy-making has been essentially unquestioned in previous decades, in part due to the dominance of traditional objective, mechanistic, reductionist science. Few have ever bothered to question the epistemological groundings of this 'technocratic' relationship between science and policy-making as, some would argue, it would be very redundant to continually revisit the 'basement of science' when such issues were settled a long time ago (Rosen, 1991). It is generally assumed, in this technocratic management approach, that if good traditional scientific information and predictions are presented to responsible decision-makers the 'right' decision will be made and the 'correct' course of action followed.

Also known as anticipatory management, this approach, "is based on the premise that it is possible to predict and anticipate the consequences of decisions and hence make a proper decision once all the necessary information is gathered to make a scientific forecast" (Kay et al., 1999, pg 7). However, as Kay et al. (1999: 7) indicated, "in situations dominated by self-organizing behaviour (i.e. ecosystem dynamics, large-scale human organizational dynamics) the properties of inherent uncertainty and emergence limit the capacity to predict how the situation will unfold". With inherent uncertainties resulting from inevitable flips to known attractors and potential flips to as yet unknown system states it is in principle, the authors conclude, not possible in many situations to construct an adequate quantitative model to make the predictions required for an anticipatory management approach.

In these situations of high uncertainty and potentially large-scale ecological and socio-economic impacts, the role of science in decision making takes on a different character, more "finding our way through partially undiscovered country rather than charting a scientifically determined course to a known end point" (Kay, et al., 1999: 16). In the realm of environmental management, there are rarely any absolute 'truths', few 'right' answers, and no one state of an ecosystem that is 'correct' for a given geographical area. There are in most cases, several possible, equally valid system states. Of these, there are economically preferable or more culturally valued ecological systems possible in a given geographical area. In these cases Kay, et al. (1999: 16-17) pointed out that, "decisions must be made about which of the systemic possibilities (i.e. attractors) to promote and which to discourage ... these decisions must be informed by science, but in the end they are an expression of human ethics and preferences and of the socio-political context in which they were made". Thus, the role of science is not to dictate what decisions should be made, but to inform the decision-making process with useful biological, geophysical, ecological, socio-economic information.

Two key questions associated with the extension of the decision-making community are who will be involved and what will their role be? The first question is especially difficult. In general though it is meant to include all relevant stakeholders. That means, as Oxley (1997: 26) indicated, "that the historical, situational, and value-based elements of post-normal science require those with experience of the particular situation, not just traditional scientists, to evaluate the policy process". Funtowicz and Ravetz (1994) are not simply referring to a one-time public consultation. They refer to a much more involved process of involvement, 'taking ownership' of an issue. In fact, as Oxley (1997: 31) noted, "the stakeholders must be invited to take ownership over and over again, at multiple levels, in an increasing number of ways". She went on to explain that, peer review in this sense

> certainly takes place through formal participation in the official administrative structure of boards and committee. But such involved commitment is not the only way to do peer review. It can be expressed by voting for a city councilor who supports zoning changes. It can be expressed by coming to a meeting ... continuing to support the management process even when surprises occur and plans do not go as expected ... (even) ongoing usage of the park in keeping with the shared goals for the area is a kind of peer review
> - Oxley, 1997: 31.

Thus, a post-normal perspective requires that, "the criteria for decision making be shifted, from scientific fact, to values, ethics and prudence" (Funtowicz et al., 1993 in Oxley, 1997: 26).

Having discussed the philosophical groundings of a complex systems theory-based approach as well as the scientific, ethical, management and decision-making implications of this body of theory through a discussion of Post-Normal Science, it is important now to move on to an exploration of the third, more practical requirement of ecosystem-based management, adaptive management.

Adaptive Management: Learning Organizations

It is clear from the ecosystem management literature that the need for organizational change from traditional static, command and control management regimes to a more flexible adaptive management approach is required if ecosystem-based management is to be fully operationalized. This is due to the complexity and uncertainty associated with complex sociobiophysical systems. C. S. Holling has been instrumental in the creation and development of adaptive management. His

(1978:7) work has provided a process "to cope with the uncertain and the unexpected. How, in short to plan in the face of the unknown". Holling (1978: 9) described adaptive environmental management as "an interactive process using techniques that not only reduce uncertainty but also benefit from it. The goal is to develop more resilient policies". He has provided six general requirements for an adaptive approach:

1. Environmental dimensions should be introduced at the very beginning of the development, or policy design process, and should be integrated as equal partners with economic and social considerations, so that the design can benefit from, and even enhance, natural forces.
2. Thereafter, during the design phase, there should be periods of intense focused innovation involving significant outside constituencies, followed by periods of stable consolidation.
3. Part of the design should incorporate benefits derived from increasing information on unknown or partially known social, economic, and environmental effects. Information can be given a value just as jobs income and profit can.
4. Some of the experiments designed to produce information can be part of an integrated research plan, but part should be designed into the actual management activities. Managers as well as scientists learn from change.
5. An equally integral part of the design is the monitoring and remedial mechanisms. They should not simply be post hoc additions after implementation.
6. In design of those mechanisms there should be a careful analysis of the economic trade-offs between structures and policies that presume that the unexpected can be designed out, and less capital-expensive mechanisms that monitor and ameliorate the unexpected.

More recently Holling (1995:30) has described an adaptive management approach as requiring, "flexible, diverse, and redundant regulation, monitoring that leads to corrective responses, and experimental probing of the continually changing reality of the external world".

In their work on adaptive management Lee and Lawrence (1986: 431) indicated that,

> adaptive management is learning by doing: by treating measures ... as experiments, the implementation of the program becomes a set of opportunities to test and improve the scientific basis for action. Those opportunities in turn, structure a systemwide planning regime of information produced by the implementation of the program.

These authors argued that adaptive management rests on five key principles that include:

1. Focus on shared long-term goals
2. Projects are inevitably experiments
3. Action is overdue
4. Information has value
5. Enhancement measures may be limited in time, but management is forever

Thus, in essence an adaptive approach is a recursive process of organizational learning through experimentation, continual monitoring, and scientific and organizational adjustment. Mitchell (1997) has brought together many seminal works on adaptive management, including those previously mentioned. Mitchell's review has drawn especially on two works (Rondinelli, 1993 and Berman, 1980) which provide comparisons of adaptive approaches and more traditional mechanistic and programmed approaches. These comparative studies highlight the very characteristics that make adaptive management appropriate to ecosystem-based management as well as alluding to the ideal organizational/institutional structure.

Rondinelli (1993) compared an adaptive management approach to what he called a 'mechanistic' management strategy. The following chart lists their respective characteristics:

Characteristics	**Management Strategy**	
	Mechanistic	**Adaptive**
Environment	Certain	Uncertain
Tasks	Routine	Innovative
Management Processes		
Planning	Comprehensive	Incremental
Decision-Making	Centralized	Decentralized
Authority	Hierarchical	Collegial
Leadership Style	Command	Participatory
Communications	Vertical, formal	Interactive, formal and informal
Coordination	Control	Facilitation
Monitoring	Conformance to plan	Adjust strategy and plan
Controls	Ex-ante	Ex-post
Use of formal rules and regulations	High	Low
Basis of staffing	Functions	Objectives
Structures	Hierarchical	Organic
Staff values	Low tolerance for ambiguity	High tolerance for ambiguity

Definite links can be drawn between the mechanistic management strategy and Maruyama's 'H' mindscape, and the adaptive strategy and the 'S' and 'G' mindscapes. Thus, the management organization appropriate to 'G'-type systems exhibits 'G'-type behaviors. This being the case, what does such an organization look like?

Paralleling Rondenelli's comparison, J. C. Wandemberg, in his work on designing sustainable organizations, contrasted 'bureaucratic' or design principle 1 (DP1) and what he referred to as 'participative democratic organizations' or design principle 2 (DP2). The characteristics of each are offered in the following:

Design Principle #1 (Bureaucratic)

- Organizational structure does not foster cooperation & participation.
- Decision-making & control by supervisors. People Goal driven (little to learn)
- Narrow & rigidly defined jobs -complicated work environment. Detailed specification of everything ("fool-proof").
- Workers focus on tasks -the big picture is irrelevant/unknown.
- Subjective Seriality (asymmetric dependence)
- Error increasing (responsibility and blame easily shifted).
- Organizational "success" (sustainability) a function of 'smart' direction from top.

Design Principle #2 (Participative Democratic Organization)

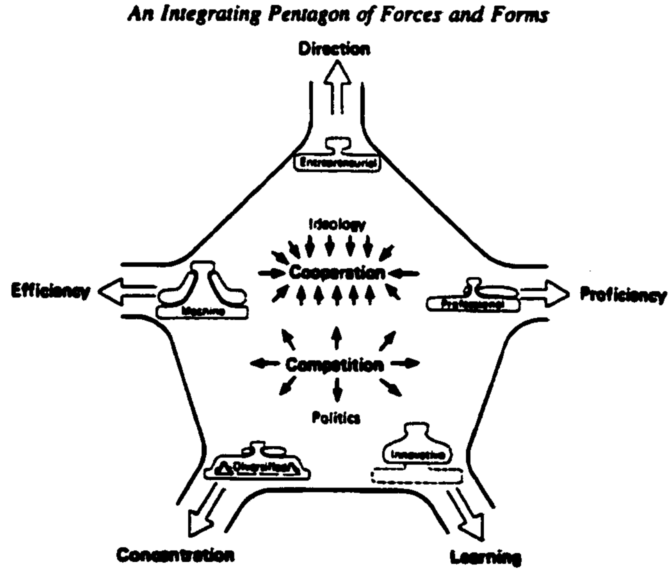
- Organizational structure predicated on cooperation & participation. People Ideal driven (plenty to learn)
- Decision-making & control by those doing the work. Little specification as possible ("Smart-proof").
- Broad & flexibly defined jobs -uncomplicated work environment.
- Workers make decisions about tasks -awareness of 'big picture' is essential.
- Complementary Seriality (symmetric dependence)
- Error attenuating (T=1-(F)n) (responsibility and blame cannot be shifted).
- Organizational success (sustainability) a function of knowledgeable, and actively adaptive collaborative behavior.

Based on the work of Ackoff and Emery, Wandemberg discussed the differences between these organizational design principles in terms of system type and characteristics. He noted that sustainable organizations are 'ideal seeking' (see Ackoff and Emery, 1972) that is, they have the ability to sacrifice a goal for the sake of an ideal (normative goal, e.g. sustainability or integrity). Thus, they have the flexibility to adapt in case the context changes, requiring a different approach to achieving their ideal. By contrast, Wandemberg described bureaucratic or DP1 organizations as efficient and 'variety-decreasing', that is, as Bella (1997a) described it they shift to 'dampen disorders'. In this sense these organizations trade adaptability for short-term efficiency. Wandemberg indicated that the more flexible, variety-increasing, ideal-seeking participative democratic organizations are much more appropriate in 'turbulent' environmental times.

In his work on management and organizational behavior, Henry Mintzberg (1989) has developed a loose classification of seven organizational/management archetypes or useful caricatures of extreme organizational types. He noted that most real-world organizations lie somewhere in the pentagon formed with these archetypes as its apexes (the Entrepreneurial Organization, the Machine Organization, the Diversified Organization, the Professional Organization and the Innovative Organization) (see Figure 8). Two of these apexes or organizational archetypes (the Diversified and the Innovative) nicely characterize the two attractors previously discussed. Mintzberg

Figure 8: Pentagon of Organizational Archetypes

An Integrating Pentagon of Forces and Forms



described a highly connected, rigid organization that he appropriately called the 'machine bureaucracy' or simply the 'machine organization'. This, like Wandemberg's DP1 organization, is a very formal, rigid and efficient organization, in which authority is centralized and the main goal is to reduce uncertainty (variety-decreasing). In contrast with this organizational type is Mintzberg's 'innovative' organization.

Mintzberg's 'Innovative Organizational' type appears to be a most appropriate model for adaptive management organizations. Having also referred to this organizational structure as 'adhocracy', Mintzberg (1989: 196) noted that this type "achieves its effectiveness by being inefficient". He described the 'innovative' organization with adjectives such as, 'fluid', 'organic' and 'selectively decentralized'. He noted that in this type of organization coordination is achieved by "mutual adjustment, encouraged by liaison personnel, integrating managers, and matrix structure" (Mintzberg, 1989:198). The main goal here is to maintain flexibility. The author described the operation of such an 'adhocracy' as using 'multidisciplinary teams of experts' which "engage in creative efforts to find a novel solution; the professional bureaucracy pigeonholes it into a known contingency to which it can apply a standard solution" (Mintzberg, 1989: 201). Given the characteristics mentioned above this appears to be a suitable model for an adaptive organization. However, given that this type of organization is extremely inefficient and difficult to maintain; and in light of the tendencies of organizations described by Bella (1996, 1997a, 1997b) to move from this type of organization towards a more rigid machine-like organization, how can an adaptive management organization be maintained?

As previously mentioned, Bella described these two organizational propensities (Wandemberg's DP1 and DP2 and Mintzberg's 'machine bureaucracy' and 'innovative organization') as two system attractors. The 'R' attractor, the efficient, bureaucratic, variety-decreasing attractor and the 'ideal-seeking', adaptive variety-increasing 'S' attractor. Bella's notion of organizational systems development toward the efficient 'R' attractor is dependent on the system's history of disturbance or 'disturbance regime'. He noted that systems require 'credible disorders' (disruptive activities questioning the level of efficiency usually based on moral grounds) to prevent systemic imbalance.

This parallels ecosystem behavior conceptually. Holling identified two attractors in his figure-eight model: a highly ordered, highly connected conservation phase and a more chaotic, more loosely connected exploitation phase. Ulanowicz explicitly dealt with this issue of connectedness with his notion of ascendency. The more ascendent the system the more connected and more efficient the system, but also the more brittle and maladaptive. These ascendent systems have fewer disordered, or unconnected elements (overhead) and thus have fewer options when the system is stressed. The level of ascendency is highly dependent on its context. Ulanowicz (1997: 83) stated that, "systems develop in the direction of more efficient imports along fewer links up to the point where environmental disruptions of those links create the need for compensatory additions from other, less-efficient sources". This results in ecosystems striking a unique balance between order and disorder in a given context and cycling between the more ordered attractor (conservation phase, ascendent) and the less ordered attractor (exploitation phase, more overhead).

These are more than just theoretical isomorphs, they reemphasize the appropriateness of an adaptive organization to the management of human activities within ecosystems. With environmental management conceptually situated between these two hierarchies, an environmental management organization must strike a unique dynamic balance between its ordered (efficient) and disordered (adaptive) elements appropriate to its context. In fact Holling (1978: 36) indicated that "those institutions that have developed policies that induced a rhythm of change, with periods of innovation followed by consolidation and back again, maintain a flexible and adaptive response". Human institutions too, follow a cyclical dynamic between two systemic attractors, maintaining a dynamic balance between order and disorder within the organizational system. 'Systemic imbalance', like the examples of ecological catastrophes offered in Gunderson , et al. (1995), occurs when this dynamic balance is manipulated to either maximize efficiency or adaptability.

Thus, referring to Kay , et al. (1999) an adaptive, ecosystem-based management organization would have to reflect this dynamic. That is, when a system is within the domain of a known attractor (i.e. the conservation phase, a climax forest community) some anticipatory management can be done, that is planning in the traditional, rational comprehensive sense, employing a more 'bureaucratic' or machine-like organizational structure. Conversely, during times of high uncertainty like the reorganization phase during which the system may either flip into the domain of a known attractor or flip to a completely new attractor, planning and management must be more adaptive, 'serendipitous' as Dempster (1997) put it, utilizing a less rigid, more 'innovative' organizational structure.

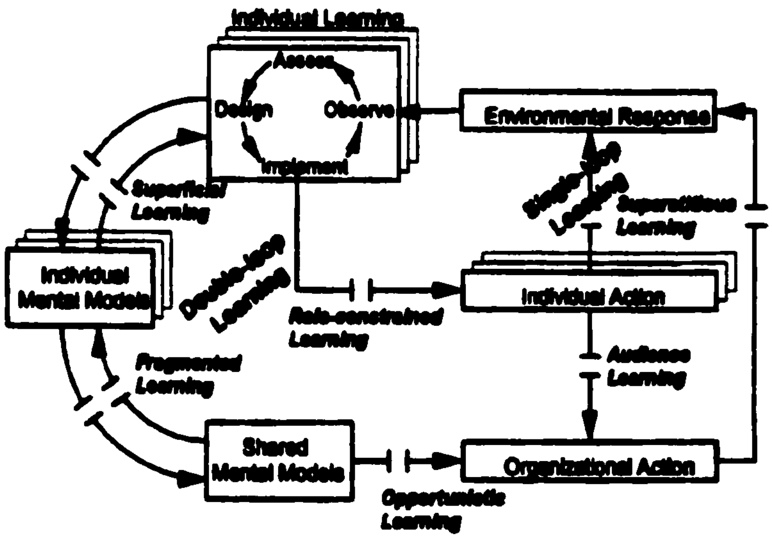
An adaptive management regime requires an organization not only to continually monitor key ecosystem variables, learn and adapt its ecological management strategies to maintain the ecosystem's dynamic tension between order and disorder/ascendency and overhead (Ulanowicz, 1997), it must also monitor itself to ensure it (as an organization) does not move into 'systemic imbalance' (Bella, 1997). But how does an organization monitor and alter its tension between adaptability and efficiency?

Both the works of Conrad (1983) and Ulanowicz (1997) provide what might be useful theoretical isomorphs from the discipline of ecology for what generates adaptability in human institutions. Both authors point to intra-system redundancies as a source of adaptability. This parallels Mintzberg's and Wandemberg's notions of a perhaps less efficient but more flexible organizational structure. Redundancies in the form of 'credible disorders' such as monitoring activities (Bella, 1997a) allow an organization to avoid becoming overly rigid and maladaptive. Conrad (1983) and Ulanowicz (1997) have also pointed to the relationship between a system and its environment as a potential source of adaptability. Adaptive organizations (Mintzberg, Wandemberg, Bella) are all synpoietic (Dempster, 1997) systems, that is they are 'open' and 'unbounded'. Therefore, flows of, for instance, information can enter or exit a synpoietic system via almost any trajectory. This increases the system's overhead and thus reduces the system's ability to anticipate the state of the environment and increases its indifference to inputs or exports from the environment. This contrasts with a more 'ascendent', 'autopoietic' system in which information is more 'packaged' and moves through more centralized, efficient channels. It is the challenge of environmental planners/managers to synchronize the organizational cycling between the ordered, efficient, bureaucratic, or 'autopoietic' organizational attractor and the adaptive, innovative, 'synpoietic' attractor with the ecosystem's cycle between the ordered 'ascendent' 'conservation' attractor and the more disordered exploitation attractor.

Having identified the attractors and the system's self-organizing dynamics about them,as well as possible methods for promoting one or the other, it is now appropriate to pose a question. Once an environmental management organization has explicitly acknowledged the need to be adaptive and even attempted to promote a more flexible, innovative management structure how can it assure that organizational learning will take place?

The work of Peter Senge (Kim and Senge, 1994) can be utilized to address this very question. Senge has also applied a dynamic systems perspective to human organizational dynamics and developed a model of an organizational learning cycle. In this cycle adapted from Kim (1993) (Figure 9) Senge made the useful differentiation between individual learning, individual mental models and shared mental models to illustrate how organizational learning can occur. But perhaps the most useful element of Senge's work is his identification of six barriers or breakdowns in organizational learning. Using March and Olsen's (1975) work in which they identified three breakdowns that result in 'incomplete learning cycles', Senge has compiled three additional barriers to organizational learning (Kim, 1993). The resulting six breakdowns in the learning cycle are listed below:

Figure 9: Cycle of Organizational Learning



Role-Constrained Learning - occurs when an individual is unable to take actions she sees as necessary because she is not permitted to do so within the organization.

Audience Learning - occurs when the individual affects organizational action in an ambiguous way.

Superstitious Learning - occurs when individuals are unable to make valid sense of environmental response.

Superficial Learning - occurs when changes in mental models are called for but do not occur.

Fragmented Learning - occurs when the link between individual mental models and shared mental models is broken.

Opportunistic Learning - occurs when new organizational actions deviate from prevailing shared mental models

These barriers to organizational learning should provide environmental managers who have explicitly attempted to promote an adaptive management approach, with further insight into ensuring the continued organizational evolution that an adaptive approach is designed to produce.

Ecosystem-Based Management

Having discussed the epistemological foundations of a complexity theory-based perspective as well as the three requirements of an adaptive, ecosystem-based approach to environmental management it is appropriate to end this chapter with a more detailed discussion of the concept of ecosystem-based management itself as described in the literature (Boyce and Haney, 1997; Christensen, et al. 1996; Grumbine1994, 1997; and Slocombe1993, 1998).

It is critical to note that the concept of ecosystem-based management or an ecosystem approach to environmental planning and management is not a new one (Bocking, 1994; Lee et al. 1982; etc.). Bocking (1994) traced the ecosystem concept back to Sir Arthur Tansley who originally coined the term in 1935. However, for the purposes of this work tracing the roots of one of the most recent manifestations of the ecosystem concept, ecosystem-based management, is sufficient.

Also it can be argued that the use of the term 'management' and in fact, the entire management paradigm with reference to conservation, restoration, planning and maintenance of ecological integrity in sociobiophysical systems is inappropriate (for instance Kay et al. 1999; and Slocombe, 1993). It implies a level of control over the ecological system and not just human activities within it. The term implementation may be more appropriate but this debate is beyond the scope of this thesis and may be addressed in the context of a Ph.D. program.

Grumbine (1994) has traced the roots of ecosystem management back to a 'few visionary ecologists' from the 30's and 40's such as Aldo Leopold (1949), and less well-known influences such as the 1932 work of the Ecological Society of America's Committee for the study of Plant and Animal Communities and U.S. biologists George Wright and Ben Thompson (1935). Later work included Lynton Caldwell's 1970 article advocating the use of ecosystems as the basis for public land policy and Frank and John Craighead's grizzly bear research in Yellowstone which focused attention on ecosystem management. And by the late eighties Grumbine (1994, pg. 28) noted "an ecosystem approach to land management was being supported by many scientists, managers and others".

Slocombe (1993) traced the origins of ecosystem-based management from three common sources: protected areas, cooperative management, and management responses to complex demands and pressures. He noted that the interest in ecosystem-based management in protected areas management "has focused both on internal ecosystem management to maintain ecosystem integrity and health and on broader approaches that recognize the need to manage an entire ecologically whole and coherent region that usually extends well beyond the protected area boundaries to include the whole ecosystem" (Slocombe, 1993, pg. 613). For cooperative management, using the example of the Australian Alps, Slocombe described an attempt to manage a very large and multi-jurisdictional region as a single ecosystem. "Each National park is managed by the appropriate state or territory government, with the federal government having some overall responsibilities, such as management of migratory species" (Slocombe, 1993, pg. 614). The third origin of ecosystem-based management Slocombe pointed to was the need to respond to complex pressures. He used the example of Prince William Sound in South Alaska as an example of multidisciplinary data collection and organization initiatives, mainly as the result of the Exxon Valdez oil spill, as a basis for ecosystem management.

Franklin (1997) in his overview of ecosystem management in Boyce and Haney's recent volume, *Ecosystem Management: Applications for Sustainable Forest and Wildlife Resources*, cited ecosystem science, the greater ecosystem concepts, landscape ecology and a dynamic perspective on ecosystems as important contributions to the notion of ecosystem-based management. Noting examples such as the Hubbard Brook forest service program and the International Biological Program, ecosystem science has drastically changed the way we look at natural systems, shifting emphasis from biological structure to ecosystem process/function. The greater ecosystem concept and landscape ecology have also impacted our understanding of natural systems, changing the way we define and bound ecosystems and environmental issues. Finally, Franklin (1997) highlighted the increased emphasis on the dynamic nature of ecosystems as being a profound contribution to the concept of ecosystem management.

Whatever the exact origins, the notion of ecosystem-based management has spawned a great deal of enthusiasm in many areas of the globe and on various levels from the local, to state/provincial, to regional and even the international. Examples from North America include the Toronto Waterfront Commission, Maryland Department of Natural Resources (DNR), Chesapeake Bay Program and the International Joint Commission work around the Great Lakes. There has also, however, been much debate over its exact meaning and over its potential on a conceptual as well as practical level. So, what exactly is ecosystem management? What are the philosophical/ethical, scientific and organizational requirements of such a concept? And how do we go about operationalizing it? Recent seminal works on the concept of ecosystem management, including Slocombe (1993, 1998), Grumbine (1994, 1997), Christensen , et al. (1996) and Boyce and Haney (1997) have attempted to address these very issues.

Slocombe in his 1993 article "Implementing Ecosystem-based Management", identified three main components of ecosystem management:

1. Defining management units
2. Developing understanding
3. Creating planning and management frameworks

The first component addresses the important issue of relevant management boundaries. Highlighting the frequent and inappropriate use of human socio-political management boundaries when dealing with ecological systems, Slocombe (1993, pg. 618) noted three precedents for redefining management units including, 'watershed-based management', 'bioregionalism', and 'protected areas management'. Examples from all of these approaches underscore the practical importance of ecologically relevant boundaries to implementing an ecosystem-based management approach. Often a prerequisite for other steps, redefining management boundaries requires new and different forms of information and communication (Slocombe, 1993). Ultimately, ecosystem management requires a change in scientific perspective that will make the debate over boundaries conceptually less critical. A shift from traditional modern, mechanistic, reductionist science which requires a clear, objective bounding of a problem, to a more holistic, systems perspective in which boundaries are relative, would require many overlapping sets of boundaries each relevant to a different perspective. However, paradigms do not shift easily and the issue of boundaries is still, and will remain for some time, a very important practical reality in implementing ecosystem-based management.

In Slocombe's description of his second component, 'developing understanding' he called for just such a shift in scientific perspective. Slocombe indicated the need for an 'holistic and interdisciplinary study of ecosystems' not only requiring knowledge of the ecological system, but also of the human socio-economic and cultural system as well as their points of interaction. Understanding these systems and their interaction requires knowledge of the dynamics of complex, self-organizing systems with hierarchical organization.

Finally, Slocombe described the 'Creation of Planning and Management Frameworks' as a component of ecosystem management. Given the nature of complex systems ecosystem-based management should be "transdisciplinary, use a systems approach and incorporate monitoring and evaluation to support participatory, cooperative, goal oriented and institutionally integrated regional planning and management of environment and development" (Slocombe, 1993, pg. 620), in essence, integrated and adaptive.

In his later work Slocombe evaluated goals for ecosystem-based management. In this work, aside from reemphasizing the need to incorporate insights from a variety of disciplinary perspectives and notions from complex systems theory, Slocombe (1998, pg. 3) noted that goals for ecosystem management need to be normative, "they ought to be principled, that is they should reflect basic, fundamental, higher values and ethics (Westra, 1993)".

A similar set of requirements surface in the work of Edward Grumbine (1994, 1997). In both of his articles, aptly entitled "What is Ecosystem Management" and "Reflections on 'What is Ecosystem Management'", Grumbine described and reflected upon ten dominant themes of ecosystem management that emerge from the literature, they are as follows:

1. Hierarchical Context
2. Ecological Boundaries
3. Ecological Integrity
4. Data Collection

5. Monitoring
6. Adaptive Management
7. Interagency Cooperation
8. Organizational Change
9. Human Embedded in Nature
10. Values

Grumbine's list underscores Slocombe's requirements, an integrated, interdisciplinary, systems-based approach; the need to emphasize ecological boundaries; the need to manage for the integrity of the system as a whole as well as the reality of the nested (hierarchic), interrelated nature of human socio-economic and ecological systems. Given the complexity and uncertainty of these systems Grumbine, as Slocombe did, called for an adaptive, integrative management approach, emphasizing appropriate data collection, monitoring and interagency cooperation and organizational change. Finally, Grumbine noted the need to reintegrate values into the science and practice of environmental management.

The recent Report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management's also provides a summary of the elements of ecosystem management. Here Christensen, et al. (1996) have identified eight elements, as follows:

1. Sustainability
2. Goals
3. Sound Ecological Models
4. Complexity and Connectedness
5. The Dynamic Character of Ecosystems
6. Context and Scale
7. Humans as Ecosystem Components
8. Adaptability and Accountability

Again, three general themes or requirements for ecosystem management are represented here: a systems approach with goals and models appropriate to the dynamic character, the complexity, connectedness and the multi-scalar nature of ecosystems; the need for an adaptive, integrative management approach; and finally the need to incorporate values such as inter-generational equity, vis-a-vis sustainability.

Franklin (1997) emphasized many of the same themes previous authors described, using examples from the field of forestry. He highlighted the multi-scalar approach of ecosystem management, that it is based on the concepts of adaptive management, and that the principle of sustainability should be incorporated, describing in detail the first two.

Thus, three main conceptual themes or requirements for ecosystem management can be drawn from these sources: (1) the adoption of a philosophical/scientific perspective which properly addresses the complexity and interrelated nature of human socio-economic and ecological systems, so that appropriate conceptual models and normative goals can be developed for management (i.e. systems-based science); (2) a shift towards a more inclusive and equitable (inter and intra-generational) ethical position (i.e. ethical governance); (3) a flexible, adaptive management organization designed to experiment, monitor, learn and adjust to a dynamic ecological context and (i.e. adaptive management).

One logical question results from this discussion of what makes an environmental management organization, ecosystem-based and adaptive (scientifically, organizationally): Are there real-world examples of adaptive, ecosystem-based organizations that successfully avoid the pathologies of Bella's 'systemic imbalance' in the ecological systems they attempt to 'manage' as well as their management/organizational system? One of the more well-documented examples of an adaptive ecosystem-based management organization is the trans-jurisdictional Chesapeake Bay Program (CBP). The subsequent chapters will, first, justify its use and describe the CBP. Then based on the background and insights of the preceding literature review, the program will be analyzed on two levels: conceptual/scientific and organizational. Analysis and conclusions will center on the CBP's conceptual view of the sociobiophysical system within which it attempts to manage as well as its organizational structure/dynamics.

Case Study

Introduction

> Achieving the wise use of America's estuaries requires both understanding these complex dynamic systems, and creating a governance approach that can effectively focus the diverse interests, authorities and institutional capacity of society to protect and restore their productivity and functioning. This is perhaps one of the most demanding challenges in the field of environmental management
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> - Imperial et al.: 1993, 173.

This statement by Imperial et al., in many respects, captures the essence of ecosystem-based management, as it underscores Slocombe's (1993: 618) three requirements: defining management units, developing understanding, creating planning and management frameworks. It also alludes not only to the complexity of estuarine ecosystems but also to the complexity of the inextricably linked human socio-economic and governance systems. Taken together these extremely complex 'bi-hierarchic' systems are exceedingly difficult to define and understand even conceptually, making the more operational matters of planning and management almost incomprehensible, even paradoxical. However, by acknowledging the uncertainty and complexity inherent in these systems and adapting management/planning measures, some environmental management regimes have met with significant conservation/restoration successes.

Probably the most successful and well documented cases of large-scale, environmental conservation/restoration efforts in North America to date are for the Great Lakes under the Great Lakes Water Quality Agreement, the Florida Everglades and the Chesapeake Bay Program. While a comparative study of two or even all three programs, especially from an organizational/governance perspective would perhaps provide the most valuable insight into defining a model for adaptive, ecosystem-based management, time and logistical constraints (such as travel expenses etc.) have limited this thesis to the study of a single case example.

The Chesapeake Bay Program was chosen as the primary case study for two main reasons. First, estuarine systems are very complex ecologically as well as socio-economically requiring the most innovative and effective governance structures and approaches. Secondly, along with the Great Lakes restoration efforts, the Chesapeake Bay Program is arguably the most internationally recognized example of adaptive, ecosystem-based management. In fact, Costanza and Greer noted (1995: 169), "the Chesapeake Bay is the largest estuary in North America and has been the subject of more scientific study and political wrangling than any other body of coastal water in the world". Hennessey (1994: 120) observed that "the governance system for the Chesapeake is worthy of study owing to a 16-year history of extensive scientific research combined with an innovative, interstate approach to program design, implementation, and evaluation". Hennessey (1994: 120) concluded that the program has "established an effective governance regime able to cope with the complexities associated with an estuarine ecosystem and the human uses of it". In short, as Costanza and Greer (1995: 170) stated, "efforts to manage the Chesapeake can be viewed as a 'best-case scenario' for ecosystem management". The program has been viewed as "an adaptive system which addressed increasingly complex issues while integrating existing management mechanisms" (Hennessey, 1997: 217).

It is the purpose of this thesis to study the scientific and organizational characteristics of adaptive, ecosystem-based management from a complex systems theory-based perspective. In subsequent chapters observations, analyses, recommendations and conclusions will be highlighted regarding the appropriateness of the current ecological conceptual model and organizational structure of the Chesapeake Bay Program based on the relevant literature and insights from complex systems theory and a Post-Normal scientific perspective. In order to study the program from this viewpoint it is necessary to gain an understanding of the history and current status of the pertinent ecological system, human socio-economic/governance system as well as a very general description of one of the many feedbacks loops within this complex 'bi-hierarchic' system. Given this, a more detailed description of the management/governance regime's history and current status will also be necessary.

General Description of the Study Area

At 290 kilometers long, holding some 18 trillion gallons of water and draining an area of approximately 166,000 square kilometers, Chesapeake Bay is the largest estuary in North America and the fourth largest in the world (Brush, 1997:127). Despite its size the bay is shaped like a shallow bowl having an average depth of only 27 feet. There are however, several deep troughs believed to be the remnants of the flooded streambeds that form the present Chesapeake Bay. The bay is located on the mid-Atlantic coast of the United States and its watershed drains parts of six states including, New York, Pennsylvania, West Virginia, Delaware, Maryland and Virginia as well as the entire District of Columbia (Chesapeake Bay Program, 1997:1). There are approximately 15 million people currently living, working and recreating in the Bay's watershed, that number is expected to be closer to 18 million as the new millennium approaches (Chesapeake Bay Program, 1997:1). It is this immense and increasing human presence within the bay ecosystem which has lead to its ecological decline.

It is the Bay's beauty and natural bounty which have lead residents and visitors to the Chesapeake's shores. The Algonquin Indians called it 'Chesepiooc', which means 'great shellfish bay', Spanish explorers referred to it as 'the best and largest port in the world', and Captain John Smith, English explorer, observed, "the country is not mountainous nor yet low but such pleasant plain hills and fertile valleys...rivers and brooks, all running most pleasantly into a fair Bay" (Chesapeake Bay Program, 1995: 2). Many of the Bay's colonial residents referred to it simply as, "the land of pleasant living" (Costanza and Greer, 1995: 172). All, however, were impressed with "the bay's size, navigability and abundance of wildlife and food" (Chesapeake Bay Program, 1995: 2).

The Chesapeake represents one of the United States most valuable natural resources. "In its heyday, the Chesapeake's shallow waters provided, acre for acre, more fish and shellfish than any other body of water in the world" (Costanza and Greer, 1995:172). More recently the Bay's shallow, nutrient-rich waters have provided for a huge commercial fishery ranked third (only to the two oceans) in the nation in a National Marine Fisheries Service study (Chesapeake Bay Program, 1995:3). The Bay also supports a $1 billion dollar recreational fishing industry as well as a host of other recreational activities including, boating, swimming, hunting and camping. And with two of the U.S.A.'s five North Atlantic ports located on the Bay it is also an vital commercial waterway.

Human uses aside, the Bay also provides a habitat for a multitude of plants and animals. The bay ecosystem provides a wide variety of habitats from "the hardwood forests of the Appalachian mountains to the saltwater marshes in the Bay" (Chesapeake Bay Program, 1997: 14). Due to the unique two-layer circulation pattern, resulting from the difference in density between fresh and saltwater, the Bay has a relatively long retention time which allows essential nutrients (as well as pollutants, unfortunately) to remain in the bay rather than being rapidly transported out to sea (Boynton, 1997: 76).

The result is a highly productive, nutrient-rich ecosystem providing perfect habitat for several species of anadromous fish like the striped perch, which spend their adult lives in the ocean but must spawn in freshwater (Chesapeake Bay Program, 1995: 14). "Shrimp, killifish and juveniles of larger fish species use submerged aquatic vegetation, tidal marshes and shallow shoreline margins as nursery areas and for refuge" (Chesapeake Bay Program, 1995: 15). Other fish species including the, "striped bass, bluefish, weakfish, American shad, blueback herring, alewife, bay anchovy and Atlantic menhaden live in the open, or pelagic, waters of the Chesapeake Bay" (Chesapeake Bay Program, 1995: 15). The many inlets, islands and wetlands provide habitat for "a multitude of species, from insects, amphibians and reptiles to birds and mammals" (Chesapeake Bay Program, 1995: 14). Also the Chesapeake is a significant stop-over for migrating waterfowl on the Atlantic Flyway.

This is, however, a stressed ecosystem (Costanza and Greer, Brush, 1997, Chesapeake Bay Program, 1995 etc.). Human activities, especially since European colonization, have had profound impacts on the ecological system, changing the system by direct influences as well as by changing its ecological context. In order to describe and understand the changes human impacts have had on the ecology of the Bay it is important to gain an understanding of the history of the ecosystem, the history of human impacts as well as efforts to conserve and rehabilitate the Chesapeake (specifically, and most notably, the Chesapeake Bay Program).

History of the Bay Ecosystem

Chesapeake Bay was formed approximately 10,000 years ago, when the last continental ice sheet, which had extended as far south as Scranton, Pennsylvania, began to recede. The subsequent rise in sea level covered the continental shelf and flooded the Susquehanna River Valley as well as the 50 major tributaries that empty into the Bay. "This complex of drowned streambeds formed the Chesapeake basin we see today" (Chesapeake Bay Program, 1995: 5). The Chesapeake Bay is a historically benthic dominated ecosystem possessing clear, shallow waters, extensive oyster reefs, benthic fish communities and shoals populated by diverse populations of submerged aquatic vegetation. However, this benthic ecosystem is, as with any ecoystem, dependent on its ecological context, in this case a historically densely forested watershed. This connection between the Chesapeake and its watershed highlights the need to look not only at the history of the bay but also at its ecological context as a nested holarchic ecosystem. "Though the waters have inundated the mouths of the bay rivers for 10,000 years, the tributaries still exhibit very direct impacts on the estuary. Much of that impact is natural and desirable: the delivery of nutrients and mixing fresh river water with saline water from the sea" (Costanza and Greer, 1995: 175).

Brush (1997: 129) has used the stratigraphy of sediment cores taken throughout the bay and its tributaries as a 'surrogate historical record of environmental history' within the Chesapeake ecosystem. The stratigraphic record for this region traces the vegetation patterns and associated climatic changes of the watershed back to the end of the last glacial period before the Susquehanna river basin was flooded. Beginning almost 12,000 years ago, when the climate was cold and wet, the surrogate stratigraphic history of the region shows "a coniferous forest consisting predominantly of fir, spruce, and pine lasting for about 2,000 years" (Brush, 1997:132). As the climate warmed, Brush (1997:132) noted, this boreal type of forest was succeeded by a closed canopy mixed coniferous-deciduous forest consisting of hemlock, pine, black gum, alder and birch which dominated the landscape for 5,000 years. At this point Brush (1997: 132) continued, "large amounts of charcoal in the sediment, accompanied by oak and hickory, indicate a warmer drier climate characterized by frequent fires". The oak hickory dominated forest spanned the approximately 3,500 years prior to European settlement. Since then, herbaceous plants, such as members of the blueberry family, increased and in the last 350 years ragweed pollen is dominant in the sedimentary record indicating something akin to 'secondary succession' or regeneration phase which generally follows the cultivation of land for agriculture.

In spite of the major climatic shifts that lead to changes in the terrestrial species composition, the landscape around the Chesapeake has remained forested. With the exception of periods characterized by frequent fires leading to increased sedimentation rates, the stratigraphic record shows that, "as long as the landscape remained forested, the estuary was little affected by what was happening on the land" (Brush, 1997:134). However, within the last 150 years approximately 80% of the watershed has been deforested (Brush, 1997: 135), removing the protective buffer which was a key element in maintaining the ecological context of the Chesapeake Bay's self-organizing ecosystem. Humans have inadvertently changed the context for the Chesapeake and only recently are we beginning to be able to understand a few of the many complex feedback loops which have been altered by human activities and lead to the most deleterious effects on the Bay ecosystem.

History of Human Impacts

"In the late 1970's, scientists began an extensive study of the Chesapeake Bay to determine the specific reasons for its decline. Three major problems were identified: excess nutrients from wastewater treatment plants, agricultural land, and developed land; sediment runoff from farms, construction sites, and other lands; and elevated levels of toxic chemicals" (State of Maryland, 1997: 4). Costanza and Greer (1995: 180), Bohlen and Friday (1997: 102-105), Boynton (1997: 76) and Brush (1997: 142) among others, also highlighted these as some of the key factors that have lead to impairment of the ecological integrity of the Chesapeake Bay ecosystem.

The result of direct (e.g. over-harvesting oyster populations) and indirect or contextual effects (e.g. deforestation and pollution changing ecological context for the bay ecosystem) of human population pressures and associated landscape changes in the watershed, these effects are the product of a history of mismanagement of human activities within the Bay ecosystem dating back to European colonization. Historians estimate that approximately 45,000 Native Americans lived in the Chesapeake Bay watershed when European settlers arrived in 1607 (USDA, 1996: 3). During the American revolution, when George Washington traveled though Annapolis, about 500,000 people lived in the state of Maryland alone. And in the two centuries that have passed since, Maryland's population has grown to almost 5 million people (Costanza and Greer, 1995: 182). Constanza and Greer (1995, pp. 183-189) tracked the growth of the region's population from the 1940's to 1986. In that time period, the watershed's population increased from, 7,579,653 to14,142,300 people. This is expected to increase by 20% by the year 2020 (Bohlen and Friday, 1997: 96). The increasing human presence has put enormous pressure on the Chesapeake Bay ecosystem.

The Bay was first used by settlers as a waterway, "the safe harbors of the Chesapeake clearly represented a boon to seafarers, particularly during an age when crossing the Atlantic in wooden ships was risky and, as (Donald) Shomette (historical writer) and others have documented, too often disastrous" (Costanza and Greer, 1995: 175). Although the sailing vessels of the colonial period would have had some impacts on the Bay, (perhaps some raw sewage, some garbage hurled overboard and some disturbance of river bottoms and near-shore sediments from hulls and especially anchors), these would have been minimal in comparison to the flushing of bilges from an oil tanker or the shore-line erosion from the substantial wake of a modern power boat or yacht (Costanza and Greer, 1995: 175).

As settlers arrived and small towns were built and eventually as immigrants crowded into cities like Baltimore, the Bay became the latrine for the growing human population. The advent of modem sewage treatment plants removed the human health dangers associated with the disposal of raw sewage, but it did not alleviate the ecological health/integrity issues associated with human waste disposal. As Costanza and Greer (1995: 177) indicated, "sewage is rich in nutrients, including phosphorous and nitrogen. The nutrients can over-enrich the bay and make it too productive for its own good". Too many nutrients results in the explosive growth of phytoplankton such as blue-green algae. This eventually results in the death of submerged aquatic vegetation due to lack of sunlight as well as hypoxic or even anoxic bottom conditions (leading to the death of benthic organisms such as oysters) as algae die and use up valuable oxygen during decomposition. Aside from sewage the bay also receives a myriad of toxic chemical compounds from industrial areas, vehicle emissions, runoff from parking lots etc.. "The areas around Norfolk Harbor (the Elizabeth River) and Baltimore (Patapsco River) have in particular been rated as 'toxic hotspots'" (Costanza and Greer, 1995: 176).

The Bay has also, of course, been a historically bountiful commercial and recreational fishery. In spite of the effects of nutrient and sediment loading, pollution and over-fishing, the

Bay still supplies literally millions of pounds of seafood annually. However, recent catch figures are a fraction of historic numbers. For instance, Boynton (1997: 89) analyzed several fishery patterns, tracks the recent history of the American Oyster commercial harvest. He noted,

> from 1929 through about 1960, combined Maryland and Virginia commercial oyster catches fluctuated between 20 and 40 million pounds per year. From 1960 through the early 1980's, combined catches decreased to 20-25million pounds per year with virtually all of the decrease occurring in Virginia waters. However, there was a rapid decline in waters of both states beginning in 1981, and this trend has persisted and even intensified through to the present time.
>
> - Boynton, 1997: 89

The striped bass and American shad fisheries have also declined in recent decades to the point where state authorities are enforcing a relatively strict ban on striped bass, and the American shad fishery has been closed entirely since the early 1980's (Boynton, 1997). "In the case of the striped bass, reduction in spawning stock size (due to overfishing) and habitat degradation appear to be the most likely causes" (Boynton, 1997:87). This being the case, the ban has resulted in increased stock sizes and successful recruitment patterns (Boynton, 1997). The same cannot be said for the American shad fishery. Despite a longer ban and the creation of fish ladders to allow for spawning migration, shad stocks have not rebounded. Boynton (1997: 87) has indicated that this is possibly due to acid rain altering pH to levels dangerous to shad larvae; however, this is only one possible explanation. The shad situation underscores for environmental managers the inextricable connections between the aquatic and terrestrial, socio-economic and natural, systems and the complexity of the Chesapeake Bay sociobiophysical system.

Historically, the link between the terrestrial and aquatic systems in the Chesapeake Bay region has been a beneficial one: "the delivery of nutrients and the mixing of fresh water with saline water from the sea" (Constanza and Greer, 1995: 175). This has provided the ecological context for the highly productive benthic dominated system. This context was maintained (as previously mentioned) by a densely forested watershed. In fact, "when the first colonists arrived on the shores of the Chesapeake, the vast old-growth forest covered close to 95% of the watershed" (USDA, 1996: 4). These forests provided the English navy of the 1600's with white pine ship masts, oak planking, and cedar timbers (USDA, 1996: 4). "Later, the settlers began to completely clear and then plow the land. By the mid-1700's, they had stripped 20 to 30% of the land to accommodate the growing population and its cash crop - tobacco" (USDA, 1996: 4). During the next hundred years, settlers began intensively clearing the land for agriculture (grain and tobacco). By the mid-1800's almost 40 - 50% of the watershed had been cleared. And from 1800 - 1850 the total cropland increased from 20 million to 76 million acres (USDA, 1996: 5). At the beginning of the 20th century only 30 - 40% of watershed's forests remained (USDA, 1996: 5). Since this time the forests of the Chesapeake Bay watershed have rebounded. "From the 1920's to the 1940's, agriculture again expanded, this time through the drainage of wetlands rather than forest clearing" (USDA, 1996: 5). And through reforestation and mine reclamation efforts 62% of the watershed was again forested by 1970.

The most recent threat to the watershed's forest cover has been from rapid urban expansion and suburbanization. Currently consuming nearly 100 acres per day, it is projected that a total of 1.7 million new housing units are to be constructed between 1990 and 2020 absorbing more than 636,000 acres of forest and farmland (USDA, 1996). This type of land use is especially destructive in terms of the context for the Chesapeake Bay ecosystem. The result is the removal of wetlands and riparian forest areas. This results initially in increased erosion and sedimentation rates and ultimately in replacing valuable buffering lands with highly impervious surfaces. "These changes reduce the extent of denitrification, physical trapping of sediments, and biological uptake of nutrients within the upper portions of the watershed" (Bohlen and Friday, 1997: 111). The sheer volume of freshwater coming off these impervious surfaces has also altered the salinity in the upper reaches of the bay.

There are now regulations that directly constrain land use decisions, i.e., zoning and land use management controls, wetlands permitting requirements, critical areas designations, etc. (Geoghegan and Bockstael, 1997: 156). However, other public policies have significant but often unintentional effects. Transportation policies and gasoline pricing can affect the rate of increase of urban expansion. Agricultural policies can affect types of crops that will prove profitable or ultimately lead farmers to sell their land for development (Geoghegan and Bockstael, 1997: 156). Lastly, "environmental policies that impose effluent standards, preclude certain practices, or provide subsidies for voluntary actions all have some effect on the profitability of putting land, or keeping land, in any given use" (Geoghegan and Bockstael, 1997: 156). Thus, human activities meant to preserve the environment in general have inadvertently undermined the ecological context of the Chesapeake Bay ecosystem.

Human Influence: An Example of Positive Feedback

As the Bay ecosystem is a complex, self-organizing entity, it is heavily dependent on inputs of matter, energy and information from the larger system (Hollick, 1993, Kay and Regier, 1999) which provides its sociobiophysical context. When these inputs are altered (rapid deforestation for example, dramatically increasing sediment load), the self-regulating, self-sustaining system must reorganize and adapt to this change in context, often resulting in a totally new self-organizing system. This is what has happened in the Chesapeake Bay ecosystem. As the watershed was rapidly cleared initially for agriculture and later for urban/suburban expansion and nutrient-rich fertilizers were introduced, along with nutrient laden sewage, and eventually effluent from sewage treatment plants, huge increases in sediment load and nutrients began to affect the Bay. Over-fishing and toxic compounds and eutrophication have devastated various commerical fish and oyster populations. Costanza and Greer (1995: 180) summarized four main impacts human activities have had on the Chesapeake Bay ecosystem:

- harvested oysters and destroyed oyster reefs
- increased algae in the water by adding more nutrients (mostly from sewage treatment plants, septic systems, fertilized fields and residential lawns)
- increased the amount of sediment in the water
- added new chemical compounds to the bay

Unfortunately for the integrity of the Bay, these impacts positively feed into one another. Nutrient loading (and associated explosion of blue-green algae populations) and increased sedimentation have reduced the amount of sunlight reaching the submerged aquatic vegetation at the bottom. This, along with the reduction in available oxygen at the bottom resulting from the decomposition of the algal blooms, and increased toxins have lead to the devastation of the highly productive benthic community. Compounding this situation was the fact that oyster populations (a key element of the benthic community) had been drastically reduced due to over-harvesting. Historically, the vast oyster populations could literally filter the volume of the Bay in less than a week keeping it crystal clear, it would now take more than a year for the drastically reduced oyster populations of today to filter the same volume of water (Costanza and Greer, 1995: 176). This self-reinforcing dynamic is pushing the Chesapeake towards a systemic threshold. The result may be a 'flip' from the highly productive benthic-dominated system to a less desired pelagic system, the inverse of the flip which has recently occurred in the Lake Erie system (Kay et al., 1999). There is a growing literature on this benthic/pelagic dynamic within shallow water bodies (Ludwig, et al., 1997; Scheffer, 1990; Scheffer, et al., 1993; and Scheffer, 1998). While both are equally viable ecosystems, the benthic system is perhaps a more 'ascendent' (Ulanowicz, 1997) system and is the system with which the socio-economic system of the region has developed and become interconnected.

Despite its detrimental effects, the human socio-economic system is highly dependent on the Chesapeake biophysical system. The oyster fishery, for example, is a multi-million dollar a year industry in the Chesapeake Bay region and provides an obvious link between the ecological and socio-economic systems at various scales. "King (1994) tallied the ex-vessel value of the 1992 Chesapeake Bay oyster harvest as $2.5 million, which generated business sales of about $7.5 million, household income of approximately $13 million and combined taxes of another $4.6 million" (Bartell, 1997:57). While ecological economists would estimate the value of the oyster populations in a more comprehensive way (perhaps including the value of their filtering potential for instance), this provides an idea of the dependencies on the biophysical system. However, as indicated the human socio-economic system has directly (over-fishing and pollution) and indirectly (changing the ecosystem's context through deforestation, agriculture, urban and suburban expansion leading to increased nutrient and sediment loading, changes in water salinity etc.) impacted the oyster populations. The oyster situation is but one example of how the Chesapeake Bay ecosystem has been impacted by the human socio-economic sub-system. And as "the Chesapeake has 200,000 people living in its drainage basin for every cubic kilometer of water in the bay ... even if all these people were minimizing their environmental impacts (which they are not), their sheer numbers are daunting to a system as sensitive as the Chesapeake" (Costanza and Greer, 1995: 195).

However, there is hope. "In 1975, Congress authorized a 5-year, $25 million study of Chesapeake Bay. The study was undertaken to estimate the nature and magnitude of threats to the Bay ecosystem" (Hennessey, 1997: 203). This study lead to the creation of perhaps the best-known and most studied example of adaptive, ecosystem-based management in the world, the Chesapeake Bay Program.

History of Environmental Management in the Chesapeake Bay Ecosystem

There have been several efforts to trace the origins and evolution of the Chesapeake Bay Program and specifically to identify the characteristics of the governance structure/dynamics that have made it an internationally recognized example of effective adaptive, ecosystem-based management (Resources for the Future 1979, Capper et al. 1981, and more recently, Imperial et al., 1993, Hennessey, 1994, Costanza and Greer, 1995, Hennessey 1997).

The work of Dr. Timothy Hennessey is perhaps one of the most recent examples of an effort to specifically examine the development of the governance/management structure of the Chesapeake Bay Program as an adaptive, ecosystem-based management initiative. Dr. Hennessey has traced the evolution of the Bay Program back to the mid 1970's and identified three general stages of development: 1976-1983 - Agenda Setting: Science and Public Choice; 1983-1986 - Choice of Governance Structure and Management Initiatives; 1987-1992 - Science and Governance: Program Implementation and Evaluation (Hennessey, 1997: 217).

While Hennessey more rigorously tracked the development of the program as an adaptive, ecosystem-based governance/management structure, Costanza and Greer's (1995) analysis has traced the perhaps less tangible roots of the environmental awareness, ecological understanding and socio-political movements that has eventually evolved into the Chesapeake Bay Program we know today. These authors argued that, "a recent chronology of bay 'management' should begin in the year 1965. In that year the U.S. Army Corps of Engineers conducted a major study of the bay, and two important pieces of legislation were passed: the Federal Water Pollution Control Act and the Federal Rivers and Harbors Act" (Costanza and Greer, 1995:197). Costanza and Greer (1995) identified three similar but overlapping stages or eras in the Program's evolution beginning with what they referred to as the "Era of Shared Experience and Raised Consciousness 1965-1976". This was followed by 1977-1983: Era of Intense Scientific Analysis with Political Backing and finally, 1983-Present: Era of Implementation and Monitoring (Costanza and Greer, 1995: 199). In the following I have integrated elements of these two chronologies so as to offer a more complete and detailed history of environmental awareness and management in the region.

1965 - 1976

Symptoms of human induced ecological change or decline are sometimes dismissed as the effects are often indirect and passed on. However, in the case of Chesapeake Bay, as Costanza and Greer (1995: 197) indicated, "the bay was and is everyone's backyard. Government bureaucrats form Washington sail and fish side by side with scientists, watermen, local politicians, and everyone else". This common experience of the bay resulted in wide-spread interest in restoration when it was realized that the ecosystem was in distress. The commitment to 'save the bay' was in evidence from the community/grass-roots level (eg. The Chesapeake Bay Foundation) to top levels of government (Senators, Congressman, and Federal Civil Servants).

The Chesapeake Bay Foundation (CBF), established in 1966 as a non-profit environmental organization, began its 'save the bay' campaign as a public education and advocacy initiative. 'Save the Bay' bumper stickers can still be seen on many cars in Maryland and other Chesapeake watershed states. As it is not a signatory to the Chesapeake Bay Agreement and lacks any concrete political/legislative authority the CBF's main role has been as a political catalyst and a watchdog, acting as both a "partner and a constructive critic" (CBF, 1993: 3) for the Chesapeake Bay Program. This strong grass-roots advocacy for Bay restoration was complemented by consistent media coverage. For instance, a reporter for the *Baltimore Sun* by the name of Tom Horton, "served as a key environmental journalist in the effort to bring the bay's problems before the public eye" (Costanza and Greer, 1995: 198). And in 1976, the Bay inspired William W. Warner's Pultizer Prize-winning novel entitled *Beautiful Swimmers* about the history of crabbing on the bay.

The decline of the Chesapeake not only called to action community environmental activists, scientists, journalists and authors but politicians as well. Maryland State Senator Bernie Fowler publicly demonstrated the deteriorating state of the bay when he waded up to his chest in the waters of the bay to show that he could no longer see his feet as he could when he was a boy growing up along the banks of the Patuxent river (despite the fact that his chest and toes were further apart). But when tracing the roots of the political force behind efforts to restore the Chesapeake two names must be cited, Senator Charles Mathias and Environmental Protection Agency administrator Russel Train.

It was the tireless efforts of these two influential men that brought the plight of the Chesapeake to the attention of Congress in the early 1970's and eventually lead, in 1975, to a 5-year $25 million EPA-funded study of the bay ecosystem. As Costanza and Greer (1995: 198) indicated, "this study was unique in both size and in its goal of supporting ecosystem management ... Unlike many purely scientific studies, this effort had political backing from the start and was aimed directly at providing answers to two fundamental questions: (1) what was responsible for the bay's decline and (2) what should be done about it?" And, "in 1976, the Environmental Protection Agency (EPA) acted in accordance with congressional directives by establishing the Chesapeake Bay Program Office and an organizational structure to management related activities" (Hennessey, 1994: 124).

1977-1983

The fledgling EPA-funded Chesapeake Bay Program was not the only government sponsored bay conservation organization. In fact, in the late 1970's and early 1980's a number of agencies were created by various units and levels of government to address the degradation of the Chesapeake. As a result there was much debate during these formative years as to how these various organizations and legislative entities would cooperate or could be integrated and what might be an appropriate governance structure to best serve the interest of conserving and restoring the bay. To this end,

> part of the directive to the EPA from Congress when it initiated the Chesapeake Bay Program was to determine which units of government should have management responsibilities for the environmental quality of the bay and to define how such management responsibility should be structured so that communication and coordination could be improved between units of government, between government units and research and educational institutions, and between government units and connected groups and individuals on Chesapeake Bay
>
> - Hennessey, 1994: 125.

This congressional directive lead to two major consulting reports (Capper et al. 1979 and Resources for the Future, 1980) which eventually formed the basis for the selection of an institutional/governance structure. Hennessey (1997:204) described the findings of these two key reports. "Capper et al. identified the many institutions involved in Chesapeake Bay evaluation and management and traced the early efforts to manage the bay". The primary conclusion of this report, Hennessey (1994, 1997) has indicated, was that the responsibility of governance should remain at the state level and any intra- or inter-jurisdictional difficulties should be resolved through cooperative efforts. As a result of this recommendation, in 1980 the Maryland and Virginia general assemblies created the Chesapeake Bay Commission made up of legislative members and citizens from both states. However, as Hennessey indicated this report left several key questions unanswered, namely was a new governance structure needed for the Bay, and if so were any of the existing institutions suitable? Or was a completely new institution required?

The Chesapeake Bay Program commissioned a second report to address these issues. The 1980 Resources for the Future paper entitled "An Evaluation of Institutional Arrangements for the Chesapeake Bay" concluded that, "regional institutions in the United States did not perform as expected in solving the problems that they were designed to address, primarily because existing local, state and federal entities tended to resist new regional institutions" (Hennessey, 1997: 206). Hennessey (1994, 1997) pointed out that the RFF report did not recommend a 'best' institution but offered a set of useful criteria for use in designing new regional institutions for ecosystem management. The report also concluded, interestingly enough, that in light of the extreme uncertainty and potentially high decision stakes (vis-a-vis Funtowiwicz and Ravetz's notion of Post-Normal science) associated with estuarine ecosystems, any management organization should be scaled appropriately to be large enough to match 'impact boundaries', yet be small enough to be flexible and responsive. Also, a multiple-institution governance system would be preferable as, "the benefits of a number of different perspectives on complex problems outweigh the potential inefficiencies of a multiple-institution structure" (Hennessey, 1997: 206). Finally, the RFF report concluded that despite potential resistence, the creation of a new institution was plausible if prospective members believed that it would be of notable advantage (Hennessey, 1994, 1997).

Drawing upon the results of these reports, the Chesapeake Bay Program identified three classes of potential governance arrangements, with ten possible institutional structures. Hennessey (1997: 206) listed these classes and institutional options as follows:

> Class 1: using existing structures
> (1) EPA Region III
> (2) EPA Region III and the Chesapeake Bay Program Management Committee
> Class 2: modifying existing structures
> (3) Chesapeake Policy Board and Management Committee
> (4) Bi-State Working Committee
> (5) Chesapeake Bay Commission
> (6) Interstate Commission of Potomac River Basin
> (7) Sesquehanna River Basin Commission
> (8) Chesapeake Bay Research Coordination Board
> Class 3: to create a new structure
> (9) Basin Commission
> (10) Comprehensive Bay-Wide Authority

Although suggested in 1977 by one of the Chesapeake Bay Program's 'founding fathers' Senator Charles Mathius, the last set of options was not deemed practical, especially in light of the RFF report recommendations and the fact that an new institution such as the Comprehensive Bay-Wide Authority would require "congressional action to create a new federal agency with broad responsibilities" (Hennessey, 1997: 209). The second class of options, that of modifying an existing institution, was also dismissed as,

> any such institution, if modified should be able to coordinate water quality and resource management programs at the state and federal level; be structured to include federal agencies such as EPA, NOAA, USDA, and others, the states of Virginia, Maryland, Pennsylvania, and the District of Columbia, as well as local governments; and have an

> advanced technical capability, be able to handle oversight of monitoring programs, maintain and use the large scale computer models, and carry out public outreach"
> - (USEPA, 1981 in Hennessey, 1997: 207).

None of the available options in this class could feasibly be modified to meet all, or even most, of these criteria.

Despite the recommendations of the Capper et al. report which suggested that the responsibilities for restoring the bay remain at the level of the individual states, "the need for immediate action and the costs involved made it essential that an existing mechanism with basinwide federal state representation be responsible to coordinating the cleanup" (Hennessey, 1994: 127). Thus, it was decided that one of the first two options would be most appropriate. As the EPA Region III alone lacked state representation and had no authority to implement programs in the areas of storm water management and fisheries, it was ultimately the second option of the EPA Region III and the Chesapeake Bay Program Management Committee, that was recommended as the basis for the governance structure for the 1983 Chesapeake Bay Agreement.

1983-1992

The 1983 Chesapeake Bay Agreement

The first bay agreement was signed by the EPA and the states of Virginia, Maryland, Pennsylvania, and the District of Columbia. "The agreement established the major elements of a cooperative structure to develop and coordinate the comprehensive Bay cleanup: namely, the Chesapeake Bay Executive Council, its Implementation Committee, and the EPA's Chesapeake Bay office" (Hennessey, 1994: 127). The Executive Council was made up of representatives from the three states, the District of Columbia and the EPA. "Operating by consensus, the council's primary functions were planning and coordination to ensure efficient implementation of programs and projects to restore the bay" (Hennessey, 1994: 127).

The Implementation Committee created by the agreement had 26 members representing the four jurisdictions, seven federal agencies and three interstate commissions (Chesapeake Bay Commission, Interstate Commission on the Potomac River Basin, and the Susquehanna River Basin Commission) (Hennessey, 1994). This, the operating arm of the executive council, included of four subcommittees, Planning, Data Management, Modelling and Research and Monitoring. These subcommittees were to be advised by the Scientific and Technical Advisory Committee, "whose membership included directors of the major bay area research institutions" (Hennessey, 1994: 128). The governance structure also included a 25 member Citizens Advisory Committee to provide public input on various conservation and restoration issues.

The Chesapeake Bay Restoration and Protection Plan 1985

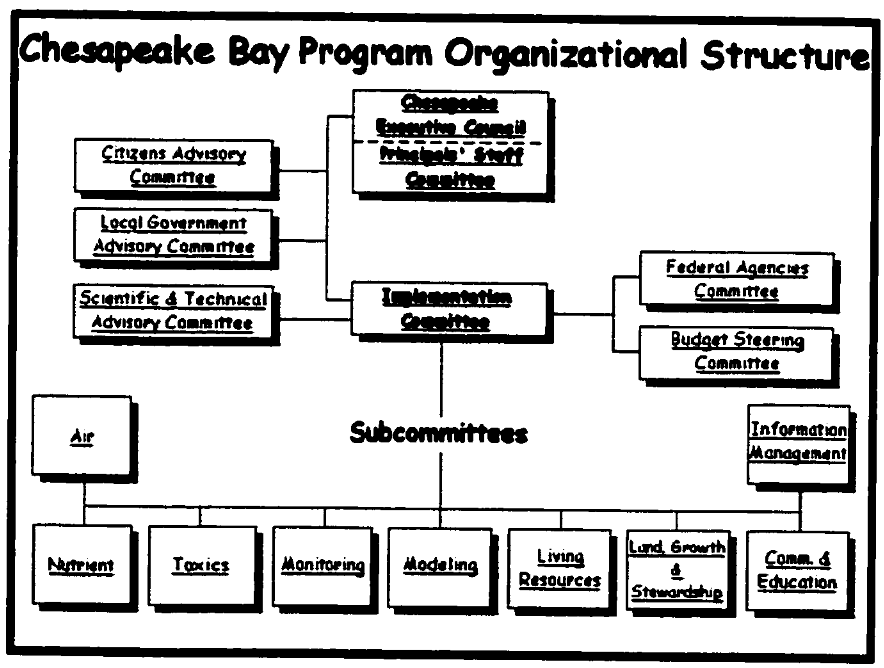
In 1985, with the governance and implementation structure in place based on the 1983 agreement, the Chesapeake Bay Restoration and Protection Plan was developed. Based on a catalogue of recommendations made by the four jurisdictions and seven federal agencies, the overarching principle of the plan was, "to improve and protect the water quality and living resources of the Chesapeake Bay estuarine system so as to restore and maintain the Bay's ecological integrity, productivity and beneficial uses and to protect public health" (Chesapeake Executive Council, 1985: 2). In order to give operational meaning to this necessarily general policy, the plan comprised five primary goals (1. Reduce nutrients, 2. Reduce toxics, 3. Protect living resources, 4. Focus environmental programs on bay impacts and 5. Establish cooperation among institutions) which were directly linked to thirty-two state and/or federal programs which involved approximately 430 individual projects. The Chesapeake Bay Restoration and Protection

Plan was a vast and complex piece of policy to implement, however it did represent, "the first clear statement of specific goals and a linkage of these goals to state programs" (Hennessey, 1994: 128).

The 1987 Chesapeake Bay Agreement

In 1987, a new Bay agreement was signed by the states of Maryland, Virginia, Pennsylvania, the District of Columbia, the EPA and the Chesapeake Bay Commission. This new agreement was meant to expand and yet more clearly define the goals of the program. To acknowledge, "the key role played by local government in the management of nonpoint and point sources of pollution" (Hennessey, 1994: 131) the governance structure had been extended to include a Local Government Advisory Committee. The structure of the Implementation committee had been reorganized since the 1983 agreement to include eight subcommittees, including four water quality subcommittees, a living resources subcommittee (as per the 1985 restoration plan). And to reflect the need for public access and the ever increasing need to mitigate the effects of population increase and urban expansion subcommittees for Growth and Development, Public Access and Public Information and Education were formed. Below is a schematic of the revised governance structure (see Figure 10). The five major

Figure 10: CBP Organizational Structure



subcommittees (water quality subcommittees grouped together) each had one or two overarching goals for a total of eight, which involved forty objectives. This new agreement also included a set of priority commitments with deadlines for each subcommittee (29 in total). Many of these priority commitments were completed between 1988 and 1992.

One of the most influential aspects of the 1987 agreement, however, was its focus on nutrient reduction and specifically the goal of a 40% reduction of nitrogen and phosphorous in the mainstem of the bay by the year 2000. In fact, "the nutrient issue was considered so important that it was included as a work group reporting directly to the Implementation Committee and charged with a full-scale reevaluation of the nutrient goal by 1991" (Hennessey, 1994: 131). The eventual reevaluation lead to a series of amendments to the bay agreement in 1992.

1992-Present

In 1992 the 1987 Chesapeake Bay agreement was amended for dual purposes, to extend the nutrient reduction program spatially (i.e. to acknowledge the importance of the tributaries in nutrient reduction) and temporally (i.e. to extend the 40% reduction beyond the year 2000). "As a result, Pennsylvania, Maryland, Virginia, and the District of Columbia began developing tributary strategies to achieve the nutrient reduction targets. The Bay Program also began reevaluating its Basinwide Toxics Reduction Strategy in order to better understand the impact toxics have on the Bay's resources" (Chesapeake Bay Program, 1999).

Ten years after the original Bay agreement was signed in 1983 the Bay program celebrated with its "Decade of Progress" by highlighting several of its conservation and restoration successes, especially the increased area of submerged aquatic vegetation and reduction in point-source pollution. The "Decade of Progress" was not only a celebration of past and current successes but also represented an opportunity to refocus conservation and restoration efforts for the future. To this end, "the Executive Council guided the restoration effort in 1993 with five directives addressing key areas of the restoration, including the tributaries, toxics, underwater Bay grasses, fish passages, and agricultural nonpoint source pollution" (Chesapeake Bay Program, 1999).

Continually re-analyzing and refocusing its efforts, the Bay program began to put a greater emphasis on conserving and restoring the Chesapeake Bay ecosystem as a whole. No longer focusing solely on the mainstem of the Bay the CBP attempted to take a more watershed oriented, or ecosystem-based view of the Bay. As a result more emphasis was placed on increasing habitat for the living resources and reducing toxics in the Bay ecosystem. In 1994 the Executive Council adopted the Chesapeake Bay Basinwide Toxics Reduction and Prevention Strategy and issued new initiatives for riparian forest buffers, habitat restoration, and reciprocal agricultural certification programs (Chesapeake Bay Program, 1999).

Reaffirming this focus on the Bay ecosystem as well as ratifying the federal government's commitment to the restoration of the Chesapeake, the 1994 Agreement of the Federal Agencies on Ecosystem Management in the Chesapeake Bay was signed. "The historic agreement outlined specific goals and commitments by federal agencies on federal lands throughout the watershed, as well as new cooperative efforts by federal agencies elsewhere" (Chesapeake Bay Program, 1999).

Other recent Chesapeake Bay Program initiatives and agreements include in 1995 the Local Government Partnership Initiative, in 1996 the Local Government Participation Action Plan, Priorities for Action for Land, Growth and Stewardship in the Chesapeake Bay Region and Riparian Forest Buffers Initiative and in 1997 the Community Watershed Initiative. Most recently in late 1998, there has been much emphasis placed on renewing the Bay agreement for the new Millennium. Chesapeake 2000 (or C2K as it has been termed) will involve six key elements:

A. A clear understanding of public interests
B. A synthesis of the new science relevant to Bay restoration and protection of long-term ecosystem health
C. An assessment of the progress to date under the 1987 Bay Agreement and subsequent directives
D. Identification of the emerging challenges to the health of the ecosystem
E. Consideration of the next generation of measurable goals
F. Independent reviews of the program from peers and experts outside the program.

The C2K agreement renewal represents the program's most recent effort to re-evaluate its scientific perspective and organizational structure to ensure that it, as an ecosystem-based environmental management entity, is appropriate to the complex system it is attempting to restore and protect.

With an understanding of the history of the ecosystem, the experience with environmental management within the system and in light of the recent C2K initiative to again evaluate the program, it is now appropriate to move into analysis of the Chesapeake Bay Program as an example of adaptive ecosystem-based management from the perspective of the most recent ecosystem science and ecosystem management frameworks summarized in Chapter 2.

Case Study Analysis

Introduction and Overview

Throughout its 23 year history, the Chesapeake Bay Program has demonstrated both the heuristic potential and empirical feasibility of the concept of adaptive, ecosystem-based management. The program is not only one of the main precursors to the U.S. Environmental Protection Agency's National Estuary Program which is currently protecting and restoring 17 estuarine ecosystems across the country, it has also become one of most-studied regional-scale examples of adaptive, ecosystem-based management around the world. It has done this by avoiding the pathologies of static, resource-centred, bureaucratically structured, comprehensive planning/management regimes described by Gunderson, Light and Holling (1995). The Chesapeake Bay Program has demonstrated an integrated approach and a flexibility that have allowed it, as an organization, to learn, adapt and evolve in the face of a complex, dynamic sociobiophysical system.

There is little doubt that the Chesapeake program has exhibited some measure of each of the three requisites of ecosystem-based management discussed in chapter 2 (systems-based scientific perspective, an appreciation of the ethical implications of the role of science in policy-making and governance, and a recognition of the need for an adaptive management approach). However, whether the program fulfills the requirements of the archetypical adaptive, ecosystem-based management organization described in the literature is open for debate especially in light of much of the complex systems theory-based literature.

What follows is an analysis of the Chesapeake Bay program as an example of adaptive, ecosystem-based management from a complex systems theory-based, post-normal perspective. It is loosely structured along the three themes or requirements of ecosystem-based management described in the literature review (systems-based science, ethical governance and adaptive management) and is divided into an analysis of the 'official' (mandated in CBP agreements and directives) and 'operational' (secondary sources including personal interviews) perspectives of the program. Many of the complexity theory-based heuristics described in the literature review have been utilized to critique the CBP's general scientific perspective (i.e., systems-based, specifically complex systems theory-based ecological science), the role of science in policy-making in the CBP (i.e., striving for more ethical governance) and adaptability and potential for organizational learning within the CBP (i.e., adaptive management).

Scientific Perspective

Originally focussed on nutrient-related issues in the mainstem of the bay, the CBP has since broadened its managerial scope to include the tributaries and the entire watershed by explicitly recognizing the interconnectedness of the sociobiophysical system's estuarine, terrestrial, human agricultural and urban/suburban subsystems. While often implicit, its conceptual model of the bay ecosystem has become more sophisticated through organizational learning via its extensive modeling and monitoring programs and various other research initiatives. However, a view of the bay ecosystem as a complex system for the purposes of decision/policy-making is still a long way off. Originally employing a more simplistic, 'H_l' mindscape (i.e., mechanistic, linear cause and effect model) the program as a whole has integrated elements of an 'S' or cybernetic conceptual model.

During the original 5-year, $25 million study, the problems facing the bay seemed to be relatively clear, that is fisheries and other living resources were in decline, nutrient loadings were increasing, and toxics were increasing to alarming levels.

> As is typically the case, however, despite a wealth of scientific information, there was a lack of consensus over what needed to be done to restore the Bay. Science helped fuel concern about the Bay, but there was no agreement on a policy agenda to address the issues science had identified. This lack of agreement was exacerbated by the number of sovereign jurisdictions governing some portion of the Bay watershed, the diversity of economic interests involved, and the inherent complexity of the Bay ecosystem. In the real world of public policy, decision-makers cannot indefinitely postpone decisions until all the evidence is assembled or all the disagreements among parties resolved. But they can postpone action if there is lack of clear consensus about the causes of pollution or its effects. This was the case in the Chesapeake Bay circa 1980
>
> - Prout & Tippie, 1984:3 from Hennessey, 1994:125.

Searching for simple cause-effect solutions for the problems in the mainstem of the bay could not yield definitive direction for policy-making as, in reality, the causes of the Bay's decline were very numerous, often involving non-linear positive feedback phenomena (e.g. the oyster example in the last chapter) and generally originating beyond the physical boundaries of the bay.

Addressing issues as complex as those involving the restoration and preservation of an estuarine ecosystem, the CBP has developed trans-disciplinary sub-committees and workgroups (including engineers, biologists, ecologists, sociologists etc.) to address issues such as Living Resources; Air; Nutrients; Toxics, Monitoring; Modeling; Land, Growth and Stewardship; Communications; and Information Management. However, this subcommittee/workgroup structure, although constantly evaluated and altered, has remained divided along sectoral, not necessarily disciplinary lines, creating small fiefdoms, limiting the potential for a truly integrated management regime.

Governance: Science and Policy-Making

The Chesapeake Bay program has always made an effort to be mindful of the issue of equity, whether it be in terms of intra-generational equity or inter-generational equity (as in sustainable development). From its inception the program included a Citizen Advisory Committee and utilized public interest surveys to allow the opinions and concerns of the residents of the watershed to be represented in the decision- and policy-making realm. As well, citizens have participated in data collection across the watershed through the citizen's monitoring program.

The concept of sustainable development has infiltrated recent policy papers and offers an ethical basis for restoring the Bay ecosystem. The potential for the democratization of the decision-making process could be greatly enhanced with insights gleaned from a post-normal scientific/decision-making perspective. Post-normal science (PNS) explicitly recognizes the high uncertainty and high decision-stakes of policy-decisions such as those under the jurisdiction of the CBP. Given the high uncertainty and high decision-stakes, a post-normal approach would require the extension of the peer community beyond the technocrats so the resulting policy would be equitable and would have been developed based on a 'rich' picture of the ecosystem (including valid perspectives beyond the traditional scientific).

Adaptive Management

> The Chesapeake Bay Program established an effective governance regime able to cope with the complexities associated with an estuarine ecosystem and the human uses of it. The designers of the Chesapeake Program rightly avoided a single-centered, hierarchical governance system and opted instead for a decentralized, cooperative system based on negotiation and compromise among decision makers at federal, state, and local government levels. This system encouraged a dynamic, creative relationship between and among scientists, citizens and elected officials. This approach fostered an organizational learning capacity that in turn led to a phased process of adjustment of

programs and structures to changing circumstances and new information
- Hennessey, 1994: 139.

Hennnessey's view of the program as an example of adaptive management is logically pragmatic. That is, it is very easy to criticize any real-world example of an adaptive management regime based on some conceptual ideal described in the literature. This can, of course, often be counter-productive. So Hennessey has provided a very positive view of the program as being a flexible, non-bureaucratic organizational entity which exhibits some degree of organizational learning in that the CBP has continually reevaluated its managerial focus. Hennessey concluded that the CBP needs to take more seriously the experimental aspects of an adaptive management approach. That is, conservation and restoration initiatives cannot always await definitive scientific proof and understanding (which is not always possible in the context of a complex sociobiophysical system) before they are implemented. Some initiatives need to be undertaken, monitored and ultimately learned from despite their outcome. The CBP's Living Resources Committee's Habitat Conservation Program is one example of such an experimental initiative. As well, as the following analysis indicates the CBP needs to become more acutely aware of the ecological dynamics and complex feed-back loops that drive the system and how as an organization it can become more in tune with these dynamics and avoid what Bella (1997) called systemic imbalance.

The Chesapeake Bay Program as a Complex Organizational System

Introduction and Overview

The previous introductory section superficially addressed how the three themes of ecosystem-based management are manifest in the CBP. This section will more extensively analyze the CBP's officially mandated and operational scientific, governance and management approaches from a complex systems-theory based, post-normal perspective.

The CBP has continually reevaluated its management foci and consequently expanded its scientific understanding of the sociobiophysical system within which it operates. From its original 1983 agreement to its recent Chesapeake 2000 reevaluation, the CBP has demonstrated an integrated, holistic approach to environmental management, an inclusive form of governance and a capacity to learn and adapt as an organization. One of the main objectives of this thesis is to compare this real-world example of adaptive, ecosystem-based management with the conceptual archetype developed through a complex systems theory-based/post-normal perspective.

With this in mind, the following section summarizes the main tenets of the 1983 agreement, the 1987 agreement, the 1992 amendments, the 1994 Habitat Restoration Directive, the 1997 Nutrient Progress and Future Directions Directive and the 1998 Chesapeake 2000 Reevaluation Directive and charts the evolution of the program's scientific perspective, as well as its approach to governance and management. The CBP's environmental management perspective will also be contrasted with the complex systems theory-based/post-normal perspective on a conceptual level. This analysis of the more formal, or officially mandated perspective will be followed by a detailed analysis based on various secondary sources and on information acquired through in-depth interviews with CBP senior scientists and other eminent scientists familiar with the Chesapeake sociobiophysical system.

1983 Agreement

This original agreement simply laid the foundations for the organizational framework of the current CBP. Although the organization has evolved substantially since, the 1983 agreement established the executive council, the implementation committee as well as the EPA's liaison office in Annapolis Maryland. The Executive Council's primary functions "were planning and coordination to ensure efficient implementation of the programs and projects to restore the bay" (Hennessey, 1994: 127). The Implementation Committee, the executive council's operating arm, was composed of four subcommittees, Monitoring, Modeling and Research, Data Management, and Planning (Hennessey, 1994:128). This early agreement laid the organizational foundation for a coordinated effort, to address the restoration of the Bay from an integrated resource perspective. While this initial agreement set no explicit goals or objectives to guide the restoration effort it did require the executive council to report annually to the signatories of the agreement and required the implementation committee to review and evaluate management plans based on monitoring data. This set the stage for the long-term, iterative approach to environmental management that the CBP is known for today.

1987 Agreement

In 1985 the executive council passed the Chesapeake Bay Restoration and Protection Plan. This represented the first explicit statement of goals linked to specific projects within the CBP. Two years later these goals were refined and the management focus of the CBP was clarified and expanded in the 1987 Chesapeake Bay Agreement. This new agreement set goals and priority commitments for the newly reorganized Implementation subcommittees which included: Living Resources; Water Quality; Population Growth and Development; Public Information, Education and Participation; Public Access; and Governance.

One of the key goals put forth in this agreement was the commitment to reduce 'controllable' nutrients (specifically nitrogen and phosphorous) by 40% by the year 2000. It continues to be one of the main management goals of the CBP. The 1987 Chesapeake Bay Agreement represented and remains a benchmark for progress within the CBP. It was a clear statement of the program's goals and a strong commitment to the restoration of the Bay. This document represents, for the purposes of the this study, the first concrete application of the CBP's scientific, governance and managerial perspective.

Science

The goals and commitments described in the 1987 agreement offer some evidence of the CBP's underlying scientific perspective, or as Maruyama termed it, their Mindscape. The terminology used in the agreement reveals some general scientific assumptions about the structure and dynamics of the ecological system within which the CBP manages human activities. For instance, the agreement's goal for living resources stated that the CBP will endeavour to,

> Provide for the restoration and protection of the living resources. Their habitats and ecological relationships. The productivity, diversity and abundance of living resources are the best ultimate measures of the Chesapeake Bay's condition. These living resources are the main focus of the restoration and protection effort. Some species of shellfish and finfish are of immense commercial and recreational value. Others are valuable because they are part of the vast array of plant and animal life that make up the Chesapeake Bay ecosystem on which all species depend. We recognize that the entire natural system must be healthy and productive.
>
> - Chesapeak Bay Program, 1987: 2.

This passage alone speaks volumes as to the general scientific perspective through which the CBP's management priorities and projects are developed. The use of the 'health' analogue, as well as the terms 'productivity, diversity and abundance of living resources' as 'the best ultimate measures of the Chesapeake Bay's condition' point to somewhat a limited conceptual model of the structure and dynamics of the ecosystem.

As previously noted in Chapter 2, the concept of ecosystem health (as implied here) refers simply to a system operating in the absence of stress. In the case of the Chesapeake, for example, this would represent a system state akin to pre-European settlement. The human health analogue is used repeatedly in the CBP literature (examples provided in the following section). While some scientists within the CBP would acknowledge that there is little or no possibility of returning the system to such a state, the use of the health analogue as a management principle can be misleading. The health analogue implicitly implies that there is a 'natural' system state which the system will inevitably return to after stress. This perspective is based on a cybernetic mindscape. This perspective could ultimately lead to the preservation of only those components of the system which are integrally connected within the system, (i.e. those components that comprise the ascendent element of the ecosystem) at the expense of those less tightly coupled to the system's 'everyday' operations (i.e. the overhead element of the system). The concept of ecological integrity, which incorporates the health analogue, is a more comprehensive normative conservation goal in this sense.

The use of the term productivity as an measure of the Bay's condition could also lead to a misinterpretation of the Chesapeake ecosystem's relatively high productivity compared to, for instance, the Baltic sea as a more 'healthy' ecosystem. Ulanowicz discusses this comparison (of the Chesapeake and the Baltic) in his discourse on his theory of ascendency. He noted that, "the Chesapeake ecosystem is far more active than the Baltic: its total system throughput is more than four times that of the Baltic. Some of the higher productivity in Chesapeake Bay can be ascribed to warmer temperatures, but higher nutrient inputs to the Chesapeake are also likely to enhance its activity" (Ulanowicz, 1997:128). Thus, if higher productivity is a restoration goal then higher nutrient loading should be encouraged. This would obviously lead to higher algal productivity in the water-column leading to increased turbidity and pushing the system towards a flip from the historic benthic to a pelagic-dominated system. This also runs counter to current management practice (i.e. the CBP's 40% nutrient reduction goal). It is an issue of maximization versus optimization within a normative goal.

Diversity and abundance of living resources as measures of the condition of the ecosystem may also yield misleading results. As demonstrated by Robert May (1973) measures of diversity as surrogates for system stability are without theoretical basis. That is, "May (1973) has pointed out that too many connections can destabilize a system" (Ulanowicz, 1997). This is not to imply that the preservation of biodiversity is completely without merit. On the contrary, some measure of diversity within an ecosystem is necessary to the resilience and continued evolution of the system (system overhead). But the preservation of diversity for diversity's sake does not provide adequate direction for management decisions. As previously discussed in chapter 2 the concept of ecological integrity, as defined by Kay (1993) provides an appropriate contextual goal within which the conservation of biodiversity can be theoretically grounded. Diversity in this context serves to maintain adequate system 'overhead' (Ulanowicz, 1997) to ensure that the system is resilient and maintains the dynamic balance between ascendency and overhead to allow the system to continue the process of self-organization.

Aside from these references in the Living Resources goals statement, the Water Quality statement also offers some insight into the general scientific assumptions of the CBP. For instance, the 1987 agreement established the 40% nutrient reduction goal for the year 2000 as well as various commitments to reduce the amount of toxics entering the Bay. These commitments are based on the assumption that the system in the absence of these stressors will return to a single 'natural' state. Insights gleaned from complex systems theory suggest otherwise. With the existence of multiple steady-states or attractors the system may be (or may have already been) pushed beyond a threshold into the domain of another attractor. Such assumptions (mostly based on H_I or S mindscapes) could ultimately lead to inefficient or inappropriate use of restoration resources (financial or otherwise).

Governance and the Role of Science in Policy-Making

The 1987 agreement laid the foundations for the CBP's dependence on good, objective, quantifiable science and yet also a continuous program of public input into management decisions and education about the Bay itself. The agreement called for the quantification of impacts and refers numerous times to the use of computer modeling results as decision-making criteria. While this may seem inconsequential it can be argued that requiring scientists to provide objective, quantitative answers to issues relating to complex sociobiophysical systems can result in a false sense of security for decision-makers as the inherent uncertainty and complexity of these systems are excessively reduced and over-simplified. As a result scientists can be forced into a 'hyper-objective' role or into the inappropriate role of acting as an organization's moral compass (discussed in detail later in the chapter).

However, with this agreement the CBP established its commitment to an inclusive, democratic form of governance based on public involvement and education. Given the inherent complexity and uncertainty as well as the pervasive consequences of management decisions within the Chesapeake Bay ecosystem this kind of inclusive governance is not only ethical but, in terms of gaining a more complete understanding of the ecosystem, fruitful.

Management

This 1987 agreement represented the CBP's commitment to efficiently restoring the Chesapeake Bay ecosystem within a highly complex ecosystem and jurisdictional framework. With three levels of government involved in the restoration effort there has always been pressure on the CBP's administration to reduce costly jurisdictional redundancies. The terms 'cooperation' and 'coordination' are used numerous times throughout the agreement in reference to the CBP's management approach. Unfortunately, recent systems-based organizational behaviour literature has indicated that this drive for organizational efficiency may be at the cost of innovation and ultimately, organizational learning. The agreement did however, call for a 'long-term' approach to management based on a strong monitoring program. It remains to be seen if the commitments to efficiency and, monitoring and adjustment have been implemented with equal vigour.

1992 Amendments

The 1992 Chesapeake Bay Agreement Amendments were the result of the 1991 nutrient reduction reevaluation mandated in the 1987 agreement. The results of this reevaluation pointed to three key shortcomings of the then current nutrient management foci. These resulted in the following recommendations: to extend the management boundaries to the watershed, to include the Bay's tributaries and even beyond (airshed); to intensify efforts to control non-point sources of pollution; and to emphasize the importance of the link between water quality conditions and the health of submerged aquatic vegetation. The amendments represent the CBP's capacity to learn as an organization and to adjust its managerial foci accordingly.

Science

It became apparent from the 1991 nutrient reevaluation that the goal of a 40% reduction in nitrogen and phosphorous could not be met without extending the CBP's management boundaries to include the tributaries and addressing the watershed as a whole. This movement toward a watershed approach to management in the Chesapeake Bay ecosystem not only represented an extension of boundaries but denoted for the CBP, a move towards a more holistic scientific perspective. Rather than simply focusing restoration efforts on the main stem of the Bay the 1991 reevaluation forced the CBP to address the nutrient issue on a more ecosystemic level. There was even reference in the 1992 amendments to acknowledging the importance of airborne deposition and the need to extend management boundaries even further to include the airshed however, this has yet be achieved as this area includes non-signatory states.

While the 1992 amendments did represent a shift towards a more holistic scientific perspective, it was within the context of the CBP's continued focus on the reduction of nutrients and toxics. While the reduction of excess nutrients and toxic substances entering the Bay are obviously critical restoration objectives they are not explicitly set within any kind of ecosystemic, normative conservation/restoration goal. Such a restoration effort undertaken without an explicit normative goal such as ecological integrity implicitly assumes (reinforced by explicit references to both the 'health' of the system and restoration to a pre-European settlement state) that the system in the absence of such stressors will return to some more 'pristine' state. The existence of multiple ecosystem attractors or states would complicate conservation efforts derived under such cybernetic assumptions.

Governance and the Role of Science in Policy-Making

The 1992 amendments renewed the CBP's commitment to inclusive governance ensuring "the broadest possible public involvement" by incorporating "public participation in the development, review and implementation of the strategies" (Chesapeake Bay Program, 1992: 1). There was no implicit or explicit reference to science or the relationship between science and policy-making in these amendments as in the 1987 agreement. However, the CBP's commitment to objective, quantitative science and their modeling program has not waned to this day.

Management

The 1992 amendments represented the next iteration of the CBP's commitment to an adaptive form of management, i.e., an approach based on the continual reevaluation of management direction based upon current science and monitoring. As Hennessey (1994) has indicated, the CBP has not to this point demonstrated the experimental aspects of an adaptive approach. Also, there is a continued emphasis on efficiency (understandable in such a complex multi-jurisdictional setting). As indicated previously (to be elaborated later) in some organizations this efficiency may come at the cost of innovation and may even tend towards systemic imbalance. The 1992 amendments explicitly stated the CBP's dual commitment to both 'cost-effectiveness' and 'equity'. While this may have represented a growing awareness of the potential implications of the continuous emphasis on efficiency, the question remains has the inclusion of the term 'equity' had any notable operational implications (to be addressed later in the chapter).

1994 Habitat Restoration Directive

In fulfilment of its commitment to "provide for the restoration and protection of living resources, their habitats, and ecological relationships" (Chesapeake Bay Program, 1994:1) the CBP's Executive Council developed the Habitat Restoration Directive. Meant to coordinate the existing habitat restoration efforts of local, state and federal agencies as well as to provide a framework for future projects, several of the commitments in this directive provide insight into the CBP's scientific, governance and managerial perspective.

Science

This directive represented a step beyond the nutrient and toxics focus while acknowledging the important links between a system's context and its structure and function. It explicitly noted how the many types of habitat within the Chesapeake ecosystem are influenced by their sociobiophysical context and how in turn the degradation and fragmentation of these habitats influenced ecosystem function (as well as the commercial and recreational values of the system). It also highlighted the importance of certain habitats (e.g., submerged aquatic vegetation) in the reduction and abatement of nutrient pollution into the Bay.

Governance and the Role of Science in Policy-Making

Once again, in the context of this directive there is significant stress on objective, quantitative results. While there is nothing inherently wrong with requiring quantitative results, especially in the context of habitat conservation (i.e. establishing restoration goals) such goals are often based upon 'lowest-common-denominator' solutions. As such, when decision-makers require such quantitative, 'objective' answers to complex questions they can often be taken as absolute. Thus, it might be assumed that when these goals are met the ecosystem will again be 'healthy'.

Management

Again demonstrating its commitment to adaptive management through continual reevaluation and organizational adjustment, the CBP redirected its management focus to acknowledge the importance of the preservation of habitat. Also, and perhaps of equal importance, several of the commitments in this directive represented the CBP's first attempt at experimental management which, as Hennessey (1994) has indicated, has been absent from the CBP's adaptive management approach. Acknowledging the "critical need to accelerate efforts to restore habitat across the basin to benefit living resources" (Chesapeake Bay Program, 1994: 1), the CBP set concrete habitat preservation goals and committed to the creation of an 'integrated habitat management plan' that would help accelerate and coordinate preservation efforts. The commitment to the preservation of habitat combined with the commitment to the production of a habitat management plan without prior intense investigation (as with their commitment to nutrient and toxic reduction based on the 5-year, $25 million study) represented a managerial experiment. This will not only benefit the Chesapeake but will allow the CBP to greatly expand its own capacity to learn as an organization.

1997 Nutrient Reductions and Future Directions Directive

Having reaffirmed their commitment to the 40% reduction of controllable nutrients in the 1992 amendments, the CBP again conducted an extensive reevaluation of this commitment in 1997. It was focussed on three key questions: Will we meet the 40 percent reduction by 2000? Are the nutrient reductions being achieved through the tributary strategies? Are we achieving the water quality necessary to support living resources? This directive represented the CBP's continued commitment to reduce nutrient loading in the Chesapeake watershed. While pointing to tangible examples of progress (cleaner rivers) and less tangible (implementation of tributary strategies and statutory deadlines), the CBP did acknowledge that it had to accelerate its efforts if it was to meet its year 2000 nutrient reduction goal.

Science

This directive explicitly stated that the CBP has learned a great deal "about how storm events, groundwater releases, and other natural and manmade conditions affect the pace of recovery for the Bay and its rivers" (Chesapeake Bay Program, 1997:1). As well, it committed to "reductions of airborne nitrogen delivered to the Bay and its watershed from all sources including states outside the watershed, and to seek improved understanding of how airborne nitrogen affects the Bay and its tributaries" (Chesapeake Bay Program 1997:1). However, it did not describe the theoretical basis for the role of nutrients, especially nitrogen in the bay ecosystem. For that we can turn to a 1994 CBP discussion paper which described some of the most recent 'Advances in Estuarine Science'. In the context of this document the authors discussed the role nutrients play as a limiting factor in primary production. The authors noted that nutrients limit the rate of algal growth and that "if more than one nutrient is available at less-than-optimum rates, then the one in shortest supply is the most limiting one and determines the growth rate". This is a reference to Liebig's Law of the Minimum which they described as a "19th-century rule for the effects of different factors on terrestrial plant yields that later was applied to the growth of phytoplankton by Blackman (1905)" (Fisher and Butt, 1994: 4). Ulanowicz (1997: 135) noted that while such "conventional methods of identifying nutrient limitation deal only with the aggregate amounts of various nutrients that are presented to the predator taxon ... (and) would correctly identify nitrogen as the element most limiting to mesozooplankton growth ... (Liebig's Law) provides no clue as to which source of that nitrogen is limiting". Ulanowicz (1997: 135) went on to note that "in the absence of any guidance to the contrary, the natural inclination is to rank the importance of various nitrogen sources according to the magnitudes drawn from each pool, and in most cases, this assumption accidently identifies the controlling source". While Ulanowicz's information theory-based ascendency theory demonstrates a connection between theory and conventional methods, it also "provides a method for identifying controls in situations for which no guidance currently exists" (Ulanowicz, 1997:136).

Governance and the Role of Science in Policy-Making

Once again the 1997 Nutrient Directive has demonstrated the CBP's continued dependence on technocratic decision-making. It explicitly called for the utilization of models to "set goals for the Virginia tributaries below the Potomac" (Chesapeake Bay Program, 1997:3). Yet in the next paragraph committed to conduct "an analysis and prepare a protocol, which will include a public participation component, to determine whether nutrient goals and reduction efforts can further be targeted to areas of persistent high loadings, especially where evidence indicates a linkage to critical living resources or human health concerns" (Chesapeake Bay Program, 1997:3). As well, it committed "to future generations that when we achieve the water quality necessary to support the living resources of the Bay, we will maintain it into the future" (Chesapeake Bay Program, 1997:3). This juxtaposition of the requirement for quantitative, objective scientific answers to policy questions with the explicit commitment to inclusive governance begs the question of how the two are balanced in program implementation (discussed in the next section).

Management

This reevaluation of the nutrient goal commitment and the resulting directive are an obvious example of the CBP's commitment to adaptive management approach. As well, the CBP has committed to "use monitoring data and the upgraded Bay Water Quality and Watershed Models to tell us if our current nutrient reduction goals will result in the water quality improvements needed to sustain living resources in the Bay and its tidal tributaries" (Chesapeake Bay Program, 1997:3). However, once again the focus on efficiency is noted but balanced by a call for equity. Finally, the need to accelerate efforts to meet the year 2000 goal indicates the need to promote experimental management.

1998 C2000/STAC Futures Project

The Executive Council's recent C2000 Directive (1998) has set the stage for the CBP's next iteration in its self-evaluation and adjustment process which will take the form of a new Chesapeake Bay Agreement in the year 2000. In this directive the CBP has committed to the enhancement of educational initiatives, incentives for the development of new technologies while at the same time ensuring that the progress which has already been made is not over taken by old and new challenges to the restoration process. As well, this document has provided a series of more normative commitments that are to direct the process towards the new Bay Agreement:

- A clear understanding of public interests
- A synthesis of the new science relevant to Bay restoration and protection of long-term ecosystem health
- An assessment of progress to date under the 1987 Bay Agreement and subsequent Directives
- Identification of the emerging challenges to the health of the ecosystem
- Consideration of the next generation of measurable goals
- Independent reviews of the program from peers and experts outside of the program.

Science

Scientifically the CBP's general perspective or mindscape has evolved. Since the 1987 agreement the CBP has demonstrated the ability to learn as an organization through an adaptive form of management. Through consistent reevaluations of its conservation and restoration efforts the CBP has expanded its managerial focus and broadened its scientific perspective. Despite continued references to the human 'health' analogue, recent work in the preliminary stages of the STAC Futures project for example has demonstrated that the CBP's 'mindscape' continues to evolve towards a 'G' mindscape or complex systems worldview.

The Futures project is an effort to construct scientifically plausible scenarios of the condition of the Bay in the year 2030 as a planning tool to aid in the development of the 2000 agreement. For this exercise the CBP has pooled its scientific resources and formed inter-disciplinary teams of scientists to address a broad range of issues including: Population and Socio-Economic Changes, Landscape and Land Use Changes, Emerging Technologies and Future Estuarine Conditions. The Future Estuarine Conditions work- group for instance, will be addressing "the potential effects of larger scale environmental changes, such as climate shifts, sea level rises, and exchanges with the coastal ocean" (STAC, 1998:5). "The end products of this Task Force should examine the ecosystem as a whole considered against the backdrop of its temporal variability" (STAC, 1998: 5).

While the emphasis remains on the issues of nutrient and toxics abatement, and habitat preservation the workgroup will also be focussing on other biophysical issues related to the restoration of the Bay including: biodiversity conservation, climate change as well as the impacts of long-term trends in temperature, precipitation, sea level, and other extreme events on the health of the estuary. While it does not completely reflect a complex systems worldview it does represent an integrated, transdisciplinary scientific approach to what they acknowledge is a 'complex system' which requires an holistic approach acknowledging the importance of macro-level structures and processes.

Governance and the Role of Science in Policy-Making

While the CBP has continued its efforts to provide the public with an opportunity to be informed and involved in the decision-making process, for the most part public participation is still mostly ad hoc in nature. That is, decision-making within the CBP is still highly technocratic and expert-oriented. Quantitative results provided through its modeling program, for instance, are emphasized in an effort to provide decision-makers with 'objective' answers to complex policy issues. While the STAC Futures project does represent an evolving scientific perspective, it reinforces the detached and decisive role of the scientist in policy and decision-making. The CBP has always implicitly understood that the Chesapeake is indeed a complex system and is now attempting to develop policy that indicates an appreciation of the ecosystem as being more than something akin to a simple machine or even a single organism. However, their current decision-making system does not appear to acknowledge the ethical issues surrounding the application of 'objective' science and expert-oriented policy-making to highly complex issues with extremely high uncertainty and pervasive decision-stakes.

Management

By committing to "an assessment of the progress to date under the Bay Agreements and directives - consideration of the next generation of measurable goals that will focus our initiatives for the future; and review and input by experts outside the Bay area so that we make the most impartial judgments for the future of the program" (Chesapeake Bay Program, 1998:1) along with a commitment to the development of a long-term monitoring strategy in its Chesapeake 2000 directive, the CBP has renewed its commitment to an adaptive management approach. However, the CBP's stress on coordination and efficiency are still evident as the C2000 documentation stated that, "every effort will be made to ensure the schedules, issue development, and meeting opportunities are compatible and not duplicative" (Chesapeake Bay Program, 1998:1). How the CBP balances flexibility versus efficiency will be discussed further in the next section.

Summary of Perspectives

In the course of this research I have attempted to gain an appreciation of the general scientific perspective, the relationship between science and policy making, and the general management/planning approach of the CBP. This has been done through an examination of the CBP documentation and through in-depth interviews with long-serving CBP scientists and other experts familiar with the CBP and the sociobiophysical issues surrounding the efforts to restore and preserve the Bay. The above represents a summary and evolution of the scientific, governance and management perspectives of the CBP as presented in several of the program's key agreements and directives. It is meant to provide the reader with a sense of the officially mandated perspective of the CBP as it has evolved over the last decade or so. It has also been presented for the purposes of contrasting it with what is presented in this thesis as a more theoretically grounded, equitable and flexible environmental planning and management approach: the complex systems theory-based/post-normal perspective. Figure 11 below summarizes as well as charts the evolution of the scientific, governance and management perspectives of the CBP from 1987 to the present while Figure 12 contrasts the current perspective with the complexity-based/post-normal perspective. The section to follow will provide the reader with a sense of how this official perspective has been translated into an operational perspective as seen through the eyes of those involved.

Figure 11: The Evolution of the CBP's Perspective

Scientific Perspective	
1987	Mechanistic, linear causality model applied to nutrient and toxics reduction issues in the main-stem of the Bay with an appreciation of some of the cybernetic, organismic qualities of the Bay ecosystem
1992	Greater appreciation of the holistic nature of the ecosystem as the CBP adopts a watershed approach to nutrient and toxics reduction
1994	Broadening the scientific and management perspective to address the issue of the Bay's 'health' by focussing on the role of habitat in ecosystem functioning *as well as* the role of nutrients and toxics
1997	Commitment to nutrient reduction reevaluated resulting in the commitments to extend management boundaries to airshed (re: airborne nutrient deposition) as well as an increasing understanding of the dynamics that influence nutrient enrichment. However, understanding of the role of nutrients in the overly enhanced productivity of the Bay ecosystem based on limited theoretical understanding of the system.
1998	STAC Futures project represents an integrated, trans-disciplinary approach to the Bay ecosystem which encompasses the issues of nutrients, toxics, habitat as well as biodiversity, climate change and long-term variability and extreme events.
Governance and the Role of Science in Policy-Making	
1987	dependence on good, objective, quantifiable science (e.g. modeling) as well as a continuous program of public input into management decisions and education about the Bay itself.
1992	little change from 1987 Agreement
1994	significant stress on objective, quantitative results
1997	emphasis on objective, quantitative results but juxtaposed with some emphasis on inclusive, democratic governance
1998	renewed commitments to good science and public involvement however, decision-making still highly technocratic and expert-oriented

Management	
1987	committed to efficiently restoring the Chesapeake Bay ecosystem within a highly complex jurisdictional framework however, 'long-term' approach to management based on its strong monitoring program reinforces commitment to adaptive management approach
1992	committed to both 'cost-effectiveness' and 'equity
1994	first attempt at experimental management
1998	continued emphasis on coordination and efficiency, reevaluation based on long-term adaptive management approach

Figure 12: The CBP's Perspective Versus a Conceptual Ideal

	CBP	Complex Systems Theory-Based/Post-Normal Perspective
Summary - Scientific Perspective	An evolving scientific perspective - from a very mechanistic HI mindscape to more of an cybernetic S mindscape and shows signs of moving in the direction of a greater appreciation of the complexity and inherent uncertainty associated with a system as complex as the Chesapeake Bay ecosystem Originally viewing the issues relating to the dynamics of the Bay and its condition as very linear, cause and effect. Analogue tweaking a machine for a return to maximum output has evolved to viewing the Chesapeake as a complex cybernetic organism who's 'vital signs' were shifting away from the preferred, 'natural' state now is gaining a greater appreciation of the complexity of the system and its relationship to its sociobiophysical context	Views an ecosystem as a complex, self-organizing entity with multiple, equally viable system states or attractors. Requiring an understanding of the dynamic balance between the tightly coupled, highly ordered, ascendent elements and the more tenuously connected, disordered, overhead elements which maintains the context for the system's continued evolution or self-organization. All of this must be considered at various scales. While the role of nutrient reduction for instance, in the restoration of the Chesapeake is critical, if it is not placed within a normative theoretical context such as that of Ulanowicz (1997) (Ascendency theory) inappropriate or at least misguided management decisions could result.

	CBP	Complex Systems Theory-Based/Post-Normal Perspective
Summary - Governance and Role of Science in Decision-Making	Decision-making process still very technocratic heavy dependence upon scientists producing quantitative, 'objective' answers however, this is juxtaposed with an explicit attempt to inform and include relevant stakeholders (e.g. concerned residents etc.) in decision-making process	Role of science: to provide decision-makers (an extended peer community of stakeholders) with narrative descriptions of the various viable ecosystem attractors and the system's behaviour about these attractors to aid in the development of a 'vision' of the a ecologically feasible and socio-economically preferred system. Once the 'vision' is developed a type of 'back-casting' is used to develop a series of goals and objectives to achieve the 'vision' including descriptions of how the system might be 'pushed' towards or away from a given attractor.
Summary - Management	Due to the jurisdictional complexity of the Chesapeake watershed the management emphasis has been on coordination and cooperation, i.e. efficiency However, there has been an obvious commitment to an adaptive management approach through a recursive process based on a long-term monitoring program and continuous reevaluation of management foci.	Acknowledgement of the complexity and inherent uncertainty of natural as well as human organizational systems involved in environmental management. To operationalize this a management organization must monitor for indicators of ecological integrity (system ascendency and overhead as well as maintaining the dynamic balance between the two i.e. maintain the context for self-organization; also must monitor the state of the management organization to ensure its current structure is suitable to the level of uncertainty associated with the current state of the ecosystem i.e., to synchronize the human organizational cyclic dynamic with the ecosystem Holling figure-eight cycle
Overall Philosophy	Mainly Cybernetic	Morphogenetic

	CBP	Complex Systems Theory-Based/Post-Normal Perspective
Causality	Homoeostatic causal-loop model - structures and patterns of heterogeneity are maintained by homeostatic causal loops	Morphogenetic causal loop model - Morphogenetic causal loops generate patterns of mutually beneficial relations among heterogeneous elements, and raise level of sophistication of the system
Certainty	sought and expected; use of experts evolving towards sought but not expected use of generalists	neither sought nor expected; specialized generalists
Overall Mindscape	S perhaps moving in direction of G	G

Through its various agreements and directives the CBP has made great strides towards the implementation of the concept of adaptive, ecosystem-based management through the evolution of its scientific perspective, inclusive governance and adaptive form of management. However, how this more 'official' scientific, governance and management perspective has been operationalized is much less tangible and has not been studied to a great extent especially from a complexity-based/post-normal perspective. In order to acquire a sense of what the general 'operational' scientific perspective, governance and management approach has been, it was necessary to conduct interviews with scientists who have been involved directly with the CBP or who have studied the Chesapeake for some time. Such individuals would have a deep (at times almost cynical) appreciation of how the CBP actually views the Bay and its role in its restoration. The following is an analysis of the CBP from a complex systems theory-based/post-normal perspective based on secondary source literature as well as interviews with five environmental management professionals with long histories in the CBP or independently associated with the restoration of the Chesapeake Bay. This will provide balance to the more 'official' perspectives just discussed and offer a richer, more complete picture of the CBP's scientific perspective, governance framework and management approach.

The Scientific Perspective of the CBP: the Health Analogue

Maruyama in his work on cognitive models indicates that "it is not easy for an individual *and indeed less so for an organization much less a culture* to switch between scientific theories that correspond to different 'mindscape' types" (Maruyama, 1980: 19) (Italics mine). Put differently, scientific paradigms, in the Kuhnian sense, do not shift easily and so it is not surprising that the complex systems theory-based perspective (G-type mindscape) has not permeated mainstream environmental science and management despite its innovative and provocative implications.

And so, in spite of the fact that the CBP is perhaps an internationally recognized example of adaptive, ecosystem-based management, and despite the fact that the nearby University of Maryland has three of the most notable complex systems theory-based ecological and environmental management academic research institutions in the U.S.A. (The Multi-Scale Experimental Ecosystem Research Center, the Chesapeake Biological Laboratories, and the School of Ecological Economics) the program has been slow to adopt this perspective for policy-making. Even though these institutions are in fact loosely affiliated with the CBP (mostly via EPA funding) little of their work is used directly for environmental management decision/policy-making.

To make generalizations about the general scientific perspective of a program as large and complex as the CBP is obviously quite difficult, and some might argue is of questionable utility. However, by looking at the literature produced by the program and interviewing scientists and environmental management professionals with long histories within and around the program, one can derive a clear sense of where, for instance, the program may sit within Maruyama's tetrahedron of mindscape types (see Chapter 2).

Much of the literature produced by the CBP in the form of agreements, policy statements, scientific and technical papers, if it alludes to macro-level/ecosystemic characteristics at all (many documents produced by the program focus on the 'ecological roles' of certain species, i.e. oysters and submerged aquatic vegetation SAV), refer to restoring the Bay ecosystem to a more 'balanced' or 'healthy' state. Often referring directly to the concepts of 'resilience' and 'ecosystem health'. Examples of explicit use of these terms include a 1991 Progress Report for the Chesapeake Executive Council which states that "the Bay has six major and 140 minor tributaries that must be improved before the Bay is indeed returned to health". A 1993 report describing the CBP's 'Strategy for the Restoration and Protection of Ecologically Valuable Species' states that the strategy's overarching goal is "to restore a more balanced ecosystem in the Chesapeake Bay". In the 1994 "Agreement of Federal Agencies on Ecosystem Management in the Chesapeake Bay" one of the main goals of the agreement is to restore "the Chesapeake watershed to a healthy ecosystem". And in a 1996 report by the U.S. Department of Agriculture and the U.S. Forest Service on "Conserving Forests in the Chesapeake" it is stated that, "resilience is a measure of an ecosystem's ability both to sustain itself over the long term and to return to the norm when pushed out of balance. An illustrative analogy is when a healthy, resilient person is exposed to the flu". It may be argued that the health analogue is prevalent in these cases as it is easy to relate to, especially for non-scientific audiences and the general public. However, interviews conducted with several resource management professionals who have been associated with the Bay program for years or even decades affirm that this is an appropriate assessment of the current mainstream ecological perspective in the CBP.

Dr. Robert Ulanowicz, (a Professor at the University of Maryland's Chesapeake Biological Laboratories since 1970) when asked to characterize the dominant scientific paradigm of the CBP, referred specifically to one of the epistemological types which he developed for a recent book and related paper. In these he describes three epistemological types, the Mechanical, the Organic, and the Stochastic. This loose classification is similar to Maruyama's four mindscapes with the exception that Ulanowicz's schema does not explicitly distinguish between his 'Stochastic' world view and the perspective (Maruyama's 'G' mindscape) which describes phenomena such as macro-level order via nonlinear positive feedback.

Ulanowicz (Pers. Comm.1999) stated that the Program is "definitely still in the mechanical mode", that is viewing the ecosystem from an hierarchic, mechanical, linear cause-effect perspective. However, on a more positive note he did indicate that the CBP had attempted to put more emphasis on habitat versus a more reductionist species by species approach. And he continued, "to their credit, they do an excellent job with their 3-D hydrological and chemical models" and added that, "they now want to add biota to the model", but cautioned that he expects "them to get bogged down quickly", no doubt in light of the inherent complexity and uncertainty associated with living, self-organizing entities. As Kay et al. (1999) indicate, situations which involve self-organizing phenomena limit our ability to quantitatively predict future events. Thus, management in these situations requires a different perspective, a different role for science in policy-making, that of providing scientific information to develop descriptions or narratives of potential system states as well as conditions preceding bifurcation points, or thresholds between such states (to be discussed further in a later section).

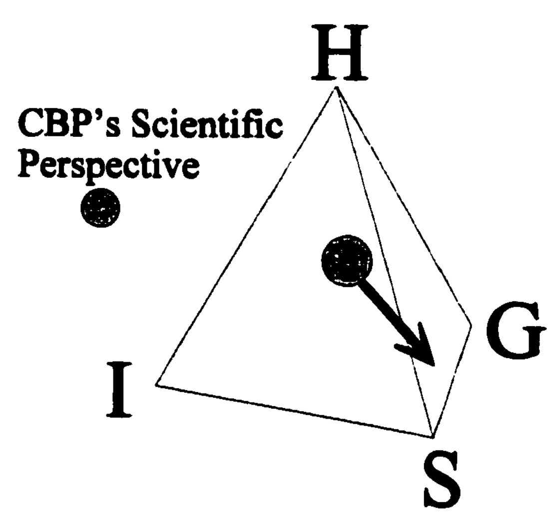
An official of the Chesapeake Bay Foundation's who has been involved with the restoration and protection of the Chesapeake in various capacities (scientist and activist) for more than two decades, validated Dr. Ulanowicz's characterization of the CBP's dominant scientific perspective as more or less mechanical, linear cause and effect. He pointed to the program's preoccupation with water quality and eutrophication, noting that generally the program looks for simple input/output relationships for nutrients and toxics in the ecosystem. He too pointed to the program's impressive modeling efforts but also cautions that these models have limitations when dealing with natural systems, especially with natural variability. He argued that while these computer models are improving, the watershed model, for instance, is limited by its static baseline calibration. The model is calibrated using 1985 as a 'typical' year. Of course, this individual indicated that there hasn't been anything resembling a 'typical' year since.

A Senior Scientist with the CBP for more than two decades, raised strikingly similar issues. He noted that the program has traditionally focused on nutrient issues in the mainstem of the Bay utilizing a simple linear cause-effect conceptual model of the Bay but that the managerial scope of the program, as well as the ecological science and understanding has broadened since. He also highlighted the CBP's historical emphasis on modeling, noting that the program has in fact been driven by modeling at the expense of other research. He cautioned against this preoccupation with modeling highlighting the problems associated with the 1985 'typical' year calibration noting that there have been 13 atypical years since. He also argued that these modeling efforts do not account for the increasing human pressure in the basin.

Finally, another Senior Scientist with the CBP provided a very positive view of the program. He indicated that the management policies of the program have often lagged behind the science and that the scientific perspective of the Bay program is advancing, attempting to reflect the complexity of the ecosystem. He argued that overall the dominant scientific 'paradigm' is something akin to Maruyama's 'S' (Homeostatic) mindscape or an organismic conceptual model of the system.

Overall, the dominant scientific mindscape of the CBP seems to lie somewhere between the 'H' and 'S' apexes on Maruyama's tetrahedron (See Figure 12). At best, the scientific mindscape that appears in the literature and in policy-papers and agreements utilizes a cybernetic or organismic conceptual model of the ecosystem which takes the form of the conceptual conservation goal of restoring ecosystem 'health'. However, this could be the result of the popularity and easy to relate to notion of the ecosystem as an organism and may in fact be an example of Kim and Senge's (1994) 'superficial learning' (when changes in mental models are called for but do not occur). That is, the CBP could be paying lip-service to the cybernetic 'mindscape' but is still operating under a mechanistic worldview. However, to some extent the ecosystem health analogue has found acceptance in the CBP.

Figure 13: Mindscape Tetrahedron



The health analogue has taken many forms since being developed by Rapport and Regier. The literature from the CBP seems to refer to ecosystem health only in the limited sense of the absence of distress. Focusing solely on being distress-free implies that the system is equilibrium-based (i.e. Maruyama's 'S' mindscape) or stable about a single attractor. This assumption reinforces the role of the scientist as the 'expert' in an expert-oriented decision-making framework as it does not allow for the possibility of, and choice between, equally viable and multiple stable states. Suter (1993) highlights the risk of confusing health assessment with disease diagnosis and cure. Kay (1991a, 1991b) also warns of the dangers of taking the health analogy too far, based on an analogy with human's relatively narrow range of 'operating conditions' in comparison to ecosystems.

In the case of the Chesapeake, the limitations of the health analogue could lead to a dangerous managerial complacency. The underlying assumption of the health analogue is that the ecosystem, if distressed, will eventually and/or with appropriate environmental management, return to a state of well being. Unfortunately, this is only one possible scenario. As previously mentioned, Kay et al. (1999) have utilized a 'fold catastrophe' model to describe the ecosystem dynamics of the Lake Erie system. Through this analysis of exergy in the system Kay et al. (1999) describe thresholds beyond which the system 'flips' to the domain of the other attractor (in both the Lake Erie system and the Chesapeake the two attractors are the benthic and pelagic dominated ecosystems).

It is arguable that the Chesapeake is approaching just such a threshold (turbidity and nutrient availability increasing and pushing system towards a pelagic dominated system). It is during these bifurcations or flips that system uncertainty is highest and management needs to be most flexible (to be dealt with further in the next section). However, if the CBP is attempting to manage human activities in the basin based on a cybernetic or 'S' mindscape (at best) utilizing the human health analogue, such a flip may not be anticipated. In this case a pelagic-dominated bay would emerge and most likely eventually become a very 'healthy' system, however many of the economic, social and cultural attributes of the benthic-dominated Bay which many of the basin's residents take for granted would be gone. Thus, an alternative management goal based on a complex systems/post-normal perspective would more appropriately reflect the dynamics of the Chesapeake as a complex, SOHO system.

On a theoretical or conceptual basis, integrity as defined by Kay provides a more explicit parsing of the elements that ecosystems require to survive and develop or evolve. By including but limiting the notion of health within the concept of integrity the narrow perspective associated with the health analogue can be avoided. Ulanowicz's notions of 'ascendency' and 'overhead' (see chapter 2) provide a theoretical explanation for limiting or parsing the notion of health within the integrity concept. "There is a fundamental incompatibility between the ordered (ascendency) and disordered (overhead) fractions - yet they are complementary aspects of what is essential to sustaining the operation and persistence of the system (Ulanowicz 1997: 94).

If the health analogue (in the limited sense noted above) is carried to its logical extreme only the ordered or ascendent fraction of an ecosystem would be preserved and the overhead would be neglected and as Ulanowicz (1997: 92) points out, "ecosystems can create too much structure and thereby become 'brittle'. Thus, efficiency can become the road to senescence and catastrophe". It is critical that these two components be kept distinct within an environmental management goal.

In this sense, the concept of ecological integrity is a more comprehensive normative conservation goal. As defined by Kay (1993), ecological integrity explicitly parses the ascendent and overhead elements of the system and requires the conservation of a unique balance between the two which allows for continued self-organization. Monitoring for ecological integrity (see Woodley, 1993) would allow the CBP to better understand how human activities are affecting the complex feed-back loops that sustain the dynamic balance between the ascendent and overhead elements of the system which allow for the system's continued self-organization about the two known attractors (the benthic and the pelagic). Monitoring would enable policy-makers to more appropriately and effectively maintain the ecosystem's integrity while at the same time allowing for sustainable human interaction with the system.

However, the use of integrity in environmental planning and management decision/policy-making would require a new relationship between science and policy-making. Explicitly acknowledging the potential for ecosystems to exhibit several, equally viable, system states removes the possibility for scientists to render an 'objective' answer regarding management initiatives.

Governance and the Role of Science in Policy-Making in the Chesapeake Bay Program

Several of the interviewees cautioned against the program's emphasis on its modeling projects. All also noted that while these models had technical and perhaps conceptual limitations they were some of the most sophisticated models used in environmental management anywhere in the world. Their cautionary remarks were more in reference to the strong role of modeling in the decision and policy-making process. In fact, several of the interviewees noted that the strong emphasis on modeling in the CBP came at the expense of other research initiatives.

While sophisticated quantitative, computer models are powerful decision-support tools, they should not be relied upon by decision-makers as a comprehensive representation of reality. "A model is simply an abstract representation of the system of interest that we can manipulate to aid our understanding" (Costanza and Greer, 1995: 202). Some of the most sophisticated hydrodynamic models (Dortch et al. 1988), models of estuarine dynamics (i.e., nutrient runoff from the watershed) (Hwang, 1990) and integrated models of the ecological and economic systems (Debellevue and Costanza, 1991) are being utilized by the Chesapeake Bay Program to understand the Bay ecosystem. However, as Costanza and Greer (1995: 203) go on to indicate, "even with the best conceivable modeling capabilities, we will always be confronted with large amounts of uncertainty about the response of the environment to human actions (Funtowicz and Ravetz, 1992)". The authors conclude that,

> to use quantitative computer modeling effectively to understand and manage complex ecological economic systems like the Chesapeake watershed, we need an integrated, multiscale, transdisciplinary, and pluralistic approach. Moreover, we need one that also acknowledges the large remaining uncertainty inherent in modeling these systems and develops new ways to deal with the uncertainty effectively
>
> \- Costanza and Greer, 1995: 203.

As previously indicated, the CBP's emphasis on modeling and modeling-related research has often been at the expense of other ecological and environmental management related research initiatives. This may not necessarily have been a conscious managerial decision but may be in fact due more to the CBP's socio-political context. As Greer (1999: 9) argued in a recent paper on science and policy-making in the CBP, "many still underestimate (and misunderstand) the value of research". Some politicians, for example, after the conclusion of the initial Chesapeake Bay Study, said "we've had enough research. Now we need action". Exasperation resulting from such comments was a common sentiment echoed in many of the interviews conducted in the course of this research.

> Greer (1999) refers to this as politicizing science. 'Our society is awash in politicized science; very often the public recognizes it and distrusts research, scientists, and associated organizations because of it'(Kenner, 1998). Brian Kenner, who warns against the politicizing of science, joins other thinkers and researchers who argue that moneyed interests often 'shape the framing and resolution of issues, including the conduct of scientific research (Jansanoff, 1997)
>
> - Greer, 1999:1.

Greer (1999: 2) argues that, "on the one hand, researchers have at times played the role of pushing the policy-envelope, complaining for example, that 'officials ... seem compelled to de-emphasize scientific evidence that might imply the need to adopt some unattractive (to them) course of action such as nitrogen removal' ... (D'Elia, 1987)". However, he continiues, "on the other hand, scientific evidence or scientific uncertainty is sometimes used to slow environmental policies: thinkers like David Orr complain, for example, that scientists too often suffer from a 'hyperobjectivity' that interferes with their function as caring human beings".

These two roles for scientists in the decision-making process can be seen to represent the two types of activities that tend to support Bella's two organizational attractors. The 'hyperobjective' role is very similar to those activities (Type 'A') which enhance or sustain Bella's 'R' attractor, or a pattern of behaviour which draws order out of disorder. Bella characterizes it as 'systemic and amoral'. The other role for scientists in the current decision-making regime of the CBP is akin to the activities (Type 'B') which support Bella's 'S' attractor, or 'disordered commotion'. This tendency is characterized by disruptive activities that disturb the overall order in the system. Bella describes the 'S' attractor as 'nonsystemic and moral'. Thus, scientists in the current decision/policy-making context are often forced into two disparate roles: the 'hyperobjective', that is they feel they must ignore ethical and moral aspects of an issue so as to provide good 'objective' scientific results; or, on the other hand, the 'moral compass', that is, they are relied upon to provide decision-makers with hard and fast, objective answers on often volatile ethical and moral issues when none are possible, and so consciously or unconsciously set their scientific objectivity aside and focus on the ethical and moral aspects of a policy issue.

Scientists are forced into these roles as the result of the technocratic decision-making philosophy based on an 'H' type mindscape which dictates that in all situations there is one distinguishable 'truth' to be uncovered. This 'truth' can be found through an objective, analytical scientific method as, according to this epistemolgical type, the world is deterministic and exhibits simple linear cause-effect dynamics. Unfortunately, this perspective is not appropriate to complex, self-organizing systems such as the Chesapeake Bay sociobiophysical system. And equally unfortunate for the CBP is the fact that several of the interviewees noted (and demonstrated through their opinions) that these 'hyperobjective' and 'moral compass' roles are accurate portrayals of the roles scientists play in the CBP policy-making process.

In such cases the traditional 'normal' (in the Kuhnian sense) scientific 'H_l' mindscape has been inappropriately applied to a situation involving organized complexity, that is to the study of a complex system. With the extreme uncertainty and relativistic nature of such systems traditional scientists are forced to render a so-called 'objective' answer to a situation where none is theoretically feasible. Funtowicz and Ravetz's proposal for a 'post-normal science' addresses this very epistemological discrepancy. Instead of forcing scientists into the role of technocrat, a post-normal scientific perspective would seek to democratize the decision making process in that it would be "akin to the workings of a democratic society, characterized by extensive participation and toleration of diversity" (Funtowicz and Ravetz, 1994: 1885). Funtowicz and Ravetz as Oxley (1997:

26) indicated, "do not, however, argue for the extension of the peer community which ascertains scientific quality in the basis of a generalized wish for the greatest possible extension of democracy in society". Rather, in such situations of high uncertainty and inherent relativism it is only prudent to include as many legitimate perspectives as possible to ensure the quality and legitimacy of the decision making process.

While currently the CBP does utilize public interest surveys and has included in its governance structure a Citizen's Advisory Committee, to what extent these efforts are ad hoc to the scientific efforts of the CBP and the opinions of the CAC are seen as equally legitimate and given equal weight as those of more traditional scientists on policy-related issues is open for debate. Ultimately, most policy related decisions are based on the 'objective' answers provided by the traditional scientists and quantitative computer-simulation models. While one can never dismiss the value of traditional scientific information as a decision-making criterion, it should be seen as the key element in the development of descriptions of potential system-states. The choice between these system-states however, should ultimately lie in the hands of a inclusive decision-making body. The CBP should take seriously the ethical as well as policy quality assurance implications of the post-normal scientific perspective.

However, as previously noted, a shift to a post-normal decision-making context is not likely to be swift. More pragmatically, scientists involved in environmental management need to find ways to better deal with the inherent complexity and uncertainty of self-organizing sociobiophysical systems. While the CBP has engaged in several elements of adaptive management (frequent reevaluation of management efforts based on continuous monitoring), "the Bay would be aided significantly if the Bay Program took more seriously the experimental aspects of adaptive management" (Hennessey, 1997: 218). As a result of the technocratic decision-making context, scientists in the CBP have little opportunity to practice the experimental aspects of an adaptive management style.

The Chesapeake Bay Program as an Adaptive Organization

Hennessey (1994 and 1997) describes the CBP as an archetype for adaptive estuarine management, noting its recursive and flexible management style. He observes that from the choice of the original governance structure to its periodic reevaluations of managerial focus via new agreements, amendments and organizational restructuring,

> one important lesson derived from the Chesapeake Bay Program experience is that the nature of large-scale estuarine ecosystems and the human uses of them create conditions of complexity, both human and natural, that severely constrain such systems from being managed in a synoptic, integrated, comprehensive manner - at least initially. Restoration and protection of the estuary can only be approached through an adaptive management and implementation process that is both evolutionary and exploratory and that relies on a positive relationship between science and management. The other essential characteristic of this system is its capacity to learn
>
> - Hennessey, 1994: 140.

In the current technocratic decision-making context, a management initiative that does not deliver the results originally expected is considered a failure, not an opportunity for organizational learning, hence the predisposition towards computer-simulation modeling within the CBP. To experiment with a simulated ecosystem is obviously less disruptive than manipulating dynamics within a real ecosystem, but it can also be an impotent measure as the inherent complexity and uncertainty associated with real-world ecosystems cannot be adequately simulated.

> Unfortunately, this treatment of programs as experiments has only begun in recent years with the Living Resources Committee. Without such a system to empirically determine what works and what does not, we have the high probability of an inefficient use of resources and insufficient accumulation of knowledge about the most successful programs and projects in terms of which to redesign the program
>
> - Hennessey, 1994: 141.

As Greer (1999:1) notes, "moneyed interests (in this case government funding) often 'shape the framing and resolution of issues, including the conduct of scientific research' (Jansanoff, 1997)". As a result, in the case of the Chesapeake Bay Program, funding for research on a particular issue is often not provided until the issue has become critical and is of concern to a large group of tax-paying constituents. Only then do decision-makers, as one interviewee put it 'pull out their scientists, put them on TV holding up plants to show what they're doing about whatever issue is of concern at the time'. This is not to say the scientists in the CBP haven't been aware of the particular issue and partly dealt with it to the extent possible without actually conducting any formal research. The scientists of the CBP often become aware of potential policy issues long in advance of them becoming politically 'hot' and devise potential management plans and proposals for research on an informal level but have little chance to do anything about it until the formal structure of the program provides funding.

Most policies in the CBP are generally developed one of two ways (of course, ultimately most policies are influenced by both): From the top down, the executive council (i.e. politicians) feels some political pressure to address a specific issue and so requests that the Implementation Committee research the issue and develop a plan; or from the bottom-up, as a scientist or environmental manager notices a problem or situation that needs to be addressed and takes it to the Implementation Committee.

For example, *Phiesteria piscicidia*, a bacteria-sized toxic dinoflagellate discovered in the late 1980's, was found in the Chesapeake in 1992 by Alan Lewitus (Greer, 1999). Lewitus discovered the tiny organism in the first place he looked, in very close proximity to the laboratory in which he worked. Greer (1999: 7) notes that, "to find a marine organism that measures no more than 10 microns the first time you look for it suggests that it must be at least relatively abundant". Several of the interviewees noted that the discovery sparked a great deal of interest within the program. Many scientists and observers noted links between outbreaks of *Phiesteria* and hog and chicken farm run-off but virtually no research was funded and little done until the issue was popularized by the media and picked up by politicians in the last several years (Mountford, Pers. Comm., 1999 and Greer, 1999).

The 40% reduction in nutrients goal, on the other hand, is an example of research providing an impetus for policy-making or the bottom-up policy vector (which was eventually 'watered-down'). The original $25 million study of the Bay revealed that one of the key issues related to the Bay's deteriorating state was that of nutrient loading. The 1987 Bay Agreement established the goal in an effort to explicitly address this issue. Of course, many argue that the 40% goal represents an example of 'lowest-common-denominator decision-making'. Several scientists in and around the program argue that the 40% reduction policy only deals with what is known as 'controllable nutrients' (excluding for example, air borne deposition); several senior scientists in the CBP indicated, that in order to make a real difference in the restoration of the bay the reduction would have to be more in the order of 50-75% and that may still not be enough to counter-act the influence of a rapidly growing human population in the basin.

These two vectors for policy development illustrate the distinction between the formal and informal organization. In many senses, these formal and informal aspects of the organization are akin to Bella's two organizational attractors ('R' ordered, rigid, amoral/'S' disordered, flexible, moral). As well, they provide examples of at least two or more of Senge's barriers to organizational learning.

As implied in Bella's work, the two roles for scientists (type 'A' and 'B' activities) in the organization reinforce and sustain the respective organizational attractors. If policy is developed 'top-down', scientists are called upon to provide decision-makers with hard, 'hyperobjective' results. As Greer indicates, in these circumstances funding often dictates the direction of research and as the issue is often in crisis there is little time to consider ethical and moral implications. This is the more 'natural' or intrinsic tendency for organizations, according to Bella. In these situations, order within the institutional system in the form of the 'status quo' is maintained. This is also an example of Kim and Senge's (1994) 'role-constrained' barrier to organizational learning. In this case the scientists may have been aware of the issue but been in essence constrained by his/her role in the organization.

If the policy is generated from the bottom-up, the scientist or environmental manager has seen or experienced some issue through the course of his or her work and is often inspired by, or at least explicitly considers the moral and ethical implications of the issue. While this policy-vector can result in true double-loop learning, that is the individual can in effect alter the organization's 'shared mental model', it can also result in 'fragmented learning' (the link between the individual mental model and the organization's shared mental model is severed) or 'audience learning' (an individual affects organizational action in ambiguous way) if the organization is not flexible or receptive enough to allow for double-loop learning.

Both of these extremes are archetypes and no policy would be completely 'hyperobjective' or completely morally or ethically driven. However, they are useful examples of Bella's two attractors and can provide some valuable insight into the dynamics of policy-making in the CBP. Ultimately policies, no matter what their origin (top or bottom), are influenced by the two attractors. The system will have organizational 'integrity' (i.e. will produce equitable but scientifically grounded policies), to use an ecological analogue, when these two elements of the system are in an appropriate dynamic tension (i.e., the dynamic tension between the Ascendent and Overhead elements in an ecosystem - Ulanowicz, 1997). However, if the organization as a system is drawn towards one attractor then it is, as Bella puts it, tending towards systemic imbalance. If the 'R' attractor (the Ascendent element) has been reinforced at the expense of the 'S', the system has lost adaptability and has become overly rigid. If the 'S' attractor is reinforced at the expense of the 'R', the system is overly flexible, morally conscious and often inefficient. Either case has potentially disastrous implications for ecosystems and organizations.

Unfortunately, it appears as though the CBP is following the natural, although untimely, organizational propensity towards rigidity and bureaucratization. In recent years the links between the governance facet of the CBP (the Executive Council) and the management facet (the Implementation Committee) have become tenuous. That is, where members of the Executive Council in previous years would have regularly attended Implementation Committee meetings, they have recently formed the Principals' Staff Committee and now send lower-level staff (with little or no decision-making authority) to the meetings. This measure, seen possibly as a way to more efficiently use Executive Council's time, has had the effect of pushing the system towards systemic imbalance as members of the Implementation Committee and subcommittee staff have less direct communication with decision-makers (i.e. the Executive Council) to make policy-recommendations. As a result, policies are becoming less balanced as the formal structure becomes more rigid. Complicating this is the complex inter-jurisdictional overlay and the consensus-based decision-making regime which require a minimum of 10 people to form a work-group to address a given issue (Mountford, Pers. Comm., 1999).

These issues illustrate the recent barriers to 'bottom-up' or research-based policy-making within the CBP. As the organization becomes more rigid and bureaucratic, as Bella indicates, activities that tend to cause disorder such as new research initiatives and monitoring practices will tend to be eliminated for the sake of efficiency. These activities have the tendency to question the direction of governance and management which, while often very necessary, require frequent reevaluation and restructuring. While the program has had a successful history with continual reevaluation and refocusing its managerial scope (mainstem of the bay, to watershed, possibly to airshed) these recent organizational trends may be evidence of Bella's tendency towards organizational rigidity and ultimately, systemic imbalance.

However, this may not be only a recent trend. The underlying organizational, subcommittee structure may itself be an impediment to adaptive, ecosystem-based management. In contrast to Hennessey's very positive view of the CBP as a flexible, adaptive organization, my own experience with the program through the course of this research, particularly through interviews, would lead me to a different conclusion. Several times in the course of interviews with environmental scientists who have been involved directly or indirectly with the program for years or even decades, the subcommittee structure was described as a series of 'fiefdoms', implying that while these subcommittees and workgroups are often transdisciplinary they are not trans-sectoral or trans-issue (fisheries, toxics etc.). This can be identified as a possible source for Kim and Senge's (1994) 'fragmented learning', where the link between individual mental models and organizational shared mental models is broken down. The result is that some individuals, or in this case small groups, have been able to learn and evolve while others lag behind. Dr. Mike Hirshfield of the Chesapeake Bay Foundation noted that due to the rigidity of the subcommittee structure the obviously interrelated fisheries management and water quality workgroups have surprisingly little contact with each other.

Carin Bisland, an EPA scientist working in the Chesapeake Program office and associate director of the Ecosystem Management workgroup has had to deal with this very issue, while attempting to operationalize the concept of ecosystem management within the CBP. She has met with a great deal of resistence when attempting to restructure workgroups or even subcommittees to make them more relevant to the ecosystem.

Another interviewee noted that when the issue of habitat fragmentation was raised no one had thought of it, possibly as a result of ecosystem-level issues such as habitat falling through the organizational gaps. This is an example of Kim and Senge's (1994) 'superstitious learning', (i.e., when individuals are not able to make valid sense of environmental response). In the case of the CBP, problems in the bay did not appear to be linked to the issue of habitat fragmentation. More recently however, the Living Resources Committee habitat restoration/protection program has offered some evidence that the CBP is attempting to focus on ecosystem-level issues such as habitat and beginning to take seriously the experimental aspects of adaptive management (Hennessey, 1994 and 1997).

Overall, however, there are many signs that the CBP may be headed toward a time of institutional inflexibility and inevitable, fundamental reorganization (cf. Holling's figure-eight model of ecosystemic, organizational dynamics). This is not to imply that the tendency towards organizational rigidity, and the resulting efficient, bureaucratic organizational system will necessarily lead to ineffective environmental management. In fact, it is prudent and logical to manage in a more comprehensive, anticipatory fashion when, for instance, in the domain of a known attractor such as the benthic-dominated system enjoyed by the residents of the Chesapeake.

It is more an issue of the environmental management organization striving to be more in 'sync' with the associated ecological system. In the case of the CBP and the Chesapeake Bay, as previously mentioned, the Bay appears to be approaching an ecological threshold and could possibly flip to the domain of a known pelagic-dominated system or an as yet unknown attractor. It is during bifurcations or flips of this nature that system uncertainty is highest and management needs to be most flexible and well-informed. This is the time for scientists to be conducting research into the feed-backs loops that are 'pushing' the SOHO system towards a flip and what possible system states may result as ecological thresholds are passed. It is also critical during these highly uncertain times that the relationship between the scientists and policy-makers to be the most direct so as to make policies sensitive to the most recent ecological knowledge. And it is also the appropriate time for experimental management. There isn't enough time, nor is it possible during such ecological phases to acquire a complete enough scientific understanding to allow for anticipatory management. It is time to attempt to enhance or decouple the 'driving' feedback loops to 'push' the system towards a desired state. And when the system has either returned to the current system or flipped to the domain of another attractor, then the organization can allow itself the luxury of returning to a more efficient bureaucratic state.

Ultimately, for the CBP, it is a matter of altering the dynamic between the two organizational attractors (Bella's 'R' and 'S' attractors). Currently, the CBP formal organizational structure resembles something akin to Bella's 'R' attractor or what Henry Mintzberg (1989) calls a 'diversified' organization (described in Chapter 2). As previously mentioned Mintzberg has developed a classification of useful caricatures of extreme organizational types. Two of these organizational archetypes (the Diversified and the Innovative) nicely characterize the two attractors previously discussed. Mintzberg's 'diversified' organizational archetype provides a useful characterization of the more rigid, formal, bureaucratic attractor. Mintzberg (1989: 155) described this type of organization as being, "not so much an integrated entity as a set of semi-autonomous units coupled together by a central administrative structure". In the case of the CBP, these 'semi-autonomous units' refer to the 'fiefdom-like' subcommittees while the 'central administrative structure' is the Executive Council/Principal's Staff Committee.

Using mostly examples from the private, corporate sector, Mintzberg did note that the diversified structure is prevalent among government agencies especially when such agencies are large organizational entities dealing with broad, complex issues like the CBP. These 'diversified' organizations are meant to effectively and efficiently manage a set of loosely interrelated yet distinct issues. However, "this configuration appears to inhibit, not encourage, the taking of strategic initiatives" (Mintzberg, 1989: 166). The problem, Mintzberg noted is that the divisional managers or in the case of the CBP, subcommittee chairs are given strategic/managerial autonomy but are responsible to, or in the case of the public sector dependent on, the central administration financially.

As a result, in the case of the CBP, subcommittee chairs have to justify their research interests and current projects by carrying them out as efficiently as possible while demonstrating the relative importance of their subcommittee within the overall organizational structure. Unfortunately, as Mintzberg (1989: 167) indicated, "at the same time, however, it seems to dampen their inclination to innovate". When in the domain of a known ecological attractor, when uncertainty about general ecosystem dynamics is low, this type of efficient, bureaucratic management is sound. But when faced with high uncertainty innovative, experimental management is required.

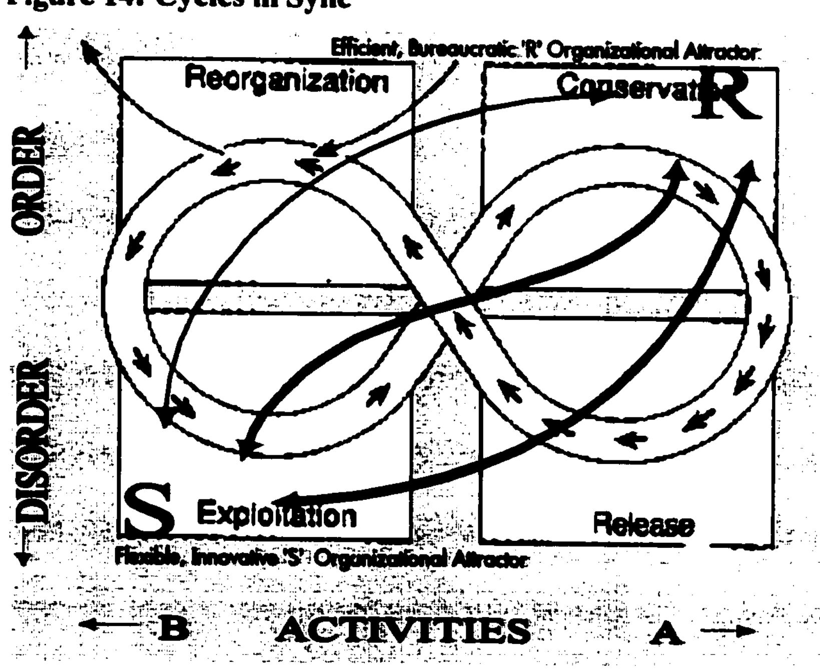
Mintzberg also described an 'innovative' organizational archetype appropriate to "environments that are both dynamic and complex" (Mintzberg, 1989: 207). He argued that, "a dynamic environment, being unpredictable, calls for organic structure; a complex one calls for decentralized structure" (Mintzberg, 1989: 207). In conditions of extreme complexity and high uncertainty, as exhibited by a SOHO system like the Chesapeake Bay ecosystem, management cannot rely on a comprehensive, anticipatory approach. "Rather, many of its actions must be decided upon individually according to the needs of the moment" (Mintzberg, 1989:210) as exhibited by the 'innovative' organizational type or the bottom-up policy vector.

However, Mintzberg cautioned that "no configuration is better suited to solving complex, ill-structured problems than this one. None can match it for sophisticated innovation. Or, unfortunately, for the costs of that innovation" (Mintzberg, 1989: 218). Similarly Bella (1997a: 635) indicated in reference to his 'S' attractor and the 'B-type' activities that support it, that they "produce disruptions in organizational systems" and are thus inefficient and costly. Monitoring, for instance, is an example of a 'B-type' activity which would promote the 'S' attractor.

Continuous monitoring is costly in a financial or human labour sense (in the case of volunteer monitoring programs). As it is also meant to provide management with data regarding the current state of the ecosystem as well as the effectiveness of current management projects, monitoring can reveal that the current management regime requires very costly restructuring. "This is simply not an efficient way to function" (Mintzberg, 1989: 218). However, during times of high uncertainty, efficiency must be sacrificed to allow for responsive, innovative management approaches.

Thus, in environmental management, it would be prudent for an organization whose natural tendency is to self-organize between two attractors (Bella's 'R' and 'S') to synchronize this dynamic with the relevant ecosystem's natural propensity to self-organize (see Figure 13). In the case of the CBP during times of low ecological uncertainty (i.e., within the domain of a known attractor, like the benthic) when general dynamics are well documented and qualitative predictions about system dynamics can be made, the 'R' or 'diversified', bureaucratic attractor should dominate the organization; during times of extreme complexity and high uncertainty (i.e., when the system is about to reorganize and possibly flip to the domain of another attractor, either known or unknown) when more research is required to understand new ecological dynamics and few if any even qualitative predictions can be made, the 'S' or

Figure 14: Cycles in Sync



innovative, adaptive attractor should dominate.

While Bella's and Mintzberg's work provide very useful heuristics, effectively describing the dynamics of an organizational system between two attractors and describing those attractors, their work does not provide much insight into why the CBP is mired in a mechanistic, or at best cybernetic, mindscape and is not avoiding the current tendency towards bureaucratization. Bella's (1996, 1997a, 1997b) work uses case examples of organizational systemic imbalance that are generally driven by a threat of, or actual reduction in monetary funding/profits (universities, Tobacco Industry and Space Shuttle Program). In the case of the CBP, funding is generally stable. As one interviewee indicated, "there are major differences as elections and parties come and go, but public interest in the Bay -- and us holding the torch steadily -- means that ALL politicians have to pay attention and at least give lip service. When they fail to deliver, they look bad against the other governors and that seems to be what keeps us plugging along".

As previously mentioned, Peter Senge's work described a cycle of organizational learning as well as identifying breakdowns in this cycle. Senge's work may provide more insight into the CBP's current scientific perspective as well as the current tendency towards organizational rigidification does not appear to be impeded/driven by financial issues but rather is the result of apparent barriers to organizational learning. In fact, in the course of this analysis several examples of Kim and Senge's (1994) breakdowns in organizational learning have been cited (role-constrained learning, fragmented learning, superstitious learning and superficial learning). If the CBP could enhance its capacity for organizational learning, evolution towards a complexity theory-based scientific mindscape would be expedited and the untimely trend towards bureaucratization might be averted.

Concluding Statements

In order for an adaptive, ecosystem-based management organization to maintain or enhance the 'integrity' of the ecological system (exhibiting ecosystem health or ascendency, resilience or overhead as well as an appropriate dynamic tension between these to allow for continued self-organization within its environmental context), it as an organization must maintain a type of organizational 'integrity'. That is, it must maintain an appropriate dynamic tension between its rigid, bureaucratic elements and its flexible, adaptive elements so as to allow itself to self-organize and evolve to effectively deal with its ecological context.

While the Chesapeake Bay Program is arguably one of the finest and most innovative examples of ecosystem-based management in the world, it does not in many ways adequately acknowledge the levels of complexity and uncertainty involved in the management of human activities within a SOHO system such as the Chesapeake Bay ecosystem. The traditional roles of science in policy-making are no longer adequate, or arguably ethical, in this complex and uncertain decision-making context. And finally, on a more pragmatic level, it is critical to acknowledge the complex dynamics that underlie, not only the biophysical system, but the human organizational system as well. As an adaptive, ecosystem-based management regime it is critical as an environmental management organization to continue to evolve and learn but also to synchronize dynamics with the dynamics of the ecosystem to ensure that the management perspective and structure is appropriate to the level of ecological complexity and uncertainty.

Conclusions

Overview

Three themes or requirements of ecosystem-based management, derived from the environmental planning and management literature (systems-based science, ethical governance and adaptive management) have been augmented with complexity theory-based heuristics to allow for an evaluation of the CBP as an example of adaptive, ecosystem-based management from a complex systems theory-based, post-normal science perspective. This systems-based planning and management perspective provides a useful counter-point to traditional, comprehensive, anticipatory planning methods as it is has its philosophical/epistemological basis in a relatively new and innovative worldview or 'mindscape'. In comparison to more traditional worldviews including the 'mechanistic', the 'stochastic' and even the 'cybernetic', the 'morphogenetic' or complex systems theory-based worldview provides environmental planning and management practitioners with a scientific perspective and a set of management heuristics appropriate to the inherent complexity, uncertainty and high decision-stakes associated with planning in sociobiophysical systems.

The view of ecosystems as complex systems provides environmental managers with a more complete understanding of the dynamics that underlie the ecological structures and processes which provide context for human economic and socio-cultural subsystems. As complex, self-organizing entities, ecosystems and their human subsystems (taken together sociobiophysical systems), exhibit non-linear negative and positive feedback allowing for new levels of organization and emergent phenomena and are characterized by discontinuous 'flips' between multiple system states. This perspective has profound implications not only for the way we understand sociobiophysical systems but also for the way we make decisions about and manage human activities within them. It has been argued that it can be detrimental to attempt to address the environmental management issues from anything but a complex systems theory-based perspective. Other planning and management regimes based on other scientific worldviews have often lead to the misinterpretation of ecological dynamics and so to mismanagement of human activities within the system (see Gunderson, Light and Holling, 1995 for examples).

It has been further argued that to manage based on the assumptions of more traditional scientific perspectives is not ethical. Given the extreme uncertainty and the fact that natural systems ultimately provide the context (that is, human subsystems are ultimately dependent upon natural systems for material, energy and information) and given the fact that ecosystems can exist in several equally viable system states, it is no longer ethical for scientists to provide decision-makers with so called, 'objective' answers to environmental management issues. A more appropriate relationship between science and policy-making in the environmental management realm is provided by the post-normal science perspective developed by Funtowicz and Ravetz (1993). This decision-making perspective is based on insights gleaned from complex systems theory and calls for an extension of the decision-making community based on a more explicit acknowledgement of the high level of uncertainty and often far-reaching decision-stakes associated with complex systems.

Finally, this complex systems theory-based environmental management perspective requires a new approach to management and planning itself. The approach, in contrast to more traditional management and planning approaches including comprehensive, anticipatory management is based on an incomplete but continuously evolving knowledge of a given ecosystem. Adaptive management, as this approach has been termed, is a recursive management approach that requires continuous monitoring and reevaluation of managerial foci and ultimately, learning on an organizational scale.

It has been argued that the dynamics that underlie complex organizational systems are similar to those of ecosystems. That is, they self-organize about two attractors: a flexible, adaptive, and yet highly disordered attractor and an efficient yet rigid attractor. As such, for an adaptive management approach to be most effective the organizational dynamics should be synchronized with the ecosystemic cycles to allow for the appropriate management approach to be matched to the level of uncertainty associated with current the ecological phase.

Thus, to operationalize an ecosystem-based management approach it should be based on a morphogenetic or complex systems theory-based scientific perspective, it should utilize a more ethical governance regime based on a post-normal decision-making perspective, and management should be based on continuous organizational learning and an appropriate management approach to the given ecosystemic phase.

While the Chesapeake Bay Program does not meet all of the above criteria it does represent one of the only regional-scale examples of an adaptive, ecosystem-based management approach and as such has made great strides towards operationalizing this environmental management perspective. Its scientific perspective has been broadened and enriched over two decades of experience. It has evolved from an 'H_I' linear cause-effect mindscape, focusing its management efforts on nutrients and toxics solely in the mainstem of the bay towards an integrated, systems-based watershed approach to the restoration of the bay through multiple management foci on habitat restoration, biodiversity conservation, climate change as well as nutrient and toxics abatement.

The CBP's governance approach (the relationship between science and policy-making) has always required sound, objective, quantitative results to even the most complex of issues implying a very technocratic, expert-oriented decision-making framework. However, this has been juxtaposed with a strong, continuous commitment to public awareness and public involvement in the decision-making process.

And of course, through an adaptive-style approach to management the CBP has demonstrated the capacity to learn as an organization. It has committed to, and continuously reevaluated its management foci and in turn expanded and developed its scientific perspective. It has been successful in addressing limitations to its current management programs, reevaluating them, learning and adapting.

Lessons Learned

While it may be easily argued that there are theoretical gaps in the CBP's general scientific perspective (e.g., the nutrient limitation example); that there has been a strong reliance on technocratic, expert-oriented decision-making within the CBP; and that the CBP has been hesitant to apply the experimental aspects of adaptive management, there is a great deal to be learned from the CBP as an example of adaptive ecosystem-based management. As Slocombe (1998) has indicated, the greatest barriers to ecosystem-based management are institutional territoriality and weak goals. It can be argued that the CBP faces these two barriers. The fact that the subcommittee structure has become overly rigid along sectoral lines (e.g., fisheries, toxics subcommittees do not communicate) is a clear example of institutional territoriality. The CBP's continued use of a limited version of the concept of ecosystem health as a normative goal could constitute an example of a weak or at least ambiguous goal. However, criticizing the CBP from this point of view would ultimately be counter-productive. The lessons to be learned from the CBP would be missed by using such a static, 'snap-shot' analytical framework. The CBP's greatest strength is its ability to learn and adapt as an organization. This ability is the product of two different but complementary elements.

Just as ecosystems require a dynamic balance between their tightly coupled, highly ordered elements and their less connected, more disordered components (Ulanowicz, 1997), so too is it with human organizations. Ascendency is the product of a system's total system throughput (a surrogate for growth or quantitative measure of the system) and the system's mutual information (a surrogate for development or qualitative measure of the system). In order to continue to evolve (continue the process of self-organization) ecosystem-based management organizations must also be able to grow and develop. In spite of its current scientific, governance and management limitations compared to a conceptual ideal, the CBP is evolving.

In the face of limitations to its current management framework (e.g. as indicated by the 1991 nutrient evaluation which lead to the 1992 amendments) it has had the ability to expand its scientific and management focus (e.g. in 1992 it expanded management boundaries from the Bay's mainstem to the edge of the watershed). It was able to do this because of unquestioned political and financial support. As indicated by several of the CBP senior scientists, funding has never been an issue for the program. The general public have had a strong commitment to, and feeling of ownership of, the Bay. One token example of the general public's commitment to the Bay's restoration is the number of 'Save the Bay' bumper stickers one would see when driving along any road in any of the signatory states around the Bay. As a result the political commitment to the Bay has been unquestioned. Since its creation there has been significant public pressure on politicians to maintain if not increase funding to the CBP (Mountford, 1999).

This in turn has resulted in significant pressure on the scientists and policy-makers within the Bay program to produce results and be responsible to the concerned public. Thus, the continuous reevaluations have not only served to redirect scientific and management focus but to demonstrate progress. These periodic reevaluations the CBP has committed to, represent what Bella (1997) called 'credible disorders' or in Holling's (1995) terms 'creative destruction' events. These credible disorders represent a 'push' towards a less rigid, more flexible system attractor and prevent what Bella (1997) refers to as 'systemic imbalance' which is the ultimate result of the inherent propensity for vast human organization systems to tend towards an overly rigid, bureaucratic attractor. Using Holling's (1995) model, the periodic reevaluations the CBP have undergone represent the system being allowed to cycle normally between the domains of the system's two attractors (similar to Bella's 'R' and 'S' attractors).

These credible disorders or creative destruction events have allowed the system (in this case the organization) to reorganize. During this reorganization period, as with ecosystems, it is the information (in ecosystems, biodiversity) available to the system that determines what form the reorganized system will take and whether or not it will be able to continue to evolve. In the case of the CBP, it has been the creativity and flexibility of the scientists and policy-makers within the program that have allowed for the expansion of the scientific perspective (overhead) balanced with the coordinated, efficient pragmatism (ascendency) that has allowed the program to meet many of its goals (albeit pragmatic ones such as the 40% nutrient reduction goal) and maintain confidence in the CBP (political support and funding).

Thus, in order to be able to evolve (grow and develop) towards a conceptual ideal of ecosystem-based management (complexity theory-based scientific perspective, post-normal governance framework, adaptive management approach) an environmental management organization must be able to set and work towards achievable goals in a coordinated, efficient manner in order to demonstrate its effectiveness. But it must also foster the creativity and flexibility or open-mindedness of the scientists and policy-makers involved in order to maintain its ability to address new issues and limitations to current scientific and management foci, adapt and learn (serendipitous planning, Dempster, 1997, 1998).

State of the Chesapeake Sociobiophysical System

While there are still limitations scientifically, with its governance and decision-making system and with its managerial style, in its two decades of existence the CBP has not only grown (as an organization) it has developed or evolved towards a more adaptive, ecosystem-based organization. As a result of this growth and development it has made some great strides towards conserving and restoring the Chesapeake to an ecosystem with integrity. With the release of the CBP's most recent "State of the Chesapeake Bay" report (Chesapeake Bay Program, 1999) it seemed appropriate to provide a brief summary of the current status of the sociobiophysical system.

> As we approach 2000, striped bass are back in record numbers, underwater grasses have rebounded since the 1980's, and sewage treatment upgrades have helped in the ongoing clean-up of rivers. We have made impressive toward the ambitious nutrient reduction goal set in 1987 ... There's more good news: in some places, living resources are beginning to respond, especially in areas where management actions have been concentrated
>
> - Chesapeake Bay Program,1999: 5).

Unfortunately, the news is not all good. There is still limited water quality improvements in some areas and "there is a disturbing trend showing significant losses of Bay grasses in the Tangier Sound area - one of the most productive areas of the Bay for blue crabs" (Chesapeake, 1999: 5). Also, "scientists estimate that approximately 21% of all the nitrogen in the Bay region comes from the air" and as the airshed extends beyond the boundaries of the signatory states reducing nitrogen to levels set in the 1987 nutrient reduction agreement will be difficult. And with the human population growing by almost 300 people per day (Chesapeake Bay Program, 1999: 5) the resulting pressure on the ecological system threatens to undo what the CBP has strived to do over the last two decades in a very short time. For the CBP to continue to effectively address the complex and dynamic issues associated with the management and planning of human activities within sociobiophysical systems it must continue to foster its scientific, governance and managerial evolution as an adaptive, ecosystem-based management organization.

Concluding Comments

The CBP's current C2K (Chesapeake 2000) initiative to reevaluate and rewrite its 1987 agreement is the perfect opportunity to address some of the very fundamental, albeit conceptual, issues raised in the context of this thesis. These include the appropriate scientific perspective; the appropriate role of science in policy-making; and the appropriate relationship between the human organizational system and the biophysical system for managing human activities within a complex, uncertain sociobiophysical system. These are, of course, the three requisites or themes of adaptive, ecosystem-based management described in the literature. More fundamentally it is crucial for any environmental management/planning organization to balance pragmatism and efficiency with creativity and flexibility in order to foster its ability to evolve towards such a conceptual ideal.

The preceding analysis was meant to illustrate the implications of a complex systems theory-based, post-normal decision-making perspective for the concept of ecosystem-based management, and in turn, to apply this enhanced version of the concept to a regional-scale example of adaptive, ecosystem-based management, the Chesapeake Bay Program. The result has been a set of three 'enhanced' requisites for, or themes of, ecosystem-based management.

Conventional comprehensive, anticipatory management, based on traditional reductionist, mechanistic science (H_I mindscape) simply cannot on its own, deal with the complexity and uncertainty inherent in self-organizing, holarchic, open (SOHO) systems such as ecosystems and human organizational/institutional systems (taken together form sociobiophysical systems). The new science of complexity provides explicative heuristics for environmental planning/management. Offering fresh insights into the structures and processes of complex, self-organizing sociobiophysical systems, this new perspective not only calls into question the inappropriate extension of conventional scientific perspectives and analogues (such as the mechanical, the stochastic and cybernetic) for the study and management of complex systems but also challenges the conventional relationship between science and policy-making and more fundamentally, the relationship between science and values.

With our predictive capabilities limited by inherent complexity and uncertainty as well as the possibility of equally viable system states, traditional scientific notions of absolute 'truth' and 'objectivity' are no longer appropriate. In these situations of high uncertainty and inherent subjectivity, scientists are no longer capable of providing completely 'objective' answers or solutions to the complex issues involved in environmental planning/management. As a result, human values cannot be extricated from the decision-making process. This often forces scientists into undesirable roles as either 'hyperobjective' technocrats or moralistic crusaders. In a 'post-normal' decision-making context, scientists would simply serve to offer another form of knowledge or perspective to complement other equally important viewpoints within an 'extended peer community' decision-making body. While a 'post-normal' decision-making perspective is appropriate to the level of uncertainty and complexity of environmental planning/management related issues, it represents a shift of paradigmatic proportions and thus represents a more normative, long-term socio-political goal.

More pragmatically, environmental managers should attempt to ensure that they acknowledge the complexity of not only the ecological system within which they attempt to manage human activities but also the inherent complexity of their own management organization. They must ensure that the human organizational system is appropriate to the level of uncertainty in a given ecological context. That is, if the ecosystem is approaching a threshold or is already in the 'reorganization' phase of a Holling figure-eight, then the human organizational system must be in a flexible, innovative system state capable of dealing with the associated inherent system uncertainty. Conversely, if the ecosystem is within the domain of a known attractor or system state, the management organization can allow itself to follow the inherent organizational propensity towards a more efficient, bureaucratic system state.

While every sociobiophysical system differs biogeochemically and ecologically as well as economically, socio-politically and culturally the heuristic potential of a complex systems theory-based, post-normal perspective utilizing an adaptive, 'serendipitous' management approach is significant in any situation of high uncertainty and extreme complexity when fact and value are inextricable. Few if any environmental management organizations will ever achieve such a conceptual ideal. What is crucial is that they continue to promote their growth and development through a pragmatic emphasis on efficiency dynamically balanced with a creative flexibility in order to foster the ability to evolve towards this ideal (continue the process of self-organization). In the case of the CBP, this has been one of its greatest strengths, its continued reevaluation, adjustment and ability to learn as an organization and ultimately evolve. And as with any renewal, the current C2K reevaluation is full of promise and hope.

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